Hip Joint Imaging Findings in Football Players with Hip and Groin Pain

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This thesis is submitted in total fulfilment

of the requirements for the degree of Doctor of Philosophy.

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LIST OF ABBREVIATIONS

aIRR	Adjusted incidence rate ratio
aOR	Adjusted odds ratio
AF	Australian football
AP	Anteroposterior
ASM	Active shape modelling
CM	Centimetre
CI	Confidence interval
CT	Computed tomography
CTA	Computed tomography arthrography
BMI	Body mass index
BML	Bone marrow lesion
dGEMRIC	Delayed gadolinium-enhanced MRI of cartilage
FADIR	Flexion adduction internal rotation
FAI	Femoroacetabular impingement
FIR	Flexion internal rotation
FORCe	Femoroacetabular impingement and hip osteoarthritis cohort
GEE	Generalised estimating equations
HAGOS	Copenhagen Hip and Groin Outcome Score
HIMRISS	Hip inflammation MRI scoring system
Hip/groin pain	Hip and/or groin pain
HOAMS	Hip osteoarthritis MRI scoring system
HR	High risk of bias
ICC	Intra-class correlation coefficient
IQR	Interquartile range
IRR	Incidence rate ratios
JSW	Joint space width
κ	Kappa
KL	Kellgren and Lawrence
LCEA	Lateral-centre-edge-angle.
LR	Low risk of bias
MD	Mean difference
mm	Millimetres

MR	Moderate risk of bias
MRA	Magnetic resonance arthrography
MRI	Magnetic resonance imaging
NHMRC	National Health and Medical Research Council
OA	Osteoarthritis
OARSI	Osteoarthritis Research Society International
OR	Odds ratio
PABAK	Prevalence adjusted bias-adjusted kappa
PD	Proton density
PROMs	Patient-reported outcome measures
RF	Radiofrequency
SCFE	Slipped capital femoral epiphysis
SHOMRI	Scoring of hip osteoarthritis with magnetic resonance imaging
SPAIR	Spectral attenuated inversion recovery
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology
T	Tesla
TE	Echo time.
THA	Total hip arthroplasty
TR	Repetition time
UK	United Kingdom
USA	United States of America
VS	Versus

LIST OF APPENDICES

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This PhD would not have been possible without my supervisory team: Professor Kay Crossley, Dr Joanne Kemp, Dr Rintje Agricola and Dr Tania Pizzari. You have each provided me with unwavering support, encouragement, inspiration and friendship over the last five years and for that I will be forever grateful.

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ABSTRACT

Hip/groin pain is common in football players. This thesis investigates the relationship between hip joint imaging findings and hip/groin pain, and the association between cam morphology and early hip osteoarthritis (OA) (cartilage defects and labral tears) in football players. This thesis includes two systematic reviews and three studies of football (soccer and Australian football (AF)) players. The first systematic review found a higher prevalence of cartilage defects, but not labral tears, in people with hip/groin pain than in those without pain. The second systematic review found a similar prevalence of cartilage defects in athletes with and without pain, with a higher prevalence of labral tears in those without pain.

Worse overall joint and labral scores were found in football players with hip/groin pain than those without. The prevalence of other imaging findings did not differ in those with and without pain. Imaging findings were not related to patient-reported pain, quality of life, or function.

The size and prevalence of bony morphology did not differ in football players with and without hip/groin pain, except in women, where higher alpha angle values (indicating greater cam morphology) were found on the Dunn 45° x-ray view in those with pain. Alpha angle magnitude was not associated with patient-reported pain, quality of life, or function.

Cam morphology (size and presence) was associated with early hip OA, particularly superolateral cartilage defects and superior labral tears. The relationship between cam morphology and early hip OA was no stronger in football players with hip/groin pain than in those without.

This research found that most hip joint imaging findings do not distinguish football players with hip/groin pain from those without. Cam morphology may be a risk factor for early hip OA in football players. Longitudinal investigations are needed to understand whether imaging findings result in worsening symptoms and joint structure.

KEYWORDS

Football, soccer, hip joint, groin, hip osteoarthritis, magnetic resonance imaging, radiography, femoroacetabular impingement.

AUSTRALIAN AND NEW ZEALAND STANDARD RESEARCH CLASSIFICATION (ANZSRC)

ANZSRC code: 110320, Radiology and Organ Imaging, 40%.

ANZSRC code: 110322, Rheumatology and Arthritis, 40%.

ANZSRC code: 110314, Orthopaedics, 20%.

FIELDS OF RESEARCH (FOR) CLASSIFICATION

FoR code: 1103, Clinical Sciences.

STATEMENT OF AUTHORSHIP

I, Joshua James Heerey, declare that this thesis includes work by the author that has been published or accepted for publication as described in the text. Except where reference is made in the text of the thesis, this thesis contains no material published elsewhere or extracted in whole or in part from a thesis submitted for the award of any other degree or diploma. No other person's work has been used without due acknowledgment in the main text of the thesis. This thesis has not been submitted for the award of any degree or diploma in any other tertiary institution. Concerning the extent of collaboration with another person or persons, although the publications involve joint authorship, I have made a significant and leading contribution to the work, equivalent to that expected for a traditional thesis. I am the primary author of all publications pertaining to the body of this thesis (4 published and 1 under review), with confirmation of authorship documentation presented in Appendix 46. I am the primary author or co-author on additional publications obtained concurrently during this thesis, listed on pages XXVII-XXXI, that are not submitted as a component of this PhD

All research procedures reported in this thesis were approved by the La Trobe University Human Ethics Committee (HEC 15-019 and HEC 16-045) and The University of Queensland Human Ethics Committee (2015000916 & 2016001694). The research presented in this thesis was supported by an Australian Government Research Training Program Scholarship and a La Trobe University Postgraduate Scholarship, with additional funding for participant radiographs and magnetic resonance imaging obtained from the National Health and Medical Research Council (NHMRC) project grant (GTN 1088683), titled *Femoroacetabular Impingement and early osteoarthritis*, and reduced service fees were granted by Imaging @ Olympic Park (Melbourne) and Qscan (Brisbane) for completion of participant radiographs and magnetic resonance imaging. This thesis has been professionally proofread for spelling, grammar, and punctuation by Sharon Coloquhoun (The Expert Editor) in accordance with the Guidelines for Editing Research Theses under the Australian Standards for Editing Practices.

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GRANTS AND FUNDING AWARDED DURING PhD

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PUBLICATIONS, PRESENTATIONS AND AWARDS ARISING FROM THIS THESIS

Peer-reviewed publications

1. Heerey JJ, Kemp JL, Mosler AB, Jones DM, Pizzari T, Souza RB, Crossley KM. What is the prevalence of imaging-defined intra-articular hip pathologies in people with and without pain? A systematic review and meta-analysis. Br J Sports Med. 2018;52(9):581-93.
2. Heerey JJ, Kemp JL, Mosler AB, Jones DM, Pizzari T, Scholes MJ, Agricola R, Crossley KM. What is the prevalence of hip intra-articular pathologies and osteoarthritis in active athletes with hip and groin pain compared with those without? A systematic review and meta-analysis. Sports Med. 2019;49:951-972.
3. Heerey JJ, Srinivasan R, Agricola R, Smith A, Kemp JL, Pizzari T, King MG, Lawrenson PL, Scholes MJ, Souza RB, Link T, Majumdar S, Crossley KM. Prevalence of early hip OA features in high-impact athletes. The femoroacetabular impingement and hip osteoarthritis cohort (FORCe) study. Osteoarthritis Cartilage. 2021; 29(3): 323-334.
4. Heerey JJ, Agricola R, Smith A, Kemp JL, Pizzari T, King MG, Lawrenson PL, Scholes MJ, Crossley KM. The size and prevalence of bony hip morphology do not differ between football players with and without hip and/or groin pain: Findings from the FORCe cohort. J Orthop Sports Phys Ther. 2021; 51(3): 115-125.

Conference presentations and posters

1. Heerey JJ, Boudreau S, Kemp J, Crossley KM. What is the location and distribution of pain in femoroacetabular impingement using a novel and quantitative method? Sports Medicine Australia Conference, Melbourne, Australia, 2016.
2. Heerey JJ, Kemp JL, Mosler AB, Jones DM, Pizzari T, Souza RB, Crossley KM. What is the prevalence of imaging defined intra-articular hip pathologies in people with and without pain? Australian Physiotherapy Association Conference, Sydney, Australia, 2017.
3. Heerey JJ, Boudreau S, Kemp J, Crossley KM. What is the location and distribution of pain in femoroacetabular impingement using a novel and quantitative method? Australian Physiotherapy Association Conference, Sydney, Australia, 2017.
4. Heerey JJ, Kemp JL, Mosler AB, Jones DM, Pizzari T, Scholes MJ, Agricola R, Crossley KM. What is the prevalence of radiographic hip osteoarthritis and imaging defined intra-articular hip pathologies in athletes with and without pain? A systematic review and meta-analysis. International Society for Hip Arthroscopy Conference, Melbourne, Australia, 2018.
5. Heerey JJ, Kemp JL, King MG, Lawrenson PR, Pizzari T, Scholes MJ, Agricola R, Crossley KM. What is the prevalence and relationship of bony morphology and features associated with early hip osteoarthritis in sub-elite football players with and without hip and groin pain? Sports Suisse Conference, Bern, Switzerland, 2018.
6. Heerey JJ, Kemp JL, Mosler AB, Jones DM, Pizzari T, Scholes MJ, Agricola R, Crossley KM. What is the prevalence of radiographic hip osteoarthritis and imaging defined intra-articular hip pathologies in athletes with and without pain? A systematic review and meta-analysis. Sports Suisse Conference, Bern, Switzerland, 2018.
7. Heerey JJ, Kemp JL, King MG, Lawrenson PR, Pizzari T, Scholes MJ, Agricola R, Crossley KM. What is the prevalence and relationship of bony morphology and features associated with early hip osteoarthritis in sub-elite football players with and without hip and groin pain? Isokinetic Medical Group Football Medicine Conference, London, England, 2019.
8. Heerey JJ, Kemp JL, King MG, Lawrenson PR, Pizzari T, Scholes MJ, Agricola R, Crossley KM. What is the prevalence and relationship of bony morphology and features associated with early hip osteoarthritis in sub-elite football players with and without hip and groin pain" OsteoArthritis Research Society International (OARSI) World Congress on Osteoarthritis, Toronto, Canada, 2019.
9. Heerey JJ, Agricola R, Smith A, Kemp JL, Pizzari T, King MG, Lawrenson PR, Scholes MJ, Crossley KM. Hip-related pain is not associated with bony hip morphology in male and female semi-elite football players? Sports Medicine Australia Conference, Sunshine Coast, Australia, 2019.

10. Heerey JJ, Srinivasan R, Smith A, Kemp JL, Pizzari T, King MG, Lawrenson PR, Scholes MJ, Souza RB, Majumdar S, Crossley KM. MRI defined intra-articular hip findings are seen in semi-elite football players with and without hip-related pain. Sports Medicine Australia Conference, Sunshine Coast, Australia, 2019.
11. Heerey JJ, Srinivasan R, Smith A, Kemp JL, Pizzari T, King MG, Lawrenson PR, Scholes MJ, Souza RB, Majumdar S, Crossley KM. Prevalence of osteoarthritis features on MRI in high-impact athletes: the femoroacetabular impingement and hip osteoarthritis cohort study. OARSI World Congress on Osteoarthritis, Vienna, Austria, 2020 - cancelled due to COVID-19.
12. Heerey JJ, Srinivasan R, Smith A, Kemp JL, Pizzari T, King MG, Lawrenson PR, Scholes MJ, Souza RB, Majumdar S, Crossley KM. Femoroacetabular impingement syndrome is associated with features of early hip osteoarthritis on MRI in high-impact athletes. OARSI World Congress on Osteoarthritis, Vienna, Austria, 2020 - cancelled due to COVID-19.

Awards

- Journal of Orthopaedic and Sports Physical Therapy (JOSPT) best poster prize

  Heerey JJ, Kemp JL, King MG, Lawrenson PR, Pizzari T, Scholes MJ, Agricola R, Crossley KM. What is the prevalence and relationship of bony morphology and features associated with early hip osteoarthritis in sub-elite football players with and without hip and groin pain? Sports Suisse Conference, Bern, Switzerland, 2018.

- British Journal of Sports Medicine editor's choice award

  Heerey JJ, Kemp JL, Mosler AB, Jones DM, Pizzari T, Souza RB, Crossley KM. What is the prevalence of imaging-defined intra-articular hip pathologies in people with and without pain? A systematic review and meta-analysis. Br J Sports Med. 2018;52(9):581-93.

ADDITIONAL PUBLICATIONS AND PRESENTATIONS DURING PhD CANDIDATURE

Additional peer-reviewed publications during PhD candidature

1. Griffin S, Kearney R, **Heerey JJ**, Cunniffe E. Sports medicine highlights from other journals. Br J Sports Med 2017;51(21):1566.
2. Kearney R, Gisselman A, Cunniffe E, **Heerey JJ**. Sports medicine highlights from other journals. Br J Sports Med 2017;51(22):1638.
3. **Heerey JJ**, Risberg MA, Magnus J, Moksnes H, Odegaard T, Crossley K, Kemp JL. Impairment-based rehabilitation following hip arthroscopy: Postoperative protocol for the hip arthroscopy international randomised controlled trial. J Orthop Sports Phys Ther 2018;48(4):336-342.
4. Van Klij P, **Heerey JJ**, Waarsing JH, Agricola R. The prevalence of cam and pincer morphology and its association with development of hip osteoarthritis. J Orthop Sports Phys Ther 2018;48(4):230-238.
5. Kearney R, Le C, Cunniffe E, **Heerey JJ**. Sports medicine highlights from other journals. Br J Sports Med 2018;52(14):944.
6. Kearney R, **Heerey JJ**, Le C, Cunniffe E. Sports medicine highlights from other journals. Br J Sports Med 2018;52(15);1007.
7. **Heerey JJ**, Le C, Green BD, Kearney R. Sports medicine highlights from other journals. Br J Sports Med 2018;52(23):1533-1534.
8. Kemp JL, Grimaldi A, **Heerey JJ**, Jones DM, Scholes MJ, Lawrenson PR, Coburn S, King MG. Current trends in sport and exercise hip conditions: Intra-articular and extra-articular hip pain, with detailed focus on femoroacetabular impingement (FAI) syndrome. Best Pract Res Clin Rheumatol 2019;33(1):66-87.
9. King MG, Semciw AI, Hart HF, Schache AG, Middleton KJ, **Heerey JJ**, Agricola R, Crossley KM. Sub-elite football players with hip-related groin pain and a positive flexion, adduction, and internal rotation test exhibit distinct biomechanical differences compared to with the asymptomatic side. J Orthop Sports Phys Ther 2018;48(7):584-593.
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11. Kemp JL, King MG, Barton C, Schache AG, Thorborg K, Roos EM, Scholes M, Grimaldi A, Semciw AI, Freke M, Risberg MA, Reiman MP, Mayes S, Pizzari T, Heerey JJ, Lawrenson PR, Ingelsrud LHH, Crossley KM. Is exercise therapy for femoroacetabular impingement in or out of FASHIoN? We need to talk about current best practice for the non-surgical management of FAI syndrome. Br J Sports Med 2019;53(19);1204-1205.
12. King MG, Heerey JJ, Schache AG, Semciw AI, Middleton KJ, Sritharan P, Lawrenson PR, Crossley KM. Lower limb biomechanics during low- and high-impact functional tasks differ between men and women with hip-related groin pain. Clin Biomech (Bristol, Avon) 2019;68:96-103.
13. O'Brien M, Bourne M, Heerey JJ, Timmins RG, Pizzari T. A novel device to assess hip strength: Concurrent validity and normative values in male athletes. Phys Ther Sport 2019;35:63-68.
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16. King MG, Semciw AI, Schache A, Middleton K, Heerey JJ, Sritharan P, Scholes M, Mentiplay B, Crossley K. Lower-limb biomechanics in football players with and without hip-related pain. Med Sci Sports Exerc 2020;52(8):1776-1784.
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19. Reiman MP, Agricola R, Kemp JL, Heerey JJ, Weir A, van Klij P, Kassarjian A, Mosler AB, Ageberg E, Hölmich P, Marstrand Warholm K, Griffin D, Mayes S, Khan KM, Crossley KM, Bizzini M, Bloom N, Casartelli N, Diamond L, Di Stasi S, Drew M, Friedman DJ, Freke M, Glyn Jones S, Gojanovic B, Harris Hayes M, Hunt M, Impellizzeri F, Ishøi L, Jones D, King MG, Lawrenson PR, Leunig M, Lewis CL, Moksnes H, Risberg MA, Scholes M, Semciw A, Serner

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20. Mosler AB, Kemp JL, King M, Lawrenson PR, Semciw A, Freke M, Jones DM, Casartelli NC, Wörner T, Ishøi L, Ageberg E, Diamond LE, Hunt M, Di Stasi S, Reiman MP, Drew M, Friedman D, Thorborg K, Leunig M, Bizzini M, Khan KM, Crossley KM, Agricola R, Bloom N, Dijkstra HP, Griffin D, Gojanovic B, Harris-Hayes M, Heerey JJ, Holmich P, Impellizzeri FM, Kassarjian A, Marstran Warholm K, Mayes S, Moksnes H, Risberg MA, Scholes MJ, Serner A, van Klij P, Lewis CL. Standardised measurement of physical capacity in young and middle-aged active adults with hip-related pain: recommendations from the first International Hip-related Pain Research Network (IHiPRN) meeting, Zurich, 2018. Br J Sports Med 2020;54(12):702-710.
21. Kemp JL, Risberg MA, Mosler A, Harris-Hayes M, Serner A, Moksnes H, Bloom N, Crossley KM, Gojanovic B, Hunt MA, Ishøi L, Mathieu N, Mayes S, Scholes MJ, Gimpel M, Friedman D, Ageberg E, Agricola R, Casartelli NC, Diamond LE, Dijkstra H, Di Stasi S, Drew M, Freke M, Griffin D, Heerey JJ, Hölmich P, Impellizzeri FM, Jones DM, Kassarjian A, Khan KM, King MG, Lawrenson PR, Leunig M, Lewis CL, Warholm KM, Reiman MP, Semciw A, Thorborg K, van Klij P, Wörner T, Bizzini M. Physiotherapist-led treatment for young to middle-aged active adults with hip-related pain: consensus recommendations from the International Hip-related Pain Research Network, Zurich, 2018. Br J Sports Med 2020;54(9):504-511.
22. Kearney R, Heerey JJ, Gisselman A, Cunniffe E. Sports medicine highlights from other journals. Br J Sports Med 2020; 54(10): 623-624.
23. Patterson BE, Crossley KM, Perraton L, Kumar AS, King MG, Heerey JJ, Barton CJ, Culvenor AG. Limb symmetry index on a functional test battery improves between one and five years after anterior cruciate ligament reconstruction, primarily due to worsening contralateral limb function. Phys Ther Sport 2020;44:67-74.
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26. Kemp JL, Østerås N, Mathiessen A, Nordsletten L, Agricola R, Waarsing JH, Heerey JJ, Risberg MA. Relationship between cam morphology, hip symptoms, and hip osteoarthritis: the Musculoskeletal pain in Ullersaker STudy (MUST) cohort. Hip Int. In press 2021.

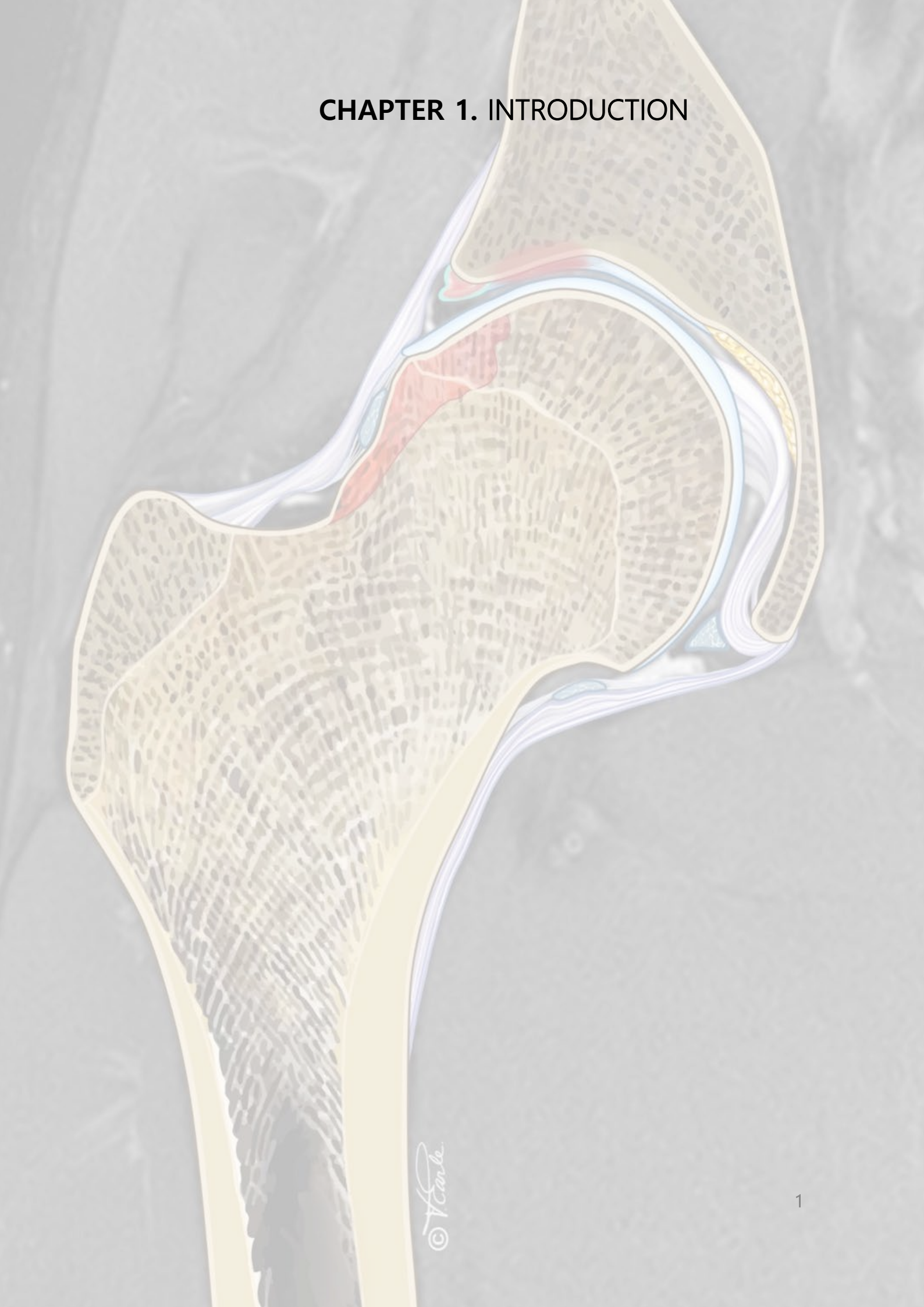
Additional invited publications during PhD candidature

1. Heerey JJ, King MG, Lawrenson PR, Kemp JL, Semciw AI, Crossley KM. Hip-related pain and FAI syndrome" Sports Medicine Australia Sport Health, April 2018.
2. Heerey JJ, King MG, Lawrenson PR, Kemp JL, Semciw AI, Crossley KM. Hip-related pain and FAI syndrome: How common is it? How does it impact on biomechanics? How does it affect muscle function? Swiss Sports and Exercise Medicine 2018;66(4):19–23.
3. Heerey JJ. Studying hip and groin pain. Australian Physiotherapy Association MPA InTouch magazine, August 2018.
4. Heerey JJ. Hip pain in younger adults. Australian Physiotherapy Association InMotion magazine, May 2019.

Presentations (invited speaker) during PhD candidature

1. Heerey JJ. Femoroacetabular impingement syndrome, Sports and Exercise Medicine Student Association (SEMSA), Annual Conference, 2016, Melbourne, Australia.
2. Heerey JJ. Femoroacetabular impingement syndrome in the adolescent athlete, Sport Medicine Australia Regional Conference, 2016, Geelong, Australia.
3. Heerey JJ. The implications of imaging findings in hip and groin pain, Lifecare Sports Medicine Lecture, 2018, Melbourne, Australia.
4. Heerey JJ. Can imaging help us with the management of hip and groin pain, Australian Physiotherapy Association Musculoskeletal Group Lecture, 2018, Melbourne, Australia.
5. Heerey JJ. Imaging in hip and groin pain: when is pathology actually pathology? La Trobe Sport and Exercise Medicine Research Centre Hip and Groin Symposium, 2018, Melbourne, Australia.
6. Heerey JJ. Hip morphology, intra-articular pathologies and symptoms in athletes, La Trobe Sport and Exercise Medicine Research Centre Early OA symposium, 2019, Melbourne, Australia.
7. Heerey JJ. What causes FAI syndrome? The Oxford-Aspetar-La Trobe Young Athlete's Hip Webinar Series (online), 2021.

CHAPTER 1. INTRODUCTION



1.1. Thesis overview

Across different football codes, hip and/or groin pain (hip/groin pain) is a common problem.(1–10) Individuals with hip/groin complaints experience impaired sports performance and report lower quality of life.(1,4,7) Long-standing hip/groin pain can be divided into three major categories: (i) defined clinical entities for groin pain (e.g., adductor-, iliopsoas-related groin pain), (ii) hip-related (e.g, femoroacetabular impingement (FAI) syndrome, acetabular dysplasia), and (iii) other causes of groin pain (e.g., urological, rheumatological conditions).(11,12) This thesis will study the relationship between hip joint imaging findings and hip/groin pain, and the development of early hip OA in football (soccer and AF) players. This chapter will provide an overview of hip joint anatomy, including the development of cam morphology. It will outline hip/groin injury epidemiology in football players. Hip/groin pain classification will then be discussed, with a particular focus on the three hip-related pain conditions, outlining epidemiology, clinical presentation, and diagnostic criteria. The relationship between hip joint imaging findings and hip/groin pain will then be explored. Finally, risk factors for hip OA will be outlined, with a focus on the role of altered or incongruent bony hip morphology.

1.2. The hip joint

The hip joint is a synovial ball-and-socket joint, formed by the head of the femur (ball) and acetabulum (socket).(13–15) The hip joint affords three degrees of freedom: flexion/extension (sagittal plane), abduction/adduction (coronal plane), and internal/external rotation (transverse plane).(13–15) Located within the outer aspect of each pelvic bone, the acetabulum faces laterally and is normally anteverted (**Figure 1.1**). The internal lunate surface of the acetabulum is covered by a thin layer of articular (hyaline) cartilage (mean thickness 1.82 millimetres (mm) ± 0.48),(16) which articulates directly with the femoral head.(14,15) The acetabular labrum (**Figure 1.1**) is a fibrocartilaginous triangle that traverses the anterior and posterior bony acetabular rim, joining with the transverse acetabular ligament inferiorly to create a continuous ring.(17,18) The labrum enhances joint stability, distributes contact stress, delivers proprioceptive feedback, and maintains negative intra-articular pressure.(14,17,18) The head of the femur is covered in articular cartilage and attached to the femoral neck.(13,14) The long axis of the femoral head-neck unit projects superomedially relative to the femoral shaft at an angle (angle of inclination) of 125°.(13,14) Together, the femoral head and acetabulum are encased by a dense fibrous capsule, which includes three ligamentous supports that restrain extra-physiological hip movements (**Figure 1.2**).(13,14,19)

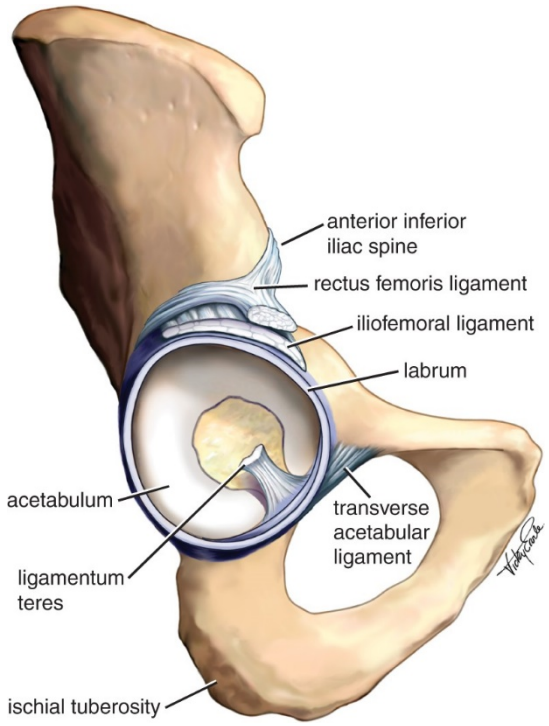


Figure 1.1. Acetabulum, acetabular labrum and ligamentum teres.
(Source: Brukner and Khan. (13) Reproduced with permission).

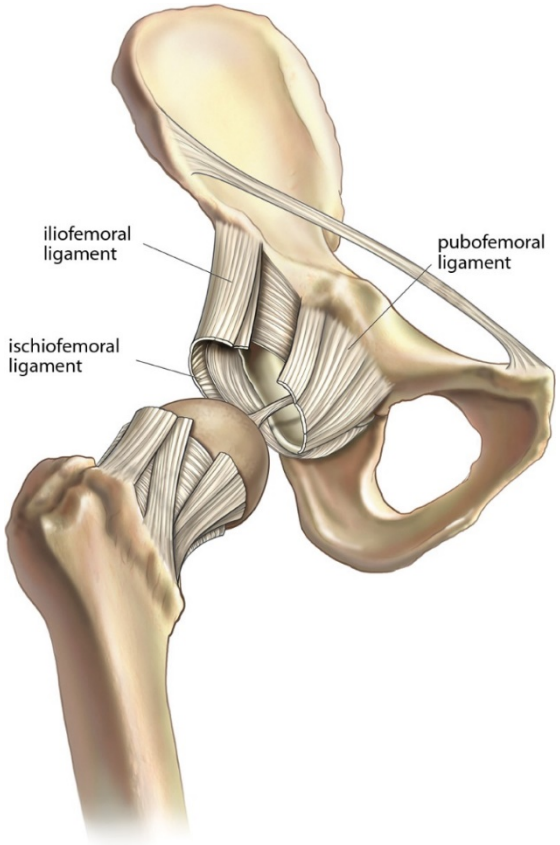


Figure 1.2. Hip capsuloligamentous complex, including iliofemoral, ischiofemoral and pubofemoral ligaments.
(Source: Brukner and Khan. (13) Reproduced with permission)

The iliofemoral ligament comprises a lateral and inferior branch that originates from the anterior inferior iliac spine and inserts along the intertrochanteric line of the femur.(14,19) The pubofemoral ligament originates from the superior pubic ramus and traverses laterally to insert in the trochanteric fossa.(14,19) The ischiofemoral ligament arises from the posteroinferior region of the acetabular rim and inserts along the posterior intertrochanteric line.(14,19) The dense capsuloligamentous complex is lined by a synovial membrane, which secretes synovial fluid to lubricate articular surfaces and reduce friction.(14,15) In addition to the extra-articular capsuloligamentous complex, the ligamentum teres is a small triangular ligament that provides neurovascular supply to the femoral head and may play a role in joint proprioception and stability.(20) Dynamic support is also provided by the surrounding hip/groin muscles.(13) The hip joint is congruent and permits effective transmission of gravitational and ground reaction forces.(14)

1.3. Development of cam morphology

During skeletal maturation, the proximal femoral head comprises three growth zones: (i) longitudinal growth plate, (ii) trochanteric growth plate, and (iii) femoral neck isthmus (Figure 1.3).(21) Collectively, they contribute to the overall length of the femur, the width of the femoral neck, size of the greater trochanter, and the neck-shaft angle.(21) Stimulation and inhibition of skeletal growth is influenced by genetic, hormonal, and environmental factors.(21) Optimal femoral anatomy is achieved when the rates of growth are similar within the three growth zones.(21) If an imbalance in growth rate occurs it may lead to the development of altered or incongruent hip morphology.(21)

Cam morphology is one anatomical variant that can develop during skeletal maturation.[32,50–52](22–24) Cam morphology is characterised by the presence of additional bone on the anterolateral head-neck junction of the proximal femur.(22–24) Mostly described in boys, cam morphology formation may begin as early as 10 years of age and occurs mostly before growth plate closure.(22–24) While the pathogenesis of cam morphology is not fully understood, epiphyseal hypertrophy and extension (along the anterosuperior femoral neck) are two proposed mechanisms.(22–24) Several studies have observed an association between high-impact physical activity (e.g., soccer) during adolescence and cam morphology development, which may explain the high prevalence of cam morphology in athletes.(22–24) Cam morphology can influence the magnitude or distribution of joint forces. Over time, this may lead to the genesis of hip/groin pain, intra-articular soft tissue damage, and eventually early hip OA.

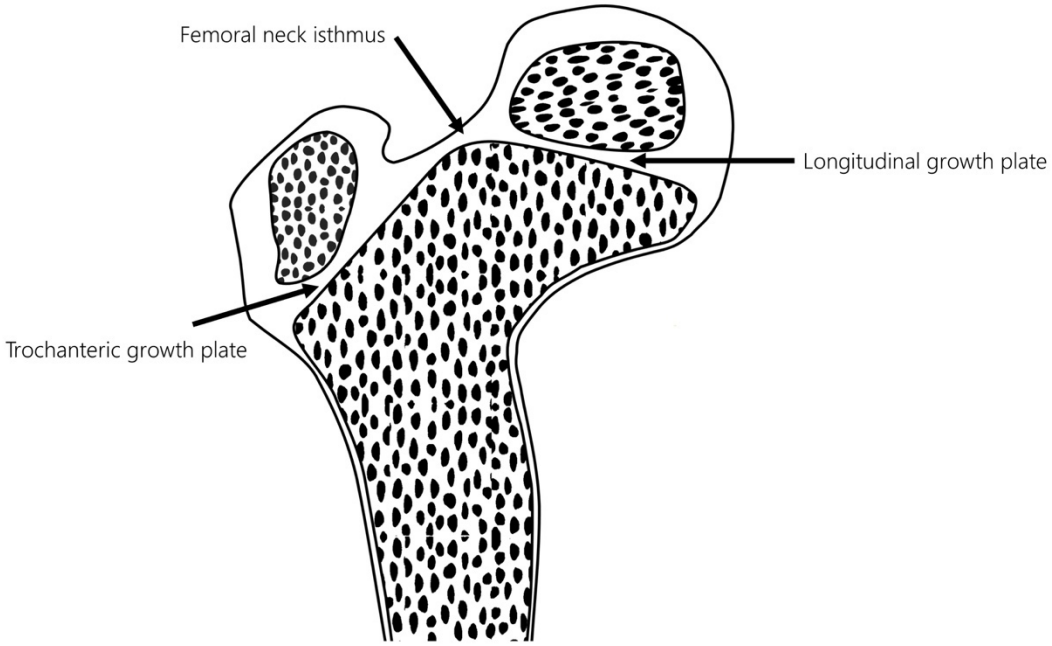


Figure 1.3. Growth zones of femoral head/neck.

1.4. Epidemiology and burden of hip/groin injuries

1.4.1. Epidemiology

Soccer is the most popular sport worldwide, with close to 270 million active participants.(25) In Australia, close to 3.5 million people participate in soccer or AF.(26,27) In soccer and AF, both men and women are at risk of injury during training or match play.(5,9,28–30) Lower limb injuries are particularly common,(2,10,28–31) accounting for up to 68% and 90% of all AF(32) and soccer injuries,(10,31) respectively. Of these, hip/groin injuries are especially frequent in both football codes.(2,7,10,31,33,34)

Hip/groin injuries accounted for 12-18% and 7% of all time-loss injuries (i.e., a player being unable to participate fully in training or match play) for male and female soccer players, respectively.(5,8–10) Hip/groin complaints may not always result in time-loss from training or match play.(1,3,4,7) For example, only 10% of groin complaints were captured with a time-loss measure, suggesting that soccer players continue to participate in training and competition despite the presence of such conditions.(3) Incidence (i.e., the number of new hip/groin injuries) ranges from 0.82 to 2.0 per 1000 player-hours of exposure in male soccer players,(5,8–10,35) with lower values in women (0.35/1000 hours).(8) Using different taxonomy, Orchard et al.(34) reported an average of 3.2 groin and 0.7 hip joint injuries (per club per season) in male AF players, with a lower incidence in women (0.38 combined hip/groin injury).(36)

In male soccer players, almost 60% of hip/groin injuries lead to moderate (8 to 28 days) or severe (>28 days) time loss from training or match play.(5,9) The severity of hip/groin injuries is lower in female soccer players, with only 14% reporting moderate to severe duration.(4) In male AF, as many as 12 matches will be missed (per club per season) due to hip/groin injuries.(34) Comparatively, less than one game (per club per season) will be lost due to hip/groin injuries in female AF.(36)

Hip/groin injuries have been characterised according to the Doha agreement, a clinically based taxonomy used in athletes.(11) In male soccer players, adductor-related injuries constitute up to 68% of all complaints.(5,9,10) Iliopsoas (3 to 12%),(5,9,10) inguinal (4 and 8%),(5,9) pubic (3 and 9%)(5,9) and other causes (3 and 18%)(5,9) of hip/groin injury are less common. Although hip-related injuries are unlikely to be a cause of time-loss in male soccer players (1 and 4%)(5,9), they are present in close to 40% of those with longstanding hip/groin complaints (i.e., >6 weeks in duration).(37) The Doha agreement has not yet been used to define hip/groin injury characteristics in female soccer or AF players.

1.4.2. Burden

Patient-reported outcome measures (PROMs) can be used to understand a person's perspective of their health regarding a specific musculoskeletal or health condition. The Copenhagen Hip and Groin Outcome Score (HAGOS) is one such measurement tool that was validated and recommended for use in studies of soccer players with hip/groin pain.(1,7) The HAGOS includes six separate subscales that assess, pain, symptoms, physical function in daily living, physical function in sport and recreation, participation in physical activities, and hip/groin quality of life.(38) Each subscale is scored separately using a 0 to 100 scale, where a score of zero equates to extreme hip/groin problems and 100 to no hip/groin problems.(38) Male and female soccer players with a current or prior history of hip/groin pain report lower HAGOS scores than their uninjured peers.(1,4,7) For example, male soccer players with greater than six weeks of hip/groin pain had lower pain (78 vs 100), symptoms (64 vs 89), sports and recreation (59 vs 100) and quality of life (55 vs 100) subscale scores than those without hip/groin pain.(7) Little is known about the self-reported disability in female AF players with hip/groin pain; however, male AF players with hip/groin pain (current or prior history) exhibit lower HAGOS symptom and quality of life subscale scores than uninjured players.(39)

Hip/groin injuries are amongst the most common and troublesome conditions in soccer and AF players. Attaining a correct diagnosis might allow for the implementation of interventions to reduce pain, improve physical function, and enable a return to sport. The following section will outline the contemporary classification of hip/groin pain.

1.5. Classification of hip/groin pain

Hip/groin pain is difficult to diagnose and manage.(40,41) The close proximity of bony, articular and musculotendinous structures and heterogeneous classification of hip/groin conditions often confuses clinicians and patients alike.(40,41) A recent review highlighted the current issues with hip/groin pain classification, where it was shown that 33 different diagnoses were used to define groin pain across 72 studies.(42)

Recent consensus statements have provided agreement on terminology and classification of hip/groin pain, in the absence of clear empirical evidence.(11,12,43,44) Foremost in improving our understanding of hip/groin pain was the Doha Agreement Meeting, where 24 international experts provided consensus on terminology and classification of groin pain in athletes.(11) Groin pain was classified using three major subheadings: i) defined clinical entities for groin pain (adductor-related, iliopsoas-related, inguinal-related, and pubic-related groin pain), ii) hip-related groin pain or iii) other causes of groin pain (**Figure 1.4**).(11) Providing a detailed classification of hip-related groin pain was considered outside of the scope of the Doha agreement meeting.(11) Other consensus statements have provided a greater understanding of hip-related groin pain. The Warwick Agreement on FAI syndrome included 22 expert clinicians and researchers from nine countries and provided consensus on terminology, assessment, treatment, and future research directions for FAI syndrome (**Figure 1.4**).(44) The Orthopaedic Section of the American Physical Therapy Association created clinical practice guidelines for non-arthritic hip joint pain, where non-arthritic hip joint pain was the term used to describe several different conditions involving intra-articular structures of the hip, including, FAI syndrome, structural instability, and acetabular labral tears.(43) Finally, the International Hip Pain Research Network meeting consisted of 38 international experts who were actively involved in research and/or clinical practice in the field of hip-related pain.(12) Hip-related pain was the agreed term to define non-arthritic pain originating from the hip joint that can result from several different conditions, including, FAI syndrome, acetabular dysplasia and/or hip instability and other hip conditions without distinct osseous morphology, such as chondral, labral and ligamentum teres conditions (**Figure 1.4**).(12) The following section will provide an overview of hip-related pain, including its three conditions.

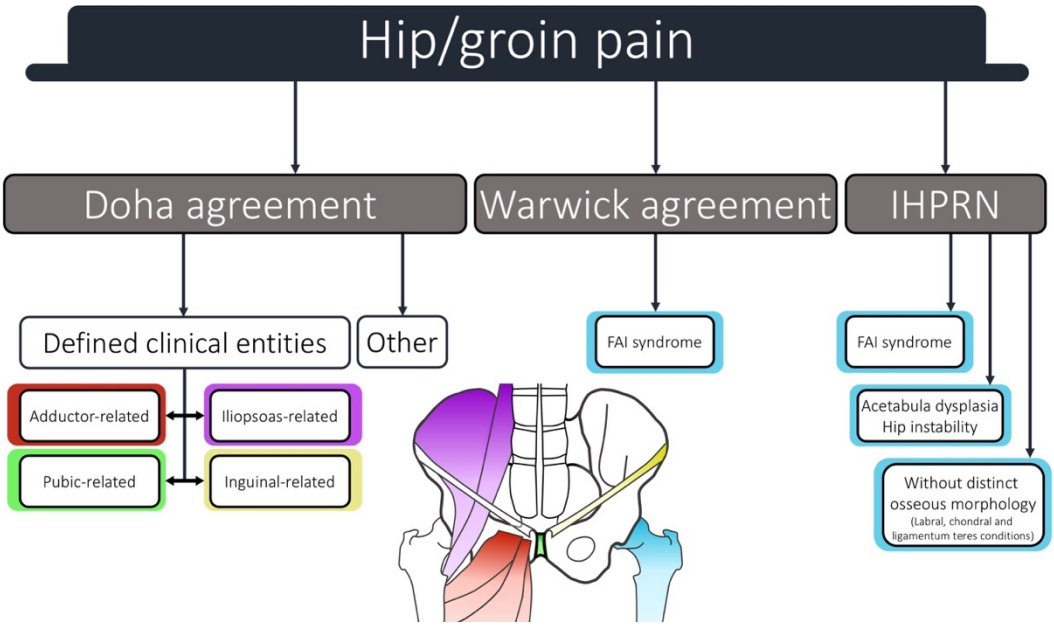


Figure 1.4. Classification of hip/groin pain.
Adapted from Weir et al. (11), Griffin et al. (44) and Reiman et al. (12)

1.6. Hip-related pain

Hip-related pain is the recommended term to describe non-arthritic hip joint disease in young and middle-aged active adults.(12) Hip-related pain can be further classified into three conditions: i) FAI syndrome, ii) acetabular dysplasia and/or hip instability, and iii) other conditions without distinct osseous morphology, which can include labral, chondral, and ligamentum teres conditions.(12) Each condition can coexist and be present with other defined clinical entities (e.g., adductor-related groin pain).(11,12)

1.6.1. Femoroacetabular impingement syndrome

Femoroacetabular impingement syndrome is a mechanical process, where alterations in bony morphology result in premature contact between the proximal femoral head-neck junction and acetabulum, resulting in pain, chondrolabral damage, and eventually hip OA.(44–46) The underlying pathomechanical process of FAI syndrome was first described in the early to mid-20th century(47,48) and then formally defined by Ganz et al. (45) in 2003. Sankar et al. (46) further developed the definition of FAI syndrome by including five essential elements: i) abnormal morphology of the proximal femur and/or acetabulum, ii) abnormal contact between these two structures, iii) especially vigorous supraphysiological motion that results in such abnormal contact and collision, iv) repetitive motion resulting in the continuous insult, and v) the presence of soft

tissue damage. In 2016, FAI syndrome was further defined by Griffin et al. (44) as "a motion-related clinical disorder of the hip with a triad of symptoms, clinical signs, and imaging findings. It represents symptomatic premature contact between the proximal femur and acetabulum". Appropriate symptoms, positive clinical examination, and imaging findings are required for a diagnosis of FAI syndrome.(44)

Pain is the primary symptom of FAI syndrome and is often aggravated with sustained activity or positions.(44) Considerable variability exists in the location, anatomical spread, and severity of pain, with seminal work by Clohisy et al. (49) describing pain in the groin region, but also within the lateral aspect of the hip, thigh (anterior or posterior), buttock and lower back (**Figure 1.5**). Symptoms can also coexist including, clicking, catching and locking.(44)

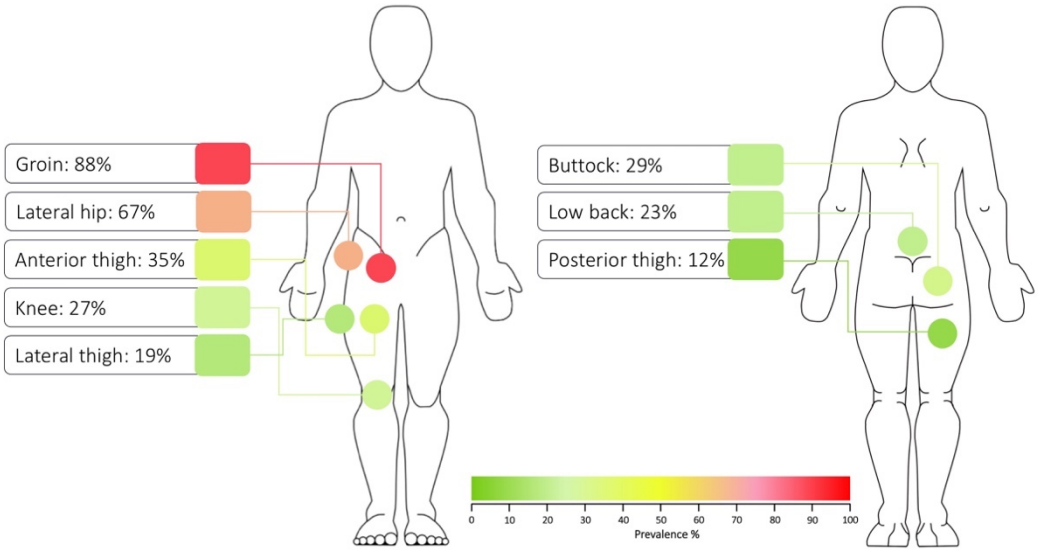


Figure 1.5. Location of pain in FAI syndrome.
Adapted from Clohisy et al. (49)

Hip impingement tests such as the flexion-adduction-internal-rotation (FADIR) and flexion-internal-rotation (FIR) test are commonly used clinical tests for FAI syndrome; however, their clinical utility is limited by high sensitivity and low specificity.(12,44) When test sensitivity is high, a negative test will rule out the disorder (e.g., FAI syndrome).(50) If test specificity is high, a positive test will rule in the disorder.(50) Therefore, hip impingement tests may be positive in people with and without FAI syndrome. Restricted range of motion, alterations in movement, and local muscular tenderness are other clinical findings present in FAI syndrome.(44)

The altered bony morphology seen in FAI syndrome is described as cam, pincer or mixed morphology.(44) Cam morphology is characterised by the presence of additional bone on the anterolateral head-neck junction of the proximal femur (**Figure 1.6**).(45,51) During terminal hip movement, cam morphology can abut against the acetabulum (i.e., cam impingement), which can lead to chondrolabral damage (**Figure 1.6**).(45) Cam impingement can also be caused by a retroverted femoral neck or head and low femoral neck shaft angle.(52) Pincer morphology can occur due to variations in the depth and/or orientation of the acetabulum,(45,53,54) causing linear contact between the acetabulum and femoral head (i.e., pincer impingement), and resulting in labral and circumferential cartilage damage (**Figure 1.6**).(45,55) The presence of cam and pincer morphology is described as mixed morphology.(54) Cam and/or pincer morphology can be identified with radiographs or cross-sectional imaging methods, such as computed tomography (CT) or magnetic resonance imaging (MRI).(44,53,56)

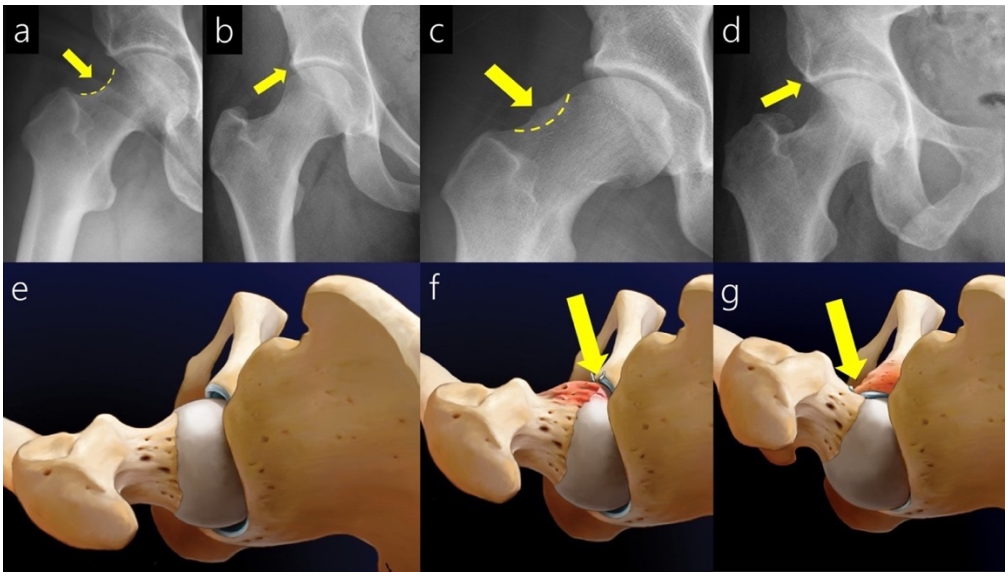


Figure 1.6. Bony hip morphology.
a) normal femoral morphology, b) normal acetabular morphology, c) cam morphology, d) pincer morphology, e) normal femoroacetabular articulation, f) cam impingement and g) pincer impingement. (Source e to g: Brukner and Khan. (13) Reproduced with permission)

An anteroposterior (AP) pelvis and lateral hip radiograph are recommended as the first imaging method to diagnose FAI syndrome.(56) Further evaluation is often completed with MRI or CT to gain a comprehensive understanding of bony anatomy (femoral and acetabular) and associated soft-tissue pathology.(56) For cam morphology, the alpha angle is used to quantify the degree of asphericity of the femoral head-neck junction (**Figure 1.7**).(51,53,56,57) A range of threshold values have been proposed (50 to 83°)(58), however, an alpha angle above 60° is recommended to define cam morphology.(56,57,59) Alpha angle values above 78° can discriminate hips more

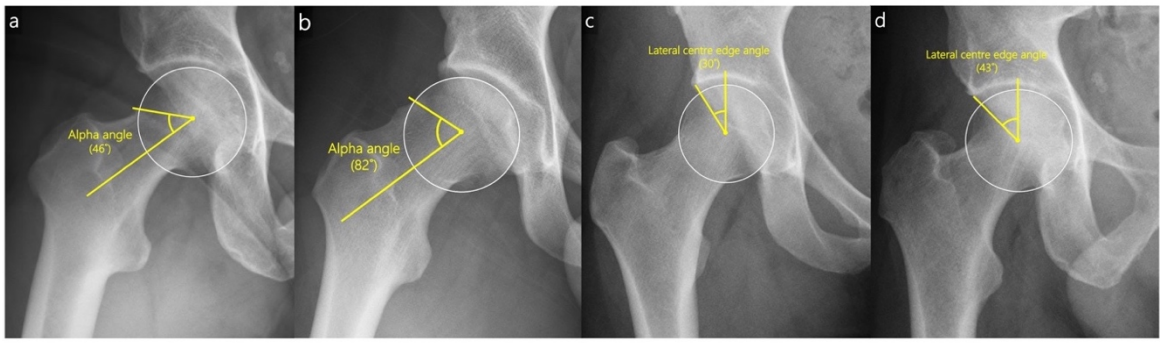


Figure 1.7. Imaging measures for bony hip morphology.
a) Dunn 45° radiograph with normal femoral morphology (alpha angle of 46°), b) Dunn 45° radiograph with cam morphology (alpha angle of 82°), c) anteroposterior radiograph with normal acetabular coverage (lateral-centre-edge-angle of 30°) and d) anteroposterior radiograph with pincer morphology (lateral-centre-edge-angle of 43°).

likely to develop end-stage hip OA.(59) Other quantitative measures exist to define cam morphology, including the triangular index, femoral offset, and offset ratio, although these measures are used sparingly in research and clinical practice.(53,56) Imaging criteria for pincer morphology include measures of increased acetabular coverage (e.g., centre-edge angle of Wiberg, lateral-centre-edge-angle (LCEA), and protrusio acetabuli) and orientation (e.g., cross-over sign, posterior wall sign).(53,54,56) The centre-edge angle (Wiberg and LCEA) is a commonly used measure, with a threshold value of above 40° used to classify pincer morphology (**Figure 1.7**).(56)

Few studies have reported the prevalence of FAI syndrome (i.e., symptoms, clinical signs, and imaging findings). While relatively common in sportspeople with hip/groin pain (45% of men and 21% of women),(37) it appears less prevalent in population-based samples.(60) The bony morphology (e.g., cam morphology) associated with FAI syndrome has been studied in far greater detail than the syndrome itself.(58,61,62) Despite this, establishing the prevalence of bony morphology in specific subgroups is difficult due to variability in threshold values and imaging methods. For cam morphology, two prior systematic reviews pooled heterogenous studies, reporting a prevalence of up to 66% in athletes, 23% in asymptomatic non-athletes, and 49% in symptomatic non-athletes.(61,62) A further systematic review did not undertake the pooling of studies, reporting a prevalence ranging from 5 to 75% in asymptomatic, symptomatic, and athletic populations.(58) Cam morphology appears to be more prevalent in men (29 to 58%) than women (5 to 36%).(58,63) Two reviews have outlined a higher prevalence of pincer morphology in asymptomatic non-athletes (57%) and athletic individuals (51%) relative to people with symptoms (29%)(61,62) The prevalence of pincer morphology appears similar in men and women.(64)

1.6.2. Acetabular dysplasia and hip instability

Acetabular dysplasia is a three-dimensional structural disorder, defined by Wilkin et al. (65) as "misalignment between the femoral head and the acetabulum secondary to changes in their shape, size, and orientation". This altered bony anatomy elicits instability, which can lead to overload and damage of chondrolabral structures and in time the development of hip OA.(65) Hip instability was defined by Shu et al. (66) as "extraphysiologic hip motion that causes pain with or without the symptom of hip joint unsteadiness". Hip instability can be caused by altered bony anatomy, functional deficits within capsuloligamentous, intra-articular or musculotendinous structures, or direct iatrogenesis.(66,67)

For acetabular dysplasia and hip instability, symptoms generally develop insidiously. Pain is often reported in the groin and/or lateral aspect of the hip and aggravated by either dynamic or static activity.(66–68) Several different clinical tests exist for acetabular dysplasia and/or hip instability (69), however their clinical utility remains limited.(69)

Acetabular coverage and/or orientation can be assessed with radiographs, CT, or MRI.(53,65) The LCEA is a key imaging parameter that evaluates the femoral head coverage provided by the superolateral aspect of the acetabulum (**Figure 1.7**).(70) An LCEA of less than 20° is the recommended threshold value for the diagnosis of acetabular dysplasia.(65) Radiologic measures, such as Tonnis angle, cross-over sign, ischial spine sign, and acetabular version angle can be used to evaluate acetabular orientation.(53,65) In contrast, no established imaging criteria exist for hip instability.(12)

In three large Scandinavian population studies, the prevalence of radiologic signs of acetabular dysplasia ranged from 1.7 to 20%.(71–73) Broadly, the prevalence of acetabular dysplasia appears to be similar in people with and without symptoms.(71,74,75) In athletes, considerable variation in prevalence is found between studies and across sports (1.9 to 37%).(76–80) Sex-based differences are minor (71,72,74).

1.6.3. Other conditions without distinct osseous morphology

Hip-related pain can be caused by isolated or combined cartilage, labral, and ligamentum teres conditions.(12) They can exist in isolation or concurrently with FAI syndrome or acetabular dysplasia/hip instability.(12) In asymptomatic people, imaging findings (e.g., cartilage, labral, and ligamentum teres changes) are considered incidental findings.(12)

I. Chondral conditions

Chondral conditions (e.g., cartilage defects, cartilage delamination) can be found on acetabular and femoral articular surfaces.(12,81) When intact, articular cartilage is aneural, avascular, and alymphatic, which limits its capacity to initiate structural repair or generate symptoms.(82,83) However, progressive chondral damage can contribute to nociception through secondary mechanisms. For example, exposure of subchondral bone that is richly innervated with nociceptors, the release of inflammatory mediators or cartilage debris that act on the synovium and initiate synovitis and chondrocyte driven release of nerve growth factor.(83,84) The anatomical location and severity of chondral conditions are associated with specific variations of bony hip morphology.(55,85,86) Chondral damage exists within the anterosuperior quadrant of the acetabulum in hips with cam morphology, whereas circumferential defects occur in those with pincer morphology. Factors such as increasing age,(85,87,88) male sex,(85,87,88) body mass index(87), and level of physical activity(85) have been linked to the presence of chondral conditions.

It is unclear if people with chondral conditions exhibit specific clinical signs and/or symptoms(12); however, as cartilage damage often coexists with other causes of hip-related pain, the clinical profile would likely be similar to that seen in other conditions (e.g., FAI syndrome, acetabular dysplasia).

Magnetic resonance imaging is the preferred technique to evaluate chondral morphology and composition (Figure 1.8).(89–91) However, assessment with MRI is challenging due to the location of the hip joint relative to the magnetic isocentre, the closely apposed and curved joint surfaces, and the thin layer of articular cartilage.(89) Magnetic resonance imaging techniques with and without contrast afford similar accuracy to assessment of chondral conditions,(92–94) with high-resolution MRI often used to circumvent the risks associated with contrast agents.(95,96) Quantitative and semi-quantitative measurement methods can be used for assessment of chondral morphology.(89) Specific MRI techniques such as delayed gadolinium-enhanced MRI of cartilage (dGEMRIC), T2 and T1rho mapping can evaluate the biochemical composition of cartilage.(89,97) Contrast-enhanced CT provides an accurate evaluation of chondral morphology(16,98), although the exposure to radiation limits its use.

There is limited literature reporting the prevalence of imaging-defined chondral conditions. Chondral conditions are more prevalent in non-athletic individuals with hip/groin pain (30 to

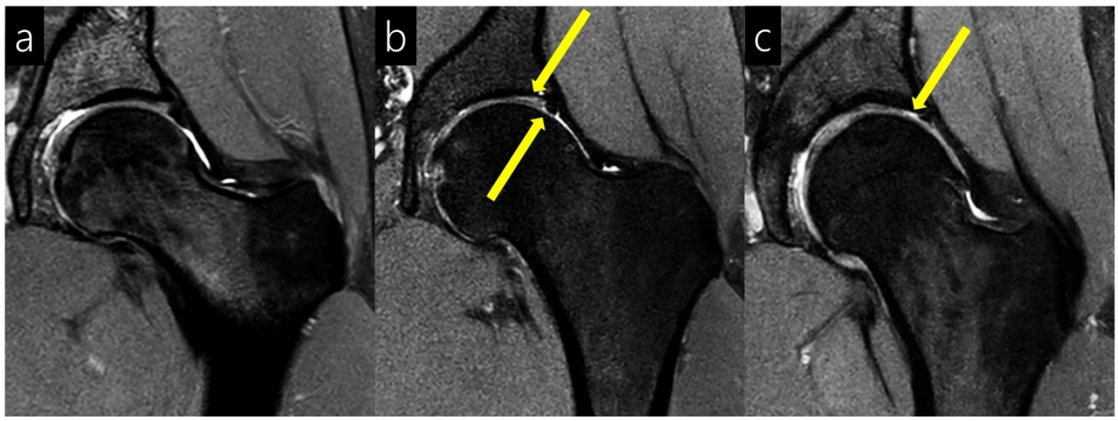


Figure 1.8. Cartilage conditions on unenhanced MRI.
a) no labral tear, b) partial thickness acetabular and femoral cartilage defects and c) full thickness acetabular cartilage defect.

95%)(99–101) than without pain (6 to 24%)(101–103), with a low prevalence reported in athletes (9%).(62) It is unclear if men or women display a higher prevalence of chondral conditions.(101,102,104) In people undergoing hip arthroscopy, over 70% have chondral conditions,(81,105) with men exhibiting more advanced damage than women.(106)

II. Labral conditions

Labral conditions (e.g., labral tears, labral degeneration) can be a source of nociception.(107) A multifactorial aetiology was proposed, involving joint trauma, congenital hip conditions, hip joint degeneration, capsular laxity, and alterations in bony morphology.(107,108) Labral conditions are classified by anatomical location and morphology (e.g., radial flap, longitudinal, peripheral).(109)

The diagnosis of labral conditions can be challenging, with symptoms, clinical findings, and diagnostic imaging recommended.(12,107) Groin pain with associated mechanical symptoms, such as clicking, or locking is common in people with labral tears.(12,107–109) On clinical examination, pain reproduced with the Thomas test may increase the probability of a labral tear being present.(12) The FADIR and FIR tests may assist in excluding labral conditions.(12)

Magnetic resonance imaging is the preferred imaging technique for labral conditions, as it provides excellent soft-tissue contrast (**Figure 1.9**).(56,107,108) Contrast-enhanced MRI is superior to unenhanced MRI for labral conditions.(12,92,110) High-resolution unenhanced techniques may also provide acceptable accuracy.(95,96) Other imaging techniques for labral conditions include contrast-enhanced CT and ultrasound.(111)

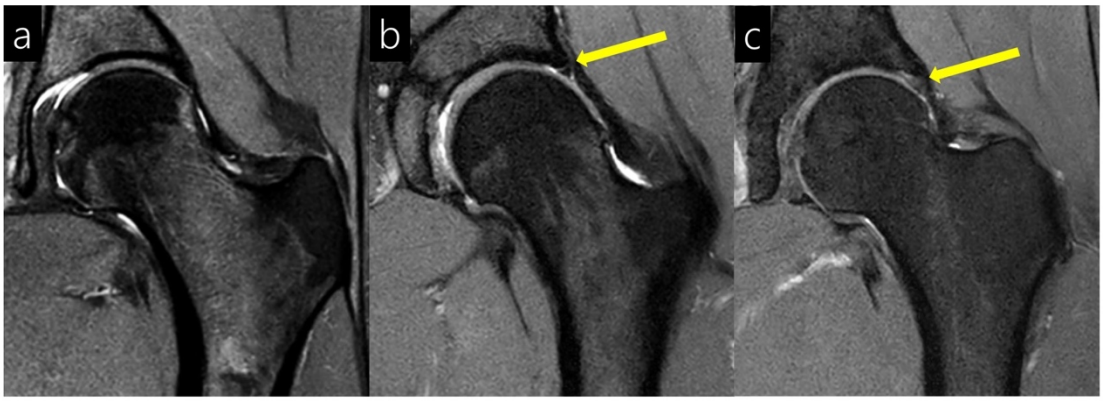


Figure 1.9. Labral conditions on unenhanced MRI.
a) no labral tear, b) labral tear chondrolabral separation and c) labral tear with maceration.

Labral tear prevalence is high in individuals with and without hip/groin pain.(61,62) Sixty-six to 82% of non-athletic individuals with pain had MRI-defined labral conditions,(99,101) with a high prevalence of incidental labral findings also found in asymptomatic non-athletes (65%).(101) Up to 65% of asymptomatic athletes had incidental labral findings on MRI.(61,62) Some, but not all studies report sex-based differences in labral condition prevalence.(102,103,112)

III. Ligamentum teres conditions

The ligamentum teres is a pyramidal-shaped ligament that acts as a secondary stabiliser of the hip joint.(20,113) Ligamentum teres conditions can be a source of nociception, with studies of people undergoing hip arthroscopy reporting a tear prevalence of 5 to 51%.(114–117) The aetiology is poorly understood but may involve hip trauma or pre-existing bony conditions, such as hip dysplasia and FAI syndrome.(20,113)

Activity-related groin pain and associated mechanical symptoms, such as clicking, popping, locking, or giving way may be present in people with ligamentum teres tears.(117) The ligamentum teres test is a useful clinical examination technique to assess the presence of ligamentum teres tears, with high sensitivity (90%) and specificity (85%).(118)

Magnetic resonance imaging is the preferred imaging technique for ligamentum teres conditions (**Figure 1.10**). Contrast-enhanced MRI can accurately assess the presence but not the severity of ligamentum teres conditions,(119) whereas unenhanced MRI techniques appear to provide variable accuracy for assessing ligamentum teres.(119)

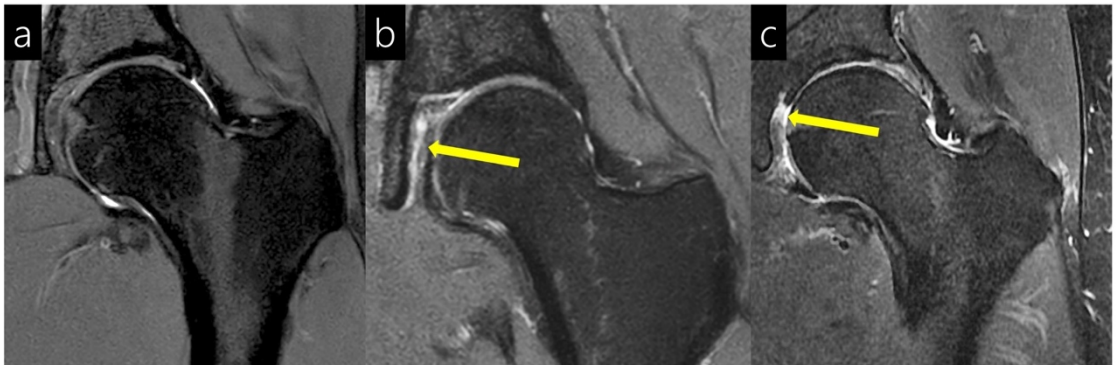


Figure 1.10. Ligamentum teres conditions on unenhanced MRI.
a) no ligamentum teres tear, b) partial thickness ligamentum teres tear and c) full thickness ligamentum teres tear.

Ligamentum teres tear prevalence is understudied in non-surgical populations. Non-athletic individuals with and without symptoms have a similar and low prevalence (2%).(102,120) Athletes appear to have a high prevalence of ligamentum teres tears (55% and 81%).(121,122) Men and women appear to have a similar prevalence of ligamentum teres tears.(122)

IV. Other imaging conditions

Although not officially defined as a cause of hip-related pain, other soft-tissue pathologies such as effusion-synovitis, paralabral cysts, subchondral cysts, and bone marrow lesions (BML) may be involved in symptom genesis and the progression of joint disease.(123–125) The clinical presentation, diagnostic criteria, and epidemiology of such features are poorly defined in the literature.

1.7. Hip joint imaging findings and hip/groin pain

In football players, the origin of hip/groin pain is multifactorial. Hip joint imaging findings may contribute to the genesis of symptoms. With the advancement of MRI techniques, an array of different soft tissue conditions can now be assessed.(89) Theoretically, a greater number of intra-articular conditions would be present in a football player with hip/groin pain. However, there is often a discordant relationship between imaging findings and pain.(126–128)

Over the past two decades, the understanding of pain and how it is generated has evolved considerably, leading to the International Association for the Study of Pain (IASP) revising the definition of pain in 2020.(129) Pain is now defined as "an unpleasant sensory and emotional

experience associated with, or resembling that associated with, actual or potential tissue damage".(129) In addition to the new definition, the IASP highlight the following key points about pain; (i) pain perception is directly influenced by biological, psychological, and social factors, (ii) nociception and pain are different: activation of nociceptors is not crucial to pain generation, and (iii) pain is a learned experience.(129)

The pain experienced will be influenced by a complex interplay between biological, psychological, and social factors.(130) At a tissue level, intra-articular structures (e.g., acetabular labrum, ligamentum teres, and synovium), except for articular cartilage, contain nociceptors.(83,131,132) Activation of nociceptors can occur due to tissue injury (actual or impending) or inflammation.(130,133) The nociceptors can elicit signals (action potentials) that travel to the dorsal horn of the spinal cord and undergo modulation (i.e., the nociceptive signal can be dialled up or down).(130,133) From the dorsal horn, signals ascend to multiple areas of the brain, including the cerebral cortex and limbic system.(130,133) The activation of these specific combinations of neurons in multiple brain areas is termed a 'pain neurotag' or 'neurosignature'.(134) The pain experience reflects one's psychological state (e.g., presence of anxiety, depression, or catastrophising) and social situation (e.g., cultural, familial or work-related factors) but is also linked with movement and what people can see and hear. These constructs can inhibit (reduce) or facilitate (increase) pain.(130) Pain is also a learned experience, meaning that over time the neurotag can fire without nociceptive input.(130) The experience of pain during an activity then becomes quite complex as it is not just the movement and nociceptive stimulus but anticipation, memory, and context of the activity. The sensory neurons in the periphery and spinal cord can become more sensitive, leading to lower levels of stimuli required to activate them.

It is currently unclear whether hip joint imaging findings are associated with hip/groin pain.(58,62,64) A review by van Klij et al. (64) concluded that there is conflicting evidence for the relation of bony morphology and hip/groin pain. In reality, symptom genesis is driven by conditions that occur secondary to altered bony morphology (e.g., labral tears, ligamentum teres tears, or synovitis). In a prospective study (n=200) of young to middle-aged individuals, cam morphology was associated with an increased risk of developing hip pain over 4 years (relative risk (RR) = 4.5, 95% confidence interval (CI): 2.3, 9.1).(135) However, in absolute terms, only 7 of the 44 hips (16%) with cam morphology developed pain, bringing into question whether cam morphology plays a key role in the development of hip/groin pain. In several studies, the link between bony hip morphology and hip/groin pain is inconsistent.(136–141) When evident,

increases in cam morphology size have trivial associations with quality of life diminution or increases in pain. For example, Dickenson et al.(140) reported that with every one-degree increase in alpha angle there was a lowering of the International Hip Outcome Tool (iHOT33) by 0.5 (out of 100). The relationship of other soft tissue conditions (e.g., chondral, labral, and ligamentum teres) and pain is understood to a lesser extent. Select features (subchondral cysts, BME, and paralabral cysts) appear related to hip/groin symptoms, but the strength of these relationships may be of little clinical relevance when present.(123) Studies of athletes have failed to find an association between key intra-articular conditions (chondral, labral, and ligamentum teres) and pain.(104,122,142) These studies have major limitations in that they were undertaken in athletes with low levels of pain (median HAGOS pain score of 100) and without clinical findings synonymous with hip-related conditions (e.g., FADIR test). Therefore, the relevance of these soft-tissue conditions in athletes with hip/groin pain warrants further investigation.

Hip-related pain conditions and hip OA may exist along a disease continuum. The onset of symptoms may signify the progression of disease (**Figure 1.11**).(83) While hip OA has long been considered a disease of older age, it can also affect young to middle-aged people (i.e., early hip OA).(143) The presence of altered or incongruent hip morphology, high levels of physical activity, and hip joint injury may be important in the pathogenesis of early OA and will be discussed in the following section.

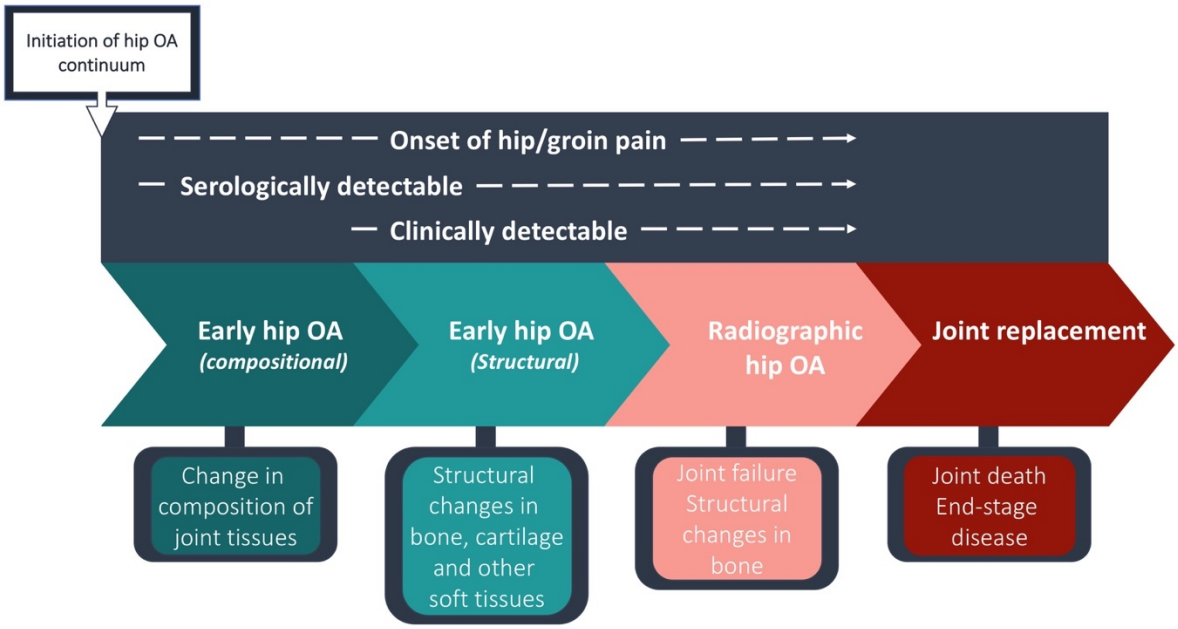


Figure 1.11. Hip osteoarthritis continuum.
Adapted from Hunter et al. (83)

1.8. Hip osteoarthritis in football players

1.8.1. What is osteoarthritis?

Osteoarthritis is characterised as an active disease of the whole synovial joint that can lead to end-stage joint failure.(144–146) Changes in articular cartilage morphology and/or composition, as well as surrounding soft tissues, such as synovium, ligaments, subchondral bone, and periarticular muscles are key features of the disease process.(89,144–146) The pathogenesis of OA involves the complex interplay between mechanical, systemic (inflammatory and metabolic), environmental and genetic factors.(145) In early OA, changes to composition (i.e., matrix macromolecular framework) and focal fibrillation of the superficial articular cartilage layer are observed.(145,147) In a bid to repair tissue damage, chondrocyte activity increases, which leads to the generation of cartilage matrix degradation products and proinflammatory mediators, which induce inflammation of the synovium and the subsequent release of inflammatory products that further alter chondrocyte activity.(145–147) There is also a concomitant increase in bony remodelling and vascular invasion.(145,148) With disease worsening, deep cartilage fissures develop, which leads to exposure subchondral bone. Subchondral remodelling further progresses with thickening of the cortical plate, reduced bone turnover, changes in bony architecture and material properties, and the development of bone marrow edema, subchondral cysts, and osteophytes.(145,146,148) In advanced OA, the structural joint deterioration is at a point where treatment options are limited.(144–146) Identifying individuals with or at risk of early hip OA may allow for interventions or therapeutic approaches that slow or even reverse disease.

Unlike the knee, imaging features of early OA have yet to be formally defined in the hip. For this thesis, intra-articular findings present on MRI in an individual without definite radiographic hip OA (i.e., Kellgren and Lawrence (KL) grading of 0 or 1) will be considered features of early OA. When intra-articular features are reported without accompanying KL grading, they will be defined as intra-articular conditions, in line with recent consensus recommendations.(12)

1.8.2. Burden

Osteoarthritis is a common cause of pain, disability, and socioeconomic burden,(149) with an estimated 300 million people worldwide affected by knee or hip OA.(150) In Australia, health-care-related costs are estimated to be $3.5 billion, which represents close to a third of all expenditures for musculoskeletal conditions.(151) Osteoarthritis also contributes to substantial indirect costs through loss in productivity, premature death, and early retirement.(149)

Furthermore, people living with OA have significantly higher rates of coexisting chronic health problems, including cardiovascular disease, diabetes, and mental or behavioural conditions.(151,152)

1.8.3. Risk factors for hip osteoarthritis

Joint (e.g., cam morphology, hip dysplasia) and whole person (e.g., age, sex, weight) level risk factors exist for hip OA.(153) Importantly, joint and whole person-level risk factors may be interrelated. For example, joint level risk factors are thought to drive the pathogenesis of hip OA, with whole person-level risk factors contributing indirectly by predisposing a person to specific joint conditions.(153)

1.8.4. Joint level risk factors

Altered or incongruent hip joint morphology plays an important role in the pathogenesis of hip OA. While specific childhood hip conditions (e.g., Legg-Calvé-Perthes disease and slipped capital femoral epiphysis (SCFE)) have long been considered a cause of early hip OA, they are outside the scope of this thesis and will not be discussed in detail. The following section will discuss the relation of hip joint morphology (cam morphology, pincer morphology, and acetabular dysplasia) and hip OA development.

I. Cam morphology

When the aspherical femoral head passes through the anterosuperior acetabulum, the chondrolabral structures are subjected to compressive and shear stresses.(45,154) With ongoing impingement, this might lead to the development of early OA, specifically cartilage and labral conditions.(45,154) The pathological interaction between cam morphology and joint soft tissues may start as early as adolescence. In adolescents undergoing hip arthroscopy, cam morphology was associated with increased odds of acetabular cartilage damage (Odds ratio (OR) = 1.80, 95%CI: 1.2, 2.6). Furthermore, young athletes with cam morphology were at greater risk of worsening joint damage (over a 5 year time period) when compared to those without (RR = 2.5, 95%CI: 1.1, 6.0).(155) It is biologically plausible that young people with cam morphology would continue along the OA continuum and develop advanced disease. While cross-sectional investigations support the association of cam morphology and chondrolabral damage in young people,(85,88,156,157) prospective studies demonstrating this causative relationship are still needed.

In middle-aged to older people, cam morphology is a strong risk factor for hip OA. Three large prospective studies have investigated the relation of cam morphology and hip OA development. First, the Cohort Hip and Cohort Knee (CHECK) cohort studied 1002 individuals in the Netherlands with clinical findings of early knee or hip OA.(158) Participants aged between 45 to 65 years underwent radiographs at study inception and at the 5-year study timepoint. In participants without definite hip OA (i.e., KL ≤1) cam morphology (alpha angle >60°) and large cam morphology (>83°) were associated with close to 4-fold and 10-fold increased odds of developing end-stage hip OA (KL 3, 4 or undergoing total hip arthroplasty (THA)), respectively. When large cam morphology was combined with reduced internal rotation (≤20°), there was a 25-fold increased odds of developing end-stage hip OA.(158) Second, the Rotterdam Study (n=4,438) included people 55 years or older without hip OA, with an average follow up of 9 years.(159) Cam morphology was associated with the development of definitive hip OA (i.e., KL≥ 2) or undergoing THA (OR = 2.11, 95%CI: 1.55, 2.87), with this association stronger in those 65 years or younger (OR = 3.07, 95%CI: 2.05, 4.60).(159) Last, the Chingford cohort (n=1003) was a study of women living in the United Kingdom aged 44 to 67 years. An association was observed between larger alpha angle values at baseline (2-year study time point) and the development of hip OA 19 years later. A one degree increase in an alpha angle above 65° was associated with a 5% and 3% increased odds of definitive hip OA (i.e., KL ≥ 2) and THA respectively.(160)

II. Pincer morphology

Pincer morphology can cause linear contact between the acetabular rim and femoral head-neck junction during terminal hip movements.(45,55,154) Repetitive pincer impingement may lead to labral conditions and in time the development of circumferential cartilage damage.(45,55,154) Not all studies of adolescents and young adults support the pathomechanism of pincer impingement.(85,87,88,112,155,161) Intra-operative findings in adolescents suggest that pincer morphology may protect acetabular articular cartilage (OR = 0.24, 95%CI: 0.08, 0.68).(87) In middle-aged to older adults, the association between pincer morphology and the development of hip OA is less apparent than found for cam morphology. Pincer morphology was not associated with the development of hip OA in older adults in the CHECK (KL 2: OR = 0.62, 95%CI: 0.26, 1.46; KL 3, 4 or THA: OR = 0.28, 95%CI: 0.07, 1.21) or Chingford cohorts (KL≥2: OR = 1.03, 95%CI: 0.92, 1.15; THA: OR = 0.97, 95%CI: 0.84, 1.12).(160,162) In fact, pincer morphology decreased the odds of hip OA (OR = 0.34, 95%CI: 0.13, 0.87) in the CHECK cohort.(162) In the Rotterdam Study, associations between pincer morphology and hip OA were only present in participants with a KL

grade of 0 at baseline (OR = 1.60, 95%CI: 1.02, 2.51) and with a follow-up duration of greater than 9 years (OR = 1.50, 95%CI 1.09, 2.07).(159)

III. Acetabular dysplasia

Acetabular dysplasia results in structural instability between the femur and acetabulum and the overload of chondrolabral tissue.(65) If left untreated, cartilage and labral conditions can develop and eventually become hip OA.(65) Young people with acetabular dysplasia exhibit features of early OA, such as lower dGEMRIC indices (i.e., lower glycosaminoglycan content), labral and cartilage conditions, and cystic changes.(85,163–166) In older adults, three population-based longitudinal studies have reported a link between acetabular dysplasia and the development of hip OA.(159,160,162) In the CHECK study, mild acetabular dysplasia (LCEA or anterior-centre-edge-angle <25°) was associated with an up to 5.5-fold increased odds of incident hip OA, with stronger associations found for end-stage hip OA. Similarly, in the Rotterdam study, acetabular dysplasia (LCEA <20°) was associated with the development of hip OA (OR = 2.19, 95%CI: 1.5, 3.2). Every degree reduction in LCEA below 28° was associated with an increased odds of hip OA (OR = 0.87, 95%CI: 0.78, 0.96) and THA (OR = 0.82, 95%CI 0.75, 0.89) in the Chingford cohort.(160)

IV. Joint injury and/or hip-related pain

Joint injury is an established risk factor for hip OA development (OR = 5.0, 95%CI: 1.4,18.2).(167) Hip-related pain and hip OA likely exist along a continuum of disease.(145,153) Labral tears are a common joint injury that can occur concurrently with FAI syndrome or acetabular dysplasia and also exist in isolation.(12,153) As outlined earlier, the labrum functions to enhance joint stability and distribute cartilage contact stress.(17) Cross-sectional investigations(99,102,142) support the deleterious effect that labral tears have on articular cartilage, but prospective studies are needed to understand their role in hip OA development.

V. Periarticular hip muscles

The hip and lower limb muscles are essential for efficient movement and shock absorption.(168) Deficits in hip muscle strength exist in people early on the hip OA continuum (i.e., hip-related pain) and in people with established hip OA.(169,170) Interventions focussing on improving muscle strength are important in the management of hip OA, although it is unclear if improving strength slows the progression of disease or can mitigate other risk factors, such as altered hip morphology.

1.8.5. Whole person-level risk factors

Whole person-level factors may influence the risk of hip OA by the effect they have on joint level risk factors. Hip OA prevalence differs between races,(171) but race is associated with hip morphology, so variation in OA prevalence between races might be explained through differences in hip morphology.

I. Physical activity

Exposure to repetitive high-impact activity may have a deleterious effect on cartilage health and expedite the development of hip OA.(172,173) Several studies have reported a link between participation in high-impact physical activity and hip OA development.(172,174,175). Petrillo et al. (175) found a higher prevalence of clinical (OR = 1.5, 95%CI: 1.1, 2.3) and radiographic (OR = 2.4, 95%CI: 1.7, 3.17) hip OA in retired male professional soccer players than in matched controls. A Swedish study (n=2077) reported that former elite-level male soccer players had 3-times the odds of undergoing THA when compared to age-matched non-athletic individuals.(173) While several theories have been proposed,(173) it is plausible that the association between high-impact physical activity and hip OA could be explained by the presence of altered hip morphology. In particular, the role of cam morphology (which has a high prevalence in athletes) warrants further investigation. Hip joint injury is a consequence of high-impact physical activity and a risk factor for hip OA.(37) Therefore, it is possible that hip joint injury may act as a mediator variable for the association between physical activity and hip OA.

II. Other factors

Increasing age, body mass index, genetic factors, heavy manual occupations, and ethnicity have all been linked with the development of hip OA.(153) A systematic review of 14,000 participants did not identify a difference in prevalence or severity of hip OA between men and women.(176) However, a subsequent population-based study of over 3 million participants found higher rates of hip OA in men in the 4th decade of life, with rates higher in women from the 5th through 7th decades.(177)

Joint and whole person risk factors exist for hip OA, although not all people exposed to these risk factors will develop OA. In the study of Agricola et al. (158) hips with cam morphology (alpha angle >83˚) and reduced hip internal rotation (≤20˚) had a 25-fold increased odds of developing end-stage hip OA than hips without either condition (**Figure 1.12**). When considered in absolute

terms, only half (53%) of the hips with both conditions developed OA (**Figure 1.12**). Measures of relative effect (e.g., OR, RR) express the likelihood of an outcome in one group (e.g., cam morphology) relative to another group (e.g., no cam morphology).(178) Absolute risk represents the likelihood of an event (e.g., hip OA) occurring in a given population (e.g., hips with cam morphology).(178) Measures of relative risk should be considered alongside absolute risk to provide context.(178)

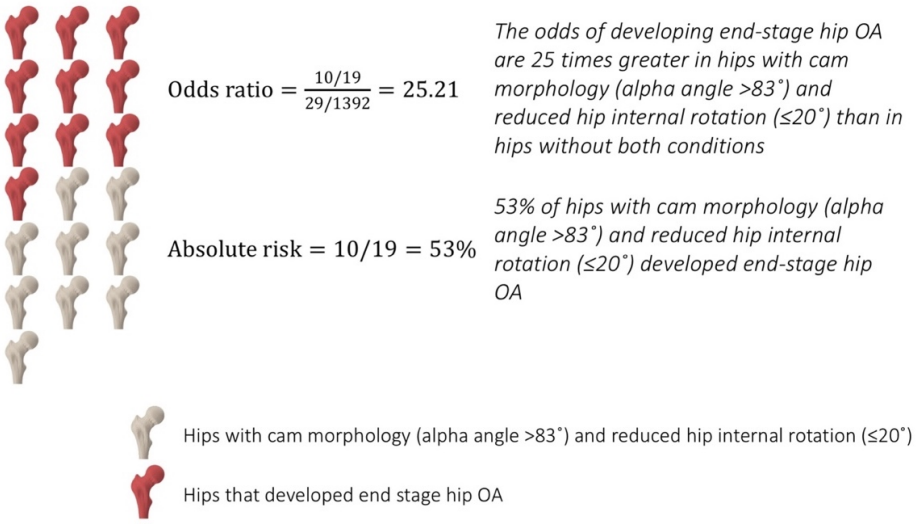


Figure 1.12. Odds ratio and absolute risk for developing hip OA.
Study data from Agricola et al. (158)

1.9. Imaging for the hip osteoarthritis continuum

The role of imaging in the diagnosis and management of hip OA has been a source of debate.(179) Hip OA can be diagnosed without imaging findings; however, the increased availability and development of different imaging methods has resulted in its ongoing use.(179) The following section will outline the commonly used imaging methods for the different stages of hip OA.

1.9.1. Radiographs

When indicated, plain radiographs of the hip joint and pelvis should be the first imaging method used in the evaluation of hip OA.(91,179) As a projection technique, radiographs can be affected by patient positioning, film to tube distance, and overlying soft-tissues.(89) Radiographs provide a two-dimensional understanding of the hip and pelvis and evaluate bony features of established hip OA (e.g., joint space narrowing, osteophytes, and subchondral sclerosis), bony hip

morphology, and other pathologies (e.g., bone tumours, fractures).(89,91,180) Quantitative (e.g., joint space width (JSW)) and semi-quantitative scoring methods, such as the KL grading, the Croft score, and the OARSI atlas are used in the assessment of hip OA.(89) Importantly, radiographs cannot visualise soft-tissue structures involved in the pathogenesis of early OA, such as articular cartilage (**Figure 1.13**), labrum, and synovitis.(89)

1.9.2. Magnetic resonance imaging

Magnetic resonance imaging provides superior visualisation of soft-tissue structure and composition (**Figure 1.13**).(89) Put simply, MRI uses a powerful magnetic field and radiofrequency (RF) pulses to provide detailed anatomical images.(181) Most clinical applications of MRI detect hydrogen atoms, which are abundant in the human body and MRI active.(181–183) When hydrogen atoms are exposed to an external magnetic field (i.e., within an MRI magnet) a net magnetisation vector is created.(181–183) The application of an RF pulse causes the net magnetisation vector to move from the longitudinal to the transverse plane.(181–183) Following the cessation of the RF pulse, the net magnetisation vector returns to the longitudinal plane, a process known as T1 relaxation.(181–183) The loss of transverse magnetisation is known as T2 relaxation.(181–183) The T1 and T2 relaxation values vary across different anatomical structures.(181–183) It is the transverse magnetisation that induces a current within a receiver coil, which becomes the MRI signal, from which magnetic resonance images can be formed.(181–183) The contrast between tissues afforded by MRI is influenced by tissue specific factors, and technical or acquisition parameters.(181–183) Repetition time (TR) and echo time (TE) are two key MRI parameters that can be manipulated to create tissue-dependent contrasts.(181–183) Repetition time (measured in milliseconds) is the time between the onset of an RF pulse and the start of the next RF pulse.(181–183) Echo time is the time between an RF pulse and the peak of the MRI signal and is also measured in milliseconds.(181–183) Specifically, TR affects T1 weighting, with TE affecting T2 weighting of an image sequence.(181–183) T1 weighted images have short TE (<30ms) and TR (<1000ms), meaning tissues with a short T1 time (e.g., fat) have higher signal intensity than tissues with a longer T1 time (e.g., water).(181–183) T1 weighted images are used to appreciate bony anatomy, fractures, and bone marrow pathologies.(181,182) T2 weighted images have a long TR (>60ms) and TE (>2000ms), enabling visualisation of tissues with longer T2 decay values (e.g., water).(181–183) T2 weighted sequences allow for recognition

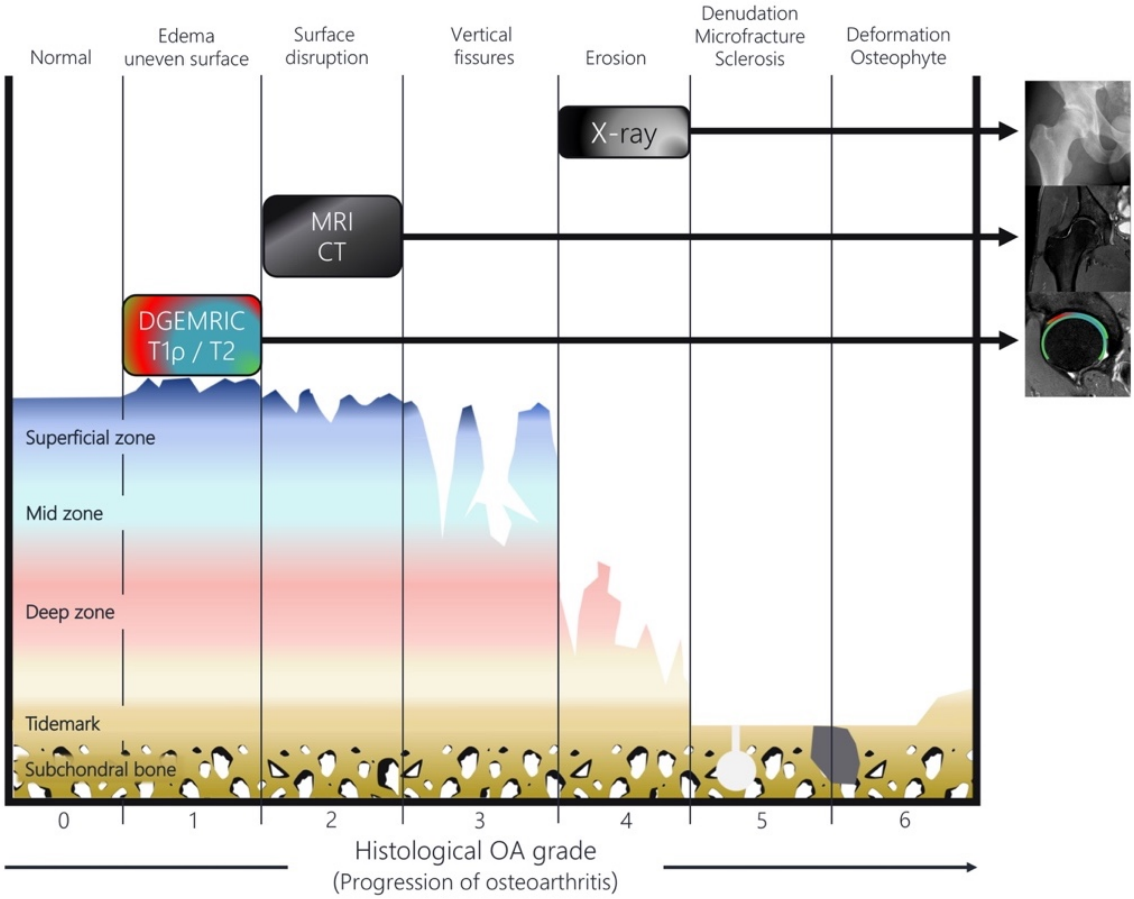


Figure 1.13. Progression of articular cartilage damage through the different stages of osteoarthritis and imaging methods that can be used for assessment.
Adapted from Pollard et al. (282)

of edema (bone or soft tissue) and evaluation of cartilage or cystic changes.(181–183) Proton density (PD) sequences that use a short TE and long TR highlight differences in PD between tissues, providing image contrast.(182) Proton density images enable appreciation of anatomic detail, in particular articular cartilage.(182,183) Magnetic resonance imaging can be performed with contrast agents (i.e., magnetic resonance arthrography).(182,183) Gadolinium is a commonly used contrast agent, which can be administered directly (intra-articular) or indirectly (intra-venous).(183) High signal intensity will be observed in tissues where contrast agent accumulates.(183) Advanced MRI techniques, including dGEMRIC, T2, and T1rho mapping can be used to evaluate articular cartilage composition (**Figure 1.13**).(89)

Quantitative and semi-quantitative MRI measures can be used to assess of intra-articular features involved in the pathogenesis of hip OA. Quantitative measures are primarily used to determine the thickness and volume of articular cartilage but can also measure BMLs and synovitis.(89) A semi-quantitative measure can characterise and monitor hip OA, and is recommended for use in

clinical research.(89) The hip osteoarthritis MRI scoring system (HOAMS) is a whole joint scoring system that evaluates 14 articular features (Table 1.1).(124) Cartilage morphology is scored in nine subregions, with BMLs and subchondral cysts evaluated in 15 subregions. The scoring of hip osteoarthritis with MRI (SHOMRI) evaluates eight features of hip OA.(123) Of these, cartilage, BMLs and subchondral cysts are evaluated in 10 different subregions (six femoral and four acetabular), with labral abnormalities scored in four different acetabular subregions (anterior, anterosuperior, superior, posterior) (Table 1.1). Comparatively, the hip inflammation MRI scoring system (HIMRISS) only measures three soft tissue features (BMLs, synovitis, and effusion) (Table 1.1).(184) Semi-quantitative measures have acceptable intra and inter-observer reliability, with select features associated with PROMs and hip range of motion measures (Table 1.1).(123,124,184)

1.9.3. Other imaging techniques

Computed tomography has shown promise to evaluate subchondral bone and articular cartilage.(91) The widespread use of CT is limited by radiation exposure and it is unknown if CT techniques are superior to other forms of imaging to evaluate OA.(91) Single-photon emission computed tomography (SPECT) and positron emission tomography (PET) are emerging imaging techniques that can evaluate macrophage activity within the synovium and bone turnover.(91)

1.10. Synopsis and thesis justification

Hip/groin complaints are common in football players.(5,7,9) Although hip-related pain is not a common cause of time-loss injury,(5,9) it is present in approximately 40% of soccer players with longstanding pain(37) and considered to be a pre-cursor to hip OA. Bony hip morphology and intra-articular conditions are used alongside symptoms and clinical findings to diagnose hip-related pain.(12) Many hip joint imaging findings are also present in athletes without pain(61,79,185–187) suggesting a complex relationship between such features and symptom genesis. Importantly, the relationship between hip joint imaging findings and hip/groin pain has yet to be comprehensively studied in soccer or AF players (Figure 1.14). Understanding this relationship may assist in identifying structural sources of hip/groin pain and subsequently improve the clinical management of football players.

Table 1.1. Semi-quantitative hip magnetic resonance imaging measures.

	MRI/MRA	No. of features	Features assessed (no. of subregions)	Reliability	Association between MRI features and radiographic/clinical measures
SHOMRI(123)	MRI	8	Articular cartilage (10); BML (10); subchondral cysts (10); labrum (4); paralabral cysts; effusion-synovitis; loose bodies; ligamentum teres	**Intra-observer** *W kappa = 0.65 to 0.79* *ICC = 0.93 to 0.98* **Inter-observer** *W kappa = 0.55 to 0.79* *ICC = 0.91 to 0.94*	**Radiographic** KL grading *(ρ = 0.21 to 0.52)* OARSI hip OA score *(ρ = 0.18 to 0.51)* **Clinical measures - PROM** HOOS-Pain *(ρ = 0.10 to 0.40)* HOOS-Symptom *(ρ = 0.03 to 0.35)* HOOS-ADL *(ρ = 0.08 to 0.44)* **Clinical measures – hip ROM** Hip flexion *(ρ = -0.01 to -0.17)* Hip abduction *(ρ = -0.04 to -0.37)* Hip adduction *(ρ = 0.00 to -0.37)* External rotation *(ρ = -0.01 to -0.27)* Internal rotation *(ρ = -0.02 to -0.33)*
HOAMS(124)	MRI MRA	14	Articular cartilage (9); BML (15); subchondral cysts (15); osteophytes; labrum; synovitis; effusion; loose bodies; attrition; dysplasia; trochanteric bursitis /insertional tendinitis; labral hypertrophy; paralabral cysts; herniation pits	**Intra-observer** *W kappa = 0.18 to 0.85* **Inter-observer** *W kappa = 0.15 to 0.85*	**Radiographic** KL grading (*P* = <0.05 for 9/14 features) **Clinical measures – PROM** HOOS-Pain (aOR = 0.28 to 7.66) HOOS-function* (aOR = 0.36 to 7.23)
HIMRISS(184)	MRI	3	BML (100) Effusion-synovitis (15)	**Inter-observer** *ICC = 0.52 to 0.70*	**Clinical measures – PROM** WOMAC-Pain (*P* = ≤ 0.001)

*Combined HOOS symptoms and sport and recreation subscales

aOR = adjusted odds ratio; ADL = activities of daily living; BML = bone marrow lesion; HIMRISS = hip inflammation MRI scoring system; HOAMS = hip osteoarthritis MRI scoring system; HOOS = hip dysfunction and osteoarthritis outcome score; ICC = intraclass correlation coefficient; KL = Kellgren and Lawrence; MRA = magnetic resonance arthrography; MRI = magnetic resonance imaging; OARSI = osteoarthritis research society international; SHOMRI = scoring of hip osteoarthritis with MRI; W = weighted; WOMAC = Western Ontario and McMaster Universities Osteoarthritis index; ρ = Spearman's rank correlation coefficient

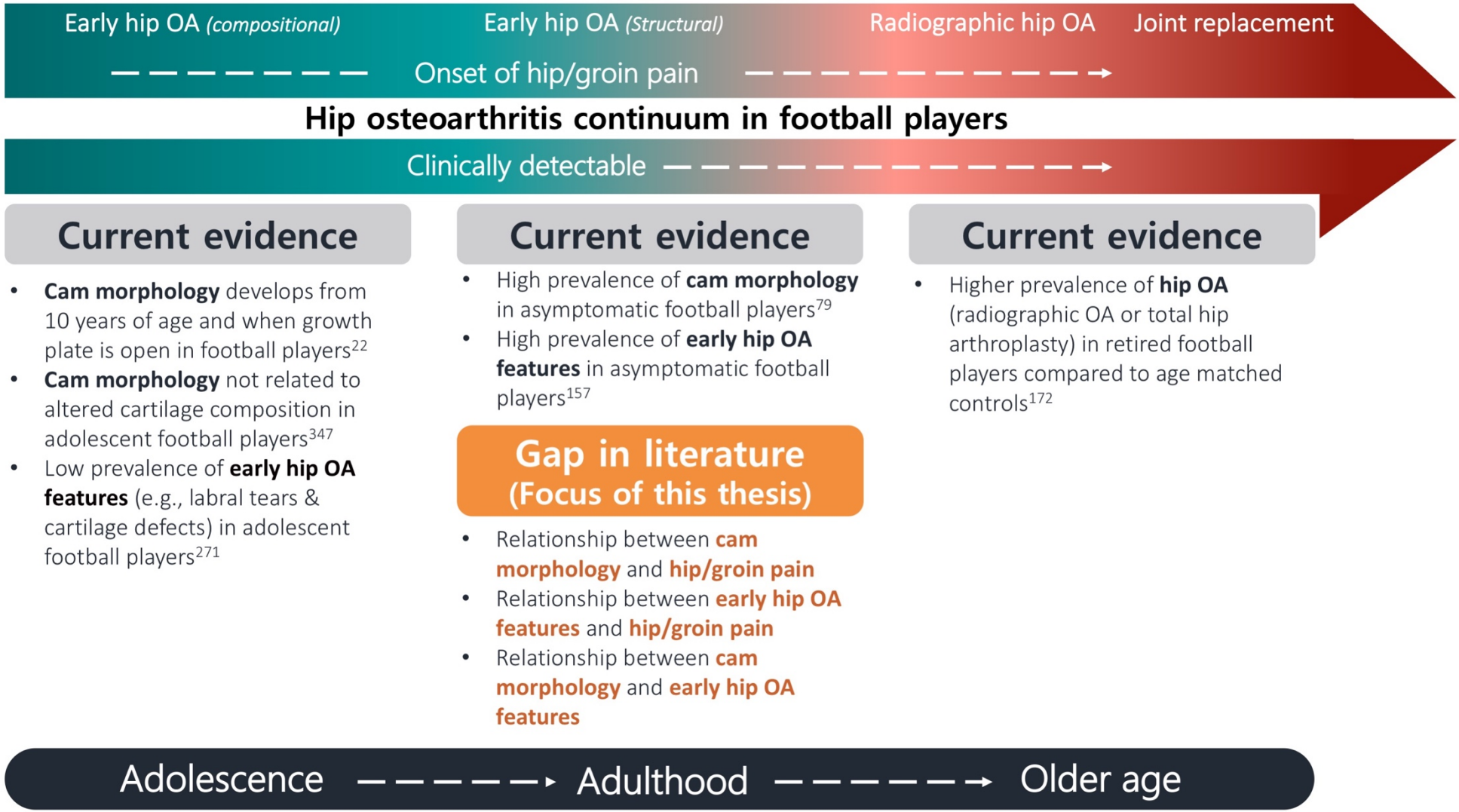


Figure 1.14. Gaps in the literature and focus of thesis.

Playing soccer is associated with an up to 9-fold greater odds of developing hip OA in later life,(172) but the underlying mechanisms for this relationship have remained unclear. Altered or incongruent hip morphology is a risk factor for developing hip OA in middle-aged to older individuals,(158–160) but its role in those with high physical activity roles (e.g., athletes) is uncertain (**Figure 1.14**). Cam morphology is of particular interest due to its high prevalence in soccer players.(79) To reduce the burden of hip OA in football players, an improved understanding of factors associated with the development of early OA is required. The period of early OA may be a time when OA progression can be slowed or even reversed.

1.11. Aims of this thesis

This thesis aims to investigate the relationship between hip joint imaging findings and hip/groin pain, and the association between cam morphology and early hip OA in football players. The previously identified gaps in literature will be addressed through the following studies that are contained in this thesis.

Study 1: Systematically appraise and synthesise the literature regarding the prevalence of imaging-defined intra-articular hip conditions in people with and without hip/groin pain.

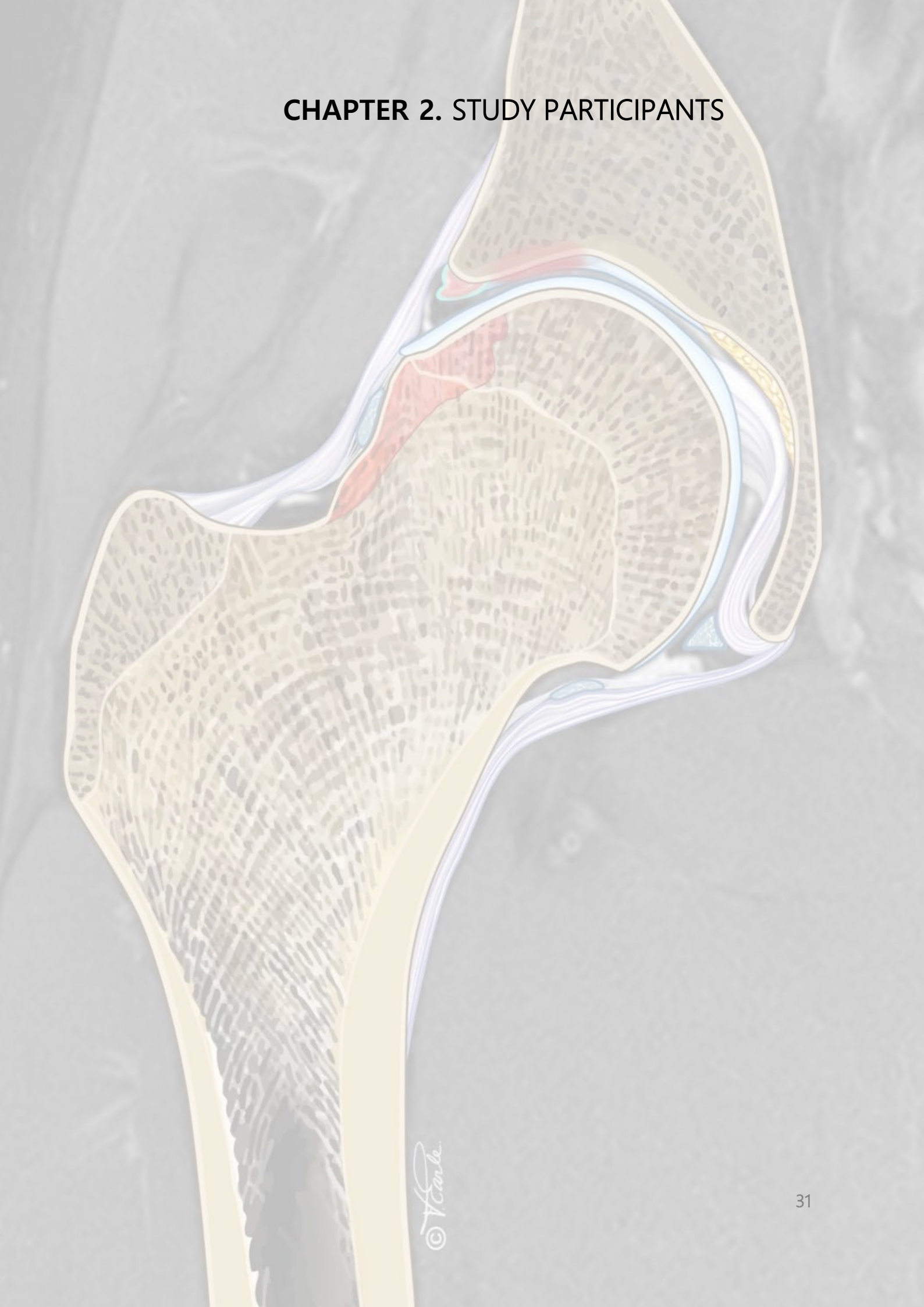
Study 2: Systematically appraise and synthesise the literature regarding the prevalence of imaging-defined intra-articular hip conditions and hip OA in athletes with and without hip/groin pain.

Study 3: Investigate if the severity and prevalence of features of early hip OA differ in football players with and without hip/groin pain.

Study 4: Investigate if the size and prevalence of bony hip morphology differ in football players with and without hip/groin pain.

Study 5: Investigate if cam morphology is associated with early hip OA and if this relationship differs between football players with and without hip/groin pain.

CHAPTER 2. STUDY PARTICIPANTS



The following chapter contains a comprehensive overview of the methods used for studies 3, 4, and 5 of this thesis.

Study 3

Heerey JJ, Srinivasan R, Agricola R, Smith A, Kemp JL, Pizzari T, King MG, Lawrenson PR, Scholes MJ, Souza RB, Link T, Majumdar S & Crossley KM.

Prevalence of early hip OA features on MRI in high-impact athletes. The femoroacetabular impingement and hip osteoarthritis cohort (FORCe) study.

Osteoarthritis and cartilage. 2021; 29(3): 323-334.

Study 4

Heerey JJ, Agricola R, Smith A, Kemp JL, Pizzari T, King MG, Lawrenson PR, Scholes MJ & Crossley KM.

The size and prevalence of bony hip morphology do not differ between football players with and without hip and/or groin pain: Findings from the FORCe cohort.

Journal of Orthopaedic and Sports Physical Therapy. 2021; 51(3): 115-125.

Study 5

Heerey JJ, Kemp JL, Agricola R, Srinivasan R, Smith A, Pizzari T, King MG, Lawrenson PR, Scholes MJ, Link T, Souza RB, Majumdar S & Crossley KM.

Cam morphology is associated with early hip OA features in young adult football players with and without hip/groin pain.

2.1. Preface

The studies presented in this thesis were undertaken as part of the femoroacetabular impingement and hip osteoarthritis cohort (FORCe) study. This chapter provides an overview of the FORCe study and the methods used for participant recruitment, eligibility, and clinical assessment for studies 3 to 5 in this thesis.

2.2. FORCe study

The FORCe study is a prospective cohort study that commenced in 2015 in Melbourne and Brisbane, Australia. The primary aims of the FORCe study were to i) evaluate changes in hip joint structure (as determined on MRI) over 2 years in sub-elite football (soccer or AF) players with hip/groin pain; ii) establish if baseline measures of potentially modifiable factors (e.g., cam morphology, hip joint contact force, muscle strength and joint range of motion) predicts changes in hip joint structure over 2 years in young adult sub-elite football players with hip/groin pain. The secondary aim of the FORCe prospective cohort study was to establish if changes in hip joint structure were associated with changes in quality of life in sub-elite football players with hip/groin pain. The data included in studies 3 to 5 were taken from the baseline timepoint of the ongoing FORCe prospective cohort study. A convenience sample of sub-elite football players without hip/groin pain was recruited to act as the control group for the FORCe study participants.

2.3. Funding

Studies 3 to 5 in this thesis were funded by an Australian NHMRC project grant titled "Femoroacetabular impingement and early osteoarthritis" (GNT 1088683).(188) A La Trobe University Postgraduate Research Scholarship was awarded to Mr. Joshua Heerey to undertake this thesis.

2.4. Ethics

Studies 3 to 5 in this thesis received ethical approval from the La Trobe University Human Ethics Committee (HEC 15-019 (Appendix 1) and HEC 16-045 (Appendix 2)) and the University of Queensland Human Ethics Committee (2015000916 (Appendix 3) and 2016001694 (Appendix 4)). All study participants were provided with and asked to read a plain language statement

(Appendices 5 to 8), and provided written informed consent (Appendices 9 to 11) before being involved in the study

2.5. Participant eligibility

2.5.1. Football players with hip/groin pain (symptomatic participants)

Male and female football players with hip/groin pain residing in Melbourne or Brisbane, Australia were eligible for inclusion into studies 3 to 5 if they fulfiled the eligibility criteria outlined in Table 2.1.

2.5.2. Football players without hip/groin pain (control participants)

Male and female football players without hip/groin pain residing in Melbourne or Brisbane, Australia were eligible for inclusion into studies 3 to 5 if they fulfiled the eligibility criteria outlined in Table 2.2.

2.6. Assessment of participant eligibility

2.6.1. Non-radiologic evaluation

Football players (symptomatic and control) who expressed interest in being involved in the study were screened for suitability verbally in person or over the phone to establish eligibility. If a participant fulfilled the study eligibility criteria, a physical screening session was undertaken by one of four trained physiotherapists (Melbourne: Mr. Joshua Heerey, Mr. Matthew King, Mr. Mark Scholes; Brisbane: Mr. Peter Lawrenson) where study eligibility was determined.

2.6.2. Radiologic evaluation

Football players (symptomatic and control) who fulfilled non-radiologic eligibility criteria underwent supine AP pelvis and Dunn 45° radiographs using a standardised protocol (see section 3.3) Features of radiographic hip OA were evaluated on the AP pelvis radiographs using the OARSI atlas by a blinded registrar orthopaedic surgeon (Dr. Rintje Agricola) with more than 10 years' experience reading pelvic radiographs. This resulted in a KL classification (grade 0-4). Participants with radiographic hip OA defined as a KL grade of 2 or greater were excluded from the study. Intra-observer reliability for KL classification was determined by Dr. Rintje Agricola completing 20

Table 2.1. Eligibility criteria for football players with hip/groin pain (symptomatic participants).

Inclusion criteria
▸ Age: 18 to 50 years. ▸ Playing in a sub-elite football competition. ▸ Undertaking at least 2 sessions (games or training) of football (soccer/AF) per week. ▸ Self-reported hip (anterior/lateral/posterior)/groin pain that fulfilled criteria 1 to 3. 1. *Gradual onset.* 2. *Greater than six months in duration.* 3. *Average hip/groin pain of >3 and <8 on an 11-point NPRS with football or football-specific movements (squatting, kicking or cutting/change of direction). + or - symptoms including clicking, giving way, locking or catching.* ▸ Positive FADIR test in at least one hip.
Exclusion criteria
▸ Self-reported history of significant hip/groin condition, specifically: > Bursitis, congenital dislocation of the hip, fracture, osteochondritis dissecans, Legg-Calvé-Perthes disease, septic or rheumatoid arthritis, slipped capital femoral epiphysis and subluxations/dislocations. ▸ Previous hip and/or pelvis surgery. ▸ KL grade 2 or greater on AP pelvis radiograph. ▸ Any lumbar spine or lower limb injury/complaint in the previous 3 months (e.g., hamstring muscle injury or sprained ankle) that resulted in the inability to weight-bear fully or undertake testing procedures. ▸ Contra-indications to radiographs (e.g., pregnancy) or MRI (i.e., claustrophobia). ▸ Received intra-articular hip injection (of any type) in the previous 3 months. ▸ Unable to understand spoken and written English.

AF = Australian football; AP = anteroposterior; FADIR = flexion-adduction-internal-rotation; KL = Kellgren and Lawrence; MRI = magnetic resonance imaging and NPRS = numerical pain rating scale.
Table adapted from Crossley et al. (188).

Table 2.2. Eligibility criteria for football players without hip/groin pain (control participants).

Inclusion criteria
▸ Age: 18 to 50 years. ▸ Playing in a sub-elite football competition. ▸ Undertaking at least 2 sessions (games or training) of football (soccer/AF) per week. ▸ Negative FADIR test in both hips.
Exclusion criteria
▸ Self-reported history of significant hip/groin condition, specifically: > Bursitis, congenital dislocation of the hip, fracture, osteochondritis dissecans, Legg-Calvé-Perthes disease, septic or rheumatoid arthritis, slipped capital femoral epiphysis and subluxations/dislocations. ▸ Lower limb surgery (e.g., anterior cruciate ligament reconstruction). ▸ KL grade 2 or greater on AP pelvis radiograph. ▸ Any lumbar spine or lower limb injury/complaint in the previous 3 months (e.g. hamstring muscle injury or sprained ankle) that resulted in the inability to weight-bear fully or undertake testing procedures. ▸ Contra-indications to radiographs (e.g., pregnancy) or MRI (i.e., claustrophobia). ▸ Unable to understand spoken and written English.

AF = Australian football; AP = anteroposterior; FADIR = flexion-adduction-internal-rotation; KL = Kellgren and Lawrence and MRI = Magnetic resonance imaging.
Table adapted from Crossley et al. (188).

radiographs twice, six months apart. Weighted kappa (κ) for KL classification was 0.87 (95%CI: 0.71, 1.00).

2.6.3. Participant recruitment

Football players with (symptomatic participants) and without hip/groin pain (control participants) were recruited via social and print media advertising or information sessions conducted at soccer or AF clubs in Melbourne and Brisbane, Australia. Symptomatic and control participants were competing in the same league/competition level and were recruited between August 2015 and October 2018. **Figures 2.1** and **2.2** provide an overview of symptomatic and control participant recruitment, respectively.

2.7. Participant questionnaires

2.7.1. Participant demographic characteristics and anthropometric information

Football players (symptomatic and control) attended either La Trobe University (Melbourne study site) or the University of Queensland (Brisbane study site) to complete baseline examinations, which included physical (hip muscle strength/range of motion and functional assessment) and biomechanical assessments. Demographic characteristics (age, sex, football code, playing level, training and competition frequency, symptom duration, and past injury history) and anthropometric information (weight and height) were collected from each participant.

2.7.2. Patient-reported outcome measures

Football players (symptomatic and control) completed the iHOT33 and HAGOS, which are recommended for use in young to middle-aged individuals with hip and groin pain.(189)

The iHOT33 is a 33-item questionnaire that evaluates the health-related quality of life in young, active people with hip conditions (**Appendix 12**).(190) The iHOT33 evaluates four different domains: i) symptoms and functional limitations; ii) sports and recreational physical activities; iii) job-related concerns; and iv) social, emotional, and lifestyle concerns. It is answered on a visual analogue scale, with a total score calculated. A score of 0 indicates the worst quality of life and a score of 100 indicates the best quality of life. The iHOT33 has sufficient test-retest reliability, internal consistency and construct validity.(189,190)

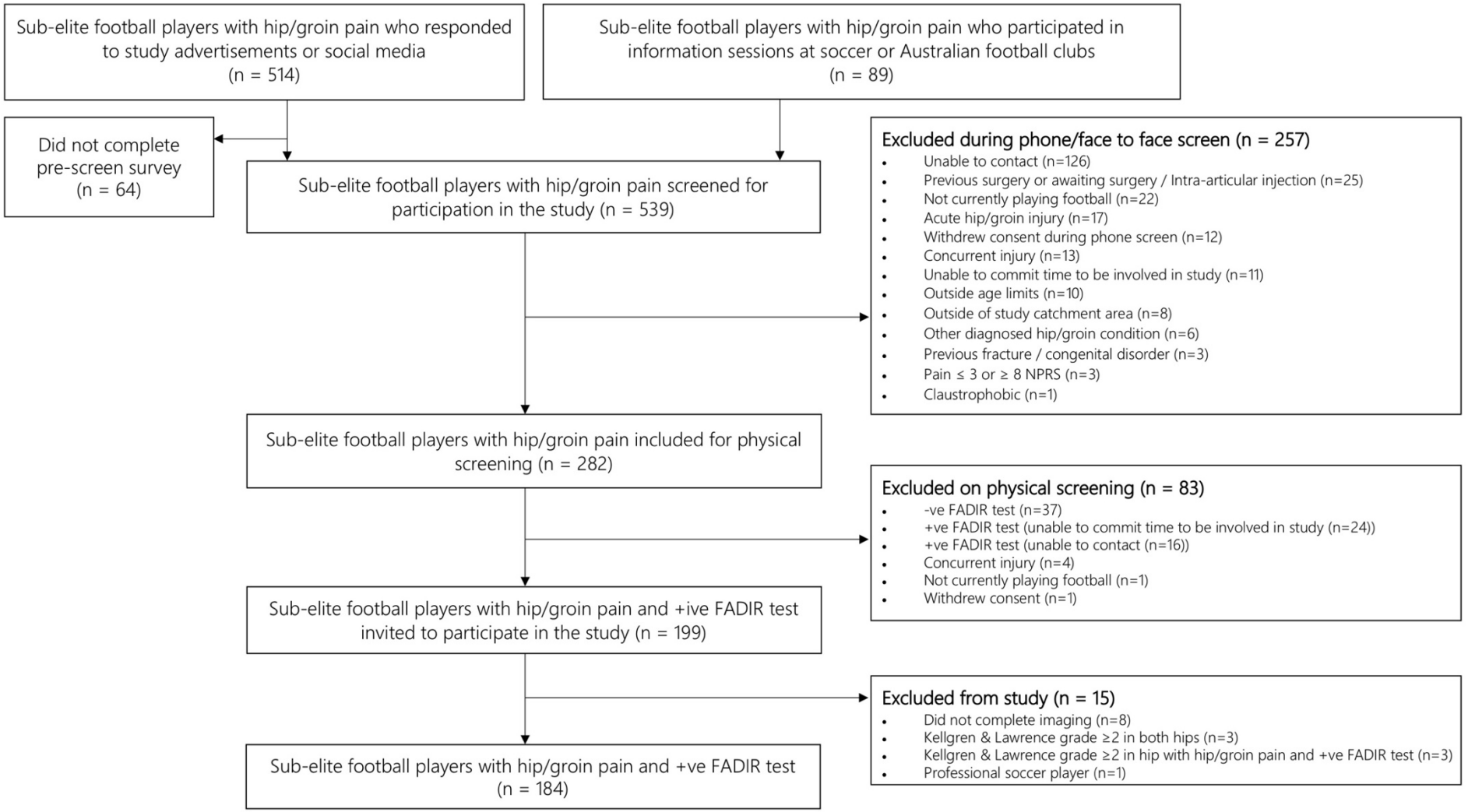


Figure 2.1. Recruitment flow chart for football players with hip/groin pain included in this thesis.

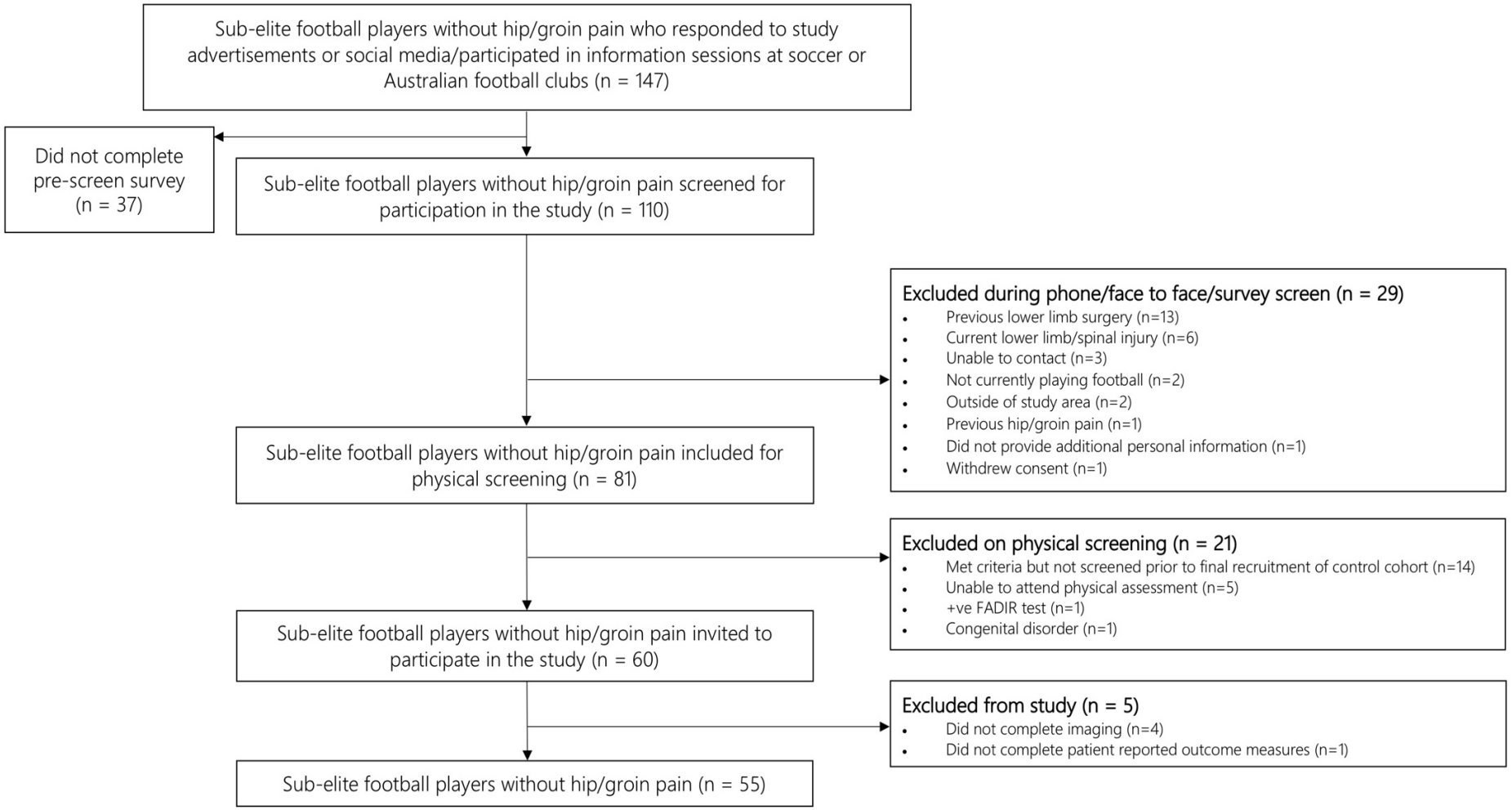


Figure 2.2. Recruitment flow chart for football players without hip/groin pain included in this thesis.

The HAGOS evaluates hip/groin problems and includes six subscales that assess pain, symptoms, physical function in daily living, physical function in sport and recreation, participation in physical activities, and hip/groin-related quality of life (Appendix 13).(38) A total score is determined for each subscale, with 0 indicating extreme hip/groin problems and 100 indicating no problems. It has sufficient test-retest reliability, internal consistency and construct validity.(38,189) For studies 3 and 4 the HAGOS pain (HAGOS-P) and symptom (HAGOS-S) subscales were used, with all six subscales used in study 5.

2.8. Classification of participant's hips

2.8.1. Football players with hip/groin pain

Football players with hip/groin pain fulfilling study eligibility had at least one symptomatic hip (Table 2.3). The contralateral hip in symptomatic football players was classified as either symptomatic or other for studies 3 and 4 of this thesis. The contralateral hip was classified as other if i) the participant reported no pain in the hip and/or groin or ii) the participant reported hip/groin pain but had a negative FADIR test (Table 2.3).

2.8.2. Football players without hip/groin pain

Both hips in the control participants were asymptomatic (Table 2.3) and were used in studies 3 to 5 in this thesis.

2.9. Participant (hip) flow through this thesis

The flow of symptomatic and control participants (hips) for studies 3 to 5 are outlined in Figure 2.3.

Table 2.3. Classification of participant hips.

	Football players with hip/groin pain (Total no. of participants = 184) (Total no. of hips = 366*)		Football players without hip/groin pain (Total no. of participants = 55) (Total no. of hips = 110)
Hip classification	Symptomatic (Total no. of hips = 290) 230 hips (M) 60 hips (W)	Other (Total no. of hips n = 76) 60 hips (M) 16 hips (W)	Control (Total no. of hips = 110) 82 hips (M) 28 hips (W)
Eligibility criteria	Hip/groin pain *and* Positive FADIR test	No hip/groin pain in the contralateral hip OR Hip/groin pain *and* Negative FADIR test	No hip/groin pain *and* Negative FADIR test

FADIR = flexion-adduction-internal-rotation; M = men; W = women.
* 2 hips excluded due to hip OA

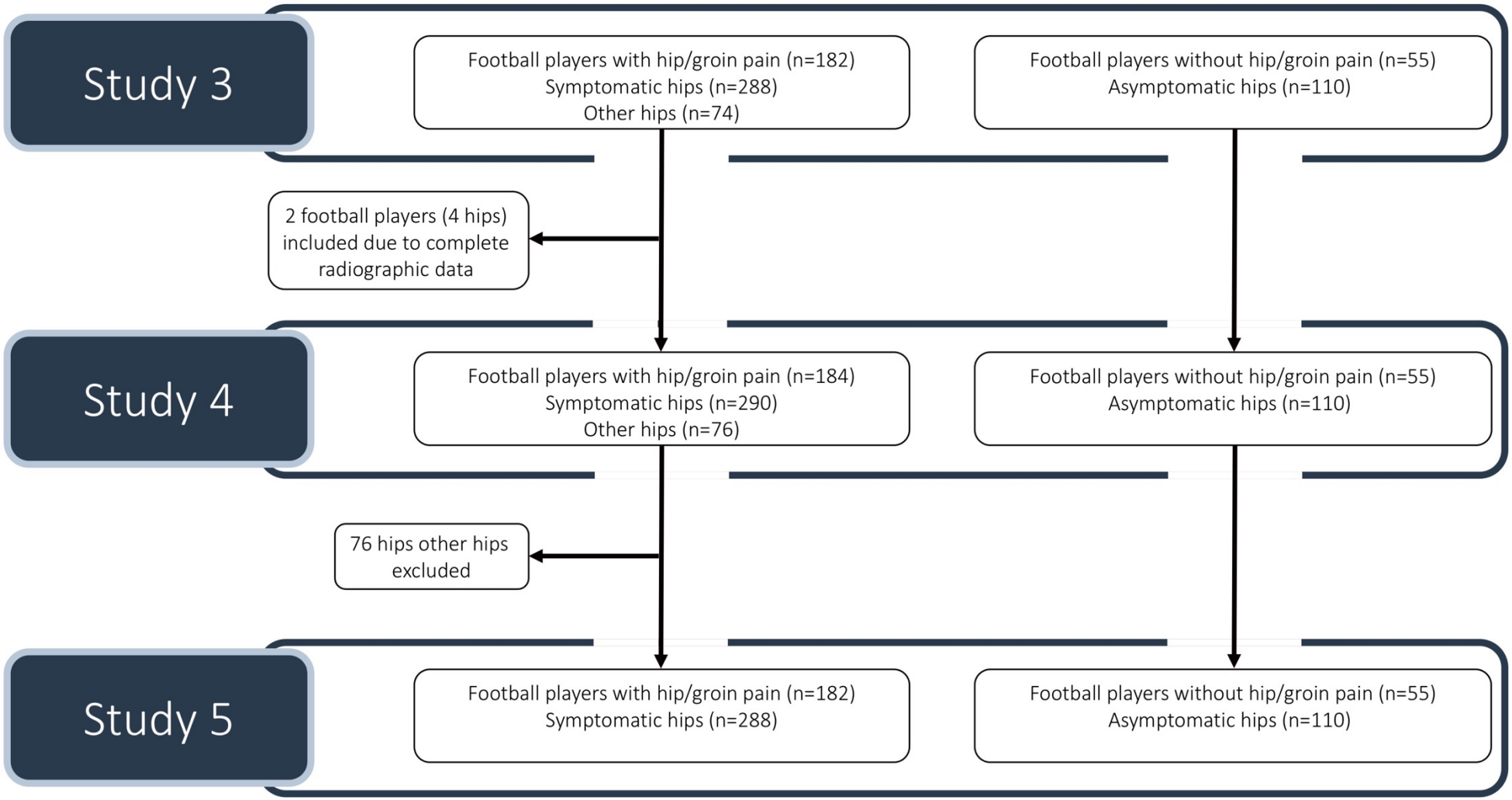
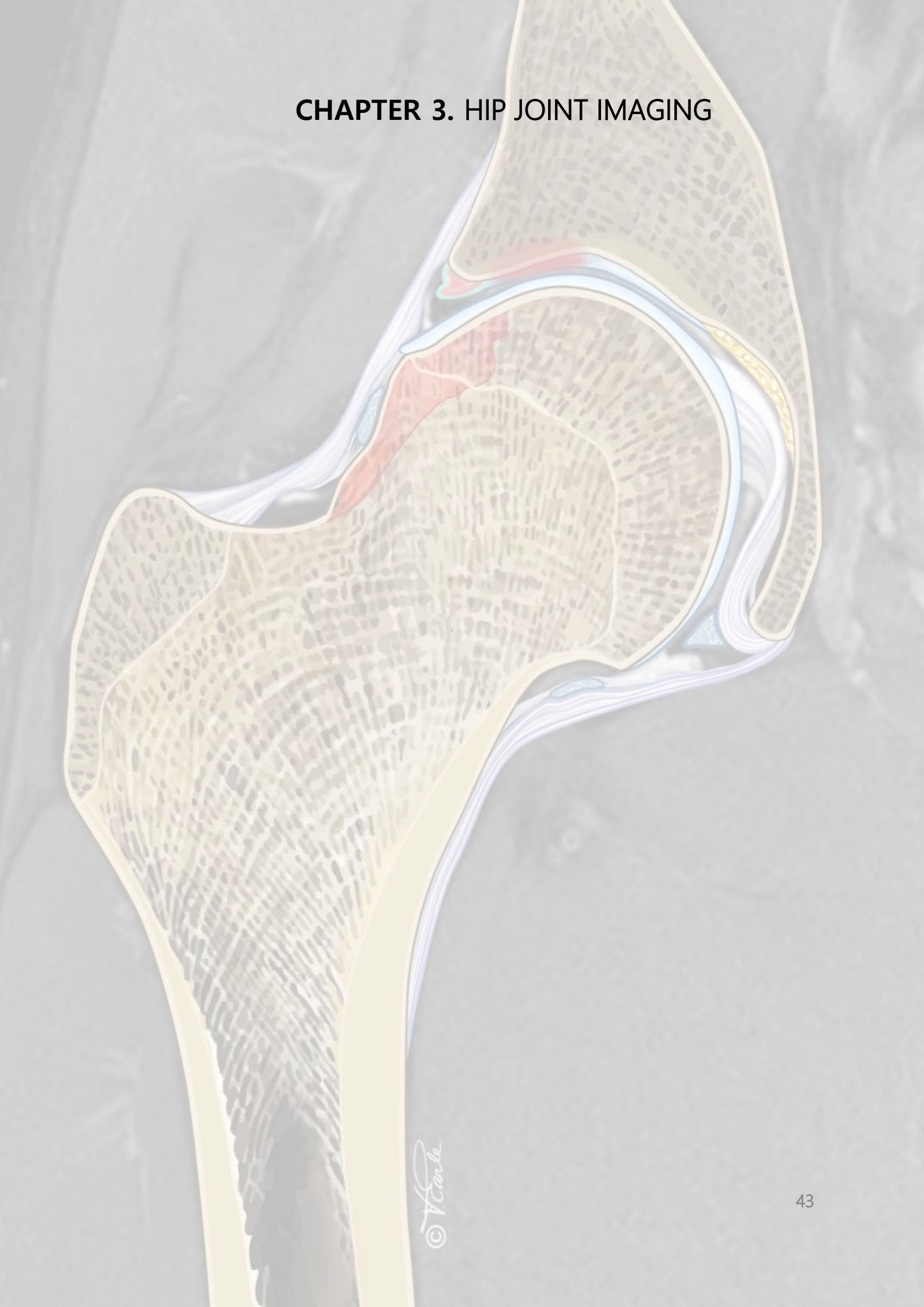


Figure 2.3. Symptomatic and control participants (hips) included in each chapter.

CHAPTER 3. HIP JOINT IMAGING



The following chapter contains a comprehensive overview of the methods used for studies 3, 4, and 5 of this thesis.

Study 3

Heerey JJ, Srinivasan R, Agricola R, Smith A, Kemp JL, Pizzari T, King MG, Lawrenson PR, Scholes MJ, Souza RB, Link T, Majumdar S & Crossley KM.

Prevalence of early hip OA features on MRI in high-impact athletes. The femoroacetabular impingement and hip osteoarthritis cohort (FORCe) study.

Osteoarthritis and cartilage. 2021; 29(3): 323-334.

Study 4

Heerey JJ, Agricola R, Smith A, Kemp JL, Pizzari T, King MG, Lawrenson PR, Scholes MJ & Crossley KM.

The size and prevalence of bony hip morphology do not differ between football players with and without hip and/or groin pain: Findings from the FORCe cohort.

Journal of Orthopaedic and Sports Physical Therapy. 2021; 51(3): 115-125.

Study 5

Heerey JJ, Kemp JL, Agricola R, Srinivasan R, Smith A, Pizzari T, King MG, Lawrenson PR, Scholes MJ, Link T, Souza RB, Majumdar S & Crossley KM.

Cam morphology is associated with early hip OA features in young adult football players with and without hip/groin pain.

3.1. Preface

The following chapter will outline the methods used for radiograph and MRI collection and assessment that were used for studies 3 to 5.

3.2. Radiograph and magnetic resonance imaging data collection

Symptomatic and control participants attended a single radiology centre in Melbourne, Australia (Imaging at Olympic Park) or one of three aligned radiology centres in Brisbane, Australia (Q-scan). Radiographs and MRI data collection were completed on the same day where possible for all participants.

3.3. Radiograph setup

3.3.1. Supine anteroposterior pelvis

Each participant was positioned on the X-ray table with hips in neutral abduction/adduction and flexion/extension. Both hips were internally rotated to 15° with the participant instructed to keep their feet in this position. The X-ray tube was aligned to the detector at a focal field distance of 100 centimetres (cm) in Melbourne and 110cm in Brisbane. The central ray was centred on the symphysis pubis and located between the ASIS and pubic symphysis.

3.3.2. Dunn 45°

Each participant was positioned on the X-ray table with one hip flexed to 45°, abducted 20° and positioned in neutral internal/external rotation. Right and left hips were collected separately. The X-ray tube was aligned to the detector at a focal field distance of 100 cm in Melbourne and 110cm in Brisbane. The central ray was centred over the hip joint.

3.4. Radiograph assessment

A physiotherapist (Mr. Joshua Heerey) blinded to hip classification (symptomatic, other, control) with 10 years of clinical experience and training in the method, analysed bony hip morphology with previously used quantitative methods.(158,162) Radiographs were transferred to a workstation and a point set was placed on predetermined locations on the surface of the femur and acetabulum using statistical shape modelling software (Active shape modelling (ASM) toolkit,

Manchester University, Manchester, United Kingdom (UK)). Twenty and 18-point models were used for AP pelvis and Dunn 45° radiographs, respectively (Figure 3.1). The alpha angle and LCEA were then calculated automatically from this point set using MATLAB v7.1.0 (MathWorks Inc, Natick, Massachusetts, United States of America (USA).

3.4.1. Alpha angle

The points placed on the femoral head and neck determined the circle of best fit around the femoral head and centre of the femoral neck, respectively. The alpha angle was calculated by the line from the centre of the femoral neck to the centre of the femoral head and the line from the centre of the femoral head to the location where the bone first leaves the circle of best fit (Figure 3.1).

3.4.2. Lateral-centre-edge-angle

The LCEA was determined by a vertical line originating from the centre of the femoral head and a corresponding line from the centre of the femoral head to the most lateral weight-bearing portion of the acetabular sulcus (Figure 3.1). The vertical line was drawn perpendicular to a horizontal line connecting the two superolateral points of both obturator foramen, to correct for potential pelvic malposition.

3.4.3. Reliability of radiographic assessment

Intra-observer reliability for bony hip morphology was determined by Mr. Joshua Heerey completing 20 radiographs (AP and Dunn 45°) twice, one week apart. Inter-observer reliability was established by a second investigator (Dr. Rintje Agricola) completing the same 20 radiographs. Intra and inter-observer reliability values are presented in Table 3.1.

Table 3.1. Results of intra- and inter-observer reliability analyses for bony hip morphology.

Radiographic view	Intra-observer reliability	Inter-observer reliability
Anteroposterior		
Alpha angle*	0.92 (0.79, 0.97)	0.76 (0.46, 0.90)
LCEA*	0.94 (0.85, 0.98)	0.63 (0.29, 0.84)
Dunn 45°		
Alpha angle*	0.93 (0.84, 0.97)	0.93 (0.84, 0.97)

LCEA = lateral-centre-edge-angle
* Intra-class correlation coefficients (95%CI).

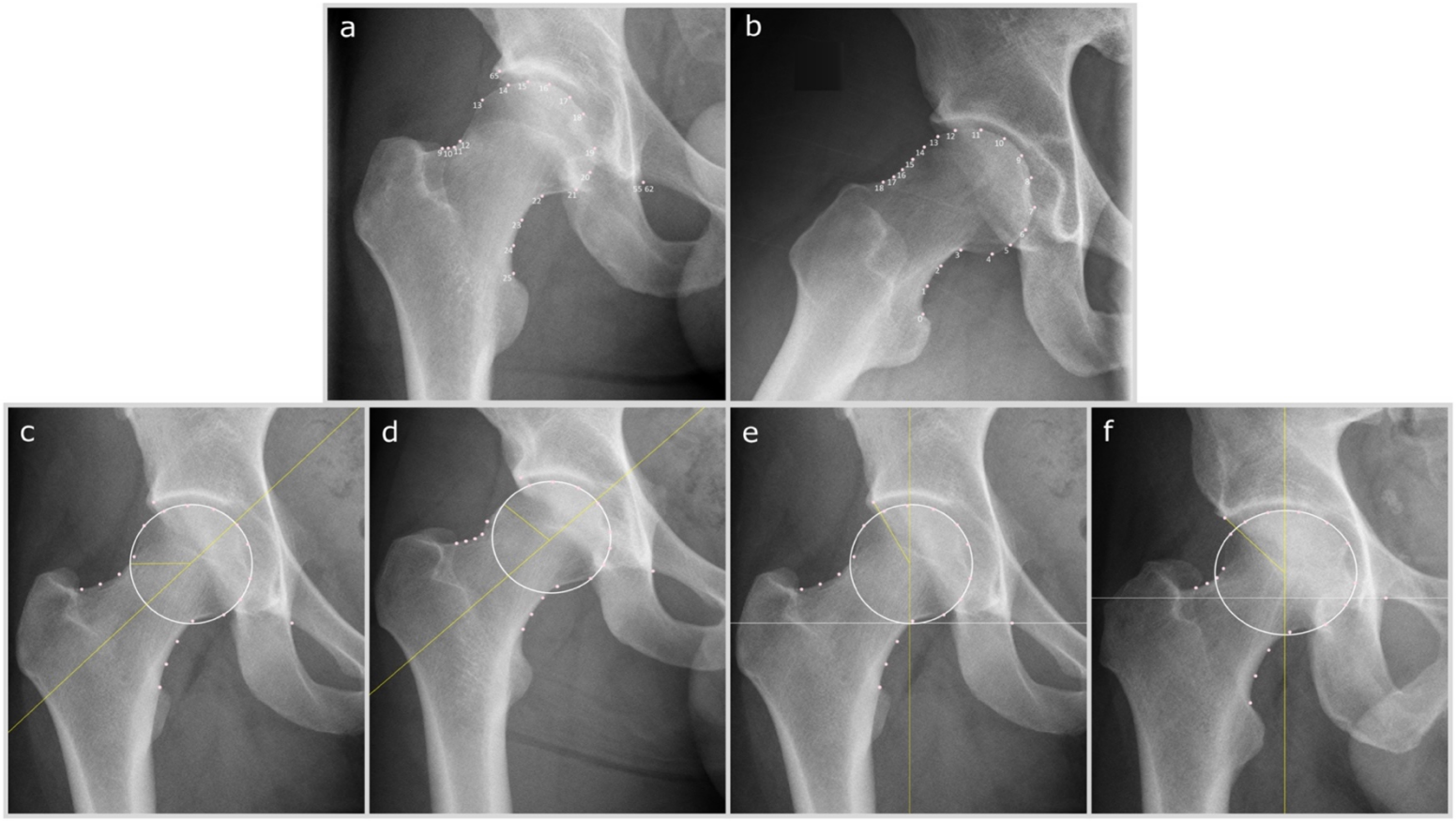


Figure 3.1. Statistical shape model and calculation of alpha angle and lateral-centre-edge-angle.

a) twenty-point shape model used for anteroposterior pelvis radiographs; b) eighteen-point shape model used for Dunn 45° radiograph; c) anteroposterior pelvis radiograph with a spherical femoral head (alpha angle of 46°); d) anteroposterior pelvis radiograph with cam morphology (alpha angle of 82°); c) anteroposterior pelvis radiograph with normal acetabular coverage (LCEA of 34°) and d) anteroposterior pelvis radiograph with pincer morphology (LCEA of 43°).

3.5. Radiograph classification

3.5.1. Cam morphology

The alpha angle determined the presence of cam morphology on the AP pelvis and Dunn 45° views. For studies 4 and 5 the alpha angle was analysed both as a continuous measure and as a dichotomous variable based on previously proposed threshold values.(57,59,158) An alpha angle >60° defined the presence of cam morphology, with an alpha angle >78° defining a large cam morphology on either the AP or Dunn views.(23,24) An alpha angle above 60° is a non-gender specific threshold for distinguishing hips with and without cam morphology.(57,59) The alpha angle threshold of >78° has been shown to best discriminate between hips that did or did not develop hip OA.(59)

3.5.2. Acetabular morphology

The LCEA on the AP pelvis radiograph described the superolateral coverage of the femoral head by the acetabulum.(162) For study 4 the LCEA was analysed using continuous and threshold values, with an LCEA of >40° and <20° used to define pincer morphology and acetabular dysplasia, respectively.(79) The threshold values for pincer morphology and acetabular dysplasia were selected based on literature,(79,159,162) which allowed for comparison with prior studies.

3.6. Magnetic resonance imaging setup

Each participant underwent an unenhanced 3.0-Tesla (T) MRI (Phillips Ingenia, The Netherlands). Participants were positioned supine with patient positioning aids used to maintain each hip in internal rotation and neutral abduction/adduction, with a 32-channel torso coil placed over the hips and pelvis, and right and left hips were imaged independently. The MRI protocol included the following sequences: coronal PD spectral attenuated inversion recovery (SPAIR), sagittal PD SPAIR, and oblique axial PD SPAIR (Table 3.2).

3.7. Magnetic resonance imaging assessment

All de-identified MRI scans were evaluated by one musculoskeletal radiologist (Dr. Ramya Srinivasan) with eight years of experience, who was blinded to radiographic and clinical findings. All images were analysed using a standard clinical picture archiving and communication system (Agfa, Ridgefield Park, New Jersey).

Table 3.2. Magnetic resonance imaging protocol.

MRI parameters	Coronal PD SPAIR	Sagittal PD SPAIR	Oblique axial PD SPAIR
Field of view (mm)	170 x 170	150 x 150	170 x 170
Slice thickness (mm)	2.5	2.5	2.5
Slice gap (mm)	1.5	1	1.5
Repetition time (ms)	2700	2675	3500
Echo time (ms)	25	25	25
Voxel size (mm)	0.70x0.70x2.5	0.7x0.75x2.5	0.75x0.75x2.5
Acquisition time (min:sec)	3:17	4:18	2:35

mm = millimetres; ms = milliseconds; MRI = magnetic resonance imaging; PD = proton density and SPAIR = spectral attenuated inversion recovery.

3.7.1. Scoring of Hip Osteoarthritis with MRI

The SHOMRI scoring system was used to evaluate eight different OA features: articular cartilage, BML, subchondral cysts, labrum, paralabral cysts, intra-articular bodies, effusion-synovitis and ligamentum teres.(123) Articular cartilage, BML, and subchondral cysts were evaluated in six femoral and four acetabular subregions (**Figure 3.2**). The anterior and posterior femoral subregions were established by measuring a 1cm distance on the anterior and posterior aspects of the femoral head, respectively (**Figure 3.3**). The anterior and posterior femoral subregions were evaluated on sagittal images. The midportion of the femoral head was outlined on the sagittal plane images and then divided into four subregions (lateral, superolateral, superomedial, and inferior) on coronal images (**Figure 3.3**). The lateral acetabular rim was used to define lateral and superolateral subregions. The superolateral and superomedial subregions were divided through a vertical line from the centre of the femoral head. The ligamentum teres was used as a landmark to define superomedial and inferior subregions. The acetabulum was subdivided into four subregions, two on sagittal (anterior and posterior) and two on coronal (superomedial and superolateral) images. The anterior and posterior acetabular subregions were determined by measuring a 1cm distance on the anterior and posterior aspect of the acetabulum, respectively (**Figure 3.3**). The superolateral and superomedial acetabular subregions were defined through the same anatomical landmarks used for the corresponding femoral subregions. Labral abnormalities (labral tears) were graded in four different subregions: anterior and posterior (axial oblique image), anterosuperior (sagittal image), and superior (coronal image). The specific OA feature assessment is outlined below.

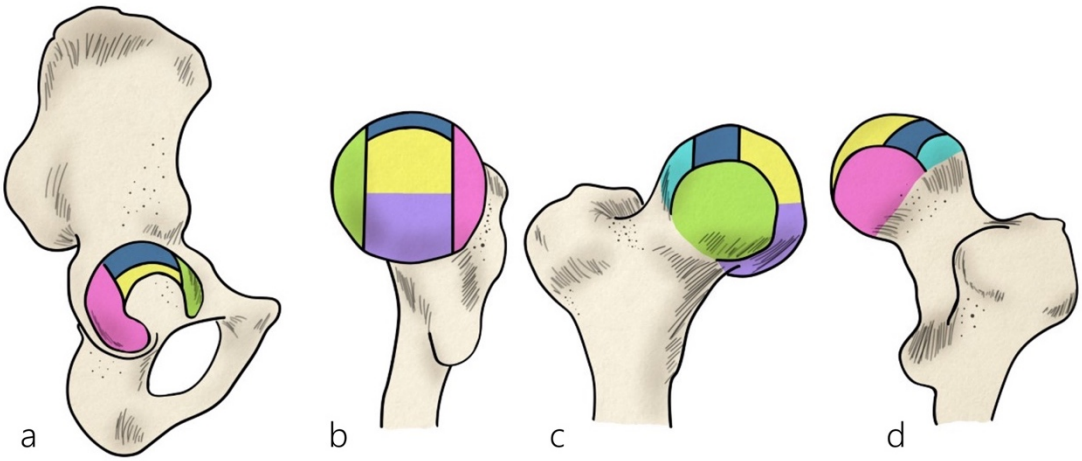


Figure 3.2. Scoring of hip osteoarthritis with MRI acetabular and femoral subregions.
a) lateral view of acetabular subregions; b) medial view of femoral subregions; c) anterior view of femoral subregions and d) posterior view of femoral subregions. Image adapted from Lee et al. (123)

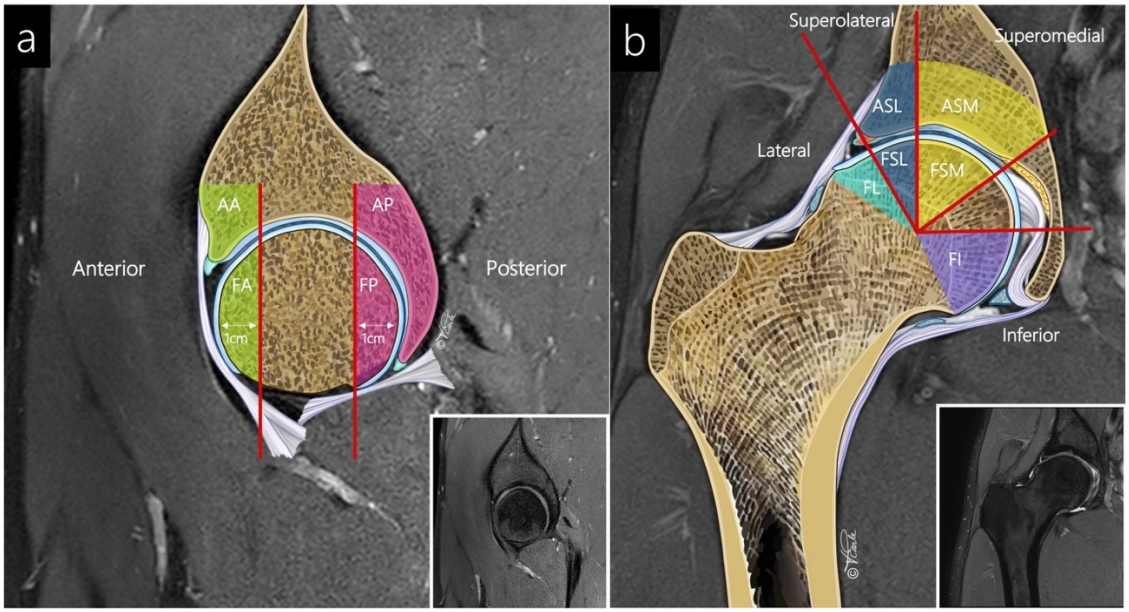


Figure 3.3. Sagittal and coronal magnetic resonance images with anatomic detail (original image inset) of acetabular and femoral subregions.
a) sagittal image with acetabular anterior (AA), femoral anterior (FA), acetabular posterior (AP) and femoral posterior (FP) subregions; b) coronal image with femoral lateral (FL), acetabular superolateral (ASL), femoral superolateral (FSL), acetabular superomedial (ASM), femoral superomedial (FSM) and femoral inferior (FI) subregions.

I. Articular cartilage (cartilage defects)

Cartilage defects were assessed in each of the 10 subregions and were defined by Lee et al. (123) as “increased signal intensity extending from the surface of the articular cartilage”. Cartilage defects were graded with a 3-point scale (**Table 3.3**): 0 for no cartilage defect, 1 for partial

Table 3.3. Scoring of hip osteoarthritis with MRI individual osteoarthritis features.

SHOMRI feature	Graded	0	1	2	3	4	5	No. subregions	Feature score
Cartilage defect	0-2	Absent	Partial thickness	full thickness				10	0-20
Bone marrow lesion	0-3	Absent	≤0.5cm	>0.5cm to ≤1.5cm	>1.5cm			10	0-30
Subchondral cyst	0-2	Absent	≤0.5cm	>0.5cm				10	0-20
Labral tear	0-5	Absent*	Abnormal signal/ fraying	Simple	Labrocartilage separation	Complex	Maceration	4	0-20
Paralabral cyst	Present/ absent	Absent	Present					-	0-1
Loose body	Present/ absent	Absent	Present					-	0-1
Effusion-synovitis	Present/ absent	Absent	Present					-	0-1
Ligamentum teres tear	0-3	Absent	Abnormal signal/ fraying	Partial	Complete			-	0-3
									0-96**

*can also include normal anatomical variants such as aplasia or hypoplasia.
** total SHOMRI score is calculated by adding together each of 8 feature scores and provides a measure of whole joint disease.

thickness cartilage defect and 2 for full thickness cartilage defect (**Figure 3.4**). Large cartilage defects that covered more than one subregion and had a maximal diameter of greater than 1cm were scored in both subregions, with defects less than 1cm scored in the subregion where more than 50 per cent of the defect was present.

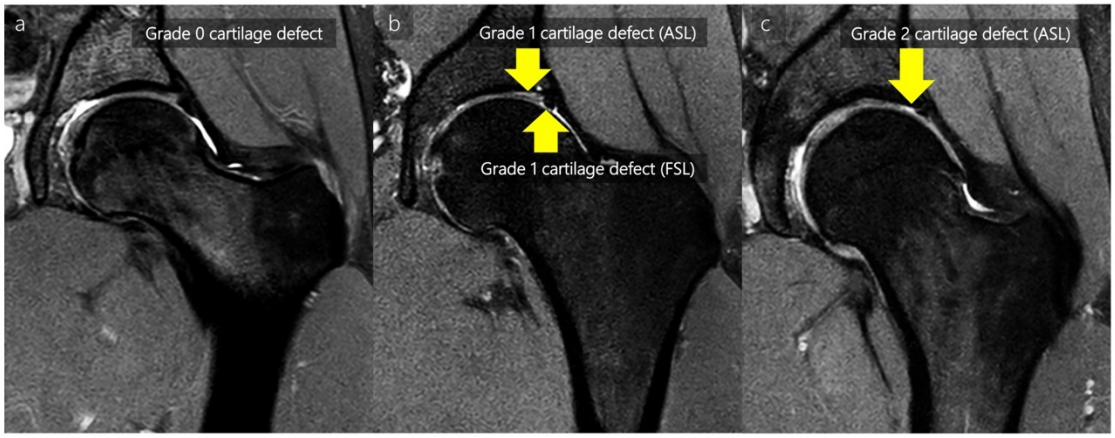


Figure 3.4. SHOMRI assessment of cartilage defects.
a) grade 0 cartilage defects (no cartilage defect present in any acetabular or femoral subregion); b) grade 1 (partial thickness) cartilage defect; c) grade 2 (full thickness) cartilage defect; ASL = acetabular superolateral subregion and FSL = femoral superolateral subregion.

II. Bone marrow lesions

Bone marrow lesions were evaluated in each of the 10 subregions and defined by Lee et al. (123) as "an ill-defined subchondral lesion hyperintense on fluid-sensitive sequences". A 4-point scale (**Table 3.3**) was used to grade the size of the BML: 0 if BML was absent, 1 if equal or less than 0.5cm in diameter, 2 if the diameter was greater than 0.5cm but equal to or less than 1.5cm, and 3 if the diameter was greater than 1.5cm (**Figure 3.5**). Bone marrow lesions were measured perpendicular to the corresponding articular surface at the point of the largest diameter.

III. Subchondral cysts

Subchondral cysts were scored in each of the 10 subregions and defined by Lee et al. (123) as a "well-defined fluid-signal bone lesion". A 3-point scale (**Table 3.3**) was used to grade the size of subchondral cysts: 0 if no subchondral cyst was present, 1 if the diameter was equal to or less than 0.5cm, 2 if the diameter was larger than 0.5cm (**Figure 3.6**). The location of greatest diameter was used to determine the size of the subchondral cysts.

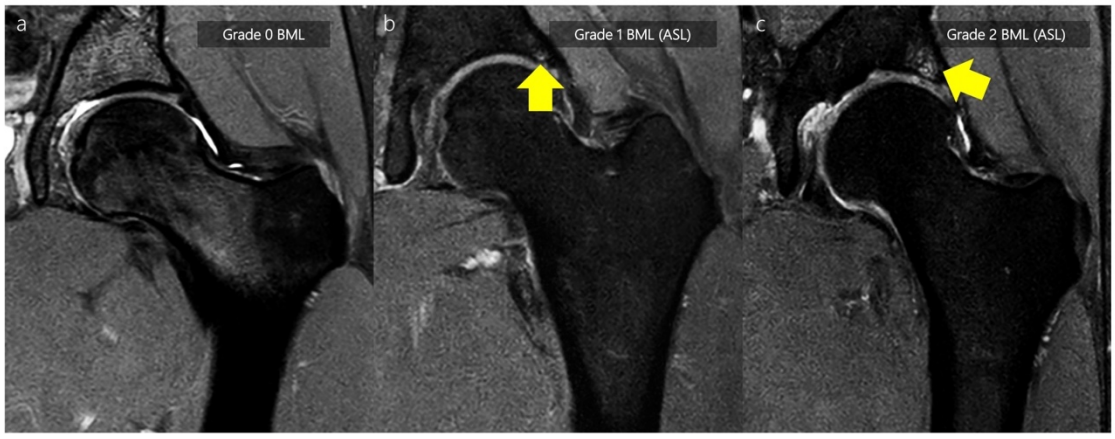


Figure 3.5. SHOMRI assessment of bone marrow lesions.

a) grade 0 BML (no BML present in any acetabular or femoral subregion); b) grade 1 (≤0.5cm) BML; c) grade 2 (>0.5cm but ≤1.5cm) BML; ASL = acetabular superolateral subregion and BML = bone marrow lesion.

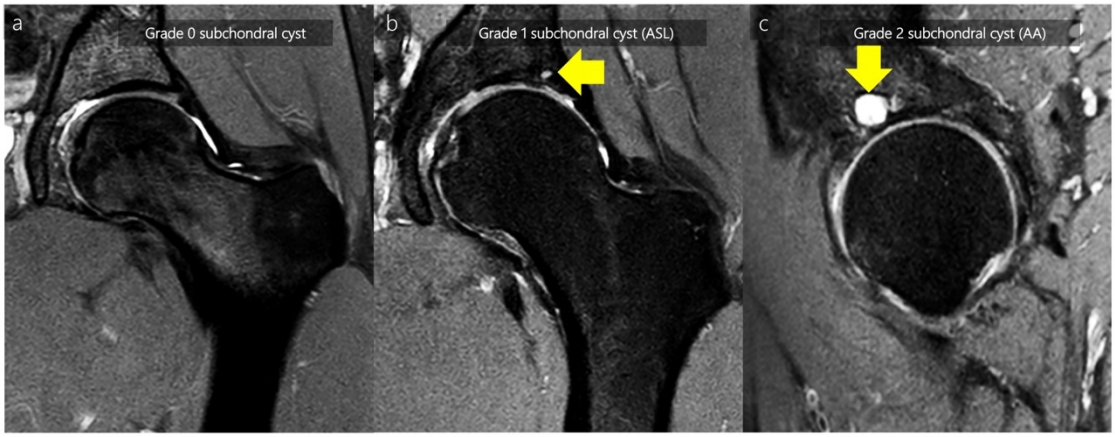


Figure 3.6. SHOMRI assessment of subchondral cysts.

a) grade 0 subchondral cyst (no subchondral cysts present in any acetabular or femoral subregion); b) grade 1 (≤0.5cm) subchondral cyst ; c) grade 2 (>0.5cm) subchondral cyst; ASL = acetabular superolateral subregion and AA = acetabular anterior subregion.

IV. Labral abnormalities (labral tears)

Labral tears were assessed in four different subregions and graded using a 6-point scale (**Table 3.3**): 0 for normal labrum (including any normal variants such as aplasia or hypoplasia), 1 if abnormal signal was present within the labrum and/or labral fraying was present, 2 for simple labral tear, 3 for tears involving labrocartilage separation, 4 for a complex tear, and 5 for labral maceration (**Figure 3.7**).(123)

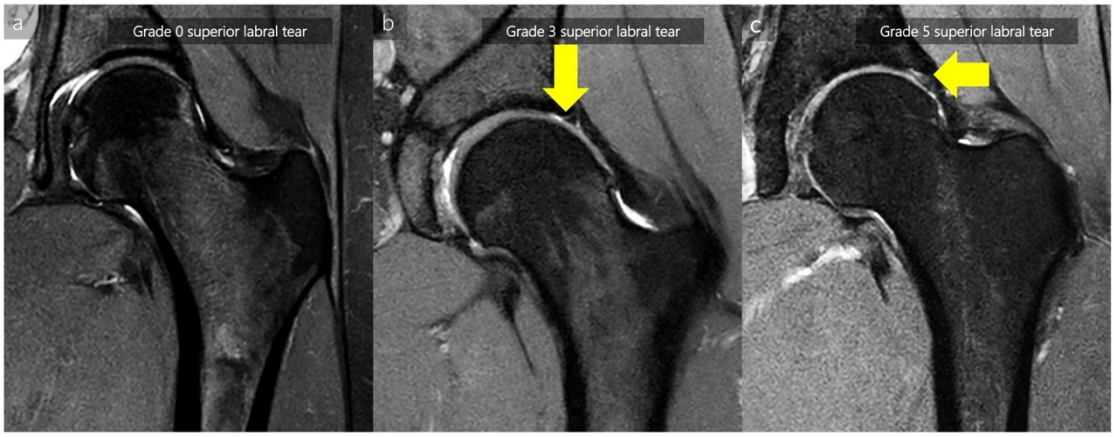


Figure 3.7. SHOMRI assessment of labral abnormalities (labral tears).
a) grade 0 labral tear (no superior labral tear present or normal variant); b) grade 3 (labrocartilage separation) labral tear and c) grade 5 (maceration) labral tear.

V. Paralabral cysts

Paralabral cysts (**Figure 3.8**) were assessed on sagittal, coronal, and axial oblique images and scored as either present or absent (**Table 3.3**).(123)

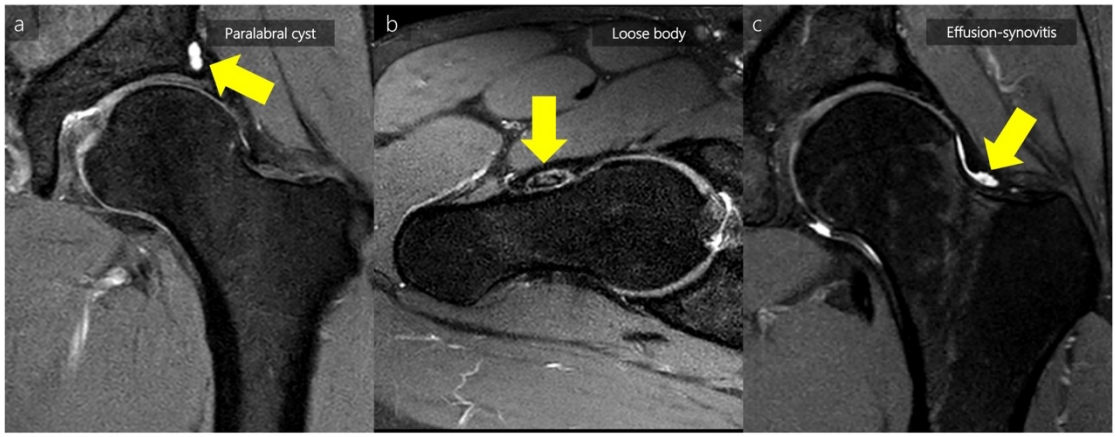


Figure 3.8. SHOMRI assessment of paralabral cysts, loose bodies and effusion-synovitis.
a) paralabral cyst; b) loose body and c) effusion-synovitis.

VI. Intra-articular loose bodies

Sagittal, coronal, and axial oblique images were evaluated for the presence of intra-articular loose bodies (**Figure 3.8**), with the features scored as either present or absent (**Table 3.3**).(123)

VII. Effusion-synovitis

Effusion-synovitis (**Figure 3.8**) was defined by Lee et al. (123) as "the presence of a hyperintense signal at the femoral neck region and was scored as present if the fluid signal had a thickness of

greater than 0.7cm on either the coronal or axial oblique images" (**Table 3.3**). The use of unenhanced MRI prevented the differentiation of effusion from synovitis.(89,191,192)

VIII. Ligamentum teres tears

Ligamentum teres tears were assessed in the coronal plane and graded using a 4-point scale (**Table 3.3**): 0 for normal ligamentum teres, 1 for the presence of signal abnormalities or fraying, 2 for a partial tear, and 3 for a complete tear (**Figure 3.9**).(123)

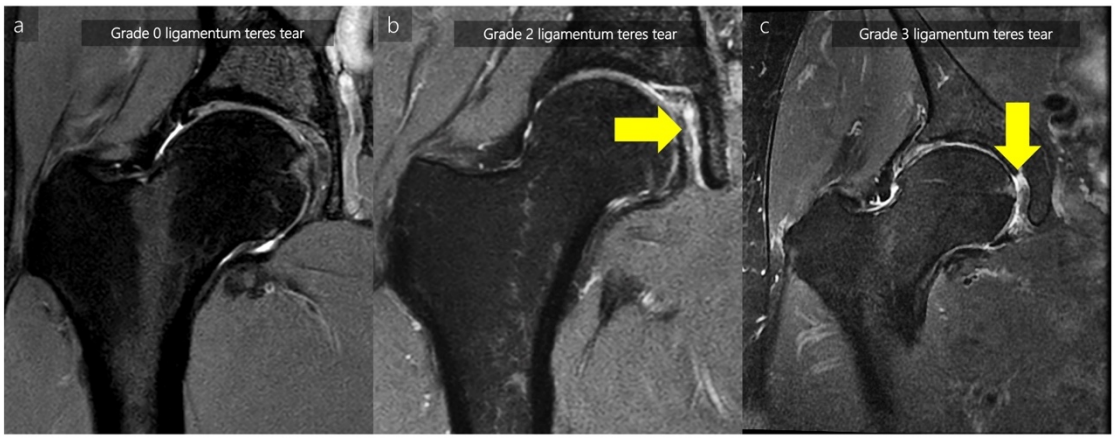


Figure 3.9. SHOMRI assessment of ligamentum teres tears.
a) grade 0 ligamentum teres tear (no ligamentum teres tear present); b) grade 2 (partial) ligamentum teres tear and c) grade 3 (full thickness) ligamentum teres tear.

3.8. Magnetic resonance imaging classification

The SHOMRI assessment findings are presented in **studies 3** and **5**. A feature score was determined for cartilage, BML, subchondral cysts, labrum, ligamentum teres and whole joint disease (i.e., total SHOMRI).(123) Feature scores provide a combined assessment of the severity and extent of disease.(193) Hip OA features were also presented as either present or absent.

3.8.1. Feature scoring

The scores for the cartilage, acetabular and femoral subregions were combined, providing a total score (0-20). Bone marrow lesions and subchondral cysts had a total feature score ranging from 0 to 30 and 0 to 20, respectively. The labrum and ligamentum teres were scored from 0 to 20 and 0 to 3, respectively. The remaining features (paralabral cysts, loose bodies, and hip effusion) were scored as present or absent. The total SHOMRI score (0 to 96) was calculated for each hip by

adding the scores for each of the eight OA features, with a higher score signifying a greater severity of whole joint degenerative change.(125,194)

3.8.2. Dichotomous scoring

A cartilage defect was scored as present if cartilage loss was observed in at least one acetabular or femoral subregion and was reported as any cartilage defect (grade 1 or grade 2) or full-thickness defect (grade 2 only). For BML and subchondral cysts, the feature was scored as present if a grade one or above was scored in at least one subregion. A labral tear was scored as present if a grade 2 or above was observed in one or more subregions. Ligamentum teres tears were scored as present if a partial (grade 2) or full-thickness tear (grade 3) was observed. The remaining three OA features (paralabral cysts, loose bodies, and effusion-synovitis) were scored as either present or absent.

3.9. Reliability of Scoring Hip Osteoarthritis with MRI measure

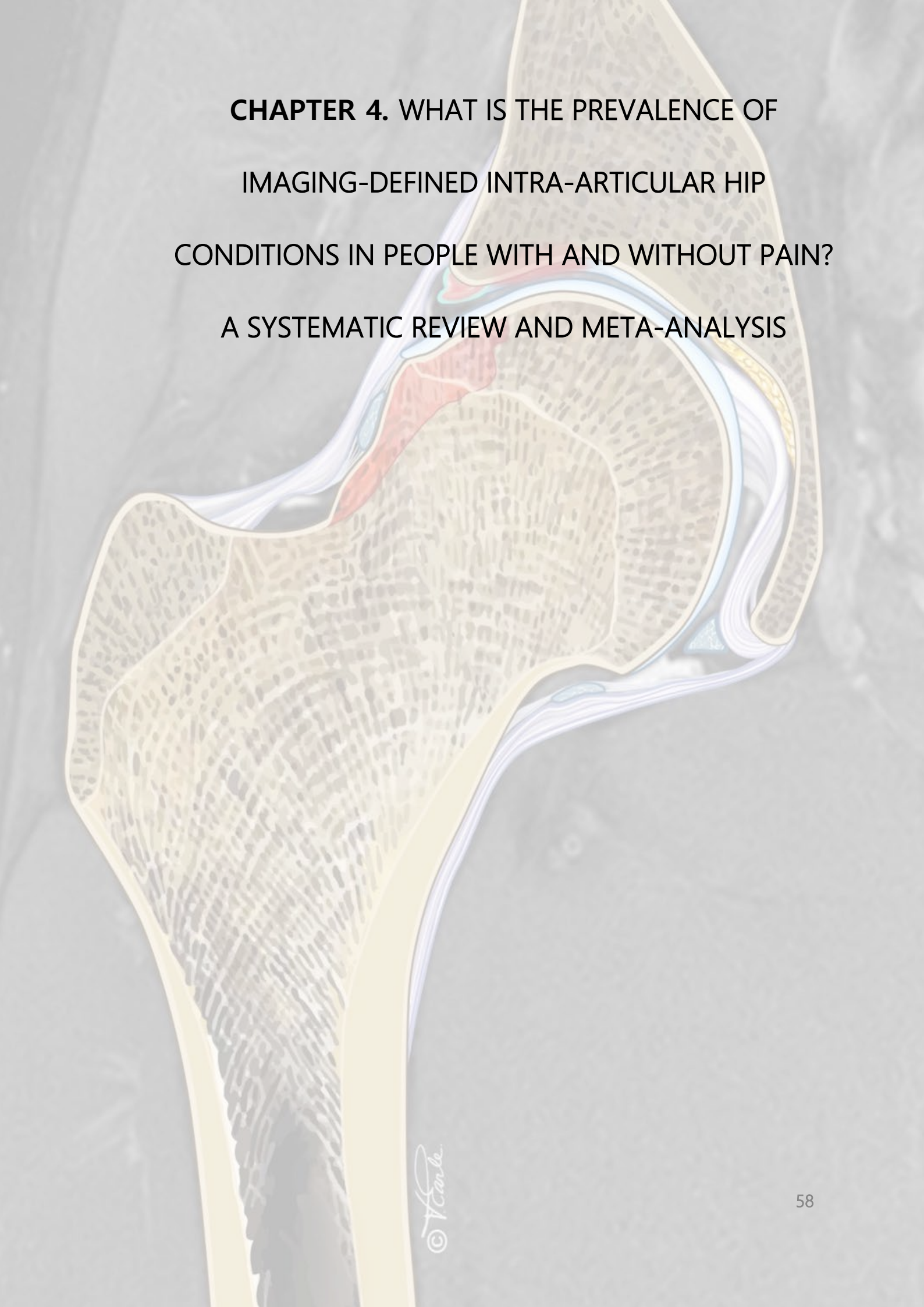
Intra-observer reliability for the SHOMRI assessment was determined by a single radiologist (Dr. Ramya Srinivasan) scoring 20 hips twice, two weeks apart. Intra-observer reliability values for OA features (total and dichotomous scoring) are presented in Table 3.4.

Table 3.4. Results of Intra-observer reliability for scoring of hip osteoarthritis with MRI.

	n*	% agreement	Kappa (95%CI)	PABAK (95%CI)	ICC (95%CI)‡
SHOMRI feature*					
Cartilage defect *any*	200	88	0.66 (0.54, 0.78)	0.76 (0.67, 0.85)	0.66 (0.28,0.85)
Cartilage defect *full*	200	98	-0.01 (-0.27, 0.01)	0.96 (0.91, 1.00)	
Bone marrow lesion	200	100	0.89 (0.67, 1.00)	0.99 (0.97, 1.00)	0.91 (0.80, 0.97)
Subchondral cysts	200	98	0.59 (0.22, 0.96)	0.96 (0.92, 1.00)	0.65 (0.30, 0.84)
Labral tear	80	90	0.77 (0.62, 0.92)	0.80 (0.67, 0.93)	0.77 (0.51, 0.90)
Ligamentum teres tear	20	80	0.60 (0.24, 0.95)	0.60 (0.25, 0.95)	0.61 (0.23, 0.83)
Paralabral cyst	20	95	0.89 (0.67, 1.00)	0.90 (0.71, 1.00)	-
Loose bodies†	20	100	-	-	-
Effusion-synovitis	20	95	0.83 (0.50, 1.00)	0.90 (0.71, 1.00)	-
Total SHOMRI		-	-	-	0.84 (0.62, 0.93)

*n describes the number of subregions scored in 20 hips.
†Feature not present in 20 hips assessed for reliability.
‡Intra-class coefficient values only used for features that provided a total score.
PABAK = prevalence adjusted bias adjusted kappa.

CHAPTER 4. WHAT IS THE PREVALENCE OF IMAGING-DEFINED INTRA-ARTICULAR HIP CONDITIONS IN PEOPLE WITH AND WITHOUT PAIN? A SYSTEMATIC REVIEW AND META-ANALYSIS



PREFACE

Chapter 1 highlighted that the relationship between hip joint imaging findings and hip/groin pain is unclear. While select studies have reported on the prevalence of chondral and labral conditions in individuals with and without hip/groin pain, no study has comprehensively synthesised the available literature. Chapter 1 reported that little is known about the prevalence of other intra-articular soft tissue features found on imaging, such as ligamentum teres tears, paralabral cysts and synovitis in individuals with and without hip/groin pain. A systematic review was undertaken to identify and evaluate the current literature on the prevalence of all intra-articular hip conditions in individuals with and without hip/groin pain.

Chapter 4 contains the following publication in its entirety (Appendix 14), with the following minor amendments: (I) The term intra-articular hip pathologies is replaced by intra-articular hip conditions to provide consistency through this thesis; (II) The term hip and groin pain is replaced by hip/groin pain to provide consistency through this thesis; (III) Figure 4.1 is a replacement preferred reporting guidelines for systematic reviews and meta-analysis (PRISMA) flow chart from the original publication, as the previous version did not have sufficient resolution and (IV) Figure 4.3 and 4.5 were included in the supplementary file in the original publication.

Heerey JJ, Kemp JL, Mosler AB, Jones DM, Pizzari T, Souza RB, Crossley KM. What is the prevalence of imaging-defined intra-articular hip pathologies in people with and without pain? A systematic review and meta-analysis. British Journal of Sports Medicine. 2018;52:581-593.

4.1. Introduction

Hip/groin pain is a common cause of loss of function in young and middle-aged adults.(7,105) The prevalence of hip/groin pain is known to be as high as 49% in athletes and 21% in population cohorts.(7,195) The occurrence of hip/groin pain increases with age,(195–197) and its impact often extends beyond activity reduction, to a reduction in participation in work and family activities.(6,7,198–200) Many different structures, sometimes referred to as clinical entities, may contribute to the development of hip/groin pain.(11,201–204) Imaging is often used to assist in the diagnosis of intra and extra-articular hip conditions.(107,110,205) With the advent of higher quality imaging, the understanding and implications of commonly seen hip morphology and pathology requires attention.(94)

Surgical management for morphological and articular conditions has increased dramatically, (206,207) with Montgomery et al. (206) highlighting a 365% increase between 2004 and 2009. However, some of the articular conditions targeted by surgical management may exist within the "normal spectrum" related to age, gender, and activity exposure. This concept is evident in a number of other anatomical regions, including the knee, shoulder, and spine.(127,208–211) With imaging findings of intra-articular hip conditions in the presence of prolonged symptoms being the catalyst for surgical interventions,(212,213) it seems prudent to explore the relationship of imaging findings and symptoms. Recent reviews have highlighted normal variants of the acetabular labrum ,(214) as well as a high prevalence of labral tears in symptomatic and asymptomatic subjects.(61,62) However, none of these reviews aimed to report the prevalence of all intra-articular hip conditions. In addition, a number of relevant studies have been published subsequent to these reviews. Therefore, the aim of this review was to determine the prevalence of intra-articular hip conditions in symptomatic and asymptomatic individuals irrespective of their sex, age, level of activity, and presence or absence of radiographic hip osteoarthritis.

4.2. Methods

This systematic review was undertaken using the PRISMA. The review protocol was registered on the PROSPERO international prospective register of systematic reviews (http://www.crd.york.ac.uk/PROSPERO) on the 16th of February 2016. Registration number: CRD42016035444.

4.2.1. Eligibility Criteria

Pre-specified inclusion criteria were: 1) studies written in English language that utilised cross-sectional, case-control, case series, and cohort designs; 2) studies that included participants with and without hip, groin and buttock pain; 3) studies that MRI, magnetic resonance arthrography (MRA) or CT with or without contrast to investigate the presence intra-articular conditions; 4) studies that had a primary outcome to determine the prevalence of intra-articular conditions (including labral tears, cartilage defects, BML, ligamentum teres tears, herniation pits) or a primary aim to report FAI syndrome prevalence and intra-articular condition prevalence. No restrictions were placed on the age of study participants. Studies were excluded if they: 1) reported prevalence of intra-articular conditions, but it was not the primary aim of the study; 2) investigated intra-articular conditions in the following hip conditions: SCFE or Legg-Calvé-Perthes disease; 3) used other forms of imaging to determine prevalence including x-ray, isotopic bone scans and ultrasound; 4) determined prevalence by arthroscopy or open surgery; 5) included less than five participants; 6) were systematic reviews, abstracts or unpublished data or 7) were not published in the English language.

4.2.2. Search strategy

A systematic search was undertaken using Medline, Pubmed, CINAHL, EMBASE, SPORTDiscus, Scopus, and Cochrane databases from inception to 19 May 2016, the search was then repeated in its entirety on 27 February 2017. In addition, reference lists of included articles were screened and citation tracking using Google Scholar was undertaken. The search strategy was independently undertaken by two authors (Mr. Joshua Heerey and Ms. Denise Jones) using database specific controlled vocabulary and keyword terms. The search strategy for each respective database can be found in supplementary Appendix 15. At the completion of database searching, all potentially eligible articles were exported into Endnote X7 (Thomson Reuters, Carlsbad, California, USA) and duplicates removed. The specified inclusion/exclusion criteria were independently applied to the yield achieved from the database and secondary searching by two authors (Mr. Joshua Heerey and Ms. Denise Jones). Full-text articles were subsequently retrieved and screened independently by each author for eligibility. Final inclusion was determined by each author (Mr. Joshua Heerey and Ms. Denise Jones) independently and then a consensus meeting was held to determine the final list of included articles. If disagreements arose in relation to the studies eligibility, a third reviewer (Dr. Joanne Kemp) was consulted to determine eligibility.

4.2.3. Risk of bias

Two authors (Mr. Joshua Heerey and Ms. Denise Jones), independently evaluated each eligible study for risk of bias, using a tool designed for prevalence papers.(215) This tool consists of 10 "yes" or "no" questions that evaluate both external (four questions) and internal validity (six questions), a "yes" is associated with low risk of bias (LR) and a "no" with a high risk of bias (HR). An article that fails to report sufficient detail to enable scoring for an item, is given a "no" which equates to HR.(215) Modification was made to question seven which evaluated the reliability of the imaging modality, with an intra-class correlation coefficient (ICC) greater than 0.40 and Cohen's κ greater than 40% considered to be LR. At the completion of scoring, each article receives an overall risk of bias score based on the number of items that demonstrate HR. The articles were then grouped into LR (0-3 items), moderate risk (MR) (4-5 items) and HR (6 or more items) derived from literature using the same tool for risk of bias appraisal.(216) If disagreements arose in relation to the study's risk of bias, a third independent reviewer (Dr. Joanne Kemp) resolved the discrepancy. Inter-rater reliability was evaluated with κ, with values above 80% considered excellent agreement, between 60% to 80% substantial agreement, 40% to 60% moderate agreement and below 40% poor to fair agreement.(217)

4.2.4. Data extraction

Data from all 29 articles were independently extracted by two authors (Mr. Joshua Heerey and Mrs. Andrea Mosler). Consensus meetings were held following data extraction of the first 10 articles, and after the completion of the 29 articles, to discuss discrepancies in the extraction and to reach consensus. A third author (Dr. Kay Crossley) was used to reach a consensus if discrepancies in data extraction occurred between the two authors. If additional data were required, the corresponding authors were contacted. Where two articles reported the same data set, the studies were examined for discrepancies and the author was contacted, if required, to seek clarity. The extracted data included: author, study design, number of study participants (and hips), demographics, imaging modality, study findings (intra-articular conditions).

4.2.5. Data synthesis and analysis

In relation to this systematic review, as none of the included studies investigated community-based populations, the term prevalence was used to define the frequency of intra-articular pathologies in each studys' included population. The prevalence of intra-articular hip conditions was determined by dividing the number of cases by the total number of participants in the

specified population. Comprehensive Meta-Analysis Software (Version 3.0, Biostat Inc., USA) was used to determine the prevalence and 95% CIs. Prevalence was presented at a per person level, and if the study did not present sufficient information to enable per person analysis, prevalence was reported per hip (if the request for per person data was not successful). In the event that a study used two or more radiologists to evaluate the presence of intra-articular pathologies, an average prevalence score was determined for each of the pathologies reported. Additional intra-articular hip conditions that were only reported in one symptomatic and asymptomatic study were displayed in supplementary content. Pooled data were presented in per person format, with per hip analysis summarized in text, and details presented in the supplementary content.

Primary subgroup analysis occurred on the presence or absence of pain. Secondary group analysis was completed on the basis of the method used to report prevalence (per person or per hip) and imaging modality (MRI, MRA, or CT).

Intra-articular hip conditions were recorded as present or absent, due to the variation in assessment, and grading of pathology in the included studies. In relation to cartilage defects, only studies that reported femoral and acetabular defects together were considered for primary analysis. Where studies reported femoral and acetabular defects independently qualitative analysis was undertaken.

Meta-analyses were undertaken only with studies adjudged to be LR and MR using a random effects model. High risk of bias studies were not included in meta-analyses in line with recent recommendations.(218,219) Qualitative analyses were undertaken when pooling of data was precluded because of clinical heterogeneity or if adjudged to be HR. The level of statistical heterogeneity for the pooled data was evaluated with Q and I^2 statistics.(218) An I^2 ≤25% represented low levels of statistical heterogeneity, 25%-≤50% moderate, ≥75% high heterogeneity.(220) Sensitivity analysis was undertaken firstly with the removal of studies using an MRI field strength less than 1.5-T and secondly in only studies using 3-T MRI.
The strength of evidence for the pooled results of this review is based on the original methods advocated by van Tulder et al. (221) and later adapted by Rathleff et al. (222).
Strong evidence: pooled results derived from three or more studies, including a minimum of two LR studies, that are statistically homogenous (p>0.05).
Moderate evidence: pooled results derived from multiple studies, including at least one LR study, which are statistically heterogeneous (p<0.05); or from multiple MR and HR studies which are statistically homogenous (p>0.05).

Limited evidence: pooled results from multiple HR or MR studies which are statistically heterogeneous ($p<0.05$).

4.3. Results

4.3.1. Search results

The review utilised the PRISMA flow diagram (**Figure 4.1**).(223) In total 343 citations were identified through the search strategy. At the completion of duplicate removal, 124 citations were screened based on title and abstract. The full-text versions of 56 articles were retrieved and subsequently assessed for eligibility using the inclusion criteria. Four additional articles(100,122,185,224) were added after the screening of reference lists and citation tracking. Thirty-one articles were subsequently excluded (**Appendix 16**) and the remaining 29 articles(68,99–104,112,120–122,142,185–187,224–237) were included for data analysis (**Table 4.1** to **4.3**).

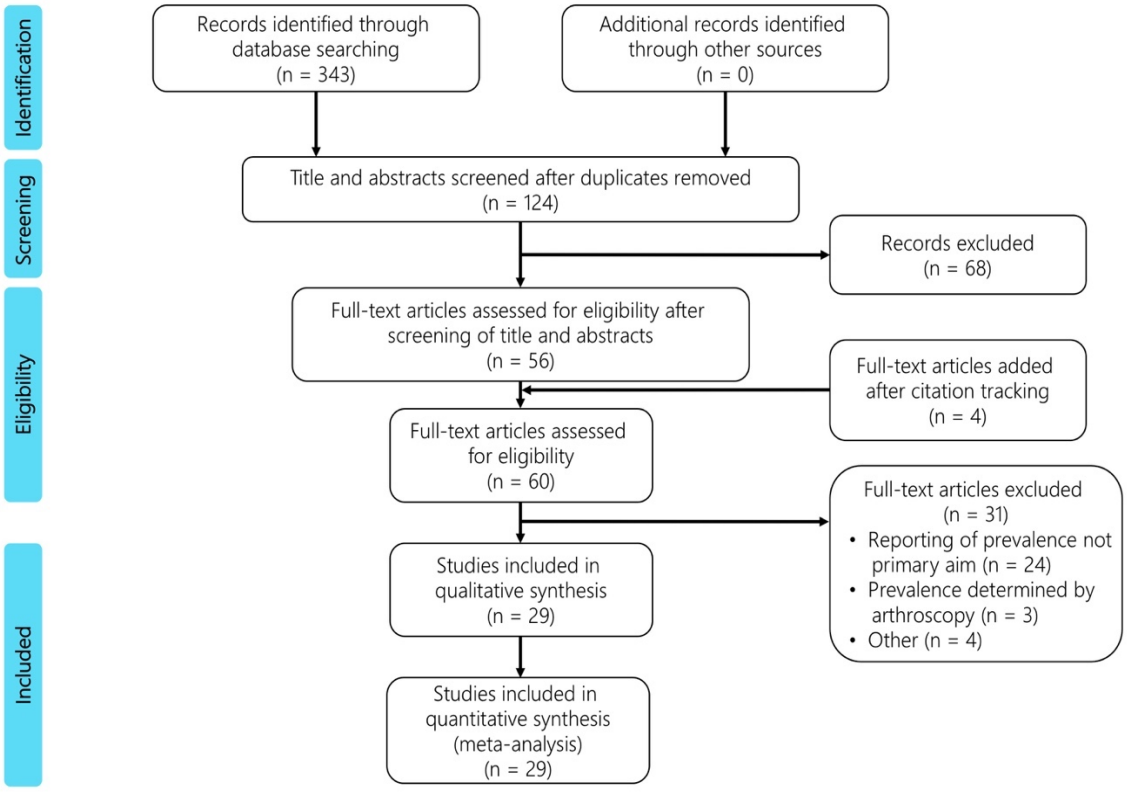


Figure 4.1. Preferred reporting guidelines for systematic reviews and meta-analysis flow diagram of search results and study selection.

Table 4.1. Included studies involving asymptomatic participants only.

Author	Study design	Study population	No. of participants (hips)	Demographics	Imaging modality	Findings (Intra-articular conditions)
Ayeni et al. (185)	Cross-sectional	**Subjects** Ice Hockey players **Controls** Non-athletic individuals	**Subjects** 20 (20) **Controls** 20 (20)	**Subjects** Age*: 20.6 Sex: 9 F/11 M **Controls** Age*: 20.1 Sex: 9 F/11 M	1.5-T MRI	**Subjects** Labral tear: 12/20; acetabular cartilage defect: 0/20; femoral cartilage defect: 2/20; herniation pit: 2/20; osseous bump: 4/20 and paralabral cyst: 0/20. **Controls** Labral tear: 12/20; acetabular cartilage defect: 3/20; femoral cartilage defect: 3/20; herniation pit: 2/20; osseous bump: 4/20 and paralabral cyst: 0/20.
Farrell et al. (228)	Cross-sectional	**Subjects** Rugby union academy players **Controls** Moderately active individuals	**Subjects** 20 (40) **Controls** No MRI	**Subjects** Age*: 22 (1.5) Sex: 20 M **Controls** Age*: 21.3 (1.7) Sex: 20 M	3-T MRI	**Subjects** Labral tear: 17/20‖; labral tear right hip: 10/20; labral tear left hip: 15/20; bilateral labral tear: 8/20; cartilage defect: 5/20; cartilage defect right hip: 3/20; cartilage defect left hip: 3/20 and bilateral cartilage defect: 1/20.
Georgiadis et al. (229)	Case series	Children	108 (216)	Age*: 11.9 (†2-18)	3-T MRI 1.5-T MRI	Labral tear per person: 2/108 and Labral tear per hip: 3/216.
Lahner et al.(224)	Cross-sectional	**Subjects** Semi-professional soccer players **Controls** Amateur soccer players	**Subjects** 22 (22) **Controls** 22 (22)	**Subjects** Age*: 23.3 (3.3) Sex: 22 M **Controls** Age*: 22.5 (3.5) Sex: 22 M	1.5T MRI	**Subjects** Labral tear: 3/22 and cartilage defect: 2/22. **Controls** Labral tear: 1/22 and cartilage defect: 1/22.
Lahner et al. (226)	Cross-sectional	**Subjects** Track and Field athletes **Controls** Non-athletes	**Subjects** 22 (44) **Controls** 22 (44)	**Subjects** Age*: 23.7 (3.0) (†18-30) Sex: 11 F/11 M **Controls** Age*: 22.4 (4.2) (†18-32) Sex: 11 F/11 M	1.5-T MRI	**Subjects** Labral tear: 2/44; acetabular cartilage defect: 1/44; femoral cartilage defect: 1/44; herniation pit: 3/44 and osseous bump: 3/44. **Controls** Labral tear: 1/44; acetabular cartilage defect: 0/44; femoral cartilage defect: 0/44; herniation pit: 1/44 and osseous bump: 0/44.
Lee et al. (103)	Cross-sectional	Medical students and allied health professionals	70 (70)	Age*: 26 (†19-41) Sex: 47 F/23 M	3-T MRI	Labral tear: 27/70; isolated labral tear: 16/70; sublabral recesses: 10/70; labral ossification: 10/70; paralabral cyst: 1/70; acetabular cartilage delamination 7/70; fibrocystic changes at head-neck junction 4/70 and intra-articular pathology with or without labral tear: 32/70.

Leunig et al. (112)	Cross-sectional	**Subjects** Young women **Controls** Young men	**Subjects** 80 (80) **Controls** 244 (244)	**Subjects** Age*: 19.3±1.3 **Controls** Age*: 20.0±0.9	1.5-T MRI	**Subjects** Labral tear: 17/80; intra-labral signal alterations: 10/80; labral avulsions: 13/80; labral deformities: 4/80 and labral ganglions: 4/80; impingement pits: 0/80 **Controls** Labral tear: 175/244; intra-labral signal alterations: 86/244; labral avulsions: 153/244; labral deformities: 27/244; labral ganglions: 65/244 and impingement pits: 41/244.
Mineta et al. (233)	Case series	Individuals who underwent abdominal or pelvic CT	NR (1178)	Age*: 58.2 (†20-89) Sex: 483 F/695 M	CT	Herniation pit: 164/1178.
Panzer et al. (235)	Case series	Individuals who had CT for polytrauma/ pelvic, abdominal or thoracic examinations	200 (400)	Age*: 55.1 (†15-96) Sex: 77 F/123 M	CT	Herniation pit (per person): 85/200; herniation pit (per hip): 107/400; >1 herniation pit (per hip): 25/400; herniation pit right hip: 65/107; herniation pit left hip: 42/107 and bilateral herniation pit: 22/400.
Philippon et al. (186)	Cross-sectional	**Subject**s Youth ice hockey players **Controls** Youth Skiers	**Subjects** 61 (61) **Controls** 27 (27)	**Subjects** Age*: 14.5 (2.7) Sex: 61 M **Controls** Age*: 15.2 (2.7) Sex: 27 M	3-T MRI	**Subjects** Labral tear: 42/61; peewee hockey players - labral tear: 13/27; bantam hockey players - labral tear: 5/8; midget hockey players - labral tear: 24/26; cartilage defect: 5/61; peewee hockey players - cartilage defect: 0/27; bantam hockey players - cartilage defect: 0/8 and midget hockey players - cartilage defect: 5/26. **Controls** Labral tear: 19/27; skier - labral tear (peewee control): 5/7; skier - labral tear (bantam control): 5/8; skier - labral tear (midget control): 9/12; cartilage defect: 1/27; skier - cartilage defect (peewee control): 0/7; skier - cartilage defect (bantam control): 0/8 and skier - cartilage defect (midget control): 1/12.
Register et al. (102)	Cross-sectional	Asymptomatic individuals	45 (45)	Age*: 38 (†18-66) Sex: 17 F/28 M	3-T MRI	Labral tears: 31/45; cartilage defect: 11/45; osseous bump: 9/45; ligamentum teres tear: 1/45; labral/paralabral cyst: 6/45; acetabular bone oedema: 5/45; fibrocystic changes to the femoral head/neck junction: 10/45; rim fracture: 5/45 ; subchondral cysts: 7/45 and osseous bump of the femoral neck: 9/45.

Schmitz et al. (68)	Case series	US air force personnel on active duty	21 (42)	Age*: 34 (†27-43) Sex: 5 F/16 M	1.5-T MRI	Labral tears: reader 1 35/42; reader 2 33/42 Paralabral cysts: reader 1 11/42; reader 2 9/42
Silvis et al. (187)	Cross-sectional	Ice hockey players	39 (39)	Age: NR Sex: 39 M	3-T MRI	Hip pathology total findings: 25/39; labral tear: 22/39; cartilage defect: 7/39 and hip effusion: 0/39
Yuan et al. (237)	Cross-sectional	**Subjects** High school student with clinical signs of FAI syndrome **Controls** High school students no clinical signs of FAI syndrome	**Subjects** 13 (22) **Controls** 13 (26)	**Subjects** Age: NR Sex: 1 F/12 M **Controls** Age: NR Sex: 1 F/12 M	3-T MRI 1.5-T MRI	**Subjects** Any abnormal hip finding: 15/22; labral tear: 14/22 and acetabular rim damage: 3/22 and cartilage defect: 1/22 **Controls** Any abnormal hip finding: 10/26; labral tear: 10/26; acetabular rim damage: 0/22 and cartilage defect: 1/26

*= mean (standard deviation); † = range.

CT = computed tomography; FAI = femoroacetabular impingement; F = female; M = male; MRI = magnetic resonance imaging; NR = not reported; T = tesla; US = united states; || = results from raw data obtained from author and > = greater than.

Table 4.2. Included studies involving symptomatic participants only.

Author	Study design	Study population	No. of participants (hips)	Demographics	Imaging modality	Findings (Intra-articular conditions)
Domb et al. (121)	Case series	Retired NFL players with hip pain	38 (62)	Age*: 33 (†27-39) Sex: 38 M	1.5-T MRI 1.5-T MRA	Labral tear: 55/62; cartilage defect (gr 1/2): 61/62; cartilage defect (gr 3): 0/62; ligamentum teres tear (partial to severe): 50/62; osteophyte: 3/62; subchondral bone cyst: 9/62; paralabral cyst: 3/62; bursitis: 0/62; loose bodies: 0/62; transverse ligament tear: 2/62; AVN: 0/62
Jayakar et al. (230)	Case series	Individuals with hip pain	192 (208)	Age*: 61 (8.9) (†50-92) Sex: 139 F/69 M	MRA	Labral tear: 152/208; labral fraying: 42/208; no labral tearing: 14/208; tonnis gr 0-1 - labral tearing: 133/182, labral fraying: 35/182, no labral tearing: 14/182; tonnis gr 2-3 - labral tearing: 19/26, labral fraying: 7/26, no labral tearing: 0/26
Kassarjian et al. (100)	Case series	Individuals with clinical signs of FAI syndrome	40 (42)	Age*: 36.5 (12) (†17-67) Sex: 18 F/22 M	1.5-T MRA	Labral tear: 42/42; cartilage defect: 40/42; triad (AA, anterosuperior cartilage abnormalities, anterosuperior labral tear): 37/42; paralabral cyst: 6/42 (6/6 triad abnormalities); herniation pit: 2/42 (2/2 triad abnormalities); os acetabuli: 17/42 (16/17 triad abnormalities)
Narvani et al. (234)	Case series	Individuals playing sport with groin pain	18 (18)	Age*: 30.5 (8.45) (17-48) Sex: 5 F/13 M	1-T MRA	Labral tear: 4/18
Neiman et al. (120)	Case series	Individuals with hip pain	229 (229)	Age*: 36.5 (14.17) (†18-67) Sex: 102 F/127 M	1.5-T MRA	Labral tear: 146/229; cartilage defect: 64/229; ligamentum teres partial tears: 2/229; ligamentum teres complete tears: 2/229; synovitis: 3/229; transient osteoporosis of the hip: 2/229
Neumann et al. (99)	Case series	Individuals with mechanical hip pain	100 (100)	Age*: 39 (13) (†17-76) Sex: 76 F/ 24 M	1.5-T MRA	Labral tear: 66/100; cartilage defect: 76/100; BML: 29/100; osteophytes: 32/100; Subchondral cysts: 23/100; Subchondral sclerosis: 22/100
Pizzolatti et al. (236)	Case series	Individuals with suspicion of labral tear	96 (108)	Age*: M 39.3 (†18-63) Age*: F 41.3 (†20-73) Sex: 59 F/37 M	0.5-T MRA 1.5-T MRA	Labral tear (per person): 96/96; labral tear (per hip): 108/108; isolated labral tears: 24/108; completely torn labrum: 43/108 hips; 1st degree labral tear: 44/108; 2nd degree labral tear: 34/108; 3rd degree labral tear: 30/108; cartilage defect: 88/108; cartilage defect in entire weight bearing zone: 46/108; 1st degree cartilage defect: 55/108; 2nd degree cartilage defect: 14/108; 3rd degree cartilage defect: 19/108

*= mean (standard deviation); † = range.

AA = alpha angle; AVN = avascular necrosis; BML = bone marrow lesion; FAI = femoroacetabular impingement; F = female; Gr = grade; M = male; MRA = magnetic resonance arthrography; MRI = magnetic resonance imaging; NFL = national football league and T = tesla.

Table 4.3. Included studies involving asymptomatic and symptomatic participants.

Author	Study design	Study population	No. of participants (hips)	Demographics	Imaging modality	Findings (Intra-articular conditions)
Dickenson et al. (227)§	Cross-sectional	**Subjects** Male golfers with hip pain **Controls** Male golfers without hip pain	**Subjects** NR (15) **Controls** NR (95)	**Subjects** Age: NR Sex: 15 M **Controls** Age: NR Sex: 95 M	1.5-T MRI	**Subjects** Labral tear: 3/15; increased labral signal: 3/15; acetabular cartilage defect 4/15; femoral cartilage defect: 1/15; acetabular subchondral oedema: 3/15; femoral subchondral oedema: 6/15; herniation pit: 4/15 and joint effusion: 1/15. **Controls** Labral tear: 22/95; increased labral signal: 21/95; acetabular cartilage defect: 6/95; femoral cartilage defect: 3/95 acetabular subchondral oedema: 10/95; femoral subchondral oedema: 10/95; herniation pit: 9/95 and joint effusion: 8/95.
Ji et al. (231)	Case-control	**Subjects** Mechanical symptoms with hip pain **Controls** Pain due to a ureter stone without hip pain	**Subjects** 151 (151) **Controls** 151 (151)	**Subjects** Age¥: 46 (12) Sex: 83F/68 M **Controls** Age¥: 46 (12) Sex: 83 F/68 M	**Subjects** CTA **Controls** CT	**Subjects** Herniation pit: 36/151. **Controls** Herniation pit: 5/151.
Kolo et al. (232)	Cross-sectional	**Subjects** Symptomatic/asymptomatic ballet dancers **Controls** Asymptomatic non-dancing individuals	**Subjects** 30 (59) **Controls** 14 (28)	**Subjects** Age*: 24.6 (†18-39) Sex: 30 F **Controls** Age*: 27.1 (†20-34) Sex:14 F	1.5-T MRI	**Subjects** Labral tear: 28/59; hips ≥ 2 labral tears: 12/59; labral degeneration: 24/59; hips ≥2 labral degenerative tears: 11/59; Labral ossification: 2/59; hips ≥ 2 ossified lesions: 2/59; acetabular cartilage defect ≤5 mm: 12/59 and acetabular cartilage defect: ≥5 mm: 17/59 herniation pit: 31/59. **Controls** Labral tear: 8/28; hips ≥ 2 labral tears: 1/28; labral degeneration: 12/28; hips ≥2 labral degenerative tears: 1/28**;** labral ossification: 4/28; hips ≥ 2 ossified lesions: 0/28; acetabular cartilage defect ≤5 mm: 4/28; acetabular cartilage defect ≥5 mm: 2/28 and herniation pit: 5/28.

Mayes et al. (142)§	Case-control	**Subjects** Hip pain last 3 months‡ **Controls** No hip pain‡	**Subjects** NR (40) **Controls** NR (156)	**Subjects** Ageβ‡: 30 (IQR 24) Ageβ‾: 34.5 (IQR 24) Sex‡: 24 F/9 M **Controls** Ageβ‡: 30.5 (IQR 20) Ageβ‾: 28 (IQR 20) Sex‡: 32 F/33 M	3-T MRI	**Subjects** Labral tear: 16/40. **Controls** Labral tear: 83/156.
Mayes et al. (122)§	Case-control	**Subjects** Hip pain last 3 months‡ **Controls** No hip pain‡	**Subjects** NR (40) **Controls** NR (156)	**Subjects** Ageβ‡: 30 (IQR 24) Ageβ‾: 34.5 (IQR 24) Sex‡: 24 F/9 M **Controls** Ageβ‡: 30.5 (IQR 20) Ageβ‾: 28 (IQR 20) Sex‡: 32 F/33 M	3-T MRI	**Subjects** Ligamentum teres tear: 20/40. **Controls** Ligamentum teres tear: 38/156.
Mayes et al. (104)§	Case-control	**Subjects** Hip pain last 3 months‡ **Controls** No hip pain‡	**Subjects** NR (40) **Controls** NR (156)	**Subjects** Ageβ‡: 30 (IQR 24) Ageβ‾: 34.5 (IQR 24) Sex‡: 24 F/9 M **Controls** Ageβ‡: 30.5 (IQR 20) Ageβ‾: 28 (IQR 20) Sex‡: 32 F/33 M	3-T MRI	**Subjects** Cartilage defect: 18/40. **Controls** Cartilage defect: 66/156.

Teichtahl et al. (225)	Cross-sectional	**Subjects** Hip pain with radiographic hip OA **Controls** No hip pain	**Subjects** 19 (19) **Controls** 141 (141)		**Subjects** Age*: 59.2 (7.6) Sex: 11 F/8M **Controls** Age*: 66.8 (7.3) Sex: 78 F/63 M	3-T MRI	**Subjects** Femoral head cartilage defect: central superolateral 17/19; central inferomedial 10/19; anterior: 12/19; posterior 14/19; acetabular cartilage defects: central superolateral 17/19; anterior 18/19; posterior 15/19; femoroacetabular: central superolateral 18/19; anterior 18/19; posterior 16/19; femoral head bone marrow lesions: central superolateral 10/19; central inferomedial 6/19; anterior 7/19; posterior 5/19; acetabular bone marrow lesions: central superolateral 13/19; central inferomedial 2/19; anterior 13/19; posterior 11/19; femoroacetabular bone marrow lesions: central superolateral 14/19; central inferomedial 6/19; anterior 14/19 and posterior 13/19. **Controls** Femoral head cartilage defect: central superolateral 45/141; central inferomedial 67/141; anterior 5/141; posterior 25/141; acetabular cartilage defects: central superolateral 37/141; anterior 26/141; posterior 50/141; femoroacetabular: central superolateral 64/141; anterior 27/141; posterior 57/141; femoral head bone marrow lesions: central superolateral 7/141; central inferomedial 6/141; anterior 2/141; posterior 4/141; acetabular bone marrow lesions: central superolateral 22/141; central inferomedial 3/141; anterior 28/141; posterior 18/141; femoroacetabular bone marrow lesions: central superolateral 27/141; central inferomedial 8/141; anterior 29/141 and posterior 20/141.
Tresch et al. (101)	Cross-Sectional	**Subjects** Individuals with FAI syndrome **Controls** Asymptomatic individuals	**Subjects** 63 (63) **Controls** 63 (63)		**Subjects** Age*: 35.3 (†20-50) **Controls** Age*: 34.4 (†20-50)	1.5-T MRI 1.5-T MRA	**Subjects** Labral tears: reader 1 37/63; reader 2 40/63; degenerated labrum: reader 1 6/63; reader 2 9/63; normal labrum: reader 1 20/63; reader 2 14/63; acetabular cartilage defect (superficial): reader 1 9/63; reader 2 21/63; acetabular cartilage defect (deep): reader 1 17/63; reader 2 12/63; normal acetabular cartilage: reader 1 37/63; reader 2 30/63 femoral cartilage defect (superficial): reader 1 13/63; reader 2 13/63; femoral cartilage defect (deep): reader 1 7/63; reader 2 5/63; normal femoral cartilage: reader 1 43/63 and reader 2 45/63. **Controls** Labral tears: reader 1 23/63; reader 2 33/63; degenerated labrum: reader 1 4/63; reader 2 8/63; normal labrum: reader 1 36/63; reader 2 22/63; acetabular cartilage defect (superficial): reader 1 5/63; reader 2 11/63; acetabular cartilage defect (deep): reader 1 0/63; reader 2 2/63; normal acetabular cartilage: reader 1 58/63; reader 2

										50/63 femoral cartilage defect (superficial): reader 1 2/63; reader 2 3/63; femoral cartilage defect (deep): reader 1 0/63; reader 2 2/63; normal femoral cartilage: reader 1 61/63 and reader 2 58/63.

¥ = median (standard deviation); β = median (interquartile range) *= mean (standard deviation); † = range.
CTA = computed tomography arthrography; CT = computed tomography; FAI = femoroacetabular impingement; F = female; IQR = interquartile range; M = male; MM = millimetre; MRA = magnetic resonance arthrography; MRI = magnetic resonance imaging; NR = not reported; OA = osteoarthritis; T = tesla; § = authors provided additional results not presented in original article; ≥ = greater than or equal to; ≤ = less than or equal to; ǂ = includes dancers and athletes; ‡ = dancers and ∓ = athletes.

4.3.2. Risk of bias within studies

The two reviewers agreed on the risk of bias items on 96% of occasions (278/290 items), with a κ-value of 0.84 (95%CI: 0.78, 0.90) representing excellent agreement.(217) Five of the 29 (17%) included articles were adjudged to be of HR, with 20 of MR and four of LR. All 29 studies had HR for items 1 and 2, which highlights the disparity of the included study populations when compared to a general population, and the inadequacies of the sampling frames used within the studies. In addition, the inability to demonstrate the reliability of the assessment method used to determine the prevalence of intra-articular conditions, the use of different imaging methods within the one study population, and the reporting of prevalence per hip instead of per person were other notable sources of bias (**Table 4.4**).

4.3.3. Study characteristics

The 29 included studies reported prevalence characteristics on 2572 participants and 4453 hips. Fourteen studies (1068 participants, 2705 hips) included only asymptomatic participants, with 10 of the studies reporting a mean age of less than 40 years of age (**Table 4.1**).(68,102,103,112,185–187,224,226,228,229,233,235,237) Eight studies investigating symptomatic participants utilised MRA to evaluate the prevalence of intra-articular conditions, with 7 studies reporting a mean age of less than 40 years of age (**Table 4.2** and **4.3**).(99–101,120,121,230,234,236) Fifteen studies investigated athletic participants,(103,104,121,122,142,185–187,224,226–228,232,234,237) with the remaining studies investigating non-athletic participants or not reporting participant activity level. Two studies(225,230) included participants with radiographic hip osteoarthritis (OA), with 25 of the remaining 27 studies not identifying if participants had radiographically confirmed hip OA(**Appendices 17** to **19**).(68,99–104,112,120–122,142,185–187,224,226–229,231,232,234–236). Magnetic resonance imaging was used in 20 studies.(68,101–104,112,121,122,142,185–187,224–229,232,237) Three studies(231,233,235) evaluated prevalence with CT (one of the three studies(231) used a case-control design and computed tomography arthrography (CTA) in a symptomatic group). The MRI field strength used in the included studies varied between 0.5 to 3.0-T, with one study(230) using MRA not reporting the field strength used.

Table 4.4. Risk of bias.

Author	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Overall risk of bias
	External validity				Internal validity						
Ayeni et al. (185)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*HR*	*LR*	*LR*	*LR*	***MR***
Dickenson et al. (227)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*LR*	*LR*	*LR*	*HR*	***MR***
Domb et al. (121)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*HR*	*HR*	*LR*	*HR*	***HR***
Farrell et al. (228)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*HR*	*LR*	*LR*	*LR*	***MR***
Georgiadis et al.(229)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*HR*	*HR*	*LR*	*LR*	***HR***
Jayakar et al. (230)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*HR*	*LR*	*LR*	*HR*	***MR***
Ji et al. (231)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*LR*	*HR*	*LR*	*LR*	***MR***
Kassarjian et al. (100)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*HR*	*LR*	*LR*	*HR*	***MR***
Kolo et al. (232)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*HR*	*LR*	*LR*	*HR*	***MR***
Lahner et al. (224)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*HR*	*LR*	*LR*	*LR*	***MR***
Lahner et al. (226)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*HR*	*LR*	*LR*	*HR*	***HR***
Lee et al. (103)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	***MR***
Leunig et al. (112)	*HR*	*HR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	***LR***
Mayes et al. (142)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	***LR***
Mayes et al. (122)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	***LR***
Mayes et al. (104)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	***LR***
Mineta et al. (233)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	*HR*	***MR***
Narvani et al. (234)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*HR*	*LR*	*LR*	*LR*	***MR***
Neiman et al. (120)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*HR*	*LR*	*LR*	*LR*	***MR***
Neumann et al. (99)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*HR*	*LR*	*LR*	*LR*	***MR***
Panzer et al. (235)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*LR*	*HR*	*LR*	*LR*	***MR***
Philippon et al. (186)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*HR*	*LR*	*LR*	*LR*	***MR***
Pizzolatti et al. (236)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*HR*	*HR*	*LR*	*LR*	***MR***
Register et al. (102)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*HR*	*LR*	*LR*	*LR*	***MR***
Schmitz et al. (68)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	*HR*	***MR***
Silvis et al. (187)	*HR*	*HR*	*HR*	*HR*	*LR*	*HR*	*HR*	*LR*	*LR*	*LR*	***HR***
Teichtahl et al. (225)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*LR*	*LR*	*HR*	*LR*	***MR***
Tresch et al. (101)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*HR*	*HR*	*LR*	*LR*	***MR***
Yuan et al. (237)	*HR*	*HR*	*HR*	*HR*	*LR*	*HR*	*HR*	*HR*	*LR*	*HR*	***HR***

HR = high risk of bias; MR = moderate risk of bias; LR = low risk of bias.

Risk of bias items: **1)** Was the study's target population a close representation of the national population in relation to relevant variables, e.g., age, sex, occupation?; **2)** Was the sample frame a true or close representation of the target population?; **3)** Was some form of random selection used to select the sample, OR, was a census taken?; **4)** Was the likelihood of non-response bias minimal?; **5)** Were data collected directly from the subjects (as opposed to a proxy)? **6)** Was an acceptable case definition used in the study?; **7)** Was the study instrument that measured the parameter of interest (e.g., prevalence of low back pain) shown to have reliability and validity (if necessary); **8)** Was the same mode of data collection used for all subjects?; **9)** Was the length of the shortest prevalence period for the parameter of interest appropriate? and **10)** Were the numerator(s) and denominator(s) for the parameter of interest appropriate?

4.3.4. Heterogeneity of included studies

Heterogeneity ranged between 46% to 83% and 87% to 93% in pooled studies investigating the prevalence of labral tears in symptomatic and asymptomatic participants respectively. In the studies investigating symptomatic participants with cartilage defects, high levels of heterogeneity were observed (98%). In studies investigating asymptomatic participants, moderate (62%) to high levels (76%) were observed.

4.3.5. Prevalence of labral tears

Twenty three studies (1910 participants, 2413 hips) reported the prevalence of labral tears.(68,99–103,112,120,121,142,185–187,224,226–230,232,234,236,237) Eleven studies reported prevalence per person,(99,101–103,112,120,185–187,224,234) whereas six studies(68,121,226,227,230,232) reported prevalence per hip. Six studies(100,142,228,229,236,237) reported prevalence per person and per hip.

I. Symptomatic participants

There was limited evidence of a pooled labral tear prevalence of 62% (95%CI: 47%, 75%) per person from five studies *(5 MR)*(99,101,120,234,236) using MRA (**Figure 4.2**). Six studies *(1 HR, 4 MR, and 1 LR)*(100,121,142,227,230,232) reported prevalence of labral tears per hip in symptomatic participants. There was limited evidence of a pooled labral tear prevalence of 92% (95%CI: 29%, 100%) per hip from two MRA studies *(2 MR)*(100,230), with moderate evidence of a pooled labral tear prevalence of 32% (95%CI: 16%, 54%) from two studies *(1 MR and 1 LR)*(142,227) using MRI (**Figure 4.3**). The remaining two studies *(1 HR and 1 MR)* reported a labral tear prevalence of 89%(121) and 48%(232) per hip respectively.

II. Asymptomatic participants

There was moderate evidence of a pooled labral tear prevalence of 54% (95%CI: 41%, 66%) per person from eight studies *(7 MR and 1 LR)*(101–103,112,185,186,224,228) using MRI (**Figure 4.2**). Three studies *(3 HR)*(187,229,237) not included in the meta-analysis reported a labral tear prevalence per person in children of 1.9%,(229) high school athletes (85%)(237) and ice hockey players (56%)(187).

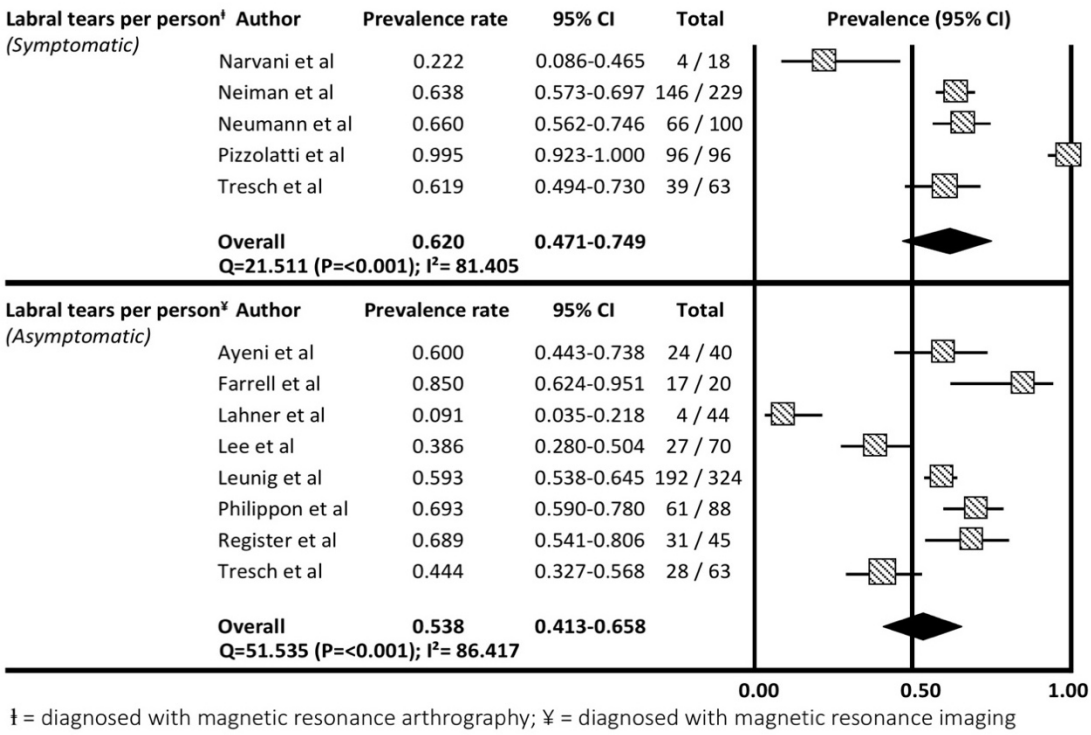


Figure 4.2. Prevalence and 95% CIs of labral tears in symptomatic and asymptomatic participants among studies that reported prevalence per person.

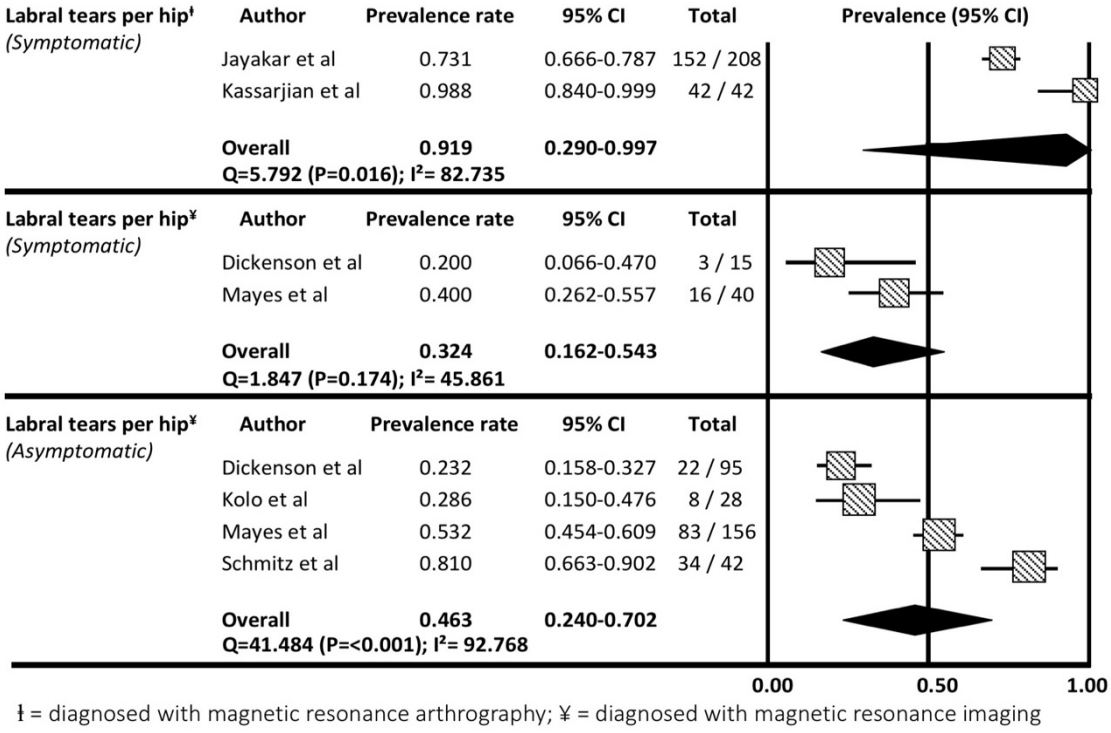


Figure 4.3. Prevalence and 95% CIs of labral tears in symptomatic and asymptomatic participants among studies that reported prevalence per hip.

Six studies *(2 HR, 3 MR, and 1 LR)*(68,142,226,227,232,237) reported prevalence of labral tears per hip in asymptomatic participants. Moderate evidence from four studies *(3 MR and 1 LR)*(68,142,227,232) using MRI demonstrated a pooled prevalence of 46% (95%CI: 24%, 70%) per hip (**Figure 4.3**). The remaining two studies *(2 HR)*(226,237) reported a labral tear prevalence per hip of 38% and 3% respectively. No studies used MRA in asymptomatic participants.

III. Sensitivity analysis

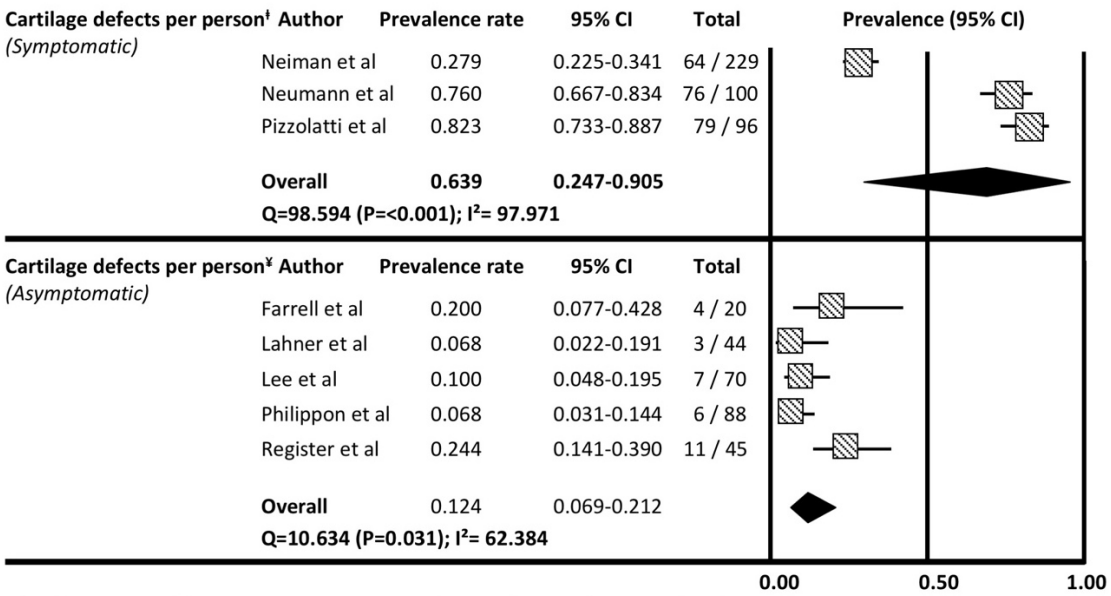
In symptomatic participants, sensitivity analysis demonstrated a pooled labral tear prevalence of 64% (95%CI: 59%, 69%; Q=0.3; p=0.861; I^2=0%) per person in studies using an MRI field strength of 1.5-T or greater. Sensitivity analysis was unable to be performed for studies using 3-T MRI due to an insufficient number of studies. The labral tear prevalence in asymptomatic participants was 56% (95%CI: 45%, 67%; Q=55.6; p=<0.001; I^2=84%) per person and 34% (95%CI: 17%, 57%; Q=69.8; p=<0.001; I^2=93%) per hip when studies using an MRI field strength less than 1.5-T were removed. In studies only using 3-T MRI in asymptomatic individuals the labral tear prevalence was 63% (95%CI: 47%, 77%; Q=22.4; p=0.000; I^2=82%) per person, with analysis not undertaken at per hip level due to an insufficient number of studies.

4.3.6. Prevalence of cartilage defects

Nineteen studies (1401 participants, 1765 hips) reported the prevalence of cartilage defects.(99–104,120,121,185–187,224–228,232,236,237) Twelve studies analysed prevalence per person(99,101–104,120,185–187,224,225,228) and four studies reported prevalence per hip.(121,226,227,232) Three studies reported prevalence using per person and per hip analysis.(100,236,237)

I. Symptomatic participants

There was limited evidence of a pooled cartilage defect prevalence of 64% (95%CI: 25%, 90%) per person from three studies *(3 MR)*(99,120,236) that utilised MRA (**Figure 4.4**). Two studies *(2 MR)*(101,225) reported acetabular and femoral cartilage defects independently. One study(225) reported femoral (53% to 90%) and acetabular (79% to 95%) defects in specified hip joint regions. The remaining study(101) reported acetabular (23% and 24%) and femoral cartilage (10% and 21%) defect prevalence.



† = diagnosed with magnetic resonance arthrography; ¥ = diagnosed with magnetic resonance imaging;

Figure 4.4. Prevalence and 95% CIs of cartilage defects in symptomatic and asymptomatic participants among studies that reported prevalence per person.

Five studies reported prevalence per hip.(100,104,121,227,232) One study *(MR)*(100) reported a cartilage defect prevalence of 95% in participants with FAI syndrome. Three *(1 HR, 1MR, and 1 LR)* of the remaining four studies used a combination of MRI and MRA (98%)(121) and MRI in isolation (45% and 49%)(104,232) to identify cartilage defects. The final study *(MR)*(227) reported on acetabular (27%) and femoral cartilage defects (7%) in golfers with hip pain.

II. Asymptomatic participants

There was limited evidence of a pooled cartilage defect prevalence of 12% (95%CI: 7%, 21%) per person, from five studies *(5 MR)*(102,103,186,224,228) using MRI (Figure 4.4). Two studies *(2 HR)* (187,237) reported cartilage defect prevalence per person in ice hockey players (18%)(187) and high school athletes (8%)(237). Moderate evidence of a pooled cartilage defect prevalence of 33% (95%CI: 16%, 56%) per hip was demonstrated from two studies *(1 MR, and 1 LR)*(104,232) utilising MRI (Figure 4.5). One study *(HR)*(237)reported a cartilage defect prevalence per hip of 4%. Five studies *(1 HR and 4 MR)*(101,185,225–227) reported the prevalence of acetabular and femoral cartilage defects independently. Acetabular cartilage defect prevalence was reported per person (2% to 35%)(101,185,225) and per hip (1% and 6%)(226,227), with femoral cartilage defects identified at per person (2% to 48%)(101,185,225) and per hip level (1% and 3%)(226,227).

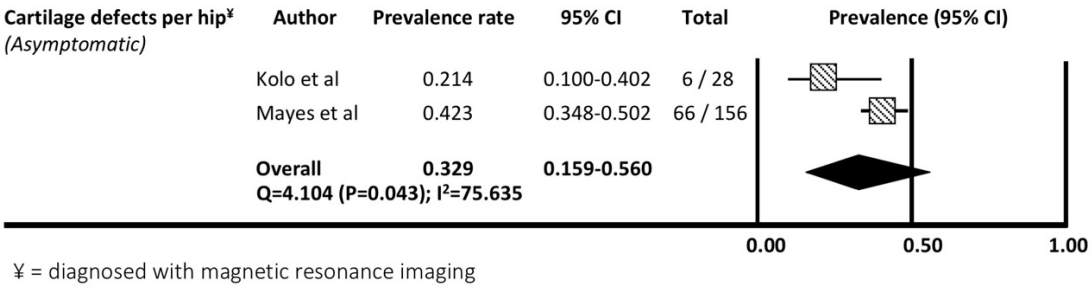


Figure 4.5. Prevalence and 95% CIs of cartilage defects in asymptomatic participants among studies that reported prevalence per hip.

III. Sensitivity analysis

In symptomatic participants, sensitivity analysis demonstrated a pooled cartilage defect prevalence of 52% (95%CI: 12%, 90%; Q=57.6; p=<0.001; I^2=99%) per person. No sensitivity analysis was performed for studies using 3-T MRI due to an insufficient number of studies. In asymptomatic participants, a cartilage defect prevalence of 13% (95%CI: 8%, 20%; Q=11.6; p=0.072; I^2=48%) per person and 22% (95%CI: 7%, 50%; Q=11.5 p=0.003; I^2=83%) per hip was identified in studies using an MRI field strength of 1.5-T or higher. In studies only using 3-T MRI a cartilage defect prevalence of 15% (95%CI: 9%, 23%; Q=9.2; p=0.055; I^2 = 57%) with no analysis undertaken at per hip level due to an insufficient number of studies.

4.3.7. Other conditions

I. Symptomatic participants

Bone marrow lesions

Three studies *(3 MR)*(99,225,227) identified the presence of BML in symptomatic participants. One study(99) reported a prevalence of 29%, with the remaining two studies(225,227) evaluating acetabular (11% to 68%) and femoral (26% to 53%) lesions independently.

Herniation pits

Four studies *(4 MR)*(100,227,231,232) reported the prevalence of herniation pits in symptomatic participants. One study(231) which utilised CTA reported a prevalence per person of 24%. Two studies(227,232) evaluated the prevalence of herniation pits per hip using MRI (27% and 52%). The final study(100) identified a prevalence of 5% in participants with FAI syndrome using MRA.

Ligamentum teres tears

Three studies evaluated the prevalence of ligamentum teres tears.(120–122) One study *(MR)*(120) reported prevalence per person (2%). Prevalence was reported per hip (81% and 50%) in two studies *(1 HR and 1 LR)*(121,122).

Paralabral cysts

Two studies *(1 HR and 1 MR)*(100,121) reported the prevalence of paralabral cysts per hip (5% and 14%).

II. Asymptomatic participants

Bone marrow lesions

Three studies *(3 MR)*(102,225,227) evaluated the presence of BML in asymptomatic participants. One study(102) reported acetabular lesions only (11%), with the remaining two studies(225,227) reporting acetabular (2% to 20%) and femoral lesions (2% to 10%) independently.

Herniation pits

Ten studies *(1 HR, 8 MR, and 1 LR*)(102,103,112,185,226,227,231–233,235) reported the prevalence of herniation pits in asymptomatic participants. Four *(3 MR and 1 LR)*(102,103,112,185) of the six studies reporting prevalence per person used MRI (6% to 22%). The remaining two studies *(2 MR)*(231,235) used CT (3% and 42%). Four studies reported prevalence per hip, three studies *(1 HR and 2 MR)*(226,227,232) utilised MRI (4% to 18%) and the remaining study *(MR)*(233) CT (14%).

Ligamentum teres tears

Two studies *(1 MR and 1 LR)*(102,122) reported the prevalence of ligamentum teres tears using MRI. One study *(LR)*(122) reported a prevalence per hip of 24%, with the other *(MR)*(102) a prevalence per person of 2%.

Paralabral cysts

Four studies *(4 MR)*(68,102,103,185) identified the prevalence of paralabral cysts in asymptomatic participants. Three studies *(3 MR)*(102,103,185) reported prevalence per person of between 0% and 13%. One study *(MR)*(68) reported a prevalence per hip of 24%.

4.3.8. Other conditions reported in less than two studies

Intra-articular conditions that were not reported in symptomatic and asymptomatic populations in two or more studies are presented in Appendix 20.

4.4. Discussion

Imaging defined intra-articular hip conditions are frequently observed in individuals with and without pain. Diagnostic imaging is now readily used to assist in the evaluation of individuals with hip and groin conditions.(107,204) However, there is often a poor association between hip symptoms and structural changes seen on imaging.(238) In total 29 studies were analysed in this review, with 25 studies adjudged to have moderate to high risk of bias. The external validity of the included studies is generally limited, with no studies investigating large population cohorts. High levels of statistical heterogeneity ($I^2 \geq 75\%$) were consistently observed within MRI and MRA studies highlighting that considerable variability exists in the prevalence of intra-articular pathologies in the studies included in this review. The results of this review provide a greater understanding of the prevalence of commonly seen hip conditions in relation to the presence or absence of pain. In summary, labral tears are prevalent in both symptomatic and asymptomatic individuals, although the prevalence is slightly higher in symptomatic groups. Importantly, the prevalence of cartilage defects, bone marrow lesions, and ligamentum teres tears was higher in symptomatic than asymptomatic groups.

Labral tears were observed in 62% of individuals with pain, and 54% of asymptomatic individuals. The high prevalence of labral tears in asymptomatic individuals is a particularly interesting finding, given the reported nociceptive ability of labral tissue(131,239) and its proposed role in hip joint health.(17,18) The questionable relationship between labral pathology and symptoms identified in this review has been mirrored recently in two papers(124,240) reporting a limited correlation between labral pathology and self-reported function in a chronic hip pain population and individuals with and without radiographic hip OA. The role that labral tissue plays in the development of symptoms appears more complex than previously thought.

Cartilage defects were evident in 64% of symptomatic individuals, considerably more than the 12% of asymptomatic individuals. Thus, it could be considered that cartilage defects might contribute to hip-related symptoms. However, recent work has highlighted a variable relationship between cartilage defects and pain.(123,124,240) Moreover, articular cartilage is considered to be aneural under normal physiological conditions.(241,242) Interestingly, of the included studies that reported acetabular and femoral cartilage defects independently, a trend highlighting a greater prevalence of acetabular cartilage defects was observed in symptomatic individuals. Our finding is consistent with studies reporting associations between acetabular cartilage damage and pain, clinical symptoms and reduction in function.(240) The presence of cartilage defects could indicate early stages of the arthritic cascade, and the involvement of other tissues such as peri-articular tissues, subchondral bone, or synovial tissue.(131,240,241,243)

This review also highlighted variability in the prevalence of herniation pits between those with and without pain. Studies using MRI demonstrated a greater prevalence in symptomatic individuals, conversely, studies using CT identified a greater prevalence in asymptomatic individuals. Paralabral cysts were identified similarly in symptomatic and asymptomatic individuals in studies using MRA and MRI respectively. However, akin to cartilage lesions, ligamentum teres tears and BML were seen more often in those with pain. Variability has been observed within the literature regarding the nociceptive ability of the ligamentum teres.(131,244) This lack of consensus is reflected in our results, with a quarter of asymptomatic individuals having imaging defined conditions. A greater understanding of the role of ligamentum teres in nociception is required to inform management decisions. The greater prevalence of BML observed in symptomatic populations is congruent with recent findings showing the association of such lesions with clinical symptoms and impaired patient-reported outcomes.(124,194,240) In addition, individuals with acetabular and femoral cartilage lesions have a greater prevalence of BML, which may demonstrate an association between such lesions and early arthritic change.(240)

Two recent reviews(61,62) have reported on the prevalence of intra-articular hip conditions. The review undertaken by Frank et al. (61) reported a higher prevalence of labral tears in asymptomatic individuals (68% v 54%), which likely reflects the eleven new studies published since the completion of their literature search, and our decision to distinguish the prevalence of pathologies by either person or hip. The review by Mascarenhas et al. (62) reported on labral tears and cartilage lesions in symptomatic, asymptomatic, and athletic individuals. The prevalence of labral tears in symptomatic individuals was lower than our results (28% vs 62%).

The variation in results can be explained through the differences seen in review aims, methods used to combine prevalence figures, and the large variation in studies included in each review.

The findings of our review should be interpreted in conjunction with the known limitations of diagnostic imaging. In particular, we highlighted that labral tears were observed on MRI in a high number of asymptomatic individuals (54%). Magnetic resonance imaging across various field strengths with and without the use of contrast agents has a variable diagnostic utility to identify labral pathology,(94,111) which may result in over or underestimation of prevalence in asymptomatic individuals. However, six of the ten studies included in the meta-analysis used 3-T MRI, which may provide better greater accuracy compared to lower field strength systems(96) and increases confidence in our findings. Contrast enhanced MRA provides the highest diagnostic accuracy in the identification of labral tears. Unfortunately, no studies including MRA on asymptomatic individuals were identified in this review. Further studies are necessary to determine if MRA findings of labral tears in asymptomatic individuals agree with the current analysis. The disparity in cartilage defects is a notable result, with this trend observed in studies using MRA and MRI. The use of low field strength MRA protocols across the studies included in the meta-analysis increases the possibility of misinterpretation of cartilage defects in symptomatic individuals. Conversely, a number of studies used 3-T MRI for analysis of cartilage defects in symptomatics and consistently demonstrated a higher prevalence. As 3-T MRI provides greater visualisation of acetabular and femoral articular cartilage,(95,96) it may be that the prevalence of cartilage defects is indeed higher in symptomatic individuals.

The decision to dichotomise the imaging findings may have resulted in an overestimation of prevalence. However, this method was deemed necessary due to the variability in methods used to grade intra-articular conditions.(123,124) The recent development of semi-quantitative methods for the assessment of hip structural conditions has shown promise with high levels of reliability and agreement.(123,124) Furthermore, these methods have shown a moderate correlation with PROMs and clinical measures.(123,240) Future research should focus on developing consensus for the grading of intra-articular conditions as this will provide a better understanding of the true spectrum of pathology.

Five of the 29 included studies were adjudged to have HR, highlighting poor study methodology in the current literature evaluating the prevalence of intra-articular hip conditions. Study populations were often attained by convenience and not deemed representative of a wider population, reducing the generalisability of the review's findings. The reliability and level of

agreement for the diagnostic criteria used to evaluate intra-articular pathologies were often not documented in studies, reducing confidence in the reported findings. The method used to determine prevalence was variable across studies. Prevalence by definition should be determined by dividing "the number of cases of a disease in a population, divided by the population number".(245) Our decision to adjudge studies reporting prevalence per hip as high risk of bias was in line with recent literature.(58) Exclusion of HR studies in the meta-analyses may increase confidence in the findings of this review. However, limited to moderate level evidence was assigned with our findings, outlining that studies of greater methodological quality are still required.

The high levels of heterogeneity observed in the pooled symptomatic and asymptomatic populations is akin to other prevalence reviews.(127,246) In relation to this review, it likely reflects variability in imaging modalities and parameters used across the included studies. Other sources of heterogeneity may include variations in age, sex, and levels of physical activity across the included studies. Interestingly, high levels of heterogeneity were present despite the exclusion of HR studies, which may indicate that study quality and heterogeneity are not directly related in this review.

4.4.1. Limitations

There are a number of limitations relating to the results of this review. Firstly, the decision to exclude studies investigating the prevalence of intra-articular hip conditions in individuals with SCFE and Legg-Calvé-Perthes disease reduces the generalisability of our findings specifically to these conditions. Secondly, a number of studies were excluded on the basis of not identifying a primary aim of reporting the prevalence of intra-articular hip conditions.(247–250) While excluded, the results from the aforementioned studies are very similar to those achieved in our review, providing validation of the results of this review. Thirdly, unpublished studies and those not published in the English language were not included in this review which may have excluded some relevant studies. A notable limitation of the studies in this review is the inclusion of participants based on the presence of hip/groin pain. Hip and groin-related pain can be caused by a number of different intra and extra-articular conditions,(11,202,204) hence the relevance of imaging defined intra-articular pathologies may be questionable in some symptomatic individuals.

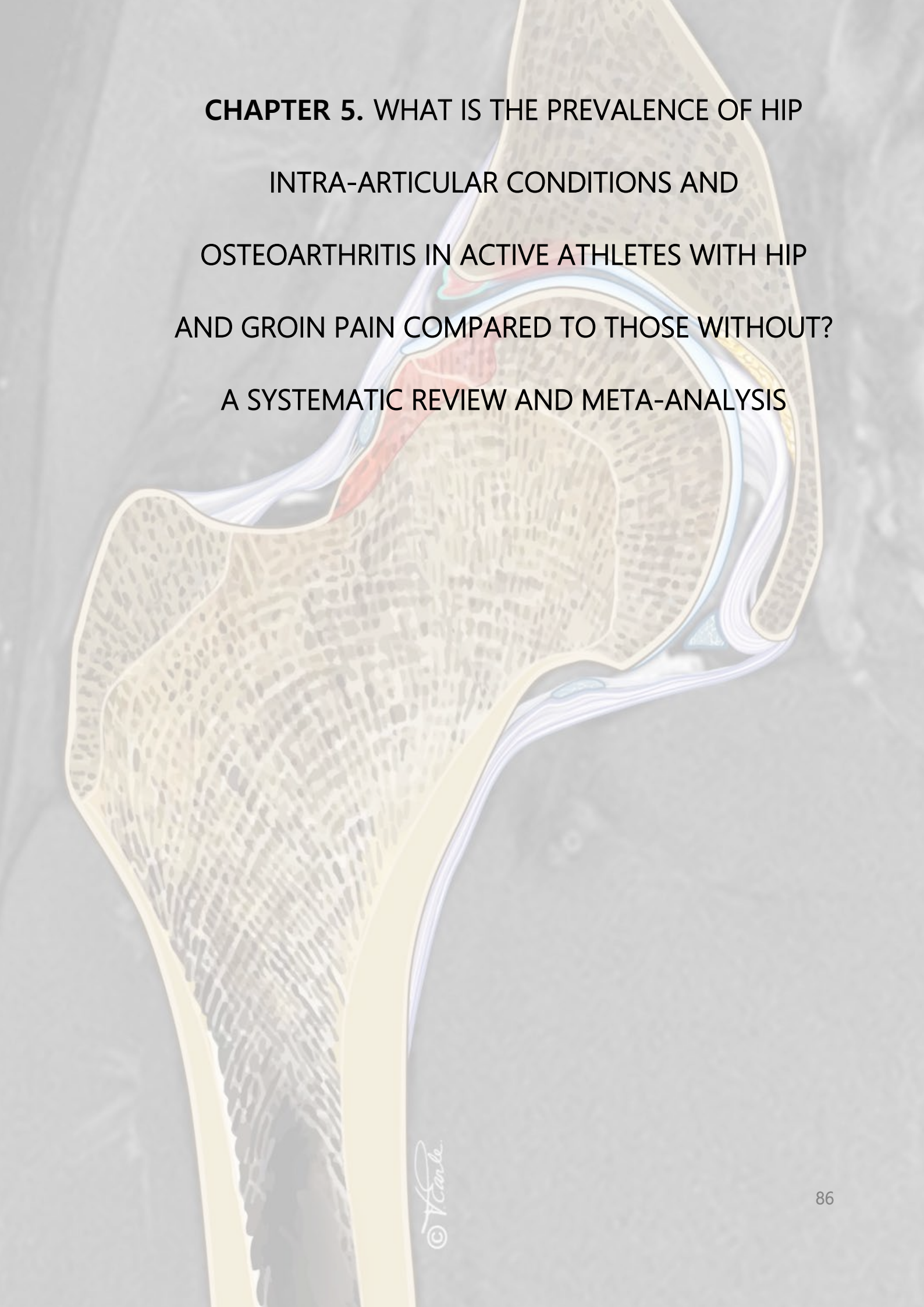
Importantly, the studies in this review evaluate highly selective populations meaning the results of this review are not interpretable beyond the inclusion criteria of the included studies.

Furthermore, there is limited comparability between the included studies which further reduces the generalisability of the reviews' findings. Consideration is needed regarding the use of the term "prevalence" to describe the findings of this review as none of the included studies evaluated community-based populations. Finally, the intra-articular pathologies identified with imaging in both symptomatic and asymptomatic individuals were not confirmed by hip arthroscopy, which is currently considered the gold standard for the diagnosis of intra-articular hip pathologies. Although this is a notable limitation, arthroscopic confirmation of intra-articular pathologies will never be a consideration in asymptomatic populations.

4.5. Conclusion

This systematic review identified 29 studies. The included studies used MRI, MRA, and CT to investigate the prevalence of intra-articular hip conditions. Most studies had a moderate to high risk of bias with only 4 low risk studies. The prevalence of cartilage pathology is higher in people with pain than those without. In contrast, the prevalence of labral pathology is similar in those with and without pain. Bone marrow lesions and ligamentum teres tears appear to be more prevalent in individuals with pain. Paralabral cysts and herniation pits are prevalent in both symptomatic and asymptomatic individuals. This review highlights the uncertainty of the relationship between intra-articular hip joint conditions on imaging and pain. A greater understanding of this relationship may improve the selection and effectiveness of conservative and surgical interventions for intra-articular hip conditions.

CHAPTER 5. WHAT IS THE PREVALENCE OF HIP INTRA-ARTICULAR CONDITIONS AND OSTEOARTHRITIS IN ACTIVE ATHLETES WITH HIP AND GROIN PAIN COMPARED TO THOSE WITHOUT? A SYSTEMATIC REVIEW AND META-ANALYSIS



PREFACE

Chapter 1 of this thesis, it was highlighted that an uncertain relationship exists between hip joint imaging findings and hip/groin pain. Chapter 4 highlighted the high prevalence of imaging-defined intra-articular hip conditions in individuals with and without pain. Specifically, labral tears were observed in 62% of individuals with pain, and 54% of asymptomatic individuals. A higher prevalence of cartilage defects was found in individuals with hip/groin pain (64%) relative to those without (12%). Herniation pits and paralabral cysts were observed in individuals with and without pain, with the prevalence of ligamentum teres tears and BMLs higher in those with pain. Fifteen of the studies included in the systematic review evaluated athletic populations. The literature reporting on the prevalence of intra-articular conditions in athletes with and without pain has never been formally appraised. Therefore, a second systematic review was undertaken to study and evaluate the current literature on the prevalence of intra-articular hip conditions in athletes with and without hip/groin pain.

Chapter 5 contains the following publication in its entirety (Appendix 21), with the following minor amendments: (I) The term intra-articular hip pathologies is replaced by intra-articular hip conditions to provide consistency through this thesis; (II) The term hip and groin pain is replaced by hip/groin pain to provide consistency through this thesis and (III) Figure 5.1 is a replacement PRISMA flow chart from the original publication, as the previous version did not have sufficient resolution.

Heerey JJ, Kemp JL, Mosler AB, Jones DM, Pizzari T, Scholes MJ, Agricola R, Crossley KM. What is the prevalence of hip intra-articular pathologies and osteoarthritis in active athletes with hip and groin pain compared to those without? A systematic review and meta-analysis. Sports Medicine. 2019;49:951-972.

5.1. Introduction

Hip/groin pain is common in athletes,(3,5,7,8,251–257) particularly those participating in football codes,(5,7,8,34,255,257) ice hockey(252) and dancing.(256) Hip/groin pain constitutes up to 18% of all time loss injuries in professional football (soccer).(5,9) Moreover, in football 59% of men and 45% of women will experience groin pain/injury during a competitive season.(3) Many athletes will experience long-standing symptoms,(7) with one in three sub-elite football players with hip/groin pain having symptoms for greater than six weeks. Chronicity of symptoms is associated with greater difficulties in activities of daily living, reduced quality of life and impaired athletic performance.(7)

A number of different and often coexisting clinical entities are proposed to cause hip/groin pain in athletes.(11,37,41,202) Hip-related groin pain in athletes often results from FAI syndrome and labral tears.(37,258–260) The bony morphology associated with FAI syndrome is characterised as cam and/or pincer morphology.(44) Cam morphology is present in up to 66% of athletes,(61,62,261) with male athletes eight times more likely to have cam morphology than non-athletes.(261) In athletes, the combination of bony morphology with the repetitive end of range hip movements performed during sporting activities may predispose to mechanical abutment and the development of symptoms and pain.(258–260) Over-time, cam morphology may result in intra-articular hip conditions, including hip OA. Cam morphology is associated with intra-articular conditions including labral tears in individuals with and without pain,(102,156,262) and increases the odds of developing OA by up to 10 times in older adults.(158) However, little is known about the risk of developing OA in athletic populations with cam morphology.(41,158)

Imaging is used to evaluate the presence of intra-articular hip conditions in athletes with hip/groin pain.(204,263) Our recent review of studies evaluating athletes and non-athletes highlighted a similar prevalence of select intra-articular hip conditions in individuals with and without pain, regardless of the level of athletic activity.(264) However, our review did not provide a detailed understanding of the prevalence of such conditions specifically in athletes. Additional reviews on the prevalence of intra-articular hip conditions including bony morphology, labral tears and cartilage defects in athletes(61,62) have not described all frequently reported intra-articular conditions. The prevalence of OA in retired athletes is known,(174,265) but the prevalence in athletes currently playing sport is not. Therefore, the aim of this review was to determine the prevalence of intra-articular hip pathologies such as labral tears, cartilage defects, ligamentum

teres tears, BML, synovitis, and OA in athletes with and without hip/groin pain who are currently playing sport.

5.2. Methods

The PRISMA were used in this systematic review. The protocol for this review was registered on the PROSPERO international prospective register of systematic reviews (http://www.crd.york.ac.uk/PROSPERO) on the 11th December 2017 (registration number: CRD42017082457).

5.2.1. Eligibility Criteria

We included studies if they: 1) were written in the English language; 2) cross-sectional, case-control, case series or cohort designs; 3) included current amateur, semi-professional or elite athletes with and without hip/groin pain; 4) utilized X-ray, MRI, MRA and/or CT to determine the presence of intra-articular hip pathologies or OA; 5) had a primary aim of reporting the prevalence intra-articular hip pathologies or OA in athletes and 6) evaluated the presence of FAI (including bony morphology) or hip dysplasia and the prevalence of intra-articular hip conditions or OA. We did not place any restrictions on the age of athletes included in the studies. We excluded studies if they: 1) reported on the prevalence of intra-articular hip conditions or OA in athletes but this was not listed as the primary aim of the study; 2) reported on the prevalence of intra-articular hip conditions or OA in retired athletes; 3) evaluated the prevalence of FAI (including bony morphology) and hip dysplasia but did not report the presence of intra-articular hip conditions or OA; 4) identified the presence of intra-articular hip conditions or OA in athletes with Legg-Calvé-Perthes disease or SCFE; 5) used ultrasound or isotopic bone scan to determine the prevalence of intra-articular hip conditions or OA; 6) used hip arthroscopy or open hip surgery to determine the prevalence of intra-articular hip conditions or OA in athletes; 7) included less than five athletes or 8) were unpublished data, abstracts or systematic reviews and/or were studies not published in the English language

5.2.2. Search strategy

Two independent authors (Mr. Joshua Heerey and Mr. Mark Scholes) undertook a comprehensive search using OVID MEDLINE, PubMed, CINAHL, EMBASE, SPORTDiscus, SCOPUS, and Cochrane databases from inception to 29 January 2018. Citation tracking using Google Scholar and the screening of reference lists of included articles was undertaken by one author (Mr. Joshua

Heerey). Database-specific controlled vocabulary and keyword terms were used for each database (Appendix 22). Endnote X7 (Thomson Reuters, Carlsbad, California, USA) was used for the management of the identified articles. Two authors (Mr. Joshua Heerey and Mr. Mark Scholes) applied the specified inclusion/exclusion criteria to the articles identified during the search process. Each author (Mr. Joshua Heerey and Mr. Mark Scholes) independently selected the articles eligible for final inclusion in the review. At the completion of this process, a consensus was achieved between the two authors on the articles to be included in the review. A third reviewer (Dr. Joanne Kemp) was utilised when the two authors could not agree upon the inclusion of an article.

5.2.3. Risk of bias

The risk of bias was independently assessed by two authors (Mr. Joshua Heerey and Ms. Denise Jones). A tool designed to determine the risk of bias in prevalence literature was utilised in the review.(215) The external validity (four questions) and internal validity (six questions) of each included article was evaluated. Each of the 10 questions is scored as LR or HR. If an article did not provide adequate information for a question to be scored, an HR was given. In relation to question one, an article was scored as LR if it was considered that the athletes were representative of a wider population of athletes playing the selected sport. In line with a recent review,(264) question seven was modified, where an article was considered LR if it reported an ICC greater than 0.40 and/or Cohen's κ greater than 40% for the method used to assess the prevalence of specific intra-articular hip conditions and/or OA. Each included article was provided with an overall risk of bias score, as determined by the number of HR items. Articles were considered LR if they had 0-3 HR items, MR if they had 4-5 HR items and HR if they had 6 or more HR items.(216) In the event of author disagreement, a third author (Dr. Joanne Kemp) was consulted. The inter-rater agreement was evaluated with κ, excellent agreement was achieved with κ values above 80%, substantial agreement (60 to 80%), moderate agreement (40 to 60%) and finally poor to fair agreement with values below 40%.(217)

5.2.4. Data extraction

Two authors (Mr. Joshua Heerey and Mrs. Andrea Mosler) independently extracted data from all 20 included articles. The data extracted from each article included: author, study design, sport, number of athletes, number of hips, sex, age, imaging method used and prevalence of intra-articular hip conditions and/or OA. In the event of disagreement between the authors on the data extracted, a third author (Dr. Kay Crossley) was consulted to reach a consensus. Authors of

the included articles were contacted if additional data were required. Authors from nine of the 20 included articles were contacted and provided additional data upon request.

5.2.5. Data synthesis and analysis

For this review, athletes were defined as individuals who competed and trained in a specific sport.(266) The athletic populations investigated in this review were not representative of community-based populations, hence the reported prevalence of intra-articular hip conditions and/or OA is representative of the frequency of such pathologies in athletic individuals with and without pain. To determine the prevalence of intra-articular hip conditions and/or OA, the number of athletes (cases) was divided by the total athlete population included in the article. We used Comprehensive Meta-Analysis Software (Version 3.0, Biostat Inc., USA) to determine the overall prevalence and 95% CIs. The prevalence of intra-articular hip conditions and OA was either reported as per person or per hip depending on the method used in the included article. Data deemed eligible for pooling were presented in either per person or per hip format. Primary subgrouping was undertaken based on the presence or absence of hip/groin pain. Secondary grouping included the type of mechanical loading placed on the hip by the sport(267,268) and imaging modality (MRI, MRA or CT) used for each specific intra-articular hip pathology.

In line with our recent review,(264) intra-articular hip conditions were reported as being present or absent. Cartilage defects were reported in the primary analysis when femoral and acetabular defects were reported together. Studies that reported acetabular and femoral cartilage separately were analysed qualitatively. A Tonnis grade of 2 or greater or a JSW of 2.0mm or less was used to define the presence of hip OA.(89,269) A Tonnis grade of 1 was used to define minor or early features of hip OA.(270) Studies reporting the prevalence of intra-articular hip conditions in less than five athletes were not included in the secondary analysis. Studies adjudged to be HR were not considered for meta-analysis.(219) Low risk and MR studies were included in meta-analyses using a random effects model. Where articles were HR or deemed clinically heterogenous, qualitative analysis was undertaken. The statistical heterogeneity present in the pooled analysis was evaluated using Q and I^2 statistics(218,220) and classified in accordance with Higgins et al. (220). Strength of evidence was assigned to the pooled results, using previously described modified criteria(221,222,264) as follows:
Strong evidence: pooled results derived from three or more studies, including a minimum of two LR studies, which are statistically homogenous ($p>0.05$).

Moderate evidence: pooled results derived from multiple studies, including at least one LR study, which are statistically heterogeneous ($p<0.05$); or from multiple MR and HR studies which are statistically homogenous ($p>0.05$).

Limited evidence: pooled results from multiple HR or MR studies which are statistically heterogeneous ($p<0.05$).

5.3. Results

5.3.1. Search results

At the completion of database searching, 847 articles were identified (**Figure 5.1**). Removal of duplicates left 470 articles for screening by title and abstract, and 69 full-text articles that were evaluated for eligibility using the listed inclusion criteria. In total, six additional articles(77,122,185,232,271,272) were retrieved and evaluated for inclusion after the completion of reference list searching and citation tracking. Fifty-five articles were excluded (**Appendix 23**), with a total of 20 articles(76–78,80,104,122,142,185–187,224,226–228,232,234,237,271–273) included in the review for qualitative and quantitative analysis (**Table 5.1** to **5.3**).

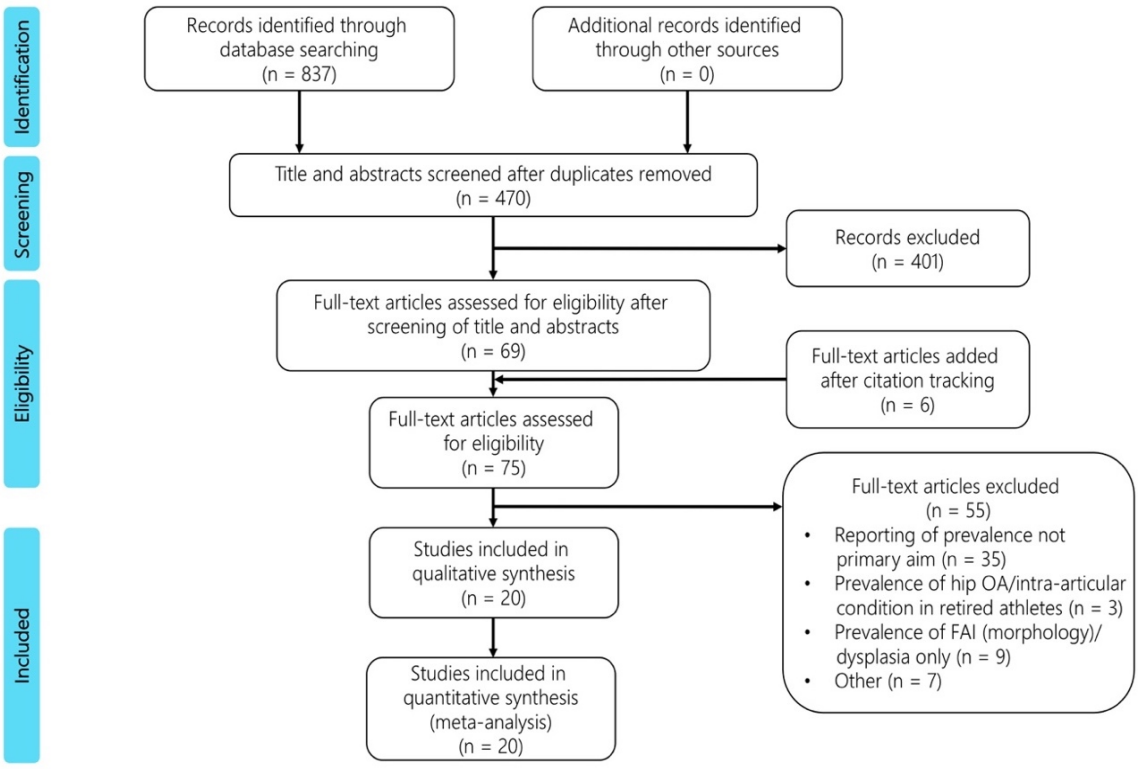


Figure 5.1. Preferred reporting items for systematic reviews and meta-analyses flow chart.

Table 5.1. Included studies involving asymptomatic athletes only.

Author	Study design	Study population	No. of participants (hips)	Demographics	Imaging modality	Findings (Intra-articular hip conditions/osteoarthritis)
Anderson et al. (273)[d]	Cross-sectional	**Subjects** Senior athletes	**Subjects** 547 (1081)	**Subjects** Age[a]: 67 (8) Sex: 246 (45%) F/ 301 (55%) M	X-ray	**Subjects** Tonnis grade 3: 30/1081 Tonnis grade 2: 156/1081; Tonnis grade 1: 352/1086; Tonnis grade 0: 543/1081; Tonnis grade 2/3: 186/1081 and Tonnis grade 0/1: 895/1081.
Ayeni et al. (185)	Cross-sectional	**Subjects** Ice Hockey players	**Subjects** 20 (20)	**Subjects** Age[a]: 20.6 Sex: 9 (45%) F/ 11 (55%) M	1.5-T MRI	**Subjects** Labral tear: 12/20; acetabular cartilage defect: 0/20; femoral cartilage defect: 2/20; herniation pit: 2/20; osseous bump: 4/20 and paralabral cyst: 0/20.
Farrell et al. (228)	Cross-sectional	**Subjects** Rugby union academy players	**Subjects** 20 (40)	**Subjects** Age[a]: 22 (1.5) Sex: 20 (100%) M	3-T MRI	**Subjects** Labral tear: 17/20[c]; labral tear right hip: 10/20; labral tear left hip: 15/20; bilateral labral tear: 8/20; cartilage defect: 4/20[c]; cartilage defect right hip: 3/20; cartilage defect left hip: 3/20 and bilateral cartilage defect: 1/20.
Kapron et al. (77)	Cross-sectional	**Subjects** Collegiate American football players	**Subjects** 67 (134)	**Subjects** Age[a]: 21 (1.9) Sex: 67 (100%) M	X-ray	**Subjects** Tonnis grade 0: 112/134; Tonnis grade 1: 22/134; Tonnis grade 2: 0/134 and Tonnis grade 3: 0/134.
Lahner et al. (224)	Cross-sectional	**Subjects** Semi-professional soccer players **Controls** Amateur soccer players	**Subjects** 22 (22) **Controls** 22 (22)	**Subjects** Age[a]: 23.3 (3.3) Sex: 22 (100%) M **Controls** Age[a]: 22.5 (3.5) Sex: 22 (100%) M	1.5T MRI	**Subjects** Labral tear: 3/22 and cartilage defect: 2/22. **Controls** Labral tear: 1/22 andcartilage defect: 1/22.
Lahner et al. (226)	Cross-sectional	**Subjects** Track and Field athletes	**Subjects** 22 (44)	**Subjects** Age[a]: 23.7 (3.0) ([b]18-30) Sex: 11 (50%) F/ 11 (50%) M	1.5-T MRI	**Subjects** Labral tear: 2/44; acetabular cartilage defect: 1/44; femoral cartilage defect: 1/44; herniation pit: 3/44 and osseous bump: 3/44.

Philippon et al. (186)	Cross-sectional	**Subject**s Youth ice hockey players **Controls** Youth Skiers	**Subjects** 61 (61) **Controls** 27 (27)		**Subjects** Age[a]: 14.5 (2.7) Sex: 61 (100%) M **Controls** Age[a]: 15.2 (2.7) Sex: 27 (100%) M	3-T MRI	**Subjects** Labral tear: 42/61; peewee hockey players - labral tear: 13/27; bantam hockey players - labral tear: 5/8; midget hockey players - labral tear: 24/26; cartilage defect: 5/61; peewee hockey players - cartilage defect: 0/27; bantam hockey players - cartilage defect: 0/8 and midget hockey players - cartilage defect: 5/26. **Controls** Labral tear: 19/27; skier - labral tear (peewee control): 5/7; skier - labral tear (bantam control): 5/8; skier - labral tear (midget control): 9/12; cartilage defect: 1/27; skier - cartilage defect (peewee control): 0/7 skier - cartilage defect (bantam control): 0/8 and skier - cartilage defect (midget control): 1/12.
Silvis et al. (187)	Cross-sectional	**Subjects** Ice hockey players	**Subjects** (39)	39	**Subjects** Age: NR Sex: 39 (100%) M	3-T MRI	**Subjects** Hip pathology total findings: 25/39; labral tear: 22/39; cartilage defect: 7/39 and hip effusion: 0/39.
Yepez et al. (271)	Cross-sectional	**Subjects** Youth soccer players	**Subjects** 56 (112)		**Subjects** Age[a]: 15.3 ([b]13-18) Sex: 56 (100%) M	1.5-T MRI	**Subjects** Labral tear: 10/112; degenerative labral tear: 2/112; cartilage defect: 3/112; herniation pit: 4/112; BML: 24/112; acetabular osteitis: 10/112 and osseous bump 49/112.
Yuan et al. (237)	Cross-sectional	**Subjects** High school student with clinical signs of FAI **Controls** High school students no clinical signs of FAI	**Subjects** 13 (22) **Controls** 13 (26)		**Subjects** Age: NR Sex: 1 (8%) F/12 (92%) M **Controls** Age: NR Sex: 1 (8%) F/12 (92%) M	3-T MRI 1.5-T MRI	**Subjects** Any abnormal hip finding: 15/22; labral tear: 14/22; acetabular rim damage: 3/22; cartilage defect: 1/22; Tonnis grade 0: 22/22; Tonnis grade 1: 0/22; Tonnis grade 2: 0/22 and Tonnis grade 3: 0/22. **Controls** Any abnormal hip finding: 10/26; labral tear: 10/26; acetabular rim damage: 0/26 and cartilage defect: 1/26.

BML bone marrow lesion, *FAI* femoroacetabular impingement, *F* female, *M* male, *MRI* magnetic resonance imaging, *NR* not reported and *T* tesla.
[a] mean (standard deviation).
[b] range.
[c] results from raw data obtained from author.
[d] author provided additional results not presented in original article.

Table 5.2. Included studies involving symptomatic athletes only.

Author	Study design	Study population	No. of participants (hips)	Demographics	Imaging modality	Findings (Intra-articular hip conditions/osteoarthritis)
Narvani et al. (234)	Case series	**Subjects** Individuals playing sport with groin pain	**Subjects** 18 (18)	**Subjects** Age[a]: 30.5 (8.45) ([b]17-48) Sex: 5 (28%) F/13 (72%) M	1-T MRA	**Subjects** Labral tear: 4/18.
Nepple et al. (80)	Case series	**Subjects** American football athletes at scouting combine	**Subjects** 107 (123)	**Subjects** Age[c]: 22.7 (20-25) Sex: 107 (100%) M	X-ray	**Subjects** Tonnis grade 0-1: 121/123; Tonnis grade 2: 2/123 and Tonnis grade 3: 0/123.

F female, *M* male and *MRA* magnetic resonance arthrography.
[a] mean (standard deviation).
[b] range.
[c] mean (range).

Table 5.3. Included studies involving asymptomatic and symptomatic athletes.

Author	Study design	Study population	No. of participants (hips)	Demographics	Imaging modality	Findings (Intra-articular hip conditions/osteoarthritis)
Dickenson et al. (227)[d]	Cross-sectional	**Subjects** Male golfers with hip pain **Controls** Male golfers without hip pain	**Subjects** NR(15) **Controls** NR (95)	**Subjects** Age: NR Sex: 15 (100%) M **Controls** Age: NR Sex: 95 (100%) M	1.5-T MRI	**Subjects** Labral tear: 3/15; increased labral signal: 3/15; acetabular cartilage defect 4/15; femoral cartilage defect: 1/15; acetabular subchondral edema: 3/15; femoral subchondral edema: 6/15; herniation pit: 4/15 and joint effusion: 1/15. **Controls** Labral tear: 22/95; increased labral signal: 21/95; acetabular cartilage defect: 6/95; femoral cartilage defect: 3/95 acetabular subchondral edema: 10/95; femoral subchondral edema: 10/95; herniation pit: 9/95 and joint effusion: 8/95.
Harris et al. (76)	Cross-sectional	**Subjects** Symptomatic/asymptomatic ballet dancers	**Subjects** 47 (94)	**Subjects** Age[a]: 23.8 (5.4) ([b]18-39)	X-ray	**Subjects** Tonnis grade 0 left hip: 40/47; tonnis grade 1 left hip: 7/47; tonnis grade 2 left hip: 0/47; tonnis grade 3 left hip: 0/47; tonnis grade 0 right hip: 42/47; tonnis grade 1 right hip: 5/47; tonnis grade 2 right

				Sex: 26 (55%) F/21 (45%) M		hip: 0/47; tonnis grade 3 right hip 0/47; medial joint space male[a]: 3.64 [0.54]; medial joint space female[a]: 3.51 [0.65]; middle joint space male[a]: 3.93 [0.37]; middle joint space female[a]: 3.86 [0.57]; lateral joint space male[a]: 4.39 [0.55]; lateral joint space female[a]: 4.39 [0.59]; total joint space male[a]: 3.98 [0.39] and total joint space female[a]: 3.92 [0.54].
Kolo et al. (232)	Cross-sectional	**Subjects** Symptomatic/asymptomatic ballet dancers	**Subjects** 30 (59)	**Subjects** Age[c]: 24.6 (18-39) Sex: 30 (100%) F	1.5-T MRI	**Subjects** Labral tear: 28/59; hips ≥ 2 labral tears: 12/59; labral degeneration: 24/59; hips ≥2 labral degenerative tears: 11/59; Labral ossification: 2/59; hips ≥ 2 ossified lesions: 2/59; acetabular cartilage defect ≤5 mm: 12/59; acetabular cartilage defect: ≥5 mm: 17/59 and herniation pit: 31/59.
Larson et al. (78)	Cross-sectional	**Subjects** Symptomatic/asymptomatic ice hockey players	**Subjects** 59 (118)	**Subjects** Age[a]: 24.2 (4.6) Sex: 59 (100%) M	X-ray	**Subjects** Joint space[b]: 4.13 (0.62).
Mariconda et al. (272)	Cross-sectional	**Subjects** Symptomatic/asymptomatic capoeira players	**Subjects** 24 (48)	**Subjects** Age[a]: 31.5 (4.5) ([b]25-42) Sex: 10 (42%) F/14 (58%) M	X-ray	**Subjects** Tonnis grade 3: 0/48; tonnis grade 2: 3/48; tonnis grade 1: 9/48; tonnis grade 0: 36/48.
Mayes et al. (142)[d]	Case-control	**Subjects** Mixed sporting population/ballet dancers with hip pain last 3 months[ef] **Controls** Mixed sporting population/ballet dancers without hip pain[ef]	**Subjects** NR (25) **Controls** NR (107)	**Subjects** Age[ae]: 27.9(4.6) Age[af]: 29 (5) Sex[ef]: 18 (72%) F/7 (28%) M **Controls** Age[ae]: 25.4 (4.7) Age[af]: 28.3 (5.6) Sex[ef]: 54 (50%) F/53 (50%) M	3-T MRI	**Subjects** Labral tear: 5/25. **Controls** Labral tear: 48/107.
Mayes et al. (122)[d]	Case-control	**Subjects** Mixed sporting population/ballet dancers with hip pain last 3 months[ef] **Controls** Mixed sporting	**Subjects** NR (25) **Controls** NR (107)	**Subjects** Age[ae]: 27.9(4.6) Age[af]: 29 (5) Sex[ef]: 18 (72%) F/7 (28%) M **Controls** Age[ae]: 25.4 (4.7) Age[af]: 28.3 (5.6)	3-T MRI	**Subjects** Ligamentum teres tear: 11/25. **Controls** Ligamentum teres tear: 22/107.

		population/ballet dancers without hip pain[ef]		Sex[ef]: 54 (50%) F/53 (50%) M		
Mayes et al. (104)[d]	Case-control	**Subjects** Mixed sporting population/ballet dancers with hip pain last 3 months[ef] **Controls** Mixed sporting population/ballet dancers without hip pain[ef]	**Subjects** NR (25) **Controls** NR (107)	**Subjects** Age[ae]: 27.9(4.6) Age[af]: 29 (5) Sex[ef]: 18 (72%) F/7 (28%) M **Controls** Age[ae]: 25.4 (4.7) Age[af]: 28.3 (5.6) Sex[ef]: 54 (50%) F/53 (50%) M	3-T MRI	**Subjects** Cartilage defect: 10/25. **Controls** Cartilage defect: 38/107.

F female, *M* male, *MM* millimeters, *NR* not reported, *MRI* magnetic resonance imaging, ≥ greater than or equal to and ≤ less than or equal to.
[a] mean (standard deviation).
[b] range.
[c] mean (range).
[d] author provided additional results not presented in original article.
[e] male dancers and male mixed athletes.
[f] female dancers and female mixed athletes.

5.3.2. Risk of bias within studies

Agreement between the two authors occurred on 91% of occasions (182/200 items). A κ value of 0.82 (95%CI 0.74, 0.90) was determined, indicating excellent agreement between authors.(217) In total, five of the 20 (25%) of the included articles were considered HR, 12 were considered MR, and 3 LR. In summary, all of the 20 included articles had HR for items 1 and 2, outlining that no study included participants that were considered representative of a wider sporting population and that participants were often selected by convenience. Thirteen of the studies (65%) did not report the reliability of the method used to determine the presence of either hip intra-articular conditions or OA.(76,77,80,185,186,224,226,228,232,234,237,271,272) Finally, 10 (50%) of the studies reported the prevalence at a per hip level and not a per person level(77,78,80,226,227,232,237,271–273) (Table 5.4).

5.3.3. Heterogeneity of included studies

Heterogeneity was considered low for pooled studies investigating the prevalence of labral tears in symptomatic athletes, and high in the studies of asymptomatic athletes. For the prevalence of cartilage defects, only studies reporting asymptomatic athletes were combined in the meta-analysis. These studies displayed moderate levels of heterogeneity (I^2 43%). When categorized by mechanical hip load, the heterogeneity observed in pooled data evaluating the prevalence of labral tears and cartilage defects ranged from low (I^2 0%) to high (I^2 96%).

5.3.4. Deviation from PROSPERO

The categorisation of sports as either linear or multi-planar was included in the original protocol submitted to PROSPERO. During the review process, a previously used method to categorise based on the mechanical load placed on the hip joint by the particular sport was identified.(267,268) To improve the generalisability of the review's findings this method was used.

5.3.5. Study characteristics.

In total, the prevalence of intra-articular hip conditions and OA was evaluated in 1335 participants and 2352 hips. Twelve studies (315 participants, 637 hips) reported the prevalence of intra-

Table 5.4. Included studies risk of bias.

Author	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Overall risk of bias for study
	External validity				Internal validity						
Anderson et al. (273)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	*HR*	***MR***
Ayeni et al. (185)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*HR*	*LR*	*LR*	*LR*	***MR***
Dickenson et al. (227)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*LR*	*LR*	*LR*	*HR*	***MR***
Farrell et al. (228)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*HR*	*LR*	*LR*	*LR*	***MR***
Harris et al. (76)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*HR*	*LR*	*LR*	*LR*	***MR***
Kapron et al. (77)	*HR*	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*LR*	*LR*	*HR*	***HR***
Kolo et al. (232)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*HR*	*LR*	*LR*	*HR*	***MR***
Lahner et al. (224)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*HR*	*LR*	*LR*	*LR*	***MR***
Lahner et al. (226)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*HR*	*LR*	*LR*	*HR*	***HR***
Larson et al. (78)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*LR*	*LR*	*LR*	*HR*	***MR***
Mariconda et al. (272)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*HR*	*LR*	*LR*	*HR*	***MR***
Mayes et al. (142)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	***LR***
Mayes et al. (122)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	***LR***
Mayes et al. (104)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	*LR*	***LR***
Narvani et al. (234)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*HR*	*LR*	*LR*	*LR*	***MR***
Nepple et al. (80)	*HR*	*HR*	*HR*	*LR*	*LR*	*LR*	*HR*	*LR*	*LR*	*HR*	***MR***
Philippon et al. (186)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*HR*	*LR*	*LR*	*LR*	***MR***
Silvis et al. (187)	*HR*	*HR*	*HR*	*HR*	*LR*	*HR*	*HR*	*LR*	*LR*	*LR*	***HR***
Yepez et al. (271)	*HR*	*HR*	*HR*	*LR*	*LR*	*HR*	*HR*	*LR*	*LR*	*HR*	***HR***
Yuan et al. (237)	*HR*	*HR*	*HR*	*HR*	*LR*	*HR*	*HR*	*HR*	*LR*	*HR*	***HR***
Overall risk of bias for item	*20 HR*	*20 HR*	*20 HR*	*3 HR*	*0 HR*	*11 HR*	*14 HR*	*1 HR*	*0 HR*	*10 HR*	
	0 LR	*0 LR*	*0 LR*	*17 LR*	*20 LR*	*9 LR*	*6 LR*	*19 LR*	*20 LR*	*10 LR*	

HR high risk of bias, MR moderate risk of bias, LR low risk of bias.

Risk of bias items: **1)** Was the study's target population a close representation of the national sporting population in relation to relevant variables, e.g., age, sex, competition level?; **2)** Was the sample frame a true or close representation of the target population?; **3)** Was some form of random selection used to select the sample, OR, was a census taken?; **4)** Was the likelihood of non-response bias minimal?; **5)** Were data collected directly from the subjects (as opposed to a proxy)?; **6)** Was an acceptable case definition used in the study?; **7)** Was the study instrument that measured the parameter of interest (e.g., prevalence of low back pain) shown to have reliability and validity (if necessary); **8)** Was the same mode of data collection used for all subjects?; **9)** Was the length of the shortest prevalence period for the parameter of interest appropriate? **10)** Were the numerator(s) and denominator(s) for the parameter of interest appropriate?

articular hip conditions in asymptomatic athletes using MRI.(104,122,142,185–187,224,226–228,237,271) Three studies (627 participants, 1237 hips) investigated the prevalence of hip OA in asymptomatic athletes using X-ray.(77,237,273) Four studies (40 hips) investigated theprevalence of intra-articular hip conditions in symptomatic athletes with MRI.(104,122,142,227) One study (18 participants, 18 hips) utilised MRA to determine the presence of intra-articular hip conditions in symptomatic athletes.(234) One study investigated intra-articular conditions in a combined population of ballet dancers with and without pain.(232) Three studies evaluated the prevalence of OA in symptomatic and asymptomatic athletes(76,78,272) and one study reported OA prevalence in only symptomatic athletes.(80) No studies evaluated symptomatic or asymptomatic athletes with CT. In total, 375 (28%) of the athletes were women and 960 were men. The included studies investigated different sports including American football (n=174),(77,80) soccer (n=100),(224,271) ice hockey (n=179),(78,185–187) ballet (n=110),(76,104,122,142,232) rugby (n=20),(228) golf (n=55),(227) skiing (n=27),(186) track and field (n=22),(226) capoeira (n=24),(272) and mixed sports (n=624).(104,122,142,234,237,273) The level of play reported in the included studies included professional,(76,78,104,122,142,187,232,234) elite,(77,80,185,187,226–228,273) semi-professional,(224) amateur or recreational(104,122,142,224,234) and youth/high school level.(186,271) Athletes participated in cutting (n=6),(104,122,142,186,224,271) flexibility (n=6),(76,104,122,142,232,272) impingement (n=4),(78,185–187) asymmetrical (n=5),(104,122,142,226,227) and endurance sports (n=1)(226) (Table 5.5).

Table 5.5. Mechanical load placed on hip joint by sport.

Athlete sports category(268)	Study
Cutting *(soccer, basketball, lacrosse, field hockey, downhill skiing, snowboarding)*	Lahner et al. (224); Mayes et al. (104,122,142); Philippon et al. (186); Yepez et al. (271)
Flexibility *(dancing, gymnastics, yoga, cheerleading, figure skating, synchronized swimming, martial arts, rock climbing)*	Harris et al. (76); Kolo et al. (232); Mariconda et al. (272); Mayes et al. (104,122,142)
Contact *(football, rugby, wrestling)*	Farrell et al. (228); Kapron et al. (77); Nepple et al. (80)
Impingement *(ice hockey, crew/rowing, baseball catching, water polo, equestrian polo, breaststroke swimming, weightlifting, bobsled, CrossFit, horseback riding)*	Ayeni et al. (185); Philippon et al. (186); Silvis et al. (187), Larson et al. (78)
Asymmetric/overhead *(baseball, softball, tennis, golf, volleyball, athletic field events, fencing, badminton, cricket, squash, racquetball, handball)*	Lahner et al. (226); Dickenson et al. (227); Mayes et al. (104,122,142)
Endurance *(track, cross-country, other running, cycling, swimming (not breaststroke), cross-country skiing, biathlon, aerobics)*	Lahner et al. (226)
Not reported	Anderson et al. (273); Yuan et al. (237); Narvani et al. (234)

5.3.6. Prevalence of labral tears

Twelve studies (484 participants, 754 hips) reported the prevalence of labral tears.(142,185–187,224,226–228,232,234,237,271) Five studies reported prevalence per person,(185–187,224,234) with four studies(226,227,232,271) reporting prevalence per hip and in the remaining three studies(142,228,237) prevalence was reported per person and per hip.

I. Symptomatic participants

One study *(MR)*(234) reported a labral tear prevalence of 22% per person, while 2 studies *(1 LR and 1 MR)*(142,227) reported labral tear prevalence per hip in symptomatic athletes. There was moderate evidence of a labral tear prevalence of 20% (95%CI: 10%, 35%) per hip from two studies *(1 LR and 1 MR)*(142,227) (Figure 5.2).

II. Asymptomatic participants

Five studies *(4 MR and 1 HR)*(185–187,224,228) reported the prevalence of labral tears per person in asymptomatic athletes. Limited evidence from 4 studies *(4 MR)*(185,186,224,228) identified a labral tear prevalence of 54% (95%CI: 22%, 83%) per person (Figure 5.3). The remaining study *(HR)*(187) reported a labral tear prevalence of 56% in ice hockey players competing at professional and collegiate levels respectively.

Five studies *(3 HR, 1 MR, and 1 LR)*(142,226,227,237,271) evaluated labral tear prevalence per hip in athletes using MRI. Moderate evidence from two studies(142,227) identified a labral tear prevalence of 33% (95%CI: 16%, 57%) per hip in asymptomatic athletes (Figure 5.2). The three HR studies(226,237,271) not included in the meta-analysis reported labral tear prevalence per hip in high school athletes (50%),(237) Brazilian youth soccer players (9%)(271) and track and field athletes (5%)(226).

III. Mixed participants

One study *(MR)*(232) evaluated symptomatic and asymptomatic ballet dancers and reported a labral tear prevalence per hip of 47%.

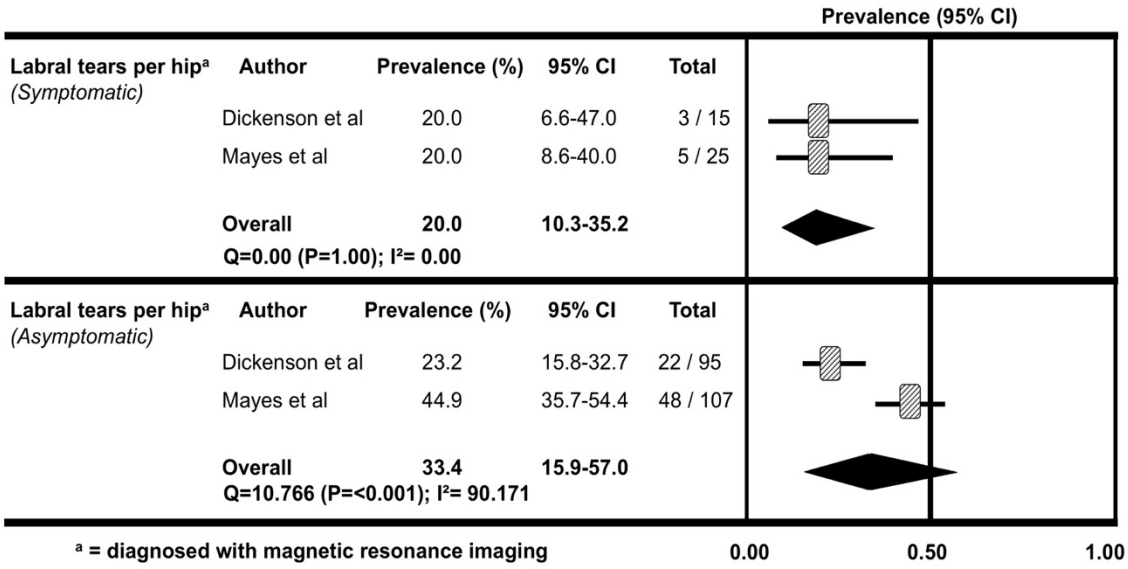


Figure 5.2. Prevalence and 95% CIs of labral tears per hip in symptomatic and asymptomatic athletes.

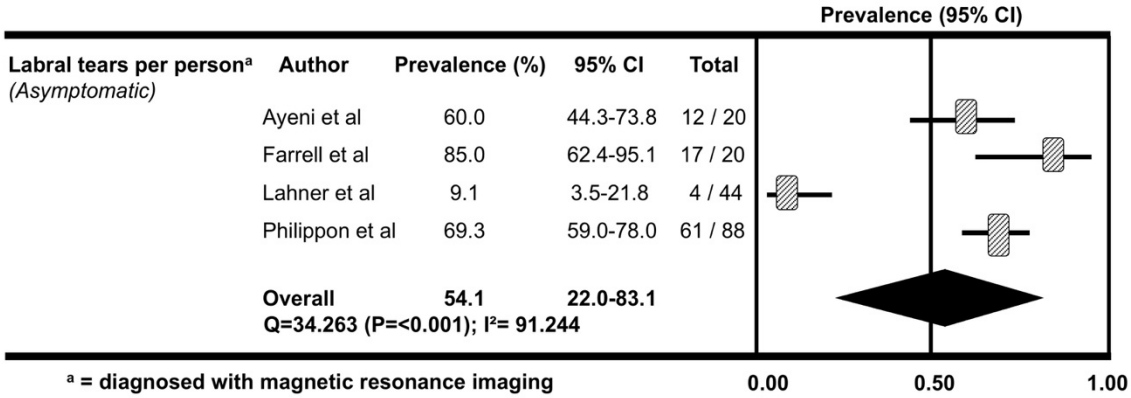


Figure 5.3. Prevalence and 95% CIs of labral tears per person in asymptomatic athletes.

5.3.7. Mechanical hip load of the various sports (labral tears)

I. Symptomatic participants

One study *(1 LR)*(142) reported a labral tear prevalence of 33% in symptomatic athletes participating in flexibility sports. Two studies *(1 MR and 1 LR)*(142,227) reported on the prevalence of labral tears in symptomatic athletes participating in asymmetrical sports. One study (MR)(227) of golfers identified a labral tear prevalence of 20%. The remaining study (*LR)*(142) included less than five symptomatic hips and was not included in the analysis. In symptomatic basketball players (cutting sport) a labral tear prevalence of 0% was identified *(LR)*(142). No studies investigated the prevalence of labral tears in symptomatic athletes participating in contact, endurance or impingement sports.

II. Asymptomatic participants

One study *(MR)*(228) reported a labral tear prevalence of 85% in athletes participating in a contact sport. Three studies *(1 HR and 2 MR)* reported the prevalence of labral tears in impingement sports. Two studies *(2 MR)*(185,186) found moderate evidence of a labral tear prevalence of 67% (95%CI: 56%, 76%) in asymptomatic ice hockey players (**Figure 5.4**). The remaining study *(HR)*(187) identified labral tears in 56% of ice hockey players without pain. One study *(LR)*(142) reported a labral tear prevalence of 43% in asymptomatic ballet dancers (flexibility sport). Limited evidence from two studies *(2 MR)*(186,224) found a labral tear prevalence of 33% (95%CI: 2%, 92%) per person in athletes participating in cutting sports (**Figure 5.4**). The remaining two studies *(1 HR and 1 LR)*(142,271) investigating asymptomatic athletes reported a labral tear prevalence per hip of 9% and 45% respectively. Three studies *(1 HR, 1 MR, and 1 LR)*(142,226,227) evaluated athletes competing in sports that place asymmetrical loads on the hip joint. Moderate evidence from two studies *(1 MR and 1 LR)*(142,227) identified a labral tear prevalence of 33% (95%CI: 13%, 61%) in asymptomatic athletes (**Figure 5.4**). The remaining study (HR)(226) in track and field athletes did not provide sufficient information to determine the labral tear prevalence in athletes performing asymmetrical sports, nor endurance athletes.

III. Mixed participants

One study *(MR)*(232) reported a labral tear prevalence of 47% in ballet dancers (flexibility sport) with and without pain.

5.3.8. Prevalence of cartilage defects

Eleven studies (466 participants, 736 hips) evaluated the prevalence of cartilage defects.(104,185–187,224,226–228,232,237,271) In total, five studies analysed prevalence per person(185–187,224,228) and five studies reported prevalence per hip.(226,227,232,237,271) Finally, cartilage defect prevalence was reported per person and per hip in one study(104).

I. Symptomatic participants

Cartilage defect prevalence was not reported per person but reported per hip by two studies *(2 MR and 1 LR)*(104,227) in symptomatic athletes. Acetabular (27%) and femoral cartilage defects (7%) were reported independently in golfers *(MR),*(227) while hip cartilage defects were reported in ballet dancers and mixed sports athletes (40%) *(LR)*(104).

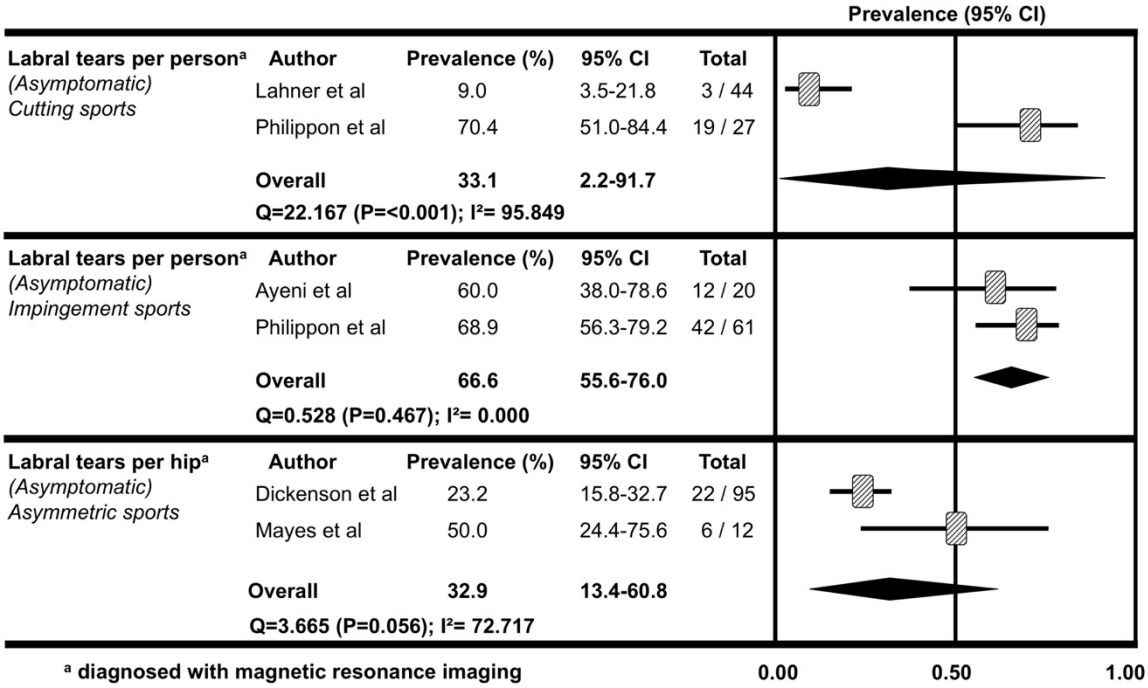


Figure 5.4. Prevalence and 95% CI of labral tears per person and per hip in asymptomatic athletes in cutting, impingement, and asymmetrical sports.

II. Asymptomatic participants

Five studies *(1 HR and 4 MR)*(185–187,224,228) reported cartilage defect prevalence per person in asymptomatic athletes. Moderate evidence from three studies *(3 MR)*(186,224,228) identified a cartilage defect prevalence of 10% (95%CI: 5%, 19%) (Figure 5.5). The two remaining studies *(1 HR and 1 MR)*(185,187) reported acetabular (0%), femoral (10%), and a combined cartilage defect prevalence of 18% in ice hockey players.

Five studies (*3 HR, 1 MR and 1 LR)*(104,226,227,237,271) evaluated cartilage defect prevalence per hip. One study *(LR)*(104) reported a cartilage defect prevalence of 36% in professional ballet dancers and mixed sports athletes. Two studies *(2 HR)*(237,271) reported on athletes competing in high school sport (4%) and youth soccer players (3%). The remaining two studies *(1 HR and 1 MR)*(226,227) evaluated acetabular and femoral cartilage defects independently in elite track and field athletes (2% and 2%)(226) and asymptomatic golfers (6% and 3%),(227) respectively.

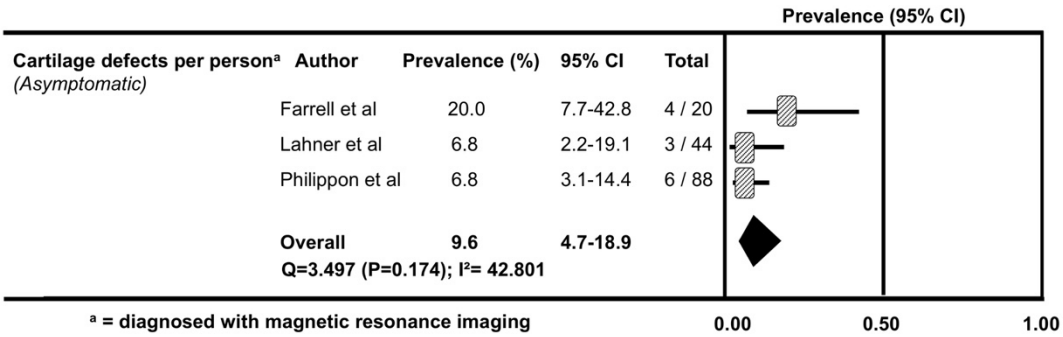


Figure 5.5. Prevalence and 95% CI of cartilage defects per person in asymptomatic athletes.

III. Mixed participants

One study *(MR)*(232) reported a cartilage defect prevalence of 49% in ballet dancers with and without pain.

5.3.9. Mechanical hip load of the various sport (cartilage defects)

I. Symptomatic participants

One study *(LR)*(104) reported a cartilage defect prevalence of 53% in symptomatic athletes participating in a flexibility sport. Two studies *(1 MR and 1 LR)*(104,227) evaluated the prevalence of cartilage defects in sports that cause asymmetrical hip loading. One study (MR)(227) in symptomatic golfers reported the prevalence of cartilage defects on the acetabulum (27%) and femur (7%) separately. The final study (*LR)*(104) included less than five symptomatic hips and was not included in the final analysis. One study *(LR)*(104)reported a cartilage defect prevalence of 17% per hip in basketball athletes (cutting sport) with hip pain. None of the included studies reported the prevalence of cartilage defects in symptomatic athletes participating in contact, impingement or endurance sports.

II. Asymptomatic participants

Three studies *(1 HR, 1 MR, and 1 LR)*(104,226,227) reported the prevalence of cartilage defects in athletes participating in sports that place an asymmetrical load on the hip joint. One study *(LR)*(104) reported a cartilage defect prevalence per hip of 50% in tennis players without pain. One *(MR)*(227) of the remaining two studies evaluated acetabular (6%) and femoral cartilage defects (3%) independently in golfers without hip pain. The remaining study *(HR)*(226) was not

included in the analysis as it combined information on athletes performing asymmetrical and endurance sports. One study *(LR)*(104) in ballet dancers (flexibility sport) reported a cartilage defect prevalence of 33%. In contact athletes, one study *(MR)*(228) identified a cartilage defect prevalence of 20%. In asymptomatic cutting athletes, moderate evidence from two studies *(2 MR)*(186,224) identified a cartilage prevalence of 5.8% (95CI: 2%, 15%) (Figure 5.6). Two additional studies *(1 HR and 1 LR)*(104,271) reported a cartilage defect prevalence per hip in asymptomatic cutting athletes of 34% (basketball players) and 3% (youth soccer players). Three studies *(1 HR and 2 MR)*(185–187) evaluated the prevalence of cartilage defects in athletes participating in impingement sports (ice hockey players). Two of the three studies *(1HR and 1 MR)*(186,187) identified a cartilage defect prevalence of 8% and 18% respectively. The remaining study reported acetabular (0%) and femoral cartilage defects (10%) independently. One study *(HR)*(226) reported the prevalence of cartilage defects in a combined population of endurance and asymmetrical/overhead athletes which resulted in the study not being included in the analysis.

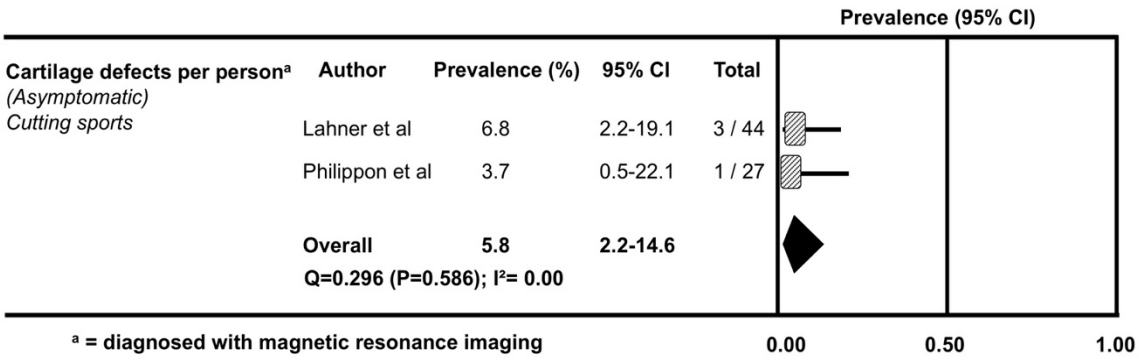


Figure 5.6. Prevalence and 95% CI of cartilage defects per person in asymptomatic athletes in cutting sports.

III. Mixed participants

One study *(MR)*(232) found a cartilage defect prevalence of 49% per hip in a population of ballet dancers (flexibility sport) with and without pain.

5.3.10. Prevalence of hip osteoarthritis

Seven studies (877 participants, 1646 hips) reported the prevalence of hip OA(76–78,80,237,272,273). Five studies (804 participants, 1504 hips) reported prevalence per

hip,(77,78,80,272,273) with two studies reporting hip OA prevalence per person and per hip(76,237).

I. Symptomatic participants

One study *(MR)*(80) reported a prevalence of hip OA per hip in symptomatic athletes. A hip OA (Tonnis grade 2 or greater/JSW of 2.0mm or less) prevalence of 2% was reported in NFL athletes attending the NFL scouting combine with a history of pain or injury around the hip.(80)

II. Asymptomatic participants

Three studies *(2 HR and 1 MR)*(77,237,273) evaluated asymptomatic athletes for hip OA using X-ray. One study *(HR)*(237) reported hip OA prevalence per person in high school athletes (0%). Two studies *(1 HR and 1 MR)*(77,273) reported early hip OA (Tonnis grade 1) and hip OA per hip. In a group of mixed senior athletes(273) the prevalence of early hip OA and hip OA was 32% and 17% respectively. The remaining study(77) reported a prevalence of early hip OA of 16%, with no collegiate NFL players having hip OA.

III. Mixed participants

Three studies *(3 MR)*(76,78,272) reported early hip OA and hip OA prevalence in athletes with and without pain. One study(76) reported prevalence per person and per hip in professional ballet dancers. Hip OA was not found in any ballet dancer using Tonnis grade and mean joint space. However, early hip OA was present in 13% of ballet dancers' hips(76). Two studies (*2 MR)*(78,272) reported hip OA per hip. One study(272) evaluating capoeira players reported hip OA (6%) and early hip OA (19%) using Tonnis grade, with the remaining study(78) reporting a mean minimum joint space of 4.1mm in ice hockey players.

5.3.11. Other conditions

I. Symptomatic participants

Bone marrow lesions.

One study *(MR)*(227) identified the presence of acetabular (20%) and femoral head BML (40%) in golfers with hip pain.

Herniation pits.

One study *(MR)*(227) evaluated the prevalence of herniation pits in golfers with hip pain (27%).

Hip joint effusion.

One study *(MR)*(227) reported a prevalence of hip joint effusion per hip of 7% in golfers with hip pain

Labral degeneration

One study *(MR)*(227) reported a prevalence of labral degeneration per hip of 20% in golfers with hip pain.

Ligamentum teres tears

One study *(LR)*(122) reported the prevalence of ligamentum teres tears per hip (44%) in symptomatic ballet dancers and mixed athletes.

II. Asymptomatic participants

Bone marrow lesions

Two studies *(1 HR and 1 MR)*(227,271) reported the prevalence of BML per hip in asymptomatic athletes. One study(271) evaluated youth soccer players (21%), with the remaining study(227) reporting acetabular (11%) and femoral BML (11%) independently in asymptomatic golfers.

Herniation pits

Four studies *(2 HR and 2 MR)*(185,226,227,271) evaluated the prevalence of herniation pits in asymptomatic athletes. One study *(MR)*(185) reported a herniation pit prevalence per person in ice hockey athletes of 10%. The remaining three studies *(2 HR and 1 MR)*(226,227,271) reported prevalence per hip in track and field athletes (7%), youth soccer players (4%), and golfers (9%).

Hip joint effusion

Two studies *(1 HR and 1 MR)*(187,227) identified the prevalence of hip joint effusion in asymptomatic athletes. One study *(MR)*(227)reported a prevalence of 8% in asymptomatic golfers. The remaining study *(HR)*(187) in ice hockey players identified a prevalence of 0%.

Labral degeneration

Two studies *(1 HR and 1 MR)*(227,271) reported a labral degeneration prevalence of 2% and 22% in asymptomatic youth soccer players and golfers respectively.

Ligamentum teres tears

One study *(LR)*(122) reported a prevalence of ligamentum teres tears per hip of 21% in a mixed population of athletes.

5.3.12. Other conditions reported in less than two studies

Pathologies that were reported in less than one study of symptomatic and asymptomatic populations are presented in Appendix 24.

5.4. Discussion

This systematic review highlights that imaging defined intra-articular hip conditions are observed in athletes with and without pain. Across the included studies, considerable heterogeneity existed in regard to the methods used to evaluate the presence of intra-articular hip conditions. Moreover, athletes participated in a wide range of sports and competition levels resulting in limited comparability between the included studies. Hence, caution should be taken when comparing differences in the prevalence of intra-articular conditions between studies and in athletes with and without pain. In particular, we identified that labral tears on MRI are observed in up to 54% of athletes without pain and 22% of athletes with pain. Cartilage defects were identified in symptomatic (7% to 40%) and asymptomatic athletes (0% to 36%). Qualitative analysis identified that bone marrow lesions, herniation pits, labral degeneration, ligamentum teres tears and joint effusion appear to be prevalent in athletes with and without pain. Our review identified that features associated with early radiographic OA (Tonnis grade 1) appear

more frequently than radiographic OA (Tonnis grade 2 or greater/JSW of 2.0mm or less) in athletes currently playing a sport, regardless of pain.

5.4.1. Review findings

Labral tears have long been considered a cause of hip/groin pain in athletes.(18,274,275) A combination of the dynamic movements performed in sport and the high prevalence of bony hip morphology, in particular cam morphology, is believed to place athletes at greater risk of labral tears. In athletes without pain, we identified moderate evidence of a labral tear prevalence per hip of 33%, while in athletes with pain, there was moderate evidence of a labral tear prevalence per hip of 20%. These findings provide further evidence of the complex relationship between labral tears and experience of pain.(123,240,262,264) Furthermore, it appears that athletes do not have a higher prevalence of labral tears than non-athletic individuals, regardless of pain status.(61,62,264) Debate exists around the optimal management of labral tears.(276–278). It is proposed that the integrity of the labrum is important for joint function and maintenance of tissue homeostasis.(276,277) Restoration of labral tissue integrity might be achieved with surgical approaches, and this may result in improved patient function and pain.(276–278) However, such approaches are supported by low levels of evidence,(276–278) and may result in a varied return to sport and/or performance rates in athletes.(279) Our findings highlight that up to one in every two asymptomatic athletes can be active in sport with a labral tear, ultimately questioning the clinical significance of labral tears in some athletes with pain. Moreover, it highlights the importance of considering "non-structural" factors in an athlete with hip/groin pain.(280) Future work should focus on gaining a greater understanding of the long-term implications for symptomatic and asymptomatic athletes with labral tears, in order to provide appropriate management of these athletes.

Cartilage defects were seen in symptomatic and asymptomatic athletes. The prevalence of cartilage defects in symptomatic athletes ranged from 7% to 40%, with three of the four studies reporting a prevalence greater than 25%. Our pooled data identified moderate evidence of a prevalence of 10% in asymptomatic athletes with a mean age of less than 25 years. In addition, five of the remaining studies not included in the meta-analysis reported a cartilage defect prevalence of less than 10%. The high prevalence of cartilage defects seen in symptomatic athletes in this review is similar to that seen in older individuals with and without pain,(124,240) but lower than our previous review.(264) Injury to the articular cartilage affects joint homeostasis, in addition to biomechanical and neuromuscular function.(281) This alteration in

joint function combined with athletic activity may accelerate hip joint degenerative change, which is known to occur more frequently in retired athletes.(173,265) However, longitudinal studies confirming this causation are currently lacking and should be a focus of future work. Importantly, articular cartilage is deficient of neural and vascular supply rendering it unable to produce pain.(83) This understanding is reflected in the variable relationship seen between cartilage defects and pain.(123,124,126,240) In relation to our findings, it is likely that the presence of cartilage defects in symptomatic athletes indicates the involvement of inflammatory mediators, subchondral bone and peri-articular tissues which are all capable of causing nociception.(83) This suggests that cartilage defects are likely to be a precursor to OA in susceptible individuals.

Our review highlights that OA is not commonly seen in athletes who are currently competing at an elite or professional level, even if they have hip/groin pain. This finding is of particular interest, as elite male athletes have a greater prevalence of OA,(265) and the likelihood of undergoing hip arthroplasty (OR = 2.5) after they have retired from sport compared to age-matched controls.(173) The prevalence of OA in asymptomatic senior athletes appears similar to that of older non-athletic populations (17% vs 15%).(127,273) In addition, our review indicates that radiographic features associated with early OA are seen in younger athletes regardless of the presence or absence of pain.(76,77,272) Our findings highlight a discordant relationship between radiographic features associated with early OA and pain in athletes currently playing a sport, which is consistent with previous work in older populations.(238) In the included studies, OA was measured using x-ray, whilst other conditions were measured using MRI or MRA. Since radiographic measures are insensitive to early changes in articular cartilage integrity,(282) our findings may underestimate the true disease prevalence in athletes. The use of imaging methods with greater sensitivity to early features of OA may be important for identifying athletes at risk of progression to OA.

Bone marrow lesions, herniation pits, labral degeneration, ligamentum teres tears, and hip joint effusions were seen in symptomatic and asymptomatic athletes. These findings are congruent with our recent review.(264) Bone marrow lesions were reported in up to 40% of athletes with pain. This relationship between pain and BML has been demonstrated previously, albeit in older non-athletic populations.(123,240) The prevalence of BML identified in this review is lower than our previous review.(264) However, BMLs are known to be seen more frequently in individuals with OA,(124,225,240) which was seen in very few athletes included in this review. In relation to ligamentum teres tears, debate currently exists regarding its role in both joint stability and pain

generation.(131,244,283–285) The only study that reported on the prevalence of ligamentum teres tears in ballet dancers and mixed sport athletes described a high prevalence in those with hip pain (44%).(122) The high prevalence of ligamentum teres tears observed in athletes may reflect the demands placed on this ligament during a sporting activity, particularly those sports requiring large ranges of hip motion. Hip joint effusion was present in athletes with and without pain. Hip joint effusion is often considered a surrogate marker of synovitis when evaluated by MRI without contrast.(286) However, optimal evaluation of synovitis requires contrast enhanced MRI,(124,286) which was not used in the two studies reporting hip joint effusion in our review. The prevalence rates identified appear similar to older populations with and without pain,(123) but lower than individuals with radiographic OA or MRI defined cartilage defects.(124,287) The association between pain, symptoms and effusion appears variable(123,124) and requires greater understanding in athletic individuals to enable appropriate intervention.

Athletes competing in sports that place contact, impingement, and flexibility loads on the hip joint appear to have a high prevalence of labral tears. In relation to cartilage defects, there appears less variation between sports when categorized by mechanical hip load. However, athletes performing flexibility, cutting, and asymmetrical sports appear to have a high prevalence of cartilage defects. None of the included studies in our review reported the prevalence of labral tears in symptomatic athletes competing in impingement or contact sports. However, existing work not included in our review highlights that labral tears appear in similar rates in athletes with and without pain competing in impingement (67% vs 69%)(185,186,274) and contact sports (85% vs 89%).(121,228) In athletes participating in flexibility sports, labral tears (33% and 43%) and cartilage defects (53% and 33%) are commonly seen in symptomatic and asymptomatic athletes respectively. This review has highlighted the large variation of prevalence of labral tears and cartilage defects in athletes with and without pain, particularly when sports are categorized by mechanical load placed on the hip joint. As such, a combination of bony morphology, which is seen in a high percentage of athletes(58,61,62,79) and specific hip load may be related to the development of specific intra-articular hip conditions in athletes.

The diagnostic accuracy of the imaging techniques used to evaluate the presence of intra-articular conditions may have influenced the findings of this review. Magnetic resonance imaging without contrast has known limitations in relation to the identification of labral tears.(92,110,111) In particular, the moderate sensitivity and specificity of MRI with 1.5 and 3 tesla field strengths may result in the over and/or underestimation of the prevalence of labral tears. Since only one of the

included studies used contrast enhanced MRI, the prevalence of labral tears reported in this review may have been under-estimated.(92,110,111) Similarly, the diagnostic accuracy of MRI without contrast for chondral defects is variable across two reviews.(92,93) We identified a higher prevalence of cartilage defects in athletes with pain compared to those without pain in studies using MRI without contrast. Five of the eleven studies used 3T MRI to evaluate cartilage defects.(104,186,187,228,237) The evaluation of cartilage defects with 3T MRI has shown superiority for the recognition of cartilage defects compared to lower field strength approaches.(95,96) Importantly, six of the remaining 11 studies used 1.5T MRI which provides only limited sensitivity for the identification of cartilage defects,(92,93) this may have resulted in the under reporting of cartilage defects in some athletes included in our review.

Seventeen of the 20 included studies were moderate to HR. In particular, the included studies evaluated athletes that were selected by convenience or from specific competitions or organizations, and not deemed representative of wider athletic populations. Future work should focus on evaluating athletes from a larger range of clubs/organizations to improve generalisability. Of the included studies, only 6 (30%) reported the reliability or extent of agreement for the methods used to determine each of the imaging defined conditions. This finding should be considered when interpreting the prevalence of intra-articular conditions in this review. Our decision to exclude HR studies from our meta-analyses is in line with recent recommendations.(219)

Moderate to high levels of heterogeneity were observed in most pooled analyses performed in this review, which may be related to the observed variability across studies in relation to sport and competition level. In addition, athlete sex, age, variation in the imaging type and specific imaging parameters should be considered. Interestingly, when data were pooled based on the mechanical hip load, two of the four pooled analyses demonstrated low levels of heterogeneity, indicating that intra-articular hip pathology prevalence may be influenced by the specific physical requirement of a sport.

5.4.2. Limitations

A number of limitations need to be considered when interpreting the findings of our review. First, several clinical entities may be associated with hip/groin pain in athletes.(11,37,41,202) In this review, we evaluated athletes based on the subjective presence or absence of pain, rather than with more objective measures.(11) In light of this, many of the imaging defined intra-articular hip

conditions may indeed be incidental findings and unrelated to an athlete's hip/groin pain. Second, careful consideration is needed when generalising the findings of our review. The included studies investigated athletes from a broad range of sports and competition levels, meaning that our findings can only be extrapolated to athletes competing at similar levels of competition and sport. The exclusion of studies investigating athletes with other hip conditions including SCFE and Legg Calve Perthes Disease reduces the generalisability of our findings to athletes with such conditions. Importantly, none of the athletes had their intra-articular conditions or OA confirmed by open or arthroscopic hip surgery. The authors acknowledge that surgery is considered the gold standard for the identification of intra-articular hip conditions. However, such an approach is not considered reasonable for athletes without hip pain. Finally, not including studies published in languages other than English may have resulted in some relevant studies not being included in this review.

5.4.3. Future directions/research priorities

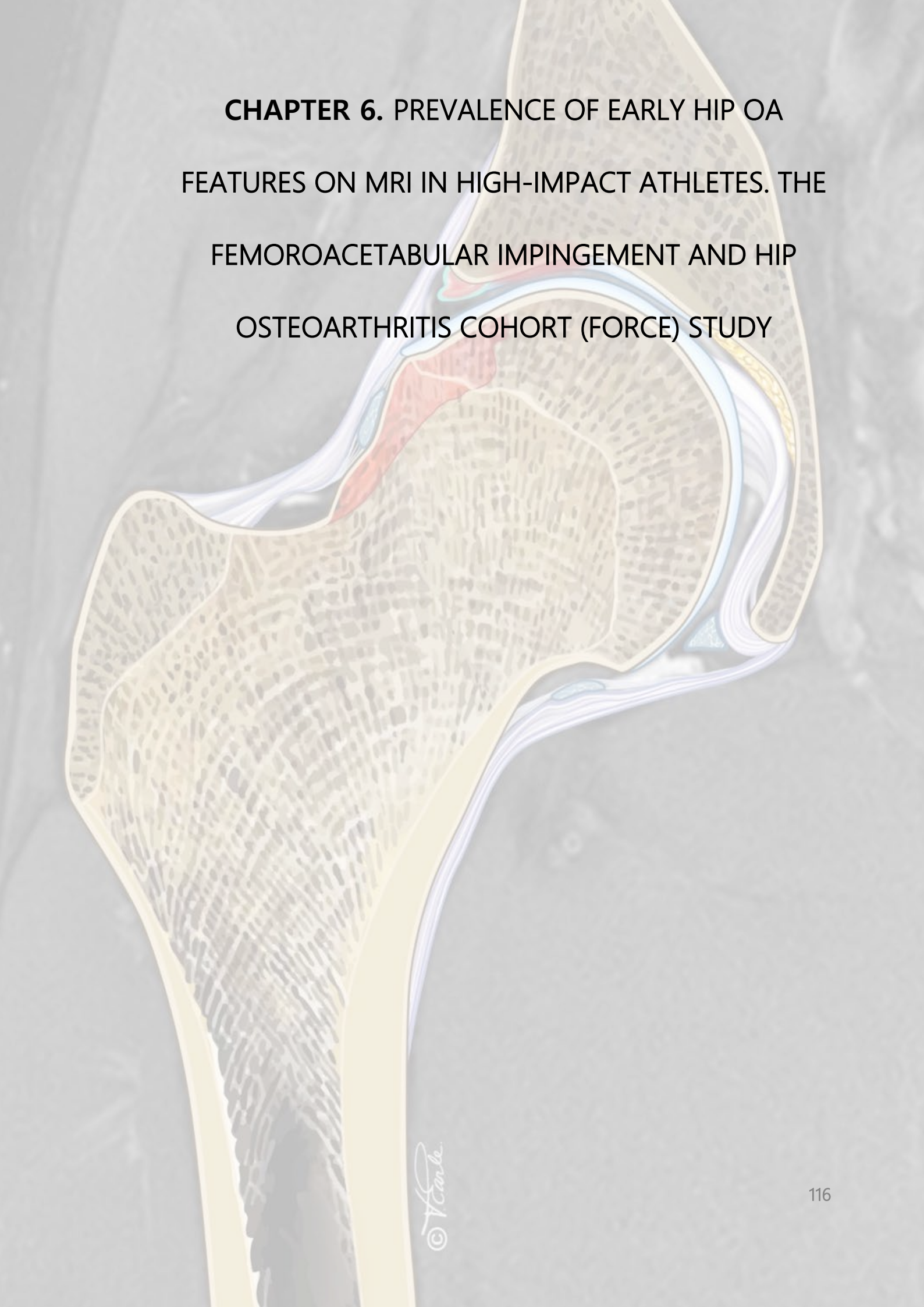
Future work should establish a greater understanding of the prevalence of intra-articular hip conditions in both symptomatic and asymptomatic athletes. To correctly select athletes for surgical interventions it would seem prudent that we understand the relevance of imaging defined intra-articular hip conditions in athletes with hip/groin pain. Future studies may choose to compare intra-articular findings between athletes of varying ages and/or competition levels, to understand the impact of age and level of play on the prevalence of findings in athletes. Using recommended clinical entities(11) to categorize an athlete with hip/groin pain may allow a greater understanding of the prevalence of intra-articular hip conditions in athletes with specific clinical presentations. Finally, longitudinal studies are required to provide evidence supporting the relationship between intra-articular conditions and OA development or progression in athletes.(188)

5.5. Conclusion

Our systematic review identified that imaging defined intra-articular hip conditions are seen in athletes with and without pain. In particular, labral tears were identified in one in every two athletes without pain, highlighting a complex, poorly understood, and potentially arbitrary (at least in some cases) relationship between labral tears and pain in athletes. Cartilage defects are seen in athletes with and without pain. Importantly, OA was rarely seen in athletes regardless if they had pain or not. Bone marrow lesions, herniation pits, hip joint effusion, labral

degeneration, and ligamentum teres tears were observed in symptomatic and asymptomatic athletes. Two out of three asymptomatic athletes competing in impingement sports had imaging defined labral tears. In summary, our findings highlight the complex relationship between structural hip conditions identified with imaging and pain in athletes.

CHAPTER 6. PREVALENCE OF EARLY HIP OA FEATURES ON MRI IN HIGH-IMPACT ATHLETES. THE FEMOROACETABULAR IMPINGEMENT AND HIP OSTEOARTHRITIS COHORT (FORCE) STUDY



PREFACE

Chapter 4 and 5 highlighted the high prevalence of imaging-defined intra-articular hip conditions in individuals with and without pain. Specifically, a higher prevalence of labral tears was found in athletes without hip/groin pain relative to those with pain in chapter 5. For cartilage, chapter 5 highlighted a similar prevalence of cartilage defects in athletes with and without pain. Chapter 5 also reported that BMLs, herniation pits, labral degeneration, ligamentum teres tears, and hip joint effusions were seen in symptomatic and asymptomatic athletes. Chapter 1 highlighted that athletes participating in high-impact sports (i.e., soccer) are at greater risk of developing hip OA in later life. Intra-articular conditions identified on imaging may represent signs of early hip OA and play an important role in the development of hip/groin pain in football players. However, none of the included studies in chapter 5 reported the prevalence of early hip OA features in male or female football players with hip/groin pain. Identifying the prevalence of early hip OA features in football players can help to understand the pathogenesis of hip OA and the identification of intra-articular structures that may be important in the genesis of hip/groin symptoms. The primary aim of the study in chapter 6 was to compare early hip OA features on MRI between football players with and without hip/groin pain. The secondary aims of the study were to compare early hip OA features separately in men and women and to evaluate the relationship between early hip OA features, the iHOT33 and HAGOS symptom and pain subscales.

Chapter 6 contains the following publication in its entirety (Appendix 25), with the following minor amendments: (I) The term hip and groin pain is replaced by hip/groin pain to provide consistency through this thesis; (II) The term bone marrow edema pattern is replaced by bone marrow lesion to provide consistency through this thesis; (III) Figure 6.2 and 6.3 were included in the supplementary file in the original publication and (IV) Table 6.5 was included in the supplementary file in the original publication.

Heerey JJ, Srinivasan R, Agricola R, Smith A, Kemp JL, Pizzari T, King MG, Lawrenson PL, Scholes MJ, Souza RB, Link T, Majumdar S, Crossley KM. Prevalence of early hip OA features in high-impact athletes. The femoroacetabular impingement and hip osteoarthritis cohort (FORCe) study. Osteoarthritis and Cartilage. 2021; 29(3): 323-334.

6.1. Introduction

Hip OA is associated with substantial personal and societal burden,(145) with its pathogenesis involving genetic, biological, biomechanical, and environmental factors.(144,145,177) Mechanical joint overload may represent one disease pathway,(145,288) with subtle alterations in bony anatomy (i.e., cam morphology) also related to hip OA development.(159,289–291) Repetitive high-impact physical activity (such as football) might even increase the risk for hip OA,(91,172) with many young adults experiencing hip-related pain with sports participation.(37) Once established, the radiological joint changes seen in OA are irreversible.(282) Identifying early disease may be important, as this may represent a point in time where interventions aimed at slowing disease progression could be effective.(282)

Radiographs are often used to evaluate hip OA but are insensitive to the soft-tissue findings seen in the early stages of OA.(91) Magnetic resonance imaging provides superior soft-tissue contrast, enabling assessment of articular cartilage, labrum and other joint features.(89,91,292) Semi-quantitative MRI measures enable structured evaluation of soft-tissues involved in the pathogenesis of OA, with such approaches recommended for use in clinical studies of hip OA.(89) The SHOMRI is a reliable and valid semi-quantitative measure, which has been used to characterise and monitor the burden of hip OA.(123)

Little is known about hip OA features on MRI in younger people participating in high-impact physical activity who are free from radiographic OA, and who have or do not have hip/groin pain.(293) Evaluating early OA features in younger active symptomatic individuals, may aid in the understanding of early hip joint degeneration and assist in establishing the relationship between specific OA features and symptoms. The aims of this study were: 1) to compare early hip OA features on MRI between people with and without hip/groin pain participating in high-impact physical activity (i.e., soccer or AF); 2) to compare early hip OA features separately in men and women and 3) to evaluate the relationship between early hip OA features, the iHOT33 and HAGOS symptom and pain subscales.

6.2. Methods

6.2.1. Study design

This case-control study used baseline data of the FORCe study. The FORCe study is an ongoing prospective study investigating changes to hip joint structures in 184 symptomatic men and women participating in high-impact physical activity (soccer or AF).(188) A convenience sample of 55 pain-free men and women participating in high-impact physical activity was recruited to match the mean age and sex distribution of the 184 symptomatic participants of the FORCe study and serve as a control group. Symptomatic and control participants were participating in the same league/competition level and were recruited between August 2015 and October 2018 from sporting clubs or organisations and via online or print advertising in Melbourne and Brisbane, Australia. This study had ethics approval (La Trobe University Human Ethics Committee [HEC 15-019 and HEC16-045] and the University of Queensland Human Ethics Committee [2015000916 & 2016001694] and all participants provided written informed consent. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines were followed.(294)

6.2.2. Participants

The eligibility criteria for symptomatic and control participants are described in **Table 2.1** and **Table 2.2**, respectively. For symptomatic participants, each hip was classified as either: 1) symptomatic or 2) other. The contralateral hip was classified as other if 1) no hip/groin was reported, or 2) hip/groin pain was reported but the participant had a negative FADIR test (**Table 2.3**). Control participants had no history of hip/groin pain and a negative FADIR test in both hips (**Table 2.3**).

6.2.3. Radiographs

Each participant underwent a supine AP pelvis radiograph using a standardised protocol (**Section 3.3)**. Features of radiographic hip OA were evaluated using the OARSI atlas(295) by a blinded registrar orthopaedic surgeon (Dr. Rintje Agricola) with more than 10 years' experience reading pelvic radiographs. This resulted in a KL classification (grade 0-4), with hip OA defined as a KL grade of 2 or greater.(296) Intra-observer reliability for KL classification had a κ of 0.87, (95% CI: 0.71, 1.0).(297)

6.2.4. Magnetic resonance imaging

Each participant underwent an unenhanced 3-T MRI (Phillips Ingenia, The Netherlands). Participants were positioned supine with patient positioning aids used to maintain each hip in internal rotation and neutral abduction/adduction, with a 32-channel torso coil placed over the hips and pelvis, with right and left hips imaged independently. The MRI protocol included the following sequences: coronal PD SPAIR, sagittal PD SPAIR and oblique axial PD SPAIR (Table 3.2).

6.2.5. SHOMRI scoring

All MRI scans were evaluated by one musculoskeletal radiologist (Dr. Ramya Srinivasan) with 8 years of experience, who was blinded to radiographic and clinical findings. The SHOMRI scoring system has been defined previously.(123) Briefly, eight different OA features were evaluated including: articular cartilage (graded 0-2), BML (graded 0-3), subchondral cysts (graded 0-2), labrum (graded 0-5), paralabral cysts (present or absent), intra-articular bodies (present or absent), effusion-synovitis (present or absent) and ligamentum teres (graded 0-3). Articular cartilage, BML, and subchondral cysts were evaluated in six femoral and four acetabular subregions, with the labrum evaluated in four acetabular subregions.(123) Intra-observer reliability was determined in 20 randomly selected hips, re-read 2 weeks after the initial scoring.

6.2.6. OA feature scoring

For cartilage, acetabular and femoral subregions were combined, providing a total cartilage score (0-20). Bone marrow lesions and subchondral cysts were evaluated in 10 subregions, with a total feature score ranging from 0 to 30 and 0 to 20, respectively. The labrum was scored in 4 subregions (0-20). Ligamentum teres was scored from 0 to 3. The remaining features (paralabral cysts, loose bodies and hip effusion) were scored as present or absent. To be consistent with previous studies,(125,194) the total SHOMRI score (0 to 96) was calculated for each hip by adding the scores for each of the eight OA features, with a higher score indicating more severe whole joint degenerative change.

6.2.7. Dichotomous scoring

Cartilage defects were scored as present if cartilage loss was evident in at least one acetabular or femoral subregion and were defined as any cartilage defect (grade 1 or grade 2) or full-thickness defect (grade 2 only). A labral tear was scored as present if a grade 2 or above finding was

reported in one or more subregions. For BML and subchondral cysts, acetabular and femoral subregions were combined, with the feature scored as present if a grade one or above was scored in at least one subregion. Ligamentum teres tears were scored as present if a partial (grade 2) or full-thickness tear (grade 3) was reported. Finally, paralabral cysts, loose bodies, and effusion-synovitis were scored as present or absent.

6.2.8. Patient-reported outcome measures

Demographic information (age, sex, height, weight, football code participation, and training/competition frequency) was collected. Each participant completed the iHOT33(190) and the HAGOS,(38) which are recommended PROMs in young to middle-aged people with hip/groin conditions.(298)

6.2.9. Statistical analysis

Data analyses were performed with SPSS version 25 (SPSS Inc, Chicago, Illinois, USA) and Stata/IC 15.0 for Windows (StataCorp LC, College Station, Texas, USA). Intra-observer reliability for OA feature scores (including total SHOMRI) were determined with ICC using a two-way mixed-effects model with absolute agreement.(299) Intra-observer reliability for individual OA features (dichotomous scoring) was determined with κ and prevalence adjusted bias adjusted kappa (PABAK). The κ statistic conveys the proportion of agreement greater than expected by chance; however, the magnitude of the κ coefficient is affected by the prevalence of a finding and bias between observers. The PABAK adjusts for differences in the prevalence of each hip OA feature and bias between observers; therefore, providing a more complete assessment of observer agreement.(300)

Linear regression models utilising generalised estimating equations (GEE) to account for within-person correlation between right and left hip data were used to evaluate differences in total SHOMRI score between symptom groups, with 95% CIs and associated *P* values estimated using bootstrapping (1000 repetitions) to account for right skew in total SHOMRI scores.(301) Differences between groups in individual OA feature scores (cartilage, BML, subchondral cysts, labral and ligamentum teres) were evaluated using negative binomial regression utilising GEE, with group differences reported as incidence rate ratios (IRR) with associated 95% CI and *P*-values. For the presence of individual OA features (dichotomous scoring), the prevalence of each feature was reported per hip for primary analysis, with per person prevalence reported

descriptively (Appendix 26). Differences between groups in feature prevalence were evaluated using logistic binomial regression utilising GEE, with group differences reported as ORs with associated 95% CI and *P*-values. For the first study aim, data from men and women were pooled and analyses adjusted for sex, age and body mass index (BMI). For the second aim of the study, differences between symptom groups were estimated in men and women separately by including an interaction term between sex and symptom group in the statistical analyses described above (total SHOMRI score, individual OA feature scores, and prevalence of OA features), adjusted for age and BMI.

For the third aim of the study, Spearman's rank correlation was used to evaluate the relationship between individual OA feature scores (including total SHOMRI score) and hip/groin pain specific PROMs (iHOT33 and HAGOS symptoms and pain subscales) in football players overall with hip/groin pain, and in men and women with hip/groin pain separately. For all analyses, the total SHOMRI and individual OA features scores were taken from the most symptomatic hip, as defined by the iHOT33, with the HAGOS subscale scores applied to this hip. The absence of non-linear relationships was evaluated graphically using a locally weighted smoothing filter.

6.3. Results

6.3.1. Participants

A total of 539 football players with hip/groin pain were screened for eligibility, with 182 (symptomatic group) included (Figure 2.1). In two symptomatic participants, one hip was excluded due to the presence of hip OA (KL ≥2), with the remaining 362 hips included for these analyses. One hundred and forty-seven asymptomatic football players were evaluated for eligibility, with 55 participants (110 hips) included in the control group (Figure 2.2). Symptomatic and control participant characteristics are presented in Table 6.1. The prevalence of KL grade 1 was low in both symptomatic (4%) and control (5%) participants. Symptomatic participants had a median symptom duration of 24 months (interquartile range (IQR) 18 to 49 months).

Table 6.1. Demographic characteristics, radiographic and patient-reported outcome measures for symptomatic and control participants.

	Symptomatic group (n=182)	Control group (n=55)
Demographic characteristics		
Age, years	26.0 (23, 30)	26.0 (23, 31)
Sex, % women	20%	25%
Height, metres	1.79 (1.73, 1.85)	1.79 (1.72, 1.85)
Weight, kg	77.9 (72, 86)	78.7 (67, 89)
BMI, kg/m^2	24.2 (23, 26)	24.3 (22, 27)
Football code, % soccer	50%	55%
Training/competition (per week), %		
2 to 3 sessions	89	82
≥4 sessions	11	18
Duration of symptoms, months*	24 (18, 49)	-
Radiographic measures		
KL grade, hips (%)		
Grade 0	347 (96%)	105 (95%)
Grade 1	15 (4%)	5 (5%)
Patient-reported outcome measures		
iHOT33	64 (50, 74)	98 (97, 100)
HAGOS–Symptoms†	61 (51, 68)	100 (93, 100)
HAGOS–Pain†	75 (65, 83)	100 (100, 100)

Values are presented as %, or median (interquartile range).
*181 symptomatic participants.
†176 symptomatic participants/54 control participants.

6.3.2. Reliability

Percent agreement ranged from 80 (ligamentum teres tears) to 100% (BML). For OA feature scores, ICCs ranged from 0.66 to 0.91. For individual features (dichotomous scoring) κ values ranged from -0.01 to 0.89, with PABAK 0.60 to 0.99 (**Table 3.4**).

6.3.3. Total SHOMRI score

In football players, higher total SHOMRI scores were observed in symptomatic (mean difference (MD) = 1.4, 95%CI: 0.7, 2.2)] and other (MD = 1.2, 95%CI: 0.1, 2.2) hips than in control hips (**Table 6.2**). When stratified by sex, a similar finding was observed in men, with symptomatic (MD = 1.8, 95%CI: 1.0, 2.7) and other (MD = 1.7, 95%CI: 0.4, 2.9) hips having higher total SHOMRI scores.

Table 6.2. Differences in total SHOMRI score between control, symptomatic and other hips.

	Mean (95%CI) total SHOMRI score			Between group comparisons	
	Control (ref)	Symptomatic	Other	Symptomatic vs control	Other vs control
				Mean difference (95%CI) ‡‡	Mean difference (95%CI)‡‡
All football players, hips†	110	288	74		
	5.3 (4.7, 5.8)	6.7 (6.2, 7.2)	6.5 (5.6, 7.4)	1.4 (0.7, 2.2)	1.2 (0.1, 2.2)
Men, hips‡	82	229	59		
	5.4 (4.7, 6.0)	7.2 (6.6, 7.8)	7.0 (6.0, 8.1)	1.8 (1.0, 2.7)	1.7 (0.4, 2.9)
Women, hips‡	28	59	15		
	4.7 (4.1, 5.4)	4.8 (3.8, 5.8)	4.3 (2.6, 6.0)	0.1 (-1.0, 1.2	-0.4 (-2.2, 1.4)

† Football players adjusted for sex, age, and BMI.

‡ Men and women adjusted for age and BMI.

‡‡ Normal based 95%CI.

In contrast, symptomatic (MD = 0.1, 95%CI: -1.0, 1.2) and other (MD = -0.4, 95%CI: -2.2, 1.4) hips had similar total SHOMRI scores to control hips in women (Table 6.2). Unadjusted total SHOMRI scores are presented in Appendix 27. An interaction between sex and symptom group was found for total SHOMRI score, whereby higher scores were found in men but not women in both symptomatic and other hips when compared to control hips (Table 6.2).

6.3.4. Individual osteoarthritis feature scores

In all football players, results for differences in cartilage score between symptomatic, other and control hips were inconclusive (Table 6.3). For men, higher cartilage scores were found in symptomatic (adjusted incidence rate ratio (aIRR) = 1.60, 95%CI: 1.15, 2.22) and other hips (aIRR = 1.61, 95%CI: 1.09, 2.39) relative to control hips. In women, differences in cartilage score between symptom groups were inconclusive (Table 6.3).

In all football players, labral scores were higher in symptomatic (aIRR = 1.33, 95%CI: 1.08, 1.64) and other hips (aIRR = 1.32, 95%CI: 1.03, 1.68) than in control hips. A similar finding was observed in men, with higher labral scores in symptomatic (aIRR = 1.38, 95%CI: 1.08, 1.76) and other (aIRR = 1.40, 95%CI: 1.06, 1.85) hips when compared to control hips. In women, results for differences in labral score between symptomatic, other and control hips were inconclusive (Table 6.3).

In all football players, differences in BML and ligamentum teres scores between symptomatic, other and control hips were inconclusive (Table 6.3). For men, results for BML, ligamentum teres and subchondral cyst scores between symptom groups were inconclusive. For women, differences in ligamentum score between symptom groups were inconclusive (Table 6.3)

Of the individual OA feature scores, an interaction between sex and symptom group was only found for cartilage, whereby higher scores were observed for men but not women in both symptomatic and other hips versus control hips (Table 6.3).

Table 6.3. Differences in individual osteoarthritis (OA) feature scores between control, symptomatic and other hips.

OA feature	Mean (95%CI) OA feature score			Incidence rate ratios (IRR)			
	Control (ref)	Symptomatic	Other	Symptomatic vs control		Other vs control	
				Unadjusted IRR (95%CI)	Adjusted IRR (95%CI)	Unadjusted IRR (95%CI)	Adjusted IRR (95%CI)
All football players, hips[†‡‡]	110	288	74				
Cartilage	1.0 (0.7, 1.3)	1.4 (1.1, 1.6)	1.3 (1.0, 1.6)	1.38 (1.01, 1.88)	1.34 (0.98,1.83)	1.38 (0.95, 2.00)	1.30 (0.89, 1.88)
BML	0.1 (0.0, 0.1)	0.1 (0.0, 0.1)	0.1 (0.0, 0.2)	1.72 (0.40, 7.44)	1.75 (0.42, 7.26)	1.98 (0.40, 9.73)	1.89 (0.39, 9.30)
Labrum	3.0 (2.5, 3.6)	4.0 (3.6, 4.5)	4.0 (3.3, 4.7)	1.30 (1.04, 1.62)	1.33 (1.08, 1.64)	1.29 (1.00, 1.67)	1.32 (1.03, 1.68)
Ligamentum teres	0.5 (0.4, 0.6)	0.6 (0.5, 0.7)	0.6 (0.5, 0.8)	1.19 (0.90, 1.56)	1.20 (0.92, 1.57)	1.26 (0.92, 1.73)	1.26 (0.93, 1.71)
Men, hips[‡]	82	229	59				
Cartilage	1.0 (0.7, 1.2)	1.5 (1.3, 1.8)	1.6 (1.1, 2.0)	1.50 (1.07, 2.11)	1.60 (1.15, 2.22)	1.56 (1.04, 2.33)	1.61 (1.09, 2.39)
BML	0.1 (0.0, 0.1)	0.1 (0.0, 0.2)	0.1 (0.0, 0.2)	1.65 (0.31, 8.84)	1.81 (0.36, 9.22)	2.21 (0.37, 13.23)	2.27 (0.38, 13.69)
Subchondral cysts	0.1 (0.0, 0.2)	0.1 (0.1, 0.2)	0.1 (0.0, 0.3)	1.10 (0.51, 2.41)	1.22 (0.56, 2.65)	1.46 (0.55, 3.87)	1.41 (0.54, 3.70)
Labrum	3.2 (2.5, 3.8)	4.3 (3.8, 4.9)	4.4 (3.6, 5.2)	1.28 (1.00, 1.64)	1.38 (1.08, 1.76)	1.30 (0.98, 1.74)	1.40 (1.06, 1.85)
Ligamentum teres	0.5 (0.3, 0.6)	0.6 (0.5, 0.7)	0.6 (0.5, 0.8)	1.24 (0.88, 1.74)	1.28 (0.93, 1.78)	1.29 (0.88, 1.90)	1.31 (0.91, 1.90)
Women, hips[‡§]	28	59	15				
Cartilage	1.0 (0.4, 1.5)	0.7 (0.4, 1.0)	0.4 (0.1, 0.8)	0.79 (0.37, 1.67)	0.73 (0.36, 1.49)	0.49 (0.18, 1.35)	0.43 (0.15, 1.22)
Labrum	2.5 (1.7, 3.3)	3.0 (2.2, 3.8)	2.6 (1.4, 3.9)	1.30 (0.84, 2.00)	1.19 (0.81, 1.74)	1.11 (0.63, 1.97)	1.05 (0.60, 1.83)
Ligamentum teres	0.6 (0.3, 0.8)	0.5 (0.4, 0.7)	0.6 (0.4, 0.9)	1.03 (0.66, 1.61)	0.98 (0.61, 1.56)	1.19 (0.70, 2.02)	1.14 (0.66, 1.97)

[†] Football players adjusted for sex, age and BMI.

[‡] Men and women adjusted for age and BMI.

[‡‡] Subchondral cysts not analysed in football players.

[§] Subchondral cysts and BML not analysed in women.

6.3.5. Prevalence of osteoarthritis features

In all football players, and men and women, results for differences in cartilage defect and labral tear prevalence between symptomatic, other and control hips were inconclusive (Table 6.4).
In all football players, symptomatic (adjusted odds ratio (aOR) = 0.46, 95%CI: 0.26, 0.81) and other (aOR = 0.38, 95%CI: 0.18, 0.77) hips had a lower prevalence of effusion-synovitis relative to control hips. In men, a lower prevalence of effusion-synovitis was also observed in symptomatic (aOR = 0.49, 95%CI: 0.25, 0.96) and other (aOR = 0.36, 95%CI: 0.15, 0.83) than in control hips. For women, results for differences in effusion-synovitis prevalence between symptom groups were inconclusive (Table 6.4). In all football players, differences in paralabral cysts prevalence between symptomatic, other and control hips were inconclusive (Table 6.4).

In men, differences in subchondral cyst, ligamentum teres tear and paralabral cysts prevalence between symptom groups were inconclusive. Lastly in women, differences in paralabral cysts prevalence between symptom groups were inconclusive. The prevalence of all OA features (including features not compared statistically due to low prevalence) in football players are presented in Figure 6.1, with men and women presented in Figure 6.2 and 6.3, respectively. No interaction was found between sex and symptom group for cartilage, labral tears, paralabral cysts, or effusion-synovitis.

6.3.6. Correlation between scoring of hip osteoarthritis with MRI feature scores, International Hip Outcome Tool and Hip and Groin Outcome Score

The total SHOMRI and individual OA features scores were not associated with iHOT33 or HAGOS symptoms and pain subscale scores in all football players, men or women separately (Table 6.5).

Table 6.4. Differences in prevalence of individual osteoarthritis (OA) features (present or absent definition) between control, symptomatic and other hips.

OA feature	Number of hips with OA feature (%)			Odds Ratios (OR)			
	Control (ref)	Symptomatic	Other	Symptomatic vs control		Other vs control	
				Unadjusted OR (95%CI)	Adjusted OR (95%CI)	Unadjusted OR (95%CI)	Adjusted OR (95%CI)
All football players, hips[†‡‡]	110	288	74				
No. of hips (%)							
Cartilage defect (any)	52 (47)	144 (50)	38 (51)	1.13 (0.67, 1.91)	1.12 (0.65, 1.92)	1.15 (0.62, 2.14)	1.11 (0.58, 2.09)
Labral tear	73 (66)	206 (72)	54 (73)	1.32 (0.77, 2.26)	1.34 (0.78, 2.30)	1.21 (0.62, 2.34)	1.21 (0.62, 2.35)
Paralabral cysts	21 (19)	74 (26)	12 (16)	1.48 (0.80, 2.71)	1.49 (0.81, 2.74)	0.80 (0.36, 1.81)	0.79 (0.35, 1.78)
Effusion-synovitis	44 (40)	67 (23)	15 (20)	0.46 (0.26, 0.81)	0.46 (0.26, 0.81)	0.37 (0.18, 0.75)	0.38 (0.18, 0.77)
Men, hips[‡§]	82	229	59				
No. of hips (%)							
Cartilage defects (any)	39 (48)	125 (55)	36 (61)	1.38 (0.76, 2.52)	1.49 (0.81, 2.74)	1.51 (0.74, 3.07)	1.55 (0.75, 3.18)
Subchondral cysts	8 (10)	24 (11)	8 (14)	1.12 (0.45, 2.76)	1.29 (0.51, 3.23)	1.36 (0.46, 4.04)	1.30 (0.43, 3.95)
Labral tear	52 (63)	166 (73)	46 (78)	1.59 (0.86, 2.93)	1.66 (0.90, 3.08)	1.71 (0.80, 3.69)	1.75 (0.81, 3.79)
Ligamentum teres tear	4 (5)	8 (4)	3 (5)	0.78 (0.18, 3.33)	0.85 (0.22, 3.35)	0.74 (0.13, 4.26)	0.78 (0.14, 4.20)
Paralabral cysts	17 (21)	63 (28)	11 (19)	1.45 (0.74, 2.85)	1.53 (0.78, 3.00)	0.88 (0.37, 2.11)	0.89 (0.37, 2.14)
Effusion-synovitis	30 (37)	52 (23)	10 (17)	0.51 (0.27, 0.98)	0.49 (0.25, 0.96)	0.36 (0.16, 0.83)	0.36 (0.15, 0.83)
Women, hips[‡§§]	28	59	15				
No. of hips (%)							
Cartilage defects (any)	13 (46)	19 (32)	2 (13)	0.48 (0.16, 1.45)	0.44 (0.14, 1.32)	0.34 (0.08, 1.43)	0.32 (0.07, 1.35)
Labral tear	21 (75)	40 (68)	8 (53)	0.70 (0.22, 2.23)	0.67 (0.21, 2.15)	0.39 (0.10, 1.55)	0.38 (0.10, 1.52)
Paralabral cysts	4 (14)	11 (19)	1 (7)	1.42 (0.36, 5.62)	1.36 (0.34, 5.36)	0.35 (0.03, 4.15)	0.35 (0.03, 4.14)
Effusion-synovitis	14 (50)	15 (25)	5 (33)	0.36 (0.12, 1.10)	0.37 (0.12, 1.14)	0.42 (0.11, 1.65)	0.43 (0.11, 1.71)

[†] Football players adjusted for sex, age and BMI.

[‡] Men and women adjusted for age and BMI.

[‡‡] Full thickness cartilage defects, BML, subchondral cysts, ligamentum teres tears and intra-articular loose bodies not analysed in football players.

[§] Full thickness cartilage defects, BML and intra-articular loose bodies not analysed in men.

[§§] Full thickness cartilage defects, BML, subchondral cysts, ligamentum teres tears and intra-articular loose bodies not analysed in women.

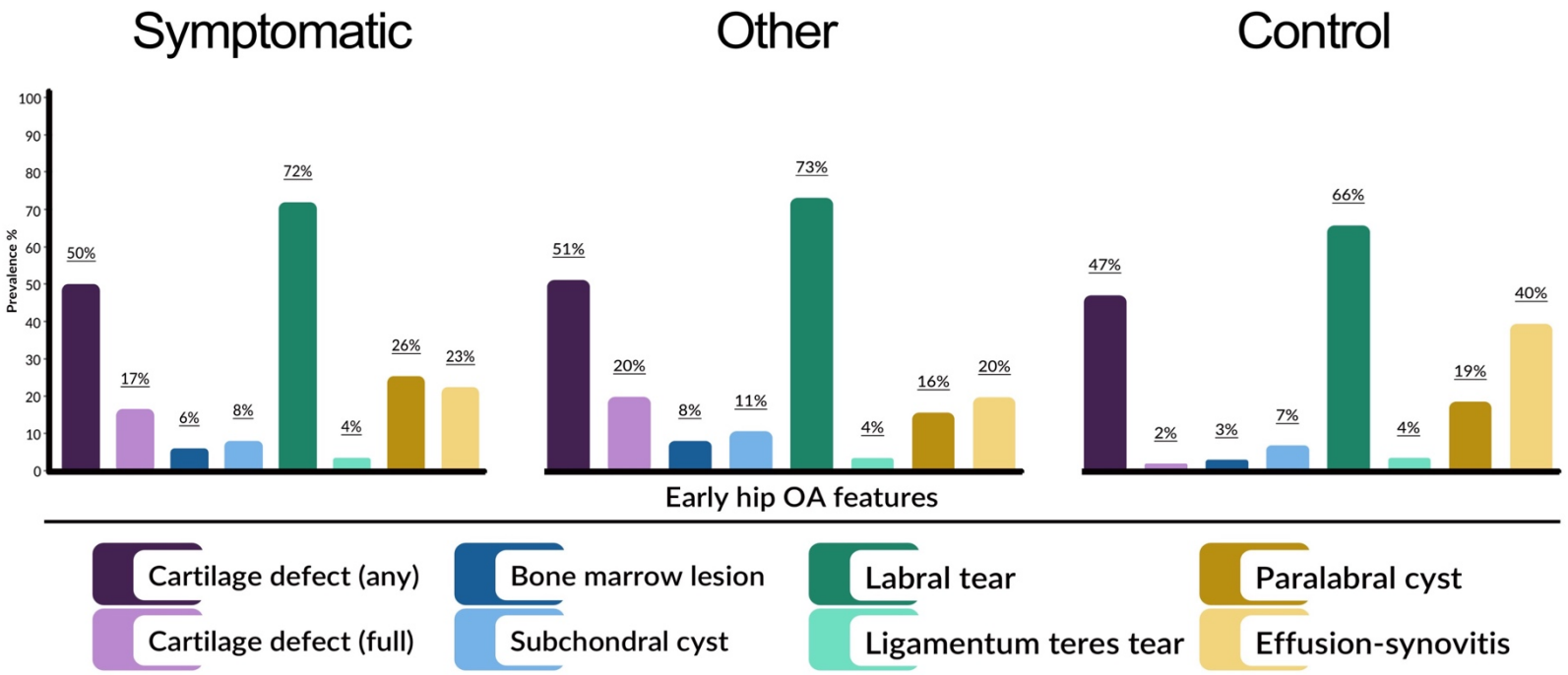


Figure 6.1. Prevalence of individual OA features in symptomatic, other and control hips in football players.
Intra-articular loose bodies were not included due to low prevalence in symptom groups (symptomatic 1%, other and control hips feature absent).

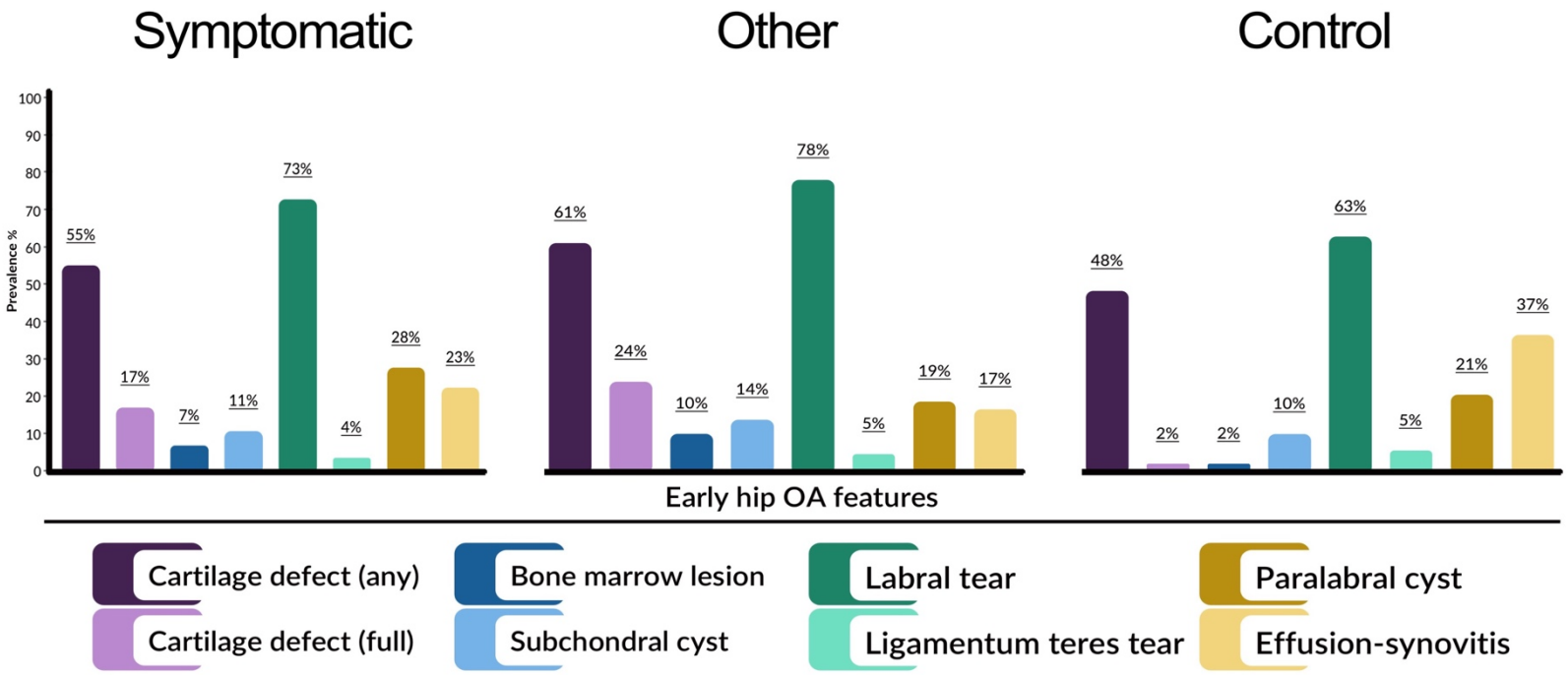


Figure 6.2. Prevalence of individual OA features in symptomatic, other and control hips in men.

Intra-articular loose bodies were not included due to low prevalence in symptom groups (symptomatic 1%, other and control hips feature absent).

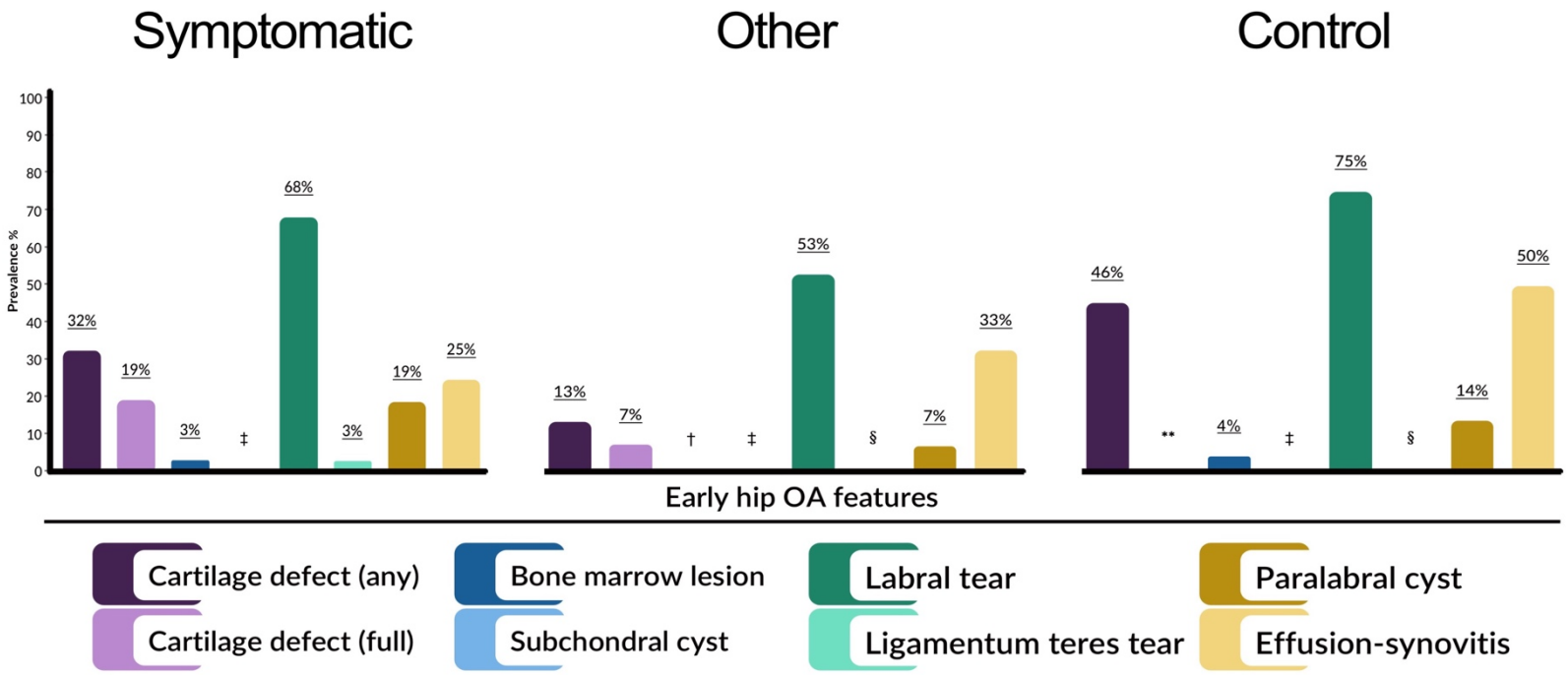


Figure 6.3. Prevalence of individual OA features in symptomatic, other and control hips in women.

Intra-articular loose bodies were not included due to low prevalence in symptom groups (symptomatic 2%, other and control hips feature absent); ** full thickness cartilage defects absent; † bone marrow lesion absent, ‡ subchondral cysts absent and § ligamentum teres tears absent.

Table 6.5. Spearman's rank correlation coefficients between SHOMRI score, individual osteoarthritis (OA) feature scores and patient-reported outcome measures in football players, men, and women with hip/groin pain.*

	Patient-reported outcome measure		
OA feature score	iHOT33	HAGOS-Symptoms†	HAGOS-Pain†
All football players (n = 182)			
Total SHOMRI	0.07, *P* = .324	-0.04, *P* = .581	0.06, *P* = .455
Cartilage	0.06, *P* = .449	-0.09, *P* = .256	0.09, *P* = .222
BML	0.04, *P* = .585	-0.07, *P* = .328	-0.04, *P* = .610
Subchondral cyst	NA	NA	NA
Labral	0.04, *P* = .557	-0.05, *P* = .503	0.02, *P* = .837
Ligamentum teres	0.07, *P* = .353	0.13, *P* = .087	0.03, *P* = .690
Men (n = 145)			
Total SHOMRI	0.07, *P* = .339	-0.09, *P* = .304	0.03, *P* = .760
Cartilage	0.03, *P* = .710	-0.15, *P* = .076	0.06, *P* = .457
BML	0.08, *P* = .339	-0.06, *P* = .514	-0.03, *P* = .766
Subchondral cyst	0.13, *P* = .120	-0.03, *P* = .754	0.13, *P* = .124
Labral	0.03, *P* = .763	-0.06, *P* = .507	0.01, *P* = .880
Ligamentum teres	0.01, *P* = .928	0.06, *P* = .455	-0.04, *P* = .657
Women (n = 37)			
Total SHOMRI	0.24, *P* = .155	0.07, *P* = .677	0.17, *P* = .338
Cartilage	0.21, *P* = .206	0.12, *P* = .490	0.14, *P* = .423
BML	NA	NA	NA
Subchondral cyst	NA	NA	NA
Labral	0.17, *P* = .328	-0.06, *P* = .719	0.02, *P* = .919
Ligamentum teres	0.28, *P* = .091	0.34, *P* = .050	0.27, *P* = .123

*Most symptomatic hip selected on International Hip Outcome Tool used for all analyses.
†Football players, n = 176; men, n = 142; women, n = 34.
NA, not estimated.

6.4. Discussion

Football players frequently exhibited MRI-defined early hip OA features. The high prevalence of early hip OA features, irrespective of symptomatic status, suggests a complex and poorly understood relationship between pain and most OA features. Football players with longstanding hip/groin pain exhibited higher total SHOMRI, labral, and cartilage scores. There was no relationship between OA feature scores (including total SHOMRI) and the iHOT33 or HAGOS.

Cartilage defects were present in 47% to 51% of football players' hips without definite radiographic hip OA, regardless of whether they had hip/groin pain or not. A higher prevalence of full thickness cartilage defects was found in symptomatic hips than control hips, with more extensive cartilage damage (i.e., higher cartilage scores) present in symptomatic hips in men. Overall, there was a low prevalence of full-thickness defects in football players (17%), suggesting that this feature is unlikely to be the primary driver of nociception. The severity of cartilage damage was not associated with either the iHOT33 or HAGOS. Osteoarthritis is an active disease that affects nearly all joint tissues, with structural changes evident in articular cartilage, synovium, subchondral bone, and surrounding muscles.(144,145,177,282) The discordant relationship between pain and cartilage damage is consistent with our earlier systematic review(293) and the knowledge that articular cartilage is deficient in neural supply, and incapable of nociception in early disease.(83) Evaluation of cartilage damage with MRI is challenging due to the closely apposed and curved joint surfaces and the thin layer of acetabular and femoral articular cartilage.(89,124) Despite this, the SHOMRI system may provide accurate grading (when compared to hip arthroscopy) of cartilage damage if performed with high resolution, unenhanced 3-T MRI, as in our study.(302). While the use of contrast-enhanced MRI might provide a superior assessment of cartilage damage,(92) such approaches are not without risk(89) and not appropriate in people without pain. Imaging-defined cartilage damage is associated with poor surgical outcomes.(303) As such, further work is needed to establish factors associated with progressive cartilage damage and the role that altered cartilage structure plays in expediating whole joint disease.

Labral findings were observed in symptomatic (68% to 73%) and control (63% to 75%) football players. The high prevalence of incidental labral findings in pain-free football players is consistent with our earlier systematic review showing labral changes on MRI in over 50% of active individuals without pain.(293) In general, higher labral scores were observed in symptomatic participants.

However, there was not a relationship between more extensive labral pathology and pain or symptom severity, consistent with earlier studies using semi-quantitative MRI measures.(123,124,240) We did not evaluate for extra-articular causes of hip/groin pain.(11) It is possible that an interrelationship may exist between labral tear severity and PROMs in football players without coexisting extra-articular conditions. High-resolution, unenhanced 3-T MRI may afford similar accuracy to contrast-enhanced approaches for the assessment of labral abnormalities.(96,304) Despite this, existing literature supports the use of contrast-enhanced over unenhanced MRI.(92,94,110,111) Therefore, the prevalence and/or severity of labral abnormalities may be underreported in both groups. Labral damage may increase cartilage loading,(305,306) possibly initiating cartilage degradation and other soft tissue changes, which may lead to the genesis of symptoms.(12) Our findings suggest that labral abnormalities might represent a normal anatomical variant in some, but not all people participating in high-impact sports. Further work is needed to understand if the location or severity of labral abnormalities is associated with the development of symptoms and/or progression of early hip OA. Clinical treatments that target labral tears require careful consideration as they may not be appropriate in some high-impact athletes.

We observed a low prevalence of BML, subchondral cysts, paralabral cysts and ligamentum teres tears. While studies in older people have described associations between BML, subchondral cysts, and pain severity,(123,240) in our younger cohort of active individuals there was inconclusive evidence of a higher prevalence. Longitudinal studies are needed to establish if BML or subchondral cysts are associated with symptom and/or disease progression in high-impact athletes. Ligamentum teres tears can be a source of hip/groin pain.(20) We did not observe a higher prevalence of ligamentum teres tears in football players with symptoms or an association between tear severity and PROMs. Reliable and accurate grading of ligamentum teres tears is challenging with unenhanced MRI.(119) Therefore, we may under-report the presence and severity of ligament teres tears, and subsequently the relationship between such findings and symptoms. The role that effusion-synovitis plays in the genesis of hip symptoms and progression of joint disease is unclear. Hip/groin pain was associated with a lower prevalence of effusion-synovitis in all football players, men and women. Our findings are consistent with prior work using unenhanced MRI(123,307) but differ to those observed in female ballet dancers.(307) By using unenhanced MRI we could not differentiate effusion from synovitis.(192,286) As such, a relationship may exist between either feature (effusion or synovitis) and symptoms. The SHOMRI has a crude scoring (present or absent), meaning we were unable to determine if the size of

effusion-synovitis was associated with symptoms. Further work is required to understand the role that the presence and/or size of effusion-synovitis plays in the pathogenesis of hip OA, in particular the progression of cartilage degradation.

In football players and men without definitive radiographic hip OA, longstanding hip/groin pain was associated with higher total SHOMRI scores, indicating a greater number and/or severity of MRI hip OA features, than pain-free controls. However, total SHOMRI scores were not associated with the iHOT33 or HAGOS, suggesting that more extensive 'whole joint' disease may be associated with the presence, but not the level of pain or symptoms. The similarity in SHOMRI scores with those of older individuals,(194) suggests that early hip joint disease may be evident in young high-impact athletes. The SHOMRI score has been used as a measure of whole joint disease(125); however, the relative importance of each specific OA feature remains unknown. Future studies may investigate if specific SHOMRI profiles exist in people who display symptoms and/or disease progression.

Our finding of no substantive relationship between the severity of hip OA features and PROMs may be influenced by the reliability of the SHOMRI measure. Intra-observer reliability values were good to excellent for most OA features. For select features (cartilage, ligamentum teres and subchondral cysts) we found only modest reliability (0.61 to 0.66). Therefore, we may under or over-report the extent of early hip OA and subsequently the relationship between certain features and symptoms. Although recommended for people with hip/groin conditions, the construct and content validity of the iHOT33 and HAGOS is still to be clarified.(189) A relationship may exist between hip OA features and PROMs that measure different dimensions (e.g., intensity and unpleasantness) of hip/groin pain and/or symptoms.

An interaction between sex and hip/groin symptoms was only evident for total SHOMRI and cartilage score, whereby higher scores were seen in symptomatic and other hips relative to control hips in men, but not women. Future studies evaluating the relationship between symptoms and features of early hip OA should consider our findings.

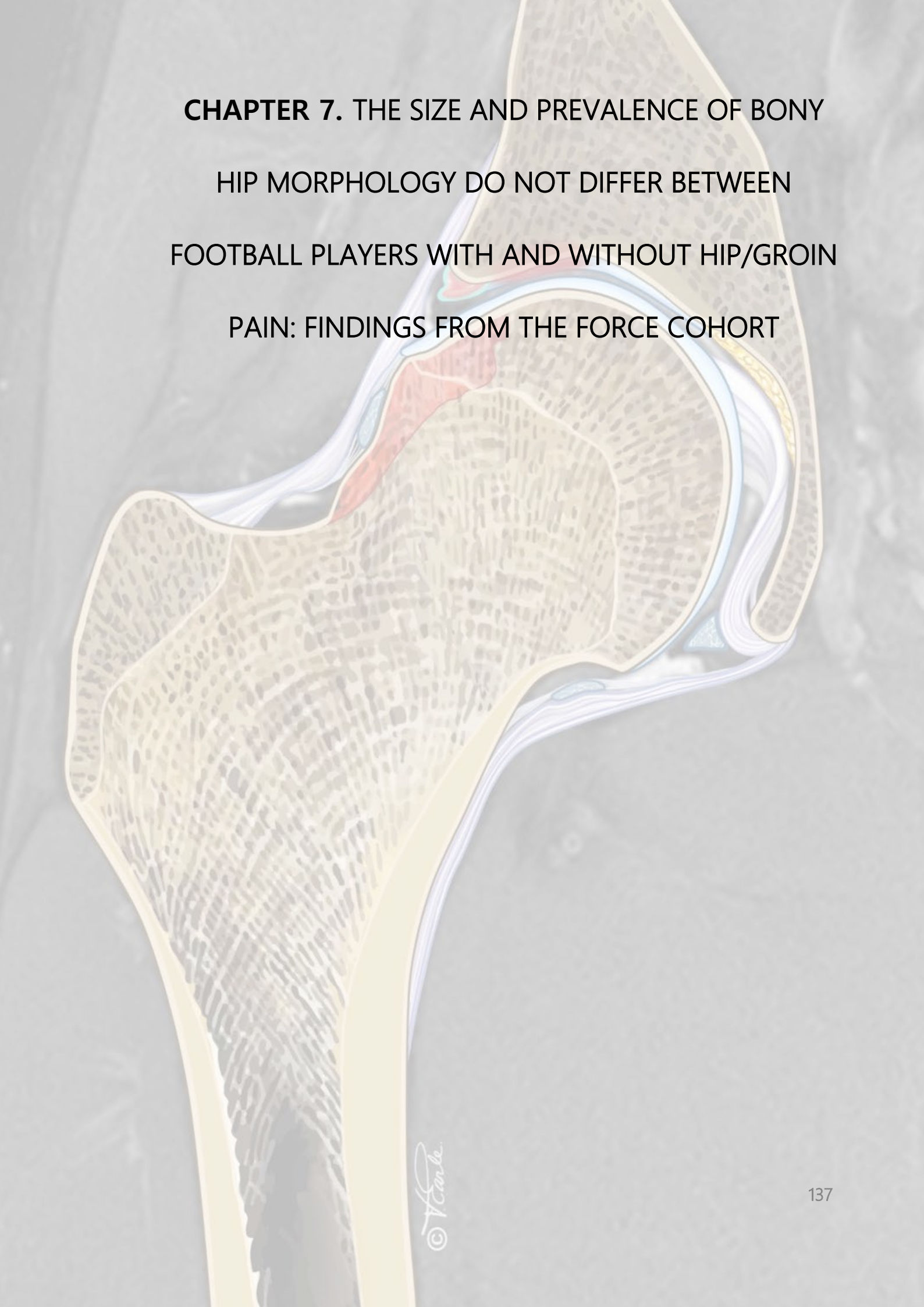
We recognise that there are a number of limitations that require consideration when interpreting our findings. First, hip/groin pain can originate from pathologies present in bony and musculotendinous structures around the hip joint, as well as the lumbar spine and pelvis.(204) Symptomatic participants were not evaluated for other clinical entities observed in high-impact

athletes,(11) meaning such conditions may have contributed to the generation of symptoms. The FADIR test is sensitive but not specific for intra-articular hip conditions,(308) which prevents us from concluding that hip/groin symptoms were being generated from the intra-articular hip pathologies alone. The SHOMRI scoring was completed by a single trained musculoskeletal radiologist and we did not establish inter-observer reliability. Our cohort consisted of soccer and AF players, and not those participating in other high-impact physical activities (e.g., ice hockey and handball). This should be considered when generalising our findings to other groups of athletes. Nonetheless, the high prevalence of OA features on MRI observed in our cohort is comparable to earlier studies of other high-impact athletes,(185,187,228) suggesting that high-impact athletes exhibit MRI-defined OA features to a similar extent. Unenhanced MRI provides variable accuracy relative to contrast-enhanced approaches for both cartilage and non-osteochondral features (labrum, ligamentum teres and synovium).(92,111,119,192) We used an optimised 3-T MRI protocol which increases confidence in our findings, as such approaches have comparable accuracy to contrast-enhanced MRI.(95,96) Further, the SHOMRI scoring system has demonstrated precision for the identification of cartilage and labral conditions when compared to hip arthroscopy.(302) We have previously reported the prevalence of bony morphology in our cohort of football players.(297) The relationship between bony morphology and early hip OA is still to be established in active high-impact athletes and will be the focus of future studies. The present case-control study precludes assumptions about causal relationships between OA features present on MRI and hip/groin pain.

6.5. Conclusion

Early hip OA features on MRI were prevalent in a high number of football players without radiographic OA. Our findings suggest a complex relationship between self-reported symptoms and most hip OA features observed on MRI. Hip/groin pain was associated with more extensive cartilage loss and higher total SHOMRI and labral scores. Labral findings were present in over 60% of football players with and without pain, questioning the clinical relevance of this specific feature. Further work is required to establish the natural history of early hip OA features and the identification of factors associated with the progression of structural disease in high-impact athletes.

CHAPTER 7. THE SIZE AND PREVALENCE OF BONY HIP MORPHOLOGY DO NOT DIFFER BETWEEN FOOTBALL PLAYERS WITH AND WITHOUT HIP/GROIN PAIN: FINDINGS FROM THE FORCE COHORT



PREFACE

Chapter 6 highlighted the high prevalence of early hip OA features in football players with and without pain. Specifically, hip/groin pain was associated with more extensive cartilage loss and higher total SHOMRI and labral scores. Consistent with chapter 4 and 5 the findings of chapter 6 indicate that labral changes can exist on MRI in over 60% of asymptomatic football players. Altered or incongruent hip morphology is a risk factor for the development of early hip OA. Chapter 1 reported that athletes (such as football players) are at greater risk of developing cam morphology and that several studies have reported on the high prevalence of cam morphology in asymptomatic athletes. However, the relationship between these morphological variations and hip/groin pain in football players remains unclear. Identifying if bony hip morphology (cam morphology, pincer morphology and acetabular dysplasia) differs in football players with and without pain can help to identify which morphological variation may be associated with hip/groin pain. The primary aim of the study in chapter 7 was to compare the size and prevalence of bony hip morphology in football players with and without hip/groin pain. The secondary aims of the study were to compare the size and prevalence of bony hip morphology separately in men and women and to evaluate the relationship between the size of bony hip morphology and hip/groin symptoms and pain as determined by PROMs.

Chapter 7 contains the following publication in its entirety (Appendix 28), with the following minor amendments: (I) The term hip and groin pain is replaced by hip/groin pain to provide consistency through this thesis; (II) Figure 7.1 to 7.3 were included in the supplementary file in the original publication and (III) Table 7.5 was included in the supplementary file in the original publication.

Heerey JJ, Agricola R, Smith A, Kemp JL, Pizzari T, King MG, Lawrenson PL, Scholes MJ, Crossley KM. The size and prevalence of bony hip morphology do not differ between football players with and without hip and/or groin pain: Findings from the FORCe cohort. J Orthop Sports Phys Ther. 2021; 51(3): 115-125.

7.1. Introduction

Up to 1 in every 5 time-loss injuries in football (soccer) occur within the hip/groin region.(5,9) The prevalence is high: over 50% of men(1,3) and 45% of women(3) report groin problems during a competition season. Hip/groin pain is often longstanding—one third of soccer players reported symptoms lasting greater than 6 weeks(7)—and associated with impaired sports performance and lower quality of life across different football codes.(6,7,39)

Hip-related pain encompasses different intra-articular hip conditions.(12) The bony hip morphology associated with FAI syndrome is characterised as cam and/or pincer morphology,(44) with the former appearing to develop during skeletal growth.(22–24) Over time, repetitive mechanical abutment between the femoral head and acetabulum may lead to hip pain, labral tears, cartilage defects, and eventually hip OA.(64)

The prevalence of imaging-defined cam and/or pincer morphology is broadly similar in male football players with (62% to 94%)(80,139) and without hip pain (50% to 95%),(77,79,139,224,228) but the size of cam morphology appears related to symptom prevalence.(139) The size and prevalence of bony hip morphology in male and female football players with hip/groin pain and positive clinical special tests (i.e., positive FADIR test) are unclear.

Our primary aim was to compare the size and prevalence of bony hip morphology in football players with and without hip/groin pain. Our secondary aims were to: (I) compare the size and prevalence of bony hip morphology separately in men and women and (II) determine the relationship between the size of bony hip morphology and hip/groin related symptoms and pain as determined by PROMs.

7.2. Methods

7.2.1. Study design and participants

This study utilised a case-control design. All symptomatic participants were recruited as part of the FORCe study,(188) with these data taken from the baseline examination. The FORCe study is an ongoing prospective study investigating changes in hip joint structures in 184 sub-elite football (soccer and AF) players.(188) A convenience sample of 55 pain-free sub-elite football players was recruited for the control group. Football players with (symptomatic group) and without (control

group) self-reported hip/groin pain and a positive FADIR test who were currently playing sub-elite football (soccer or AF) were recruited in Melbourne and Brisbane, Australia, between August 2015 and October 2018. Symptomatic and control football players were recruited from the same league/competition level via social and print media advertising or information sessions conducted at soccer or AF clubs.

The eligibility criteria for symptomatic participants were described previously,(188) and are reported in Table 2.1. Each of the symptomatic participants' hips was classified as 1) symptomatic or 2) other (Table 2.3). The hip was classified as other if 1) there was no pain in the hip/groin, or 2) there was a negative FADIR test. In the control group (for eligibility criteria see Table 2.2), both hips were asymptomatic (Table 2.3). We followed the STROBE guidelines.(294) The study had ethics approval (La Trobe University Human Ethics Committee [HEC 15-019/HEC 16-045] and The University of Queensland Human Ethics Committee [2015000916/2016001694]) and participants provided informed consent.

7.2.2. Radiographs

Each participant underwent a supine AP pelvis and a Dunn 45° radiograph of each hip, taken with standardised protocols in Melbourne, Australia and Brisbane, Australia (Section 3.3) A physical therapist (Mr. Joshua Heerey) with 10-years of clinical experience and training in the methodology, and who was blinded to hip classification, analysed bony hip morphology (quantitative methods).(158) Briefly, a point set was placed on predetermined locations on the surface of the femur and acetabulum using statistical shape modelling software (ASM toolkit, Manchester University, Manchester, UK). The alpha angle and LCEA were then calculated using MATLAB v 7.1.0 (MathWorks Inc, Natick, Massachusetts, USA). Radiographic hip OA was defined as a KL score of 2 or greater,(296) with grading performed by a registrar orthopaedic surgeon (Dr. Rintje Agricola) with 11 years' experience reading pelvic radiographs. Intra-observer reliability was determined by one investigator completing 20 images twice, one week apart for bony hip morphology (Mr. Joshua Heerey) and 6-months apart for KL classification (Dr. Rintje Agricola). For bony hip morphology, inter-observer reliability was determined by a second investigator (Dr. Rintje Agricola) completing 20 images. Moderate to good reliability was found for bony hip morphology (Table 3.1), with substantial agreement demonstrated for KL classification (Section 2.6).

7.2.3. Cam morphology

The alpha angle determined the presence of cam morphology on the AP pelvis and Dunn 45° views (Section 3.4).(51) Continuous alpha angle was our primary outcome and determined the size of cam morphology. Based on previously proposed threshold values,(79,158) an alpha angle >60° defined the presence of cam morphology, with an alpha angle >78° defining a large cam morphology on either the AP pelvis or Dunn 45° views.

7.2.4. Acetabular morphology

The LCEA on the AP pelvis view described the superolateral coverage of the femoral head by the acetabulum (Section 3.4).(162) The LCEA was analysed using continuous and threshold values, with an LCEA of >40° and <20° used to define pincer morphology and acetabular dysplasia, respectively.(79)

7.2.5. Patient-reported outcome measures

Participant characteristics (age, sex, height, weight, football code participation, and training/competition frequency) were collected. The iHOT33(190) and HAGOS(38) are recommended for use in young to middle-aged individuals with hip/groin pain(189,298) and were completed by each participant. The iHOT33 is a 33-item health-related quality of life questionnaire; a total score of 100 indicates the best quality of life.(190) The HAGOS includes 6 subscales (pain, symptoms, function in daily living, function in sport and recreation, participation in physical activities and hip and/or groin-related quality of life); a total score of 100 for each subscale indicates no hip/groin problems.(38) As we were particularly interested in hip/groin pain and symptoms, only HAGOS-P and HAGOS-S subscales were analysed.

7.2.6. Sample size

A sample size of 184 symptomatic and 55 control football players provided 80% power to detect differences in alpha angle between symptomatic and control hips of at least 5.5 degrees, assuming a within-person correlation of 0.7 and a common standard deviation of 14 degrees.

7.2.7. Statistical analysis

Data analyses were performed using SPSS version 25 (SPSS Inc, Chicago, Illinois, USA) and Stata/IC 15.0 (StataCorp LC, College Station, Texas, USA). Differences between symptomatic and control

football players for the iHOT33, HAGOS-P and HAGOS-S subscales were evaluated using Mann-Whitney U tests. Intra- and inter-observer reliability for alpha angle and LCEA was determined with ICC using a 2-way mixed-effects model with absolute agreement. Weighted Cohen's κ was used to establish intra-observer reliability for KL grading. The level of reliability (ICC) and agreement (κ) was determined using previously defined criteria.(217,299)

For all analyses, when data from men and women were combined, they were defined as football players, when separated by sex, they were defined as men or women. For the first and second aim of this study, all analyses were undertaken at a per hip level. Symptomatic hips were considered as cases. There were two control groups; hips classified as other, and hips from asymptomatic participants. Differences in continuous radiographic measures between groups were determined with linear regression models and GEE to account for the nonindependence of bilateral hip measures. Estimates of difference between symptomatic, other and control hips are presented with accompanying *P* values and 95% CIs estimated with bootstrapped standard error (1000 repetitions) to account for departures in normality.(301)

For additional analyses, bony hip morphologies were considered as dichotomous variables (cam, large cam, pincer, or acetabular dysplasia). For cam and large cam, only hips with an AP pelvis and Dunn 45° radiograph were included in analyses. For hips with pincer morphology or acetabular dysplasia, a comparison was made to reference hips with an LCEA of ≥20° and ≤40°.(162) We used logistic regression with GEE to estimate differences between symptom groups, with results presented as OR with 95% CIs and *P* values. Pincer morphology in women and hip dysplasia in both men and women were reported descriptively, but not compared due to the low prevalence of each morphology. The prevalence of bony hip morphology per person is presented descriptively in Appendix 29.

For the second aim, we evaluated differences between symptom groups in men and women separately by including an interaction term (symptom group*sex). All analyses in football players (men and women combined) were adjusted for sex.

For the third aim, only data from symptomatic participants were included in analyses. Alpha angle and LCEA values were taken from the most symptomatic hip, as defined by the iHOT33, with the HAGOS-S and HAGOS-P scores applied to this hip. The relationships between continuous radiographic measures and the iHOT33, HAGOS-S, and HAGOS-P were evaluated using Pearson's

correlation coefficient. For all analyses, correlation coefficients are presented with accompanying 95% CI and *P* values. Scatterplots with a locally weighted smoother were fitted to the data to confirm the absence of nonlinear associations or influential outliers.

7.3. Results

7.3.1. Participant characteristics

Of the 603 sub-elite football players with hip/groin pain, 184 football players fulfilled the eligibility criteria for the present study (**Figure 2.1**). Two hips from two football players with hip/groin pain were excluded due to the presence of hip OA (KL ≥2) leaving 366 hips for analysis. In seven symptomatic men (14 hips), a standing, not supine, AP pelvis radiograph was taken, which were included in the overall analyses, with a sensitivity analysis performed by removing the radiographs (**Appendices 30** and **31**). Twelve participants (24 hips) had non-standardised Dunn radiographs, and the data were excluded. The number of hips classified as symptomatic, other or control is presented in **Table 2.3**. Fifty-five football players (110 hips) without hip/groin pain were recruited as the control group (**Figure 2.2**). Demographic characteristics of symptomatic and control football players are presented in **Table 7.1**. The iHOT33, HAGOS-S, and HAGOS-P subscale scores for symptomatic and control participants are presented in **Table 7.2**.

Table 7.1. Demographic characteristics for symptomatic and control football players.*

Demographics	Symptomatic group (n=184)	Control group (n=55)
Age, yearsr	26.0 (23-30)	26.0 (23-31)
Sex, % women	21%	26%
Height, metres	1.79 (1.73-1.84)	1.79 (1.72-1.85)
Weight, kg	78.5 ± 12.8	77.9 ± 13.5
BMI, kg/m^2	24.1 (23-26)	24.3 (22-27)
Football code, % soccer/AF	50.5/49.5	54.5/45.5
Training/competition, %		
2 to 3 sessions	89	82
≥4 sessions	11	18
Duration of symptoms, months‡	24 (18-50)	-

Abbreviations: BMI, body mass index, and AF, Australian football.
* Values are presented as %, median (interquartile range) or mean ± standard deviation.
† Combined training and competition sessions per week.
‡183 symptomatic participants.

Table 7.2. Patient-reported outcome measures for symptomatic and control football players.*

PROMs	Symptomatic group (n=184)	Control group (n=55)	*P* value
iHOT33	64 (50-74)	98 (97-100)	<0.001
HAGOS–S[†]	61 (50-68)	100 (93-100)	<0.001
HAGOS–P[†]	75 (65-83)	100 (100-100)	<0.001

Abbreviations: PROMs, patient-reported outcome measures; HAGOS, Copenhagen hip and groin outcome score; iHOT, international hip outcome tool; P, pain subscale and S, symptoms subscale.
* Values are presented as median (interquartile range) .
[†]178 symptomatic participants/54 control participants.

7.3.2. Comparison of bony hip morphology in football players

There was no difference in alpha angle between symptom groups in either the AP or Dunn view (**Table 7.3**). For LCEA, values did not differ between symptom groups. The prevalence of cam morphology, large cam morphology, pincer morphology, and acetabular dysplasia was not different between symptom groups (**Table 7.4**).

7.3.3. Comparison of bony hip morphology in men and women

In men, the alpha angle on the AP and Dunn views did not differ across the three symptom groups (**Table 7.3**). In women, symptomatic hips had a slightly larger alpha angle (5.9°, 95%CI: 1.2°, 10.6°) compared to control hips on the Dunn, but not the AP view (**Table 7.3**). Regarding LCEA, symptom groups did not differ in either men or women (**Table 7.3**). The prevalence of cam and large cam morphology was not different between the three symptom groups in either men or women (**Table 7.4**). In men, the prevalence of pincer morphology was not different across symptom groups (**Table 7.4**). Due to the low prevalence, statistical analysis was not undertaken in men for acetabular dysplasia or in women for pincer morphology and acetabular dysplasia.

7.3.4. Relationship between bony morphology, International Hip Outcome Tool 33 and Copenhagen Hip and Groin Outcome Score

In all football players, men and women, there were no associations between alpha angle (AP or Dunn view) and iHOT33 or HAGOS (symptoms and pain) (**Table 7.5** and **Figures 7.1** to **7.3**). In all football players and men, LCEA was not associated with iHOT33 or HAGOS. In women, LCEA was

Table 7.3. Differences in size of bony hip morphology between symptomatic, other and control hips in football players, men and women.

	Alpha angle (degrees)		LCEA (degrees)
	AP View	Dunn 45° View‡§II	
Football players (No. of hips)			
Estimated marginal means (95%CI)†			
Control (110)	59.2° (55.9°, 62.4°)	66.5° (64.3°, 68.6°)	31.5° (30.4°, 32.6°)
Symptomatic (290)	59.9° (58.1°, 61.7°)	68.8° (67.2°, 70.5°)	30.8° (30.1°, 31.5°)
Other (76)	59.3° (56.8°, 61.8°)	68.2° (65.6°, 70.7°)	30.4° (29.1°, 31.8°)
Between group differences (95%CI), *P* value			
Symptomatic vs control*	0.7° (-3.0°, 4.4°), *P* = .701	2.4° (-0.3°, 5.1°), *P* = .085	-0.7° (-2.1°, 0.6°), *P* = .297
Others vs control*	0.1° (-3.9°, 4.1°), *P* = .963	1.7° (-1.7°, 5.1°), *P* = .326	-1.1° (-2.9°, 0.7°), *P* = .217
Symptomatic vs other*	0.6° (-1.8°, 3.0°), *P* = .607	0.7° (-2.2°, 3.5°), *P* = .648	0.4° (-1.0°, 1.8°), *P* = .571
Men (No. of hips)			
Estimated marginal means (95%CI)			
Control (82)	61.3° (57.4°, 65.2°)	70.3° (67.7°, 73.0°)	32.4° (31.2°, 33.7°)
Symptomatic (230)	62.4° (60.4°, 64.5°)	71.6° (69.7°, 73.4°)	31.2° (30.4°, 31.9°)
Other (60)	62.2° (59.3°, 65.1°)	71.3° (68.3°, 74.3°)	31.0° (29.5°, 32.5°)
Between group differences (95%CI), *P* value			
Symptomatic vs control*	1.1° (-3.3°, 5.5°), *P* = .627	1.2° (-2.0°, 4.5°), *P* = .456	-1.2° (-2.8°, 0.3°), *P* = .109
Others vs control*	0.9° (-3.9°, 5.7°), *P* = .714	1.0° (-3.0°, 5.0°), *P* = .621	-1.4° (-3.4°, 0.6°), *P* = .158
Symptomatic vs other*	0.2° (-2.5°, 2.8°), *P* = .891	0.2° (-3.1°, 3.5°), *P* = .897	0.2° (-1.4°, 1.7°), *P* = .827
Women (No. of hips)			
Estimated marginal means (95%CI)			
Control (28)	51.2° (45.3°, 57.1°)	53.4° (49.8°, 56.9°)	28.7° (26.7°, 30.6°)
Symptomatic (60)	50.9° (47.1°, 54.6°)	59.3° (56.0°, 62.6°)	29.6° (28.1°, 31.2°)
Other (16)	48.6° (43.8°, 53.4°)	57.1° (52.1°, 62.0°)	28.4° (25.5°, 31.2°)
Between group differences (95%CI), *P* value			
Symptomatic vs control*	-0.3° (-7.4°, 6.8°), *P* = .927	5.9° (1.2°, 10.6°), *P* = .014	1.0° (-1.6°, 3.6°), *P* = .450
Others vs control*	-2.6° (-10.0°, 4.8°), *P* = .488	3.7° (-2.6°, 9.9°), *P* = .248	-0.3° (-3.9°, 3.3°), *P* = .880
Symptomatic vs other*	2.3° (-3.2°, 7.8°), *P* = .418	2.2° (-3.5°, 8.0°), *P* = .446	1.3° (-1.8°, 4.3°), *P* = .415

Abbreviations: AP, anteroposterior and LCEA, lateral-centre-edge-angle.
*Referent group.
†Estimated marginal means presented for football players were adjusted for sex.
‡ Dunn 45° in football players (control = 108 hips; symptomatic = 276 hips; other = 68 hips).
§ Dunn 45° in men (control = 80 hips; symptomatic = 219 hips; other = 53 hips).
II Dunn 45° in women (control = 28 hips; symptomatic = 57 hips; other = 15 hips).

Table 7.4. Differences in prevalence of bony hip morphology between symptomatic, other and control hips in football players, men and women.

	Cam morphology		Pincer morphology‡ǁ**	Acetabular dysplasia§#††
	Alpha angle >60°	Alpha angle >78°	LCEA >40°	LCEA <20°
Football players (No. of hips)				
Prevalence (%)				
Control (108)	68 (63)	39 (36)	8 (8)	3 (3)
Symptomatic (276)	195 (71)	106 (38)	20 (7)	11 (4)
Other (68)	45 (66)	30 (44)	12 (17)	5 (8)
Odds ratio (95%CI), *P* value†				
Symptomatic vs control*	1.34 (0.72, 2.47), *P* = .355	1.06 (0.59, 1.91), *P* = .852	1.05 (0.39, 2.79), *P* = .925	1.36 (0.30, 6.20), *P* = .691
Others vs control*	1.12 (0.55, 2.29), *P* = .762	1.23 (0.63, 2.43), *P* = .544	1.87 (0.64, 5.44), *P* = .254	3.38 (0.70, 16.35), *P* = .130
Symptomatic vs other*	1.20 (0.73, 1.95), *P* = .471	0.86 (0.56, 1.32), *P* = .486	0.56 (0.27, 1.16), *P* = .118	0.40 (0.15, 1.06), *P* = .064
Men (No. of hips)				
Prevalence (%)				
Control (80)	61 (76)	34 (43)	7 (9)	0 (0)
Symptomatic (219)	171 (78)	97 (44)	17 (8)	10 (4)
Other (53)	40 (75)	29 (55)	11 (19)	3 (6)
Odds ratio (95%CI), *P* value				
Symptomatic vs control*	1.13 (0.54, 2.36), *P* = .746	1.10 (0.58, 2.08), *P* = .770	1.02 (0.35, 2.92), *P* = .977	NA
Others vs control*	0.94 (0.40, 2.19), *P* = .884	1.50 (0.72, 3.12), *P* = .277	1.86 (0.59, 5.86), *P* = .290	NA
Symptomatic vs other*	1.20 (0.68, 2.11), *P* = .520	0.73 (0.46, 1.16), *P* = .188	0.55 (0.25, 1.17), *P* = .120	NA
Women (No. of hips)				
Prevalence (%)				
Control (28)	7 (25)	5 (18)	1 (4)	3 (11)
Symptomatic (57)	24 (42)	9 (16)	3 (5)	1 (2)
Other (15)	5 (33)	1 (7)	1 (7)	2 (13)
Odds ratio (95%CI), *P* value				
Symptomatic vs control*	2.09 (0.62, 7.08), *P* = .237	0.90 (0.21, 3.89), *P* = .886	NA	NA
Others vs control*	1.79 (0.43, 7.39), *P* = .423	0.26 (0.03, 2.70), *P* = .260	NA	NA
Symptomatic vs other*	1.17 (0.46, 2.97), *P* = .743	3.43 (0.55, 21.53), *P* = .188	NA	NA

Abbreviations: LCEA, lateral-centre-edge-angle and NA, not estimated.
* Referent group.
† Odds ratios presented for football players were adjusted for sex.
‡ Pincer morphology in football players (control = 107 hips; symptomatic = 279 hips; other = 71 hips).
§ Acetabular dysplasia in football players (control = 102 hips; symptomatic = 270 hips; other = 64 hips).
II Pincer morphology in male football players (control = 82 hips; symptomatic = 220 hips; other = 57 hips).
Acetabular dysplasia in male football players (control = 75 hips; symptomatic = 213 hips; other = 49 hips).
** Pincer morphology in female football players (control = 25 hips; symptomatic = 59 hips; other = 14 hips).
†† Acetabular dysplasia in female football players (control = 27 hips; symptomatic = 57 hips; other = 15 hips).

Table 7.5. Pearson's correlation coefficients between bony hip morphology and patient-reported outcome measures in football players, men and women with hip/groin pain.*

	Patient-reported outcome measures		
Bony hip morphology	iHOT33	HAGOS-S	HAGOS-P
Football players (n=184)			
Alpha angle (AP)†	0.03 (-0.12, 0.17), *P* = .726	-0.04 (-0.19, 0.11), *P* = .572	0.00 (-0.15, 0.15), *P* = .999
Alpha angle (Dunn 45°)‡	-0.09 (-0.24, 0.06), *P* = .251	-0.10 (-0.25, 0.05), *P* = .198	0.03 (-0.12, 0.18), *P* = .708
LCEA†	-0.10 (-0.25, 0.04), *P* = .163	-0.04 (-0.19, 0.11), *P* = .615	-0.11 (-0.26, 0.03) *P* = .129
Men (n= 146)			
Alpha angle (AP)§	0.00 (-0.16, 0.17), *P* = .958	-0.05 (-0.22, 0.12), *P* = .556	0.03 (-0.14, 0.20), *P* = .712
Alpha angle (Dunn 45°)II	-0.14 (-0.31, 0.02), *P* = .093	-0.15 (-0.32, 0.02), *P* = .087	-0.05 (-0.22, 0.13), *P* = .609
LCEA§	-0.06 (-0.23, 0.10), *P* = .461	0.00 (-0.17, 0.17), *P* = .999	-0.07 (-0.23, 0.10), *P* = .426
Women (n=38)			
Alpha angle (AP)#	0.05 (-0.29, 0.38), *P* = .790	-0.17 (-0.52, 0.18), *P* = .339	-0.31 (-0.65,0.02), *P* =.068
Alpha angle (Dunn 45°)**	0.05 (-0.30, 0.40), *P* = .788	-0.16 (-0.53, 0.20), *P* = .364	0.02 (-0.34, 0.39), *P* = .903
LCEA#	-0.31 (-0.63, 0.01), *P* = .059	-0.22 (-0.57, 0.13), *P* = .206	-0.37 (-0.70, -0.05), *P* = .027

Abbreviations: iHOT33, International Hip Outcome Tool; HAGOS, Copenhagen Hip and Groin Outcome Score; S, symptoms subscale; P, pain subscale; AP, anteroposterior and LCEA, lateral centre-edge angle.

* The hip selected on the iHOT33 was used for all analyses.

† iHOT33, n=184; HAGOS-S, n=178; HAGOS-P, n=178.

‡ iHOT33, n=173; HAGOS-S, n=167; HAGOS-P, n=167.

§ iHOT33, n=146; HAGOS-S, n=143; HAGOS-P, n=143.

II iHOT33, n=137; HAGOS-S, n=134; HAGOS-P, n=134.

iHOT33, n=38; HAGOS-S, n=35; HAGOS-P, n=35.

** iHOT33, n=36; HAGOS-S, n=33; HAGOS-P, n=33.

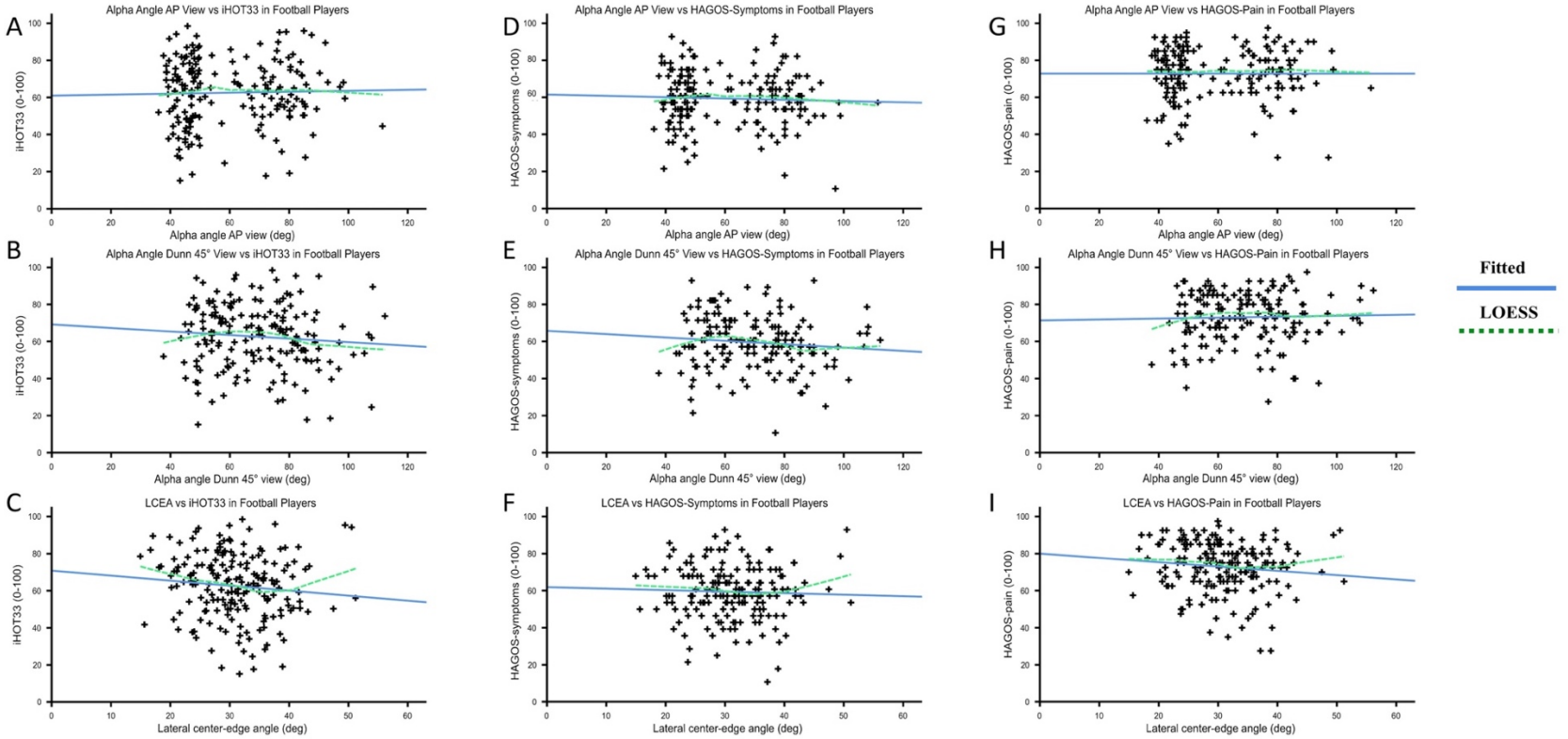


Figure 7.1. Scatter plots of bony hip morphology vs patient-reported outcome measures in football players with hip/groin pain.*

Abbreviations: iHOT33; international hip outcome tool; HAGOS; hip and groin outcome score; LCEA, lateral centre-edge angle and LOESS, locally estimated scatter plot smoothing

*A) Alpha angle AP view vs iHOT33; B) Alpha angle Dunn 45° view vs iHOT33; C) Lateral centre-edge angle (LCEA) vs iHOT33; D) Alpha angle AP view vs HAGOS-Symptoms; E) Alpha angle Dunn 45° view vs HAGOS-Symptoms; F) LCEA vs HAGOS-Symptoms; G) Alpha angle AP view vs HAGOS-Pain; H) Alpha angle Dunn 45° view vs HAGOS-Pain and I) LCEA vs HAGOS-Pain.

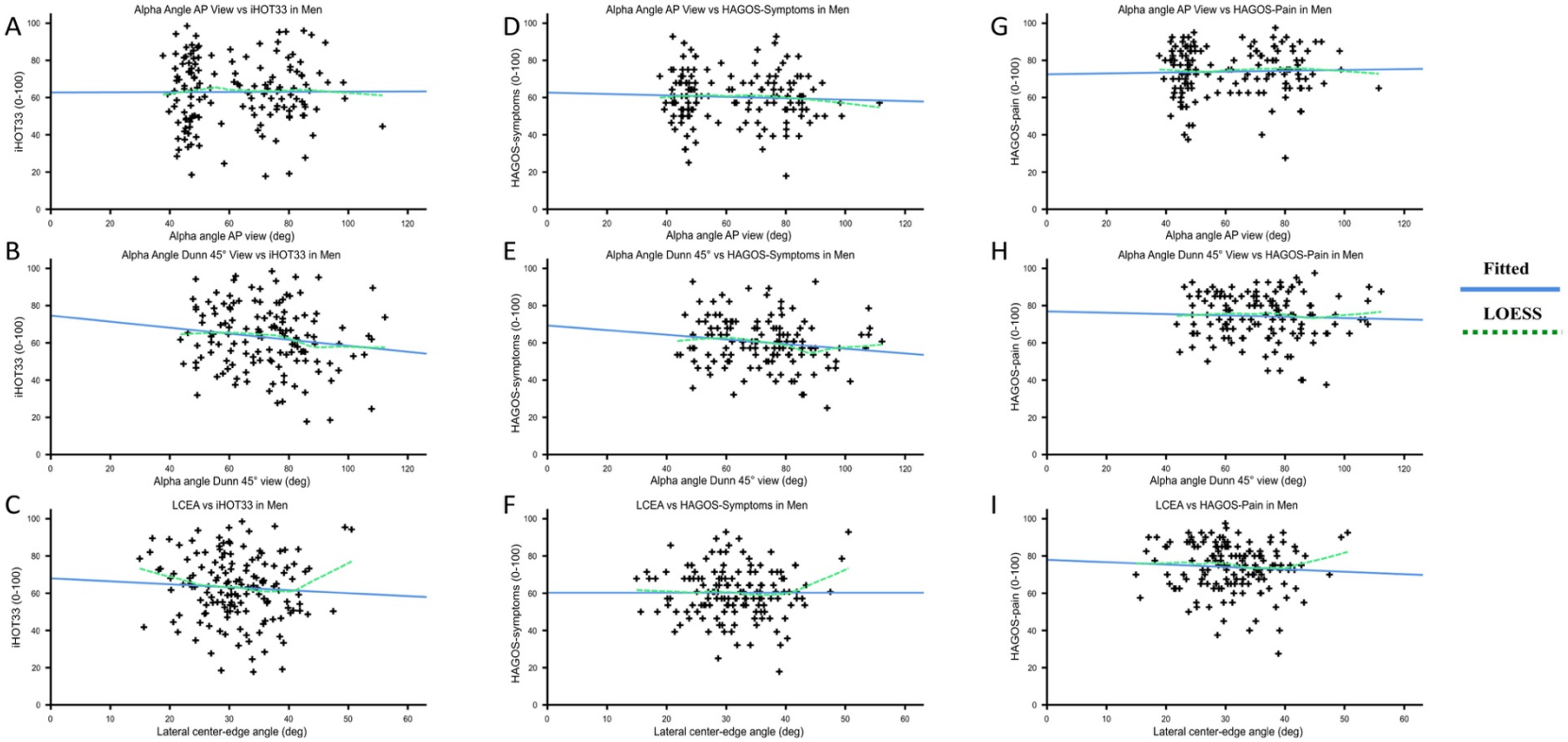


Figure 7.2. Scatter plots of bony hip morphology vs patient-reported outcome measures in men with hip/groin pain.*

Abbreviations: iHOT33; international hip outcome tool; HAGOS; hip and groin outcome score; LCEA, lateral centre-edge angle and LOESS, locally estimated scatter plot smoothing.

*A) Alpha angle AP view vs iHOT33; B) Alpha angle Dunn 45° view vs iHOT33; C) Lateral centre-edge angle (LCEA) vs iHOT33; D) Alpha angle AP view vs HAGOS-Symptoms; E) Alpha angle Dunn 45° view vs HAGOS-Symptoms; F) LCEA vs HAGOS-Symptoms; G) Alpha angle AP view vs HAGOS-Pain; H) Alpha angle Dunn 45° view vs HAGOS-Pain and I) LCEA vs HAGOS-Pain.

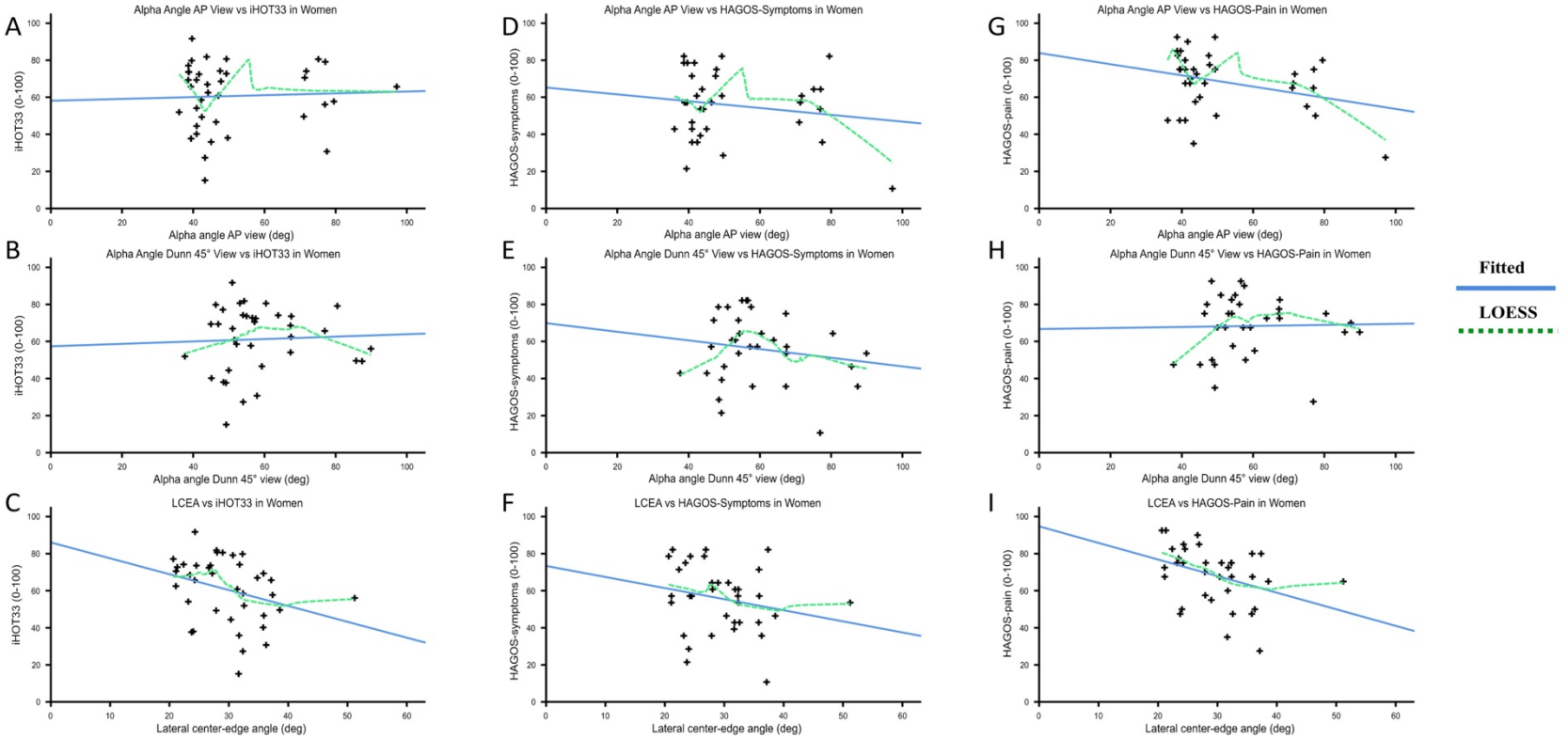


Figure 7.3. Scatter plots bony hip morphology vs patient-reported outcome measures in women with hip/groin pain.*

Abbreviations: iHOT33; international hip outcome tool; HAGOS; hip and groin outcome score; LCEA, lateral centre-edge angle and LOESS, locally estimated scatter plot smoothing.

*A) Alpha angle AP view vs iHOT33; B) Alpha angle Dunn 45° view vs iHOT33; C) Lateral centre-edge angle (LCEA) vs iHOT33; D) Alpha angle AP view vs HAGOS-Symptoms; E) Alpha angle Dunn 45° view vs HAGOS-Symptoms; F) LCEA vs HAGOS-Symptoms; G) Alpha angle AP view vs HAGOS-Pain; H) Alpha angle Dunn 45° view vs HAGOS-Pain and I) LCEA vs HAGOS-Pain.

not associated with iHOT33 or HAGOS-S, but there was an association between LCEA and HAGOS-P (r = -0.374, 95%CI: -0.70, -0.05, P = .027) (Table 7.5 and Figures 7.1 to 7.3).

7.4. Discussion

We compared the size and prevalence of bony hip morphology in football players with and without hip/groin pain and a positive FADIR test. In football players, the size and prevalence of bony hip morphology did not differ between symptomatic and pain-free hips. In men and women, LCEA and prevalence of cam, large cam, and pincer morphology were not different between symptom groups. Women with hip/groin pain, but not men had a larger alpha angle (5.9°, 95%CI: 1.2°, 10.6°) when compared to controls. Acetabular morphologies were not common in football players. There was no relationship between alpha angle or LCEA and the iHOT33 or HAGOS in all football players or men, with only LCEA associated with HAGOS-P in women.

7.4.1. Cam morphology is a common finding in football players with and without hip/groin pain and positive FADIR test

Our lack of substantive differences in football players may reflect similar activity levels between groups and highlights the importance of considering physical activity when evaluating the link between cam morphology and symptoms. Women had a slightly larger alpha angle (5.9°, 95%CI: 1.2°, 10.6°) in symptomatic hips than in control hips, but the clinical significance of this difference is uncertain. Seventy-six percent of male and 25% of female hips without pain had cam morphology, which is consistent with some,(77,79,139) but not all studies(224,228,309–312) of men and women participating in football codes. The prevalence of large cam morphology did not differ between symptom groups in either football players, men or women. In men, 43% to 57% of hips had a large cam morphology, which is higher than reports in elite male football players (0% to 36%).(79,313) Discrepancies may be explained by different alpha angle threshold values and/or imaging techniques. Consistent with earlier studies,(63,76,310,314,315) men had a higher prevalence of cam and large cam morphology than women. Cam morphology was common in football players; however, the size and prevalence of this bony feature did not differ between those with and without longstanding hip/groin pain.

7.4.2. Pincer morphology and acetabular dysplasia are rarely seen in football players

Football players with hip/groin pain had a similar and low prevalence of pincer morphology (7% vs 8%) and acetabular dysplasia (4% vs 3%) as controls. Differences in pincer morphology prevalence with prior reports (0% to 33%),(77,79,309,311,314) may be explained by the different definitions of pincer morphology. We observed a low prevalence of acetabular dysplasia in football players (3% to 8%), men (0% to 6%), and women (2% to 13%), as previously reported.(77,79,80,311)

7.4.3. The size of bony hip morphology is mostly unrelated to pain and symptom severity

In men and women, higher alpha angles were not associated with symptom or pain severity (i.e., lower PROM scores), which contrasts earlier findings in athletic(140,272) and non-athletic populations.(316) In our large cohort, we evaluated the most symptomatic hip in active football players with longstanding hip/groin pain (>6 months) and did not find a relationship between the size of cam morphology and hip/groin specific PROMs. In women, increasing LCEA values (indicating greater acetabular coverage) were associated with lower HAGOS-P values (indicating higher levels of pain). However, this result needs to be confirmed with larger studies. Future studies might also explore whether bony hip morphology displays a relationship with other PROMs, especially those measuring different dimensions of pain and symptoms.

7.4.4. Clinical implications

Two out of every three pain-free hips had cam morphology, and it is unlikely that bony hip morphology is the sole factor related to the development and/or severity of hip/groin symptoms in football players. Careful examination of all potential sources of nociception,(11,41,204) and more centrally mediated contributors to symptoms is required in patients with hip/groin pain. For example, adductor-related groin pain may be present in up to 69% of football players with long-standing symptoms.(202,317)

7.4.5. Limitations and future research directions

We included football players with self-reported hip/groin pain and a positive FADIR test. Therefore, the pathoanatomical source of symptoms, if one exists, cannot be truly known. Contributors to long-standing hip/groin pain, including adductor-, iliopsoas-, pubic- and inguinal-related groin pain may have been associated with the hip/groin symptoms.(11) The poor specificity of the FADIR test means that our findings cannot be assumed to be specific to hip-related pain.(308,318)
Radiographs (AP pelvis and Dunn 45°) cannot provide three-dimensional visualisation of femoral anatomy, potentially underreporting the size and prevalence of cam morphology. However, alpha angle values obtained from radiographs, as used in our study, have an acceptable correlation with those seen on MRI(319) and CT(320).

We may have underestimated pincer morphology prevalence, as we did not assess focal acetabular retroversion (determined by the cross-over sign). However, radiographic assessment of focal over coverage has poor reproducibility(321) and may overestimate the prevalence of such findings.(322)

There is a risk of selection bias, as both symptomatic and control football players responded to study advertisements or participated in information sessions and may not represent all football players. The presence of cam morphology was not established in control football players before inclusion, which may reduce the likelihood of oversampling. We did not establish the age when football players started regular training or competitive football and differences between groups may have influenced our findings.(313) Symptomatic and control football players participated in at least two training sessions per week, but training intensity or duration may have differed between groups.

While the structural, construct and content validity of the IHOT33 and HAGOS, and their utility in non-surgical populations is unclear,(189) they are recommended for use in young to middle-aged people with hip/groin pain.(189,298) The small number of female football players may have prevented us from detecting differences between symptom groups for size and prevalence of bony morphology.

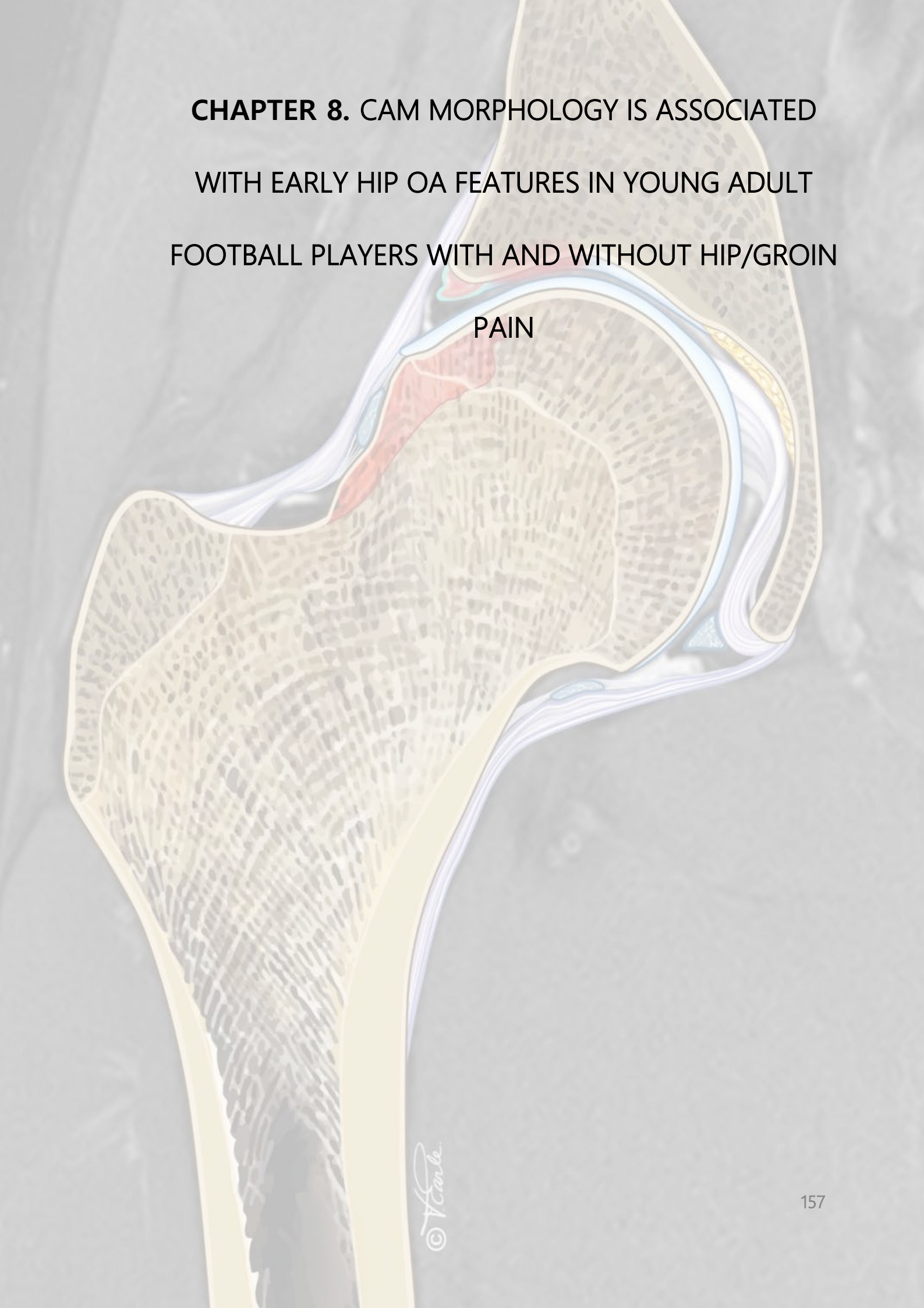
Future studies evaluating the relationship between pain and cam morphology should consider participants' current and/or past activity levels to ensure these factors do not influence findings.

Long-term prospective studies could confirm or refute our findings and/or establish if cam morphology is associated with the development or worsening of symptoms, or structural joint deterioration (including hip OA) in football players. Although such studies require considerable resources and time to complete, they are essential to answer prognostic questions.

7.5. Conclusion

In football players, the size and prevalence of bony hip morphology did not differ between hips with and without hip/groin pain. Cam morphology was present in 76% of men and 25% of women and mostly unrelated to the presence or severity of hip/groin symptoms.

CHAPTER 8. CAM MORPHOLOGY IS ASSOCIATED WITH EARLY HIP OA FEATURES IN YOUNG ADULT FOOTBALL PLAYERS WITH AND WITHOUT HIP/GROIN PAIN



PREFACE

Chapter 7 highlighted the high prevalence of bony hip morphology in football players with and without pain. In particular, a high prevalence of cam morphology was found in football players with (71%) and without (63%) hip/groin pain. Chapter 1 highlighted that participation in football is associated with up to a 2-fold greater odds of developing hip OA in later life when compared to matched controls. Despite the link between football and hip OA, the underlying mechanism for this relationship has remained unclear. As identified in chapter 7 cam morphology is present in a high number of football players and is an established risk factor of hip OA in middle-aged and older community dwelling individuals. However, the role that cam morphology plays in the pathogenesis of early hip OA in football players has yet to be comprehensively studied. It is also unknown if the relationship between cam morphology and early hip OA is stronger in football players with hip/groin pain when compared to those without. The primary aims of the study in chapter 8 were to examine the relationship between cam morphology and presence, location and severity of early hip OA features (specifically cartilage defects and labral tears) in football players with and without hip/groin pain and to investigate if the association between cam morphology and early hip OA features is stronger in football players with hip/groin pain.

8.1. Introduction

Playing football may increase a person's risk of developing hip OA in later life,(172) possibly related to the presence of cam morphology, which is characterised by extra bone at the anterolateral head-neck junction,(45) and is present in almost two-thirds of football players.(79,297) Despite an uncertain relationship between cam morphology and pain,(64,297) it does increase the odds of developing hip OA in people aged at least 44 years old.(64,158–160) The relationship between cam morphology, symptoms and early hip OA features (i.e., cartilage and labral damage) in young adult football players is unknown.

Cam morphology is critical to the diagnosis of FAI syndrome,(44) and athletes undergoing surgery for FAI syndrome have cartilage and labral pathology.(85,268) For football players with hip/groin pain who continue to play (i.e., not seeking surgery), it is unclear if cam morphology is related to early hip OA features.

The aims of this study were to 1) examine the relationship between cam morphology and presence and severity of early hip OA features (cartilage defects and labral tears) in young adult football players with and without hip/groin pain; 2) examine the relationship between cam morphology and the presence of cartilage defects and labral tears in specific anatomical subregions in football players with and without hip/groin pain and 3) investigate if the association between cam morphology and early hip OA features is stronger in young adult football players with hip/groin pain.

8.2. Methods

8.2.1. Study design and recruitment

This case-control study is part of the FORCe study. The FORCe study is a prospective study investigating changes to hip joint structures over 2 years in 184 sub-elite football players (soccer or AF) with long-standing hip/groin pain (>6 months) aged between 18 to 50 years, described previously.(188,297) A convenience sample of 55 pain-free sub-elite football players aged between 18 to 50 years was recruited to match the mean age and sex distribution of the FORCe cohort and serve as control participants.(297) Symptomatic and control participants competing in the same league/competition level were recruited between August 2015 and October 2018 from

sporting clubs or via online and print advertising, with recruitment undertaken in Melbourne and Brisbane, Australia. The data for this study are taken from baseline examinations. All study participants provided written informed consent prior to being involved in this study.

8.2.2. Study participants

I. Hip/groin pain group

Eligibility criteria are presented in **Table 2.1**. Briefly, inclusion criteria were self-reported hip/groin pain (>6 months in duration) that was >3 and <8 on an 11-point numerical pain rating scale with football or football specific movements; participation in ≥2 football sessions (training or competition) per week and a positive FADIR test, that elicited either hip (anterior, lateral or posterior) or groin pain in at least one hip. Exclusion criteria were a history of previous pathological hip conditions and radiographic hip OA (i.e., KL ≥2).

II. Control group

For control participants, inclusion criteria were no prior history of hip/groin pain; participation in ≥2 football sessions per week and a negative FADIR test in both hips (**Table 2.2**). Exclusion criteria were similar to the hip/groin pain group, but also included previous lower limb surgery (e.g., knee reconstruction).

8.2.3. Radiographs

Standardised supine AP pelvis and bilateral Dunn 45° radiographs were obtained for each participant. For the AP radiograph, the participant was placed supine, with both legs internally rotated 15°. For the Dunn 45° radiograph, the hip was flexed to 45°, abducted 20° and positioned in neutral rotation.

8.2.4. Cam morphology

For each radiograph, one investigator (Mr. Joshua Heerey) positioned a set of landmark points to the surface of the proximal femur and acetabulum using statistical shape modelling software (ASM toolkit, Manchester University, Manchester, UK), followed by automatic calculation of the alpha angle (MATLAB v 7.1.0. MathWorks Inc, Natick, Massachusetts, USA). Due to the disadvantages of dichotomising a continuous measure,(323) we used continuous alpha angle as a primary measure, but also present the results using recommended alpha angle threshold values:

cam morphology, >60° to ≤78; large cam morphology and >78° on either the AP or Dunn 45° view.(158,159) For intra-observer reliability, the ICC for alpha angles were 0.92 and 0.93 for AP and Dunn 45°, respectively (Table 3.1). Inter-observer reliability ICC was 0.76 for AP and 0.93 for Dunn 45° (Table 3.1).

8.2.5. Magnetic resonance imaging acquisition and scoring

All participants underwent a non-contrast 3-T MRI (Phillips Ingenia, The Netherlands). Participants were positioned supine, hips fixed in internal rotation and neutral abduction/adduction with patient positioning aids, and a 32-channel torso coil placed over the hips and pelvis, with right and left hips imaged separately. The MRI sequences acquired were coronal PD SPAIR, sagittal PD SPAIR and oblique axial PD SPAIR (Table 3.2).

Each MRI was evaluated using the SHOMRI scoring system by one musculoskeletal radiologist (Dr. Ramya Srinivasan) with 8 years' experience who was blinded to clinical and radiographic findings. Morphological changes to cartilage and the labrum are important features of early hip OA,(91) and were selected as outcome measures. Cartilage defects were graded from 0 to 2 (0=no defect, 1=partial defect or 2=full thickness defect) and scored in 10 (4 acetabular and 6 femoral) subregions , providing a total cartilage score per hip of 0 to 20 (Section 3.7). A cartilage defect was present if a partial or full thickness defect was reported. For the superolateral, superomedial, anterior and posterior subregions, acetabular and femoral cartilage defects were combined. Labral abnormalities were graded from 0 to 5 (0=normal or normal variant [e.g., aplasia, hypoplasia], 1=abnormal signal or fraying, 2=simple tear, 3=labrocartilage separation, 4=complex tear or 5=maceration) and scored in 4 subregions (anterior, posterior, anterosuperior and superior), with a total labral score per hip of 0 to 20. A labral tear was scored as present when graded ≥ 2. The SHOMRI subregions (Section 3.7) were used to describe the location of cartilage defects and labral tears for each hip. Intra-observer agreement for cartilage defect (0 to 2) and labral tear grading (0 to 5) had κ values of 0.62 and 0.77, respectively (Table 3.4). For scoring of features as either present or absent, PABAK values were 0.76 for cartilage defects and 0.80 for labral tears (Table 3.4).

8.2.6. Patient-reported outcome measures

For each participant, demographic characteristics were recorded and the iHOT33(190) and HAGOS(38) were completed. The iHOT33 and HAGOS are recommended for young adults with hip and/or groin conditions.(189,298)

8.2.7. Statistical analysis

Data analyses were performed with Stata/IC 16.1 for Mac (StataCorp LC, College Station, Texas, USA). All analyses were undertaken at a per hip level, with cam morphology (evaluated both as a continuous (alpha angle) and dichotomous (cam morphology and large cam morphology) variable) considered as the independent variable and early hip OA features the dependent variable. For the first study aim, logistic regression (presence of OA features) and negative binomial regression (severity of OA features) models with GEE (to allow for within-person correlation between right and left hip data) were used to determine whether cam morphology was associated with cartilage defects and labral tears. Models were checked for linearity of continuous alpha angle associations by graphical assessment and testing models with nonlinear terms for superior fit. Odds ratios and IRR with associated 95% CIs and *P* values are presented. For the second study aim, logistic regression models with GEE were used to estimate the relationship between cam morphology and the presence of cartilage defects and labral tears in specific anatomical subregions (cartilage defects = superolateral, superomedial, and lateral; labral tears = superior and anterosuperior), with results presented as OR with 95% CIs and *P* values. The remaining subregions for cartilage defects (inferior, anterior, and posterior) and labral tears (anterior and posterior) were not compared statistically as there was a low prevalence in all hips. For threshold values only, we also present the location of cartilage defects and labral tears in specific subregions separately in symptomatic and control hips. The probability (presence and location of cartilage defects and labral tears) and severity (cartilage and labral score) of OA features were estimated for levels of cam morphology (continuous = 5° increments in alpha angle from 40° to 110° (the range was determined from the lowest and highest alpha angle values from football players in the study); dichotomous = cam morphology and large cam morphology) from adjusted regression models. For study aim three, an interaction term (cam morphology*symptoms) was incorporated into all regression models to test if the association between cam morphology and early hip OA features was stronger in those football players with symptoms. For all analyses, symptomatic and control hips were combined, and models adjusted for sex, age, BMI, KL grade, and symptoms (presence of hip/groin pain).

8.3. Results

8.3.1. Participants

Of the 184 eligible football players, 182 (288 hips, 20% female, median age 26 (IQR 7), 50% soccer) were included (Table 8.1 and Figure 2.1). The two excluded participants had incomplete MRI data. Twelve participants (22 hips with hip/groin pain and 2 control hips) had AP, but not Dunn 45° radiographs due to protocol deviations. A further two hips (two participants) with hip/groin pain were excluded due to the presence of hip OA. A standing and not a supine AP pelvis radiograph were taken in seven participants (14 hips) with hip/groin pain, with these radiographs included in the overall analysis. Fifty-five football players (110 hips, 25% female, median age 26 (IQR 8), 55% soccer) formed the control group (Table 8.1 and Figure 2.2).

8.3.2. Association between cam morphology and presence of early hip OA features

I. Alpha angle (continuous)

Greater AP and Dunn 45° alpha angles were associated with cartilage defects (Table 8.2). Greater AP and Dunn 45° alpha angles were associated with labral tears (Table 8.3). Figure 8.1 and Appendix 32 specifies the probability of a cartilage defect or labral tear for values of alpha angle (AP and Dunn 45°) in 5° increments. For example, in a football player with an alpha angle of 60°, the probability of having a cartilage defect was 50% (95%CI: 44, 56).

II. Cam morphology (threshold values)

Hips with large cam (aOR = 2.58, 95%CI: 1.5, 4.6) and cam morphology (aOR 2.12, 95%CI: 1.2, 3.7) had a higher prevalence of cartilage defects than hips without cam morphology (Appendix 33 and 34). Hips with large cam (aOR 2.53, 95%CI: 1.3, 4.7), but not cam morphology had a higher prevalence of labral tears than hips without cam morphology (Appendix 33 and 34).

Table 8.1. Demographic characteristics, radiographic, and patient-reported outcome measures for hip/groin pain and control participants.

	Hip/groin pain group (n=182)	Control group (n=55)
Demographic characteristics		
Age, years	26.0 (23, 30)	26.0 (23, 31)
Sex, % women	20%	25%
Height, metres	1.79 (1.73, 1.85)	1.79 (1.72, 1.85)
Weight, kg	77.9 (72, 86)	78.7 (67, 89)
BMI, kg/m^2	24.2 (23, 26)	24.3 (22, 27)
Football code, % soccer	50%	55%
Training/competition session (per week), %		
2 to 3 sessions	89	82
≥4 sessions	11	18
Duration of symptoms, months*	24 (18, 49)	-
Imaging measures		
KL grade, hips (%).		
Grade 0	347 (96%)	105 (95%)
Grade 1	15 (4%)	5 (5%)
Alpha angle (AP), degrees	52 (45, 76)	48 (43, 78)
Alpha angle (Dunn 45), degrees†	69 (56, 79)	65 (55, 75)
Patient-reported outcome measures		
iHOT33	64 (50, 74)	98 (97, 100)
HAGOS–Symptoms‡	61 (51, 68)	100 (93, 100)
HAGOS–Pain‡	75 (65, 83)	100 (100, 100)
HAGOS–ADL‡	80 (70, 95)	100 (100, 100)
HAGOS–Sports/Recreation‡	66 (52, 77)	100 (100, 100)
HAGOS–PA§	63 (38, 75)	100 (100, 100)
HAGOS–QOL‡	60 (50, 70)	100 (100, 100)

Values are presented as %, or median (interquartile range).
*181 symptomatic participants.
†274 symptomatic hips /108 asymptomatic hips.

‡176 symptomatic participants/54 control participants.
§175 symptomatic participants/54 control participants.
BMI, body mass index; KL, Kellgren and Lawrence; AP, anteroposterior; IHOT, International Hip Outcome Tool; HAGOS, Copenhagen hip and groin outcome score; ADL, activities of daily living; PA, physical activity and QOL, quality of life.

Table 8.2. Association between alpha angle and presence of cartilage defects for all hips.[*§]

		Cartilage defect (present or absent)			
	No. of hips	Unadjusted OR (95%CI) *P*-value	Interaction term† *P*-value	Adjusted OR (95%CI)* *P*-value	Interaction term† *P*-value
Radiographic variable					
Alpha angle (AP view)	398	1.03 (1.02, 1.04) <0.001	0.946	1.03 (1.01, 1.04) <0.001	0.756
Alpha angle (Dunn 45° view)	382	1.03 (1.01, 1.04) 0.001	0.441	1.02 (1.00, 1.04) 0.024	0.659

*Adjusted for age, sex, body mass index, KL grade and symptoms.
§ Hip/groin pain and control hips.
†Alpha angle by presence of symptoms (hip/groin pain and positive FADIR test).
AP, anteroposterior; OR, odds ratio.

Table 8.3. Association between alpha angle and presence of labral tears for all hips.[*§]

		Labral tear (present or absent)			
	No. of hips	Unadjusted OR (95%CI) *P*-value	Interaction term† *P*-value	Adjusted OR (95%CI)* *P*-value	Interaction term† *P*-value
Radiographic variable					
Alpha angle (AP view)	398	1.02 (1.01, 1.04) 0.004	0.564	1.02 (1.01, 1.04) 0.005	0.662
Alpha angle (Dunn 45° view)	382	1.02 (1.00, 1.04) 0.012	0.572	1.02 (1.00, 1.04) 0.017	0.477

*Adjusted for age, sex, body mass index, KL grade, and symptoms.
§ Hip/groin pain and control hips.
†Alpha angle by presence of symptoms (hip/groin pain and positive FADIR test).
AP, anteroposterior; OR, odds ratio.

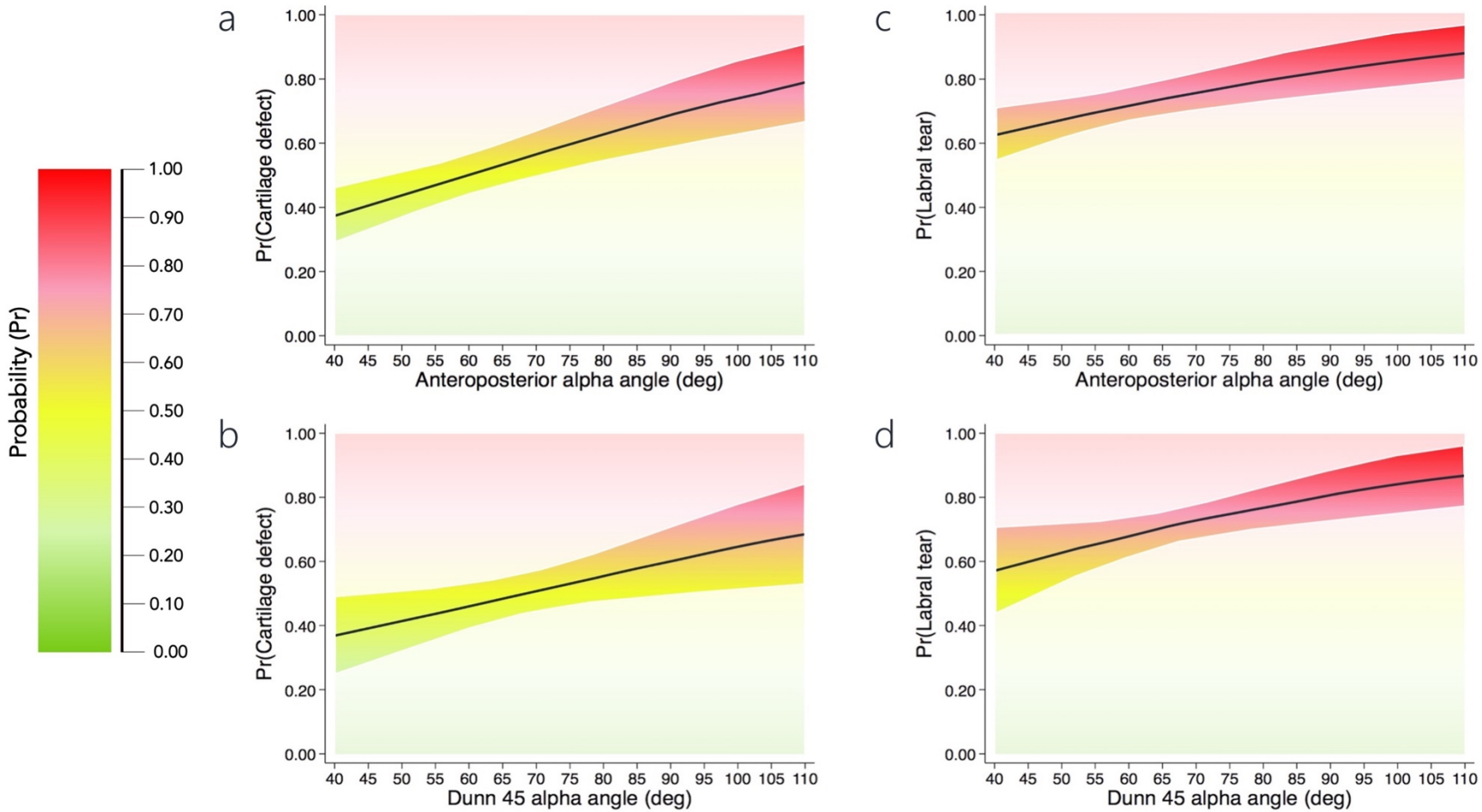


Figure 8.1. Probability plots from 0 (0%) to 1 (100%) of early hip OA features (presence) for values of alpha angle in 5° increments.
a) cartilage defect (anteroposterior alpha angle); b) cartilage defect (Dunn 45° alpha angle); c) labral tear (anteroposterior alpha angle) and d) labral tear (Dunn 45° alpha angle).

8.3.3. Association between cam morphology and location of early hip OA features

I. Cartilage defects

Alpha angle (continuous)

Greater AP and Dunn 45° alpha angles were associated with superolateral, but not superomedial or lateral cartilage defects (**Table 8.4**). The probability of a superolateral cartilage defect for values of alpha angle in 5° increments is presented in **Figure 8.2** and **Appendix 35.**

Cam morphology (threshold values)

Hips with large cam (aOR = 4.67, 95%CI: 2.5, 8.9) and cam morphology (aOR = 2.62, 95%CI 1.4 to 5.0) had a higher prevalence of superolateral cartilage defects than hips without cam morphology (**Figure 8.3** and **Appendices 36** and **37**). The prevalence of superomedial and lateral cartilage defects was similar in hips with large cam morphology, cam morphology, and without cam morphology (**Figure 8.3** and **Appendix 36**). The prevalence of inferior (**Figure 8.3**), anterior and posterior (**Figure 8.4**) cartilage defects was low in all hips. Cartilage defect location is described separately for symptomatic and control hips in **Figure 8.5** (coronal plane) and **Figure 8.6** (sagittal plane). For example, in football players with large cam morphology, superolateral cartilage defects were present in those with (54%) and without hip/groin pain (64%).

II. Labral tears

Alpha angle (continuous)

Greater AP and Dunn 45° alpha angles were associated with superior, but not anterosuperior labral tears (**Table 8.5**). The probability of a superior labral tear for values of alpha angle in 5° increments is presented in **Figure 8.2** and **Appendix 37**.

Cam morphology (threshold values)

Hips with a large cam (aOR 3.41, 95%CI: 1.8, 6.3) and cam morphology (aOR 1.98, 95%CI: 1.1, 3.7) had a higher prevalence of superior labral tears than hips without cam morphology (**Figure 8.7** and **Appendix 38**). The prevalence of anterosuperior labral tears did not differ between hips with a large cam morphology, cam morphology, and without cam morphology (**Appendix 38**). There was a low prevalence of anterior and posterior labral tears in all hips (**Figure 8.7**). Labral tear location is

Table 8.4. Association between alpha angle and location of cartilage defects for all hips.[*§]

	Odds ratios (OR)			
	Unadjusted OR (95%CI) *P*-value	Interaction term† *P*-value	Adjusted OR (95%CI)* *P*-value	Interaction term† *P*-value
Cartilage defect location				
Superolateral subregion				
Alpha angle (AP view)	1.04 (1.02, 1.05) <0.001	0.851	1.03 (1.02, 1.05) <0.001	0.749
Alpha angle (Dunn 45° view)	1.04 (1.03, 1.06) <0.001	0.525	1.04 (1.02, 1.05) <0.001	0.822
Superomedial subregion				
Alpha angle (AP view)	1.00 (0.98, 1.02) 0.960	0.252	1.00 (0.98, 1.02) 0.975	0.213
Alpha angle (Dunn 45° view)	0.99 (0.96, 1.01) 0.417	0.724	0.99 (0.96, 1.01) 0.302	0.833
Lateral subregion				
Alpha angle (AP view)	1.01 (0.99, 1.02) 0.290	0.622	1.01 (0.99, 1.02) 0.303	0.451
Alpha angle (Dunn 45° view)	1.00 (0.98, 1.01) 0.823	0.472	1.00 (0.98, 1.01) 0.700	0.642

*Adjusted for age, sex, body mass index, KL grade, and symptoms.
§ Hip/groin pain and control hips.
†Alpha angle by presence of symptoms (hip/groin pain and positive FADIR test.)
AP, anteroposterior.

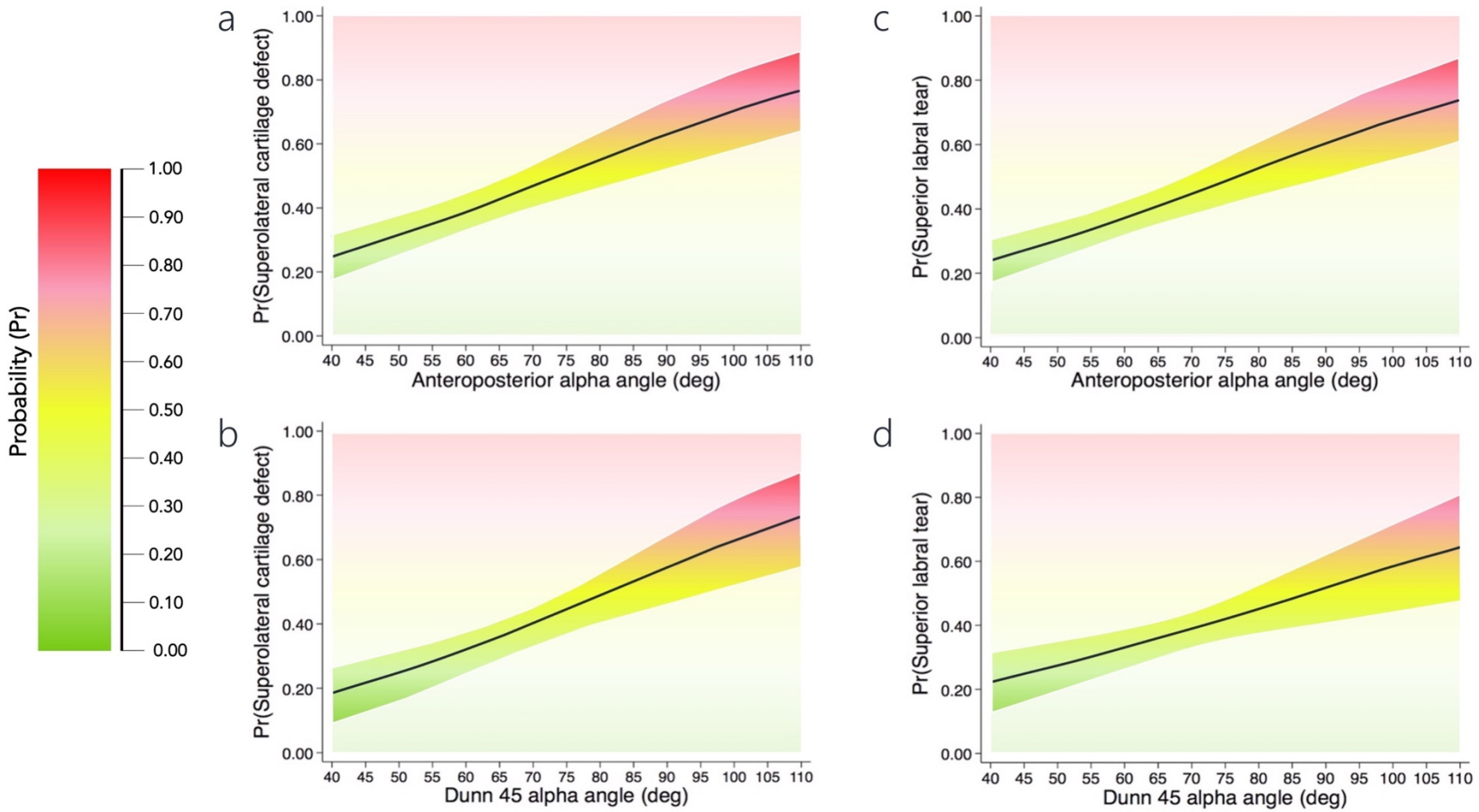


Figure 8.2. Probability plots from 0 (0%) to 1 (100%) of early hip OA features (location) for values of alpha angle in 5° increments.
a) superolateral cartilage defect (anteroposterior alpha angle); b) superolateral cartilage defect (Dunn 45° alpha angle); c) superior labral tear (anteroposterior alpha angle) and d) superior labral tear (Dunn 45° alpha angle).

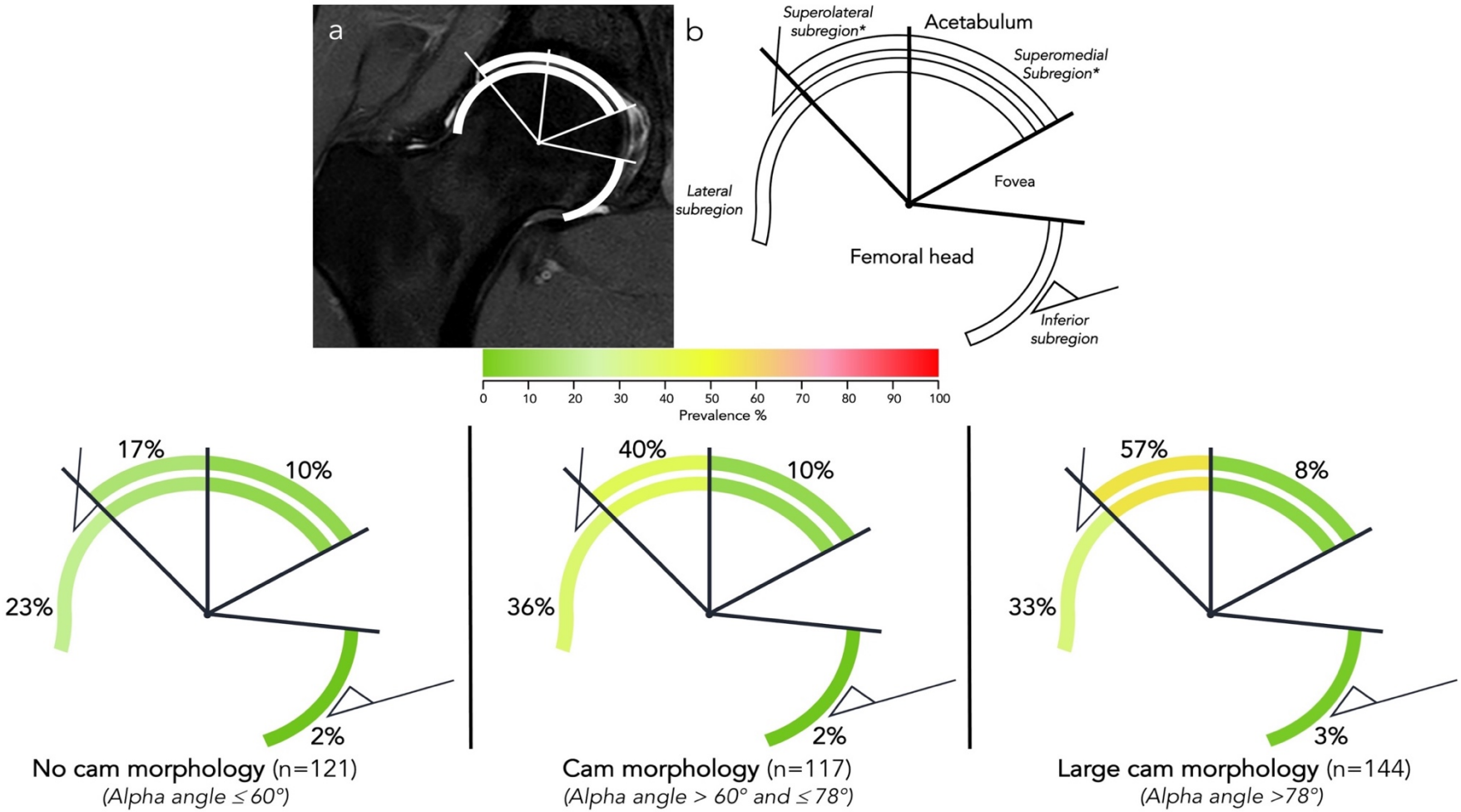


Figure 8.3. Location and prevalence of cartilage defects (coronal plane) in all hips (hip/groin pain and control groups combined) with large cam morphology, cam morphology and without cam morphology.

a) coronal MRI with SHOMRI subregions (in white) used for cartilage assessment; b) schematic of coronal subregions used for cartilage assessment; * = cartilage defect present in either femoral or acetabular cartilage and n = number of hips.

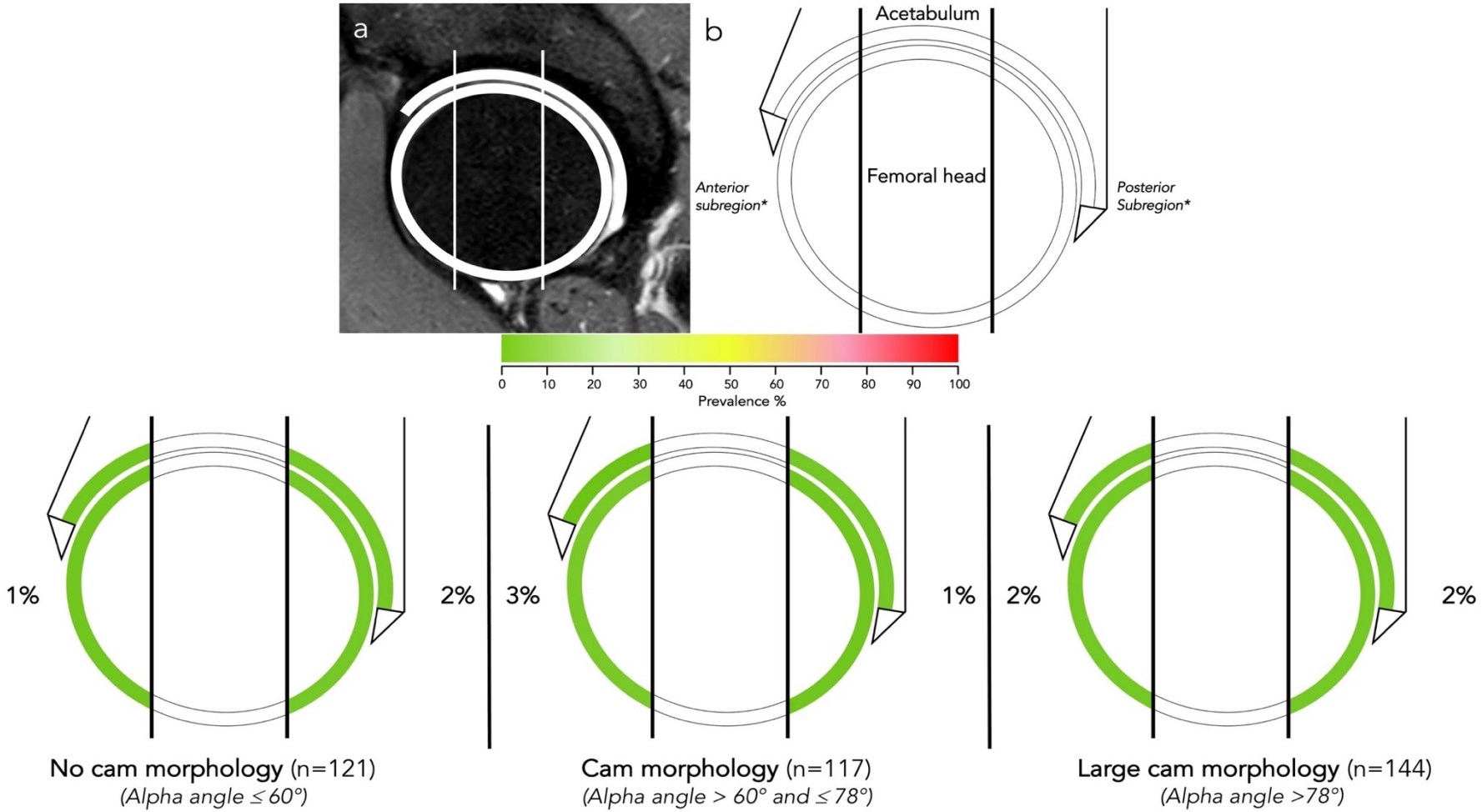


Figure 8.4. Location and prevalence of cartilage defects (sagittal plane) in all hips (hip/groin pain and control groups combined) with large cam morphology, cam morphology, and without cam morphology.

a) sagittal MRI with SHOMRI subregions (in white) used for cartilage assessment; b) schematic of sagittal subregions used for cartilage assessment; *= cartilage defect present in either femoral or acetabular cartilage and n = number of hips.

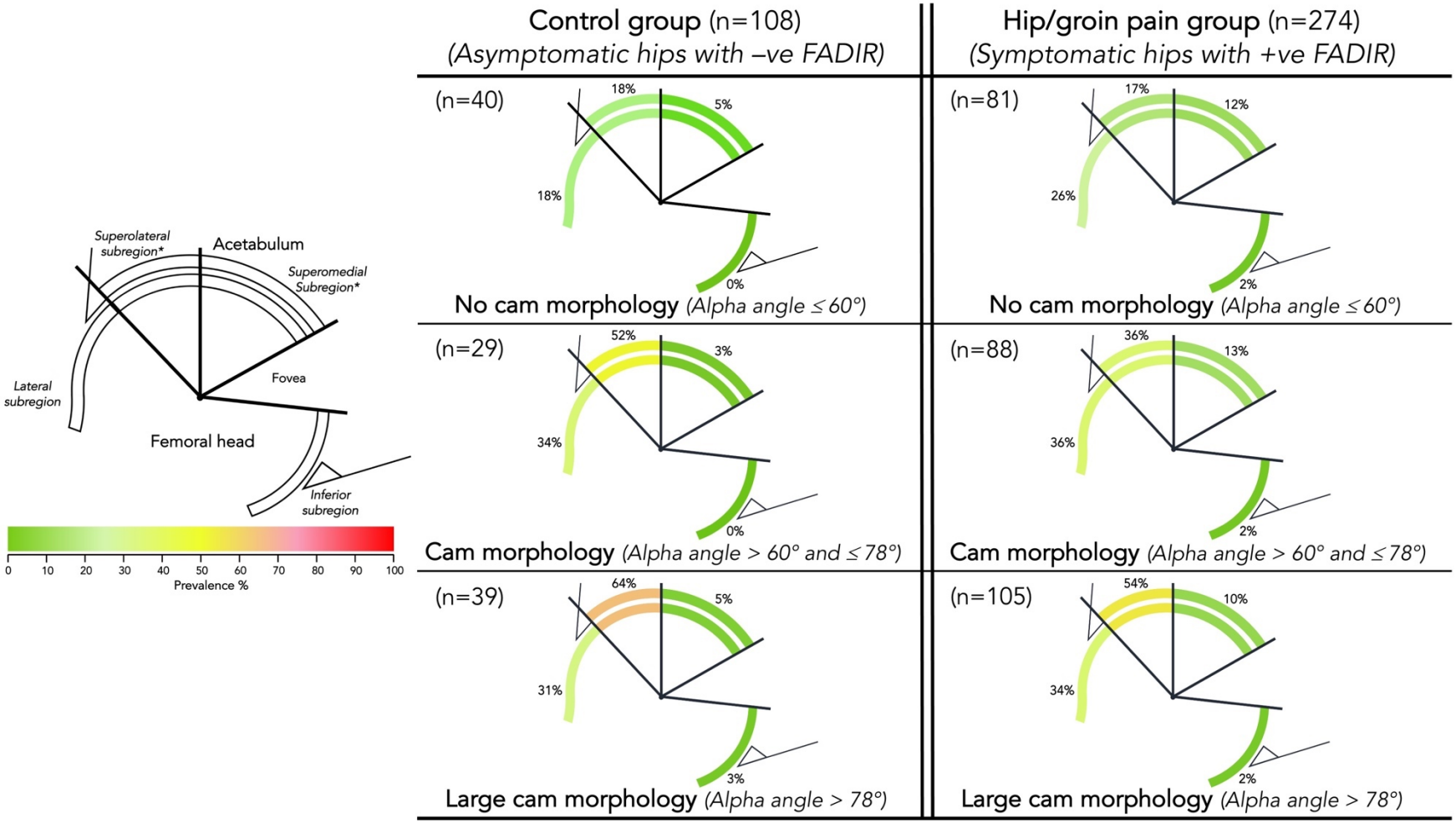


Figure 8.5. Location and prevalence of cartilage defects (coronal plane) in hip/groin pain and control hips stratified by alpha angle threshold.
*= cartilage defect present in either femoral or acetabular cartilage and n = number of hips.

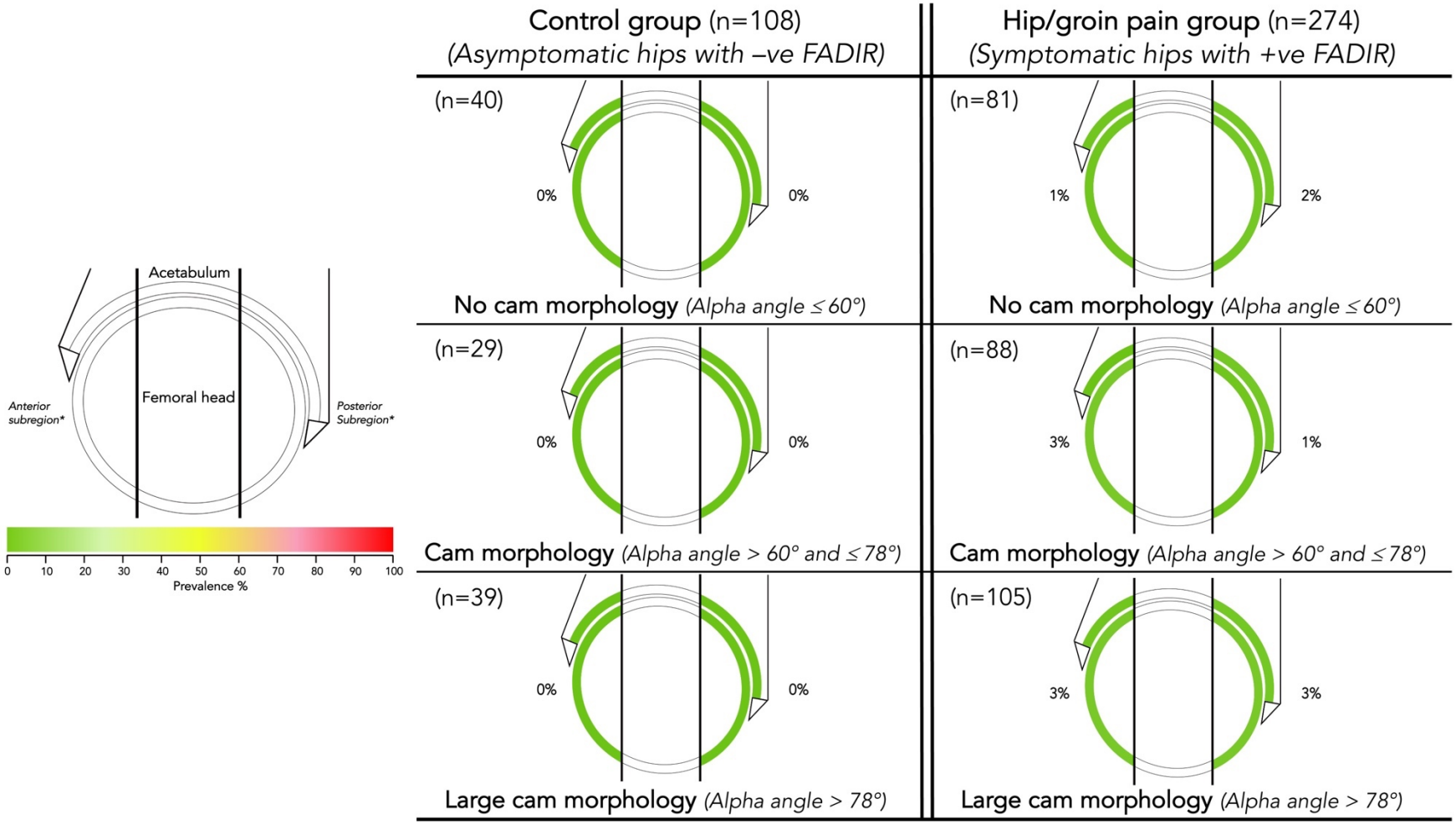


Figure 8.6. Location and prevalence of cartilage defects (sagittal plane) in hip/groin pain and control hips stratified by alpha angle threshold.

*= cartilage defect present in either femoral or acetabular cartilage and n = number of hips.

Table 8.5. Association between alpha angle and location of labral tears for all hips.*§

	Odds ratios (OR)			
	Unadjusted OR (95%CI) *P*-value	Interaction term† *P*-value	Adjusted OR (95%CI) *P*-value	Interaction term† *P*-value
Labral tear location				
Superior subregion				
Alpha angle (AP view)	1.03 (1.02, 1.05) <0.001	0.371	1.03 (1.02, 1.05) <0.001	0.484
Alpha angle (Dunn 45° view)	1.03 (1.02, 1.05) <0.001	0.558	1.03 (1.01, 1.04) 0.003	0.937
Anterosuperior subregion				
Alpha angle (AP view)	1.00 (0.99, 1.02) 0.489	0.145	1.01 (0.99, 1.02) 0.342	0.189
Alpha angle (Dunn 45° view)	1.01 (0.99, 1.02) 0.263	0.577	1.01 (1.00, 1.03) 0.128	0.616

*Adjusted for age, sex, body mass index, KL grade, and symptoms.
§ Hip/groin pain and control hips.
†Alpha angle by presence of symptoms (hip/groin pain and positive FADIR test).
AP, anteroposterior.

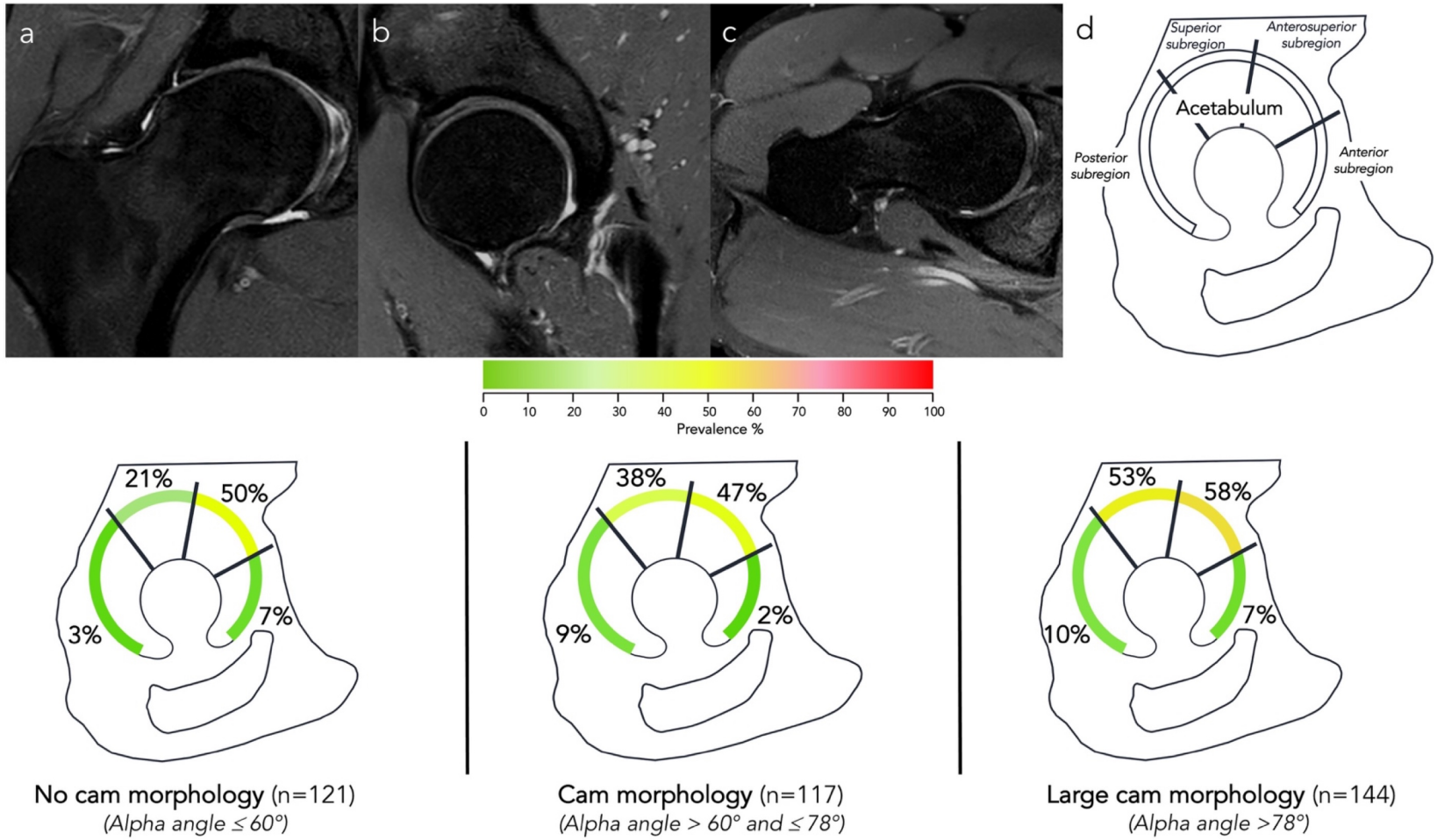


Figure 8.7. Location and prevalence of labral tears in all hips (hip/groin pain and control groups combined) with large cam morphology, cam morphology and without cam morphology.

a) coronal MRI used for assessment of superior labral tears; b) sagittal MRI used for assessment of anterosuperior labral tears; c) axial oblique MRI used for assessment of anterior and posterior labral tears and d) schematic of subregions used for labral assessment and n = number of hips.

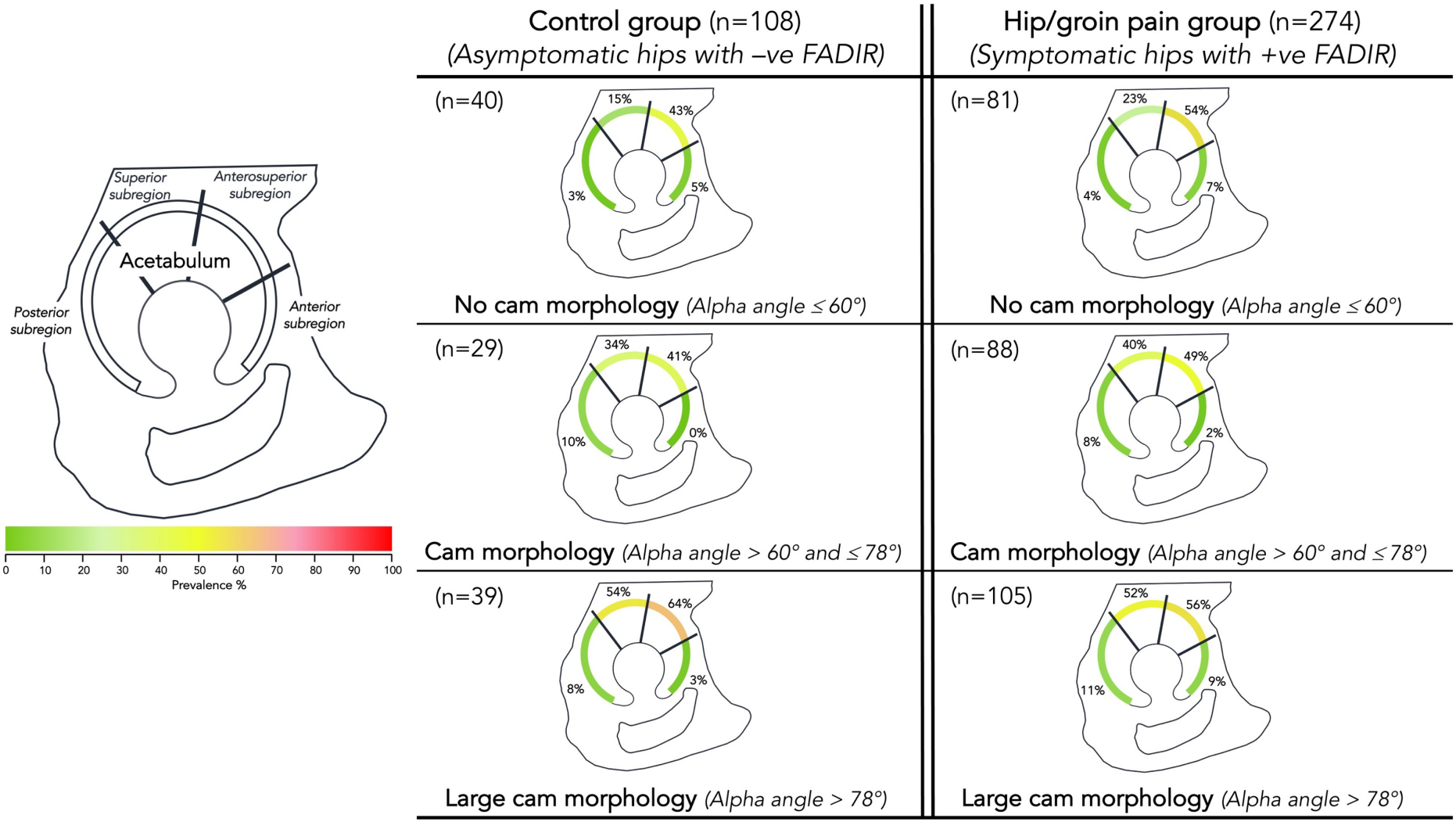


Figure 8.8. Location and prevalence of labral tears in hip/groin pain and control hips stratified by alpha angle threshold.
n = number of hips.

described separately for symptomatic and control hips in **Figure 8.8**. For instance, in football players with a large cam morphology, anterosuperior labral tears were present in those with (56%) and without hip/groin pain (64%).

8.3.4. Association between cam morphology and severity of early hip OA features

I. Alpha angle (continuous)

Greater AP (aIRR = 1.01, 95%CI: 1.0, 1.2), but not Dunn 45° alpha angle was associated with worse cartilage scores (**Appendix 39**). Greater AP (aIRR = 1.01, 95%CI: 1.0, 1.0) and Dunn 45° alpha angle (aIRR = 1.01, 95%CI 1.0, 1.0) was associated with worse labral scores (**Appendix 40**). Predicted cartilage and labral scores for values of alpha angle in 5° increments are presented in **Appendices 41** and **42**.

II. Cam morphology (threshold values)

Hips with a large cam (aIRR = 1.53, 95% CI 1.0, 2.3) and cam morphology (aIRR = 1.53, 95%CI 1.0, 2.3) had worse cartilage scores than hips without cam morphology (**Appendix 43**). Hips with a large cam (aIRR 1.45, 95%CI: 1.2, 1.8), but no cam morphology had worse labral scores than hips without cam morphology (**Appendix 44**).

8.3.5. Interaction between cam morphology and symptoms (hip/groin pain and positive FADIR test)

There was no evidence for a difference in presence or size of the association between cam morphology (continuous or threshold) and early hip OA features (cartilage defects or labral tears) between football players with and without symptoms (**Tables 8.2** to **8.5** and **Appendices 33, 36, 38** to **40, 43** and **44**).

8.4. Discussion

Cam morphology size and presence were associated with early hip OA features in football players. Cam morphology was mostly associated with superolateral cartilage defects and superior labral tears. We did not observe a difference in the presence or size of association between cam morphology and early hip OA features in football players with and without symptoms.

8.4.1. Cam morphology and early hip OA features in football players

Playing football is associated with an up to 9-fold greater odds of developing hip OA in later life,(172) but the underlying mechanism for this relationship has remained unclear. Cam morphology is a risk factor for hip OA in middle-aged to older populations,(158–160) and is thought to contribute to early hip disease in active football players.(297) Our findings suggest that cam morphology is associated with cartilage defects and labral tears in young football players (median age, 26), but that the association of cam morphology with joint damage is no greater in football players with symptoms (including a positive FADIR test) than in those without.

A dose-response association was found between cam morphology and early hip OA features in football players, similar to reports from people undergoing hip arthroscopy.(324–326) For example, an increasing AP alpha angle from 40 to 78° was associated with a 3-fold increase in the odds of having a cartilage defect. It is unclear whether this relationship remains the same during the aging process in football players and/or if cartilage and labral damage is expediated into hip OA in those with cam morphology.

Combined with others,(156,327–329) our findings in football players might implicate cam morphology as a risk factor for early hip OA. The progression of joint disease may involve the interplay between bony parameters, hip and/or pelvic biomechanics, and muscle function, and be unrelated to symptoms. Future prospective studies are needed to determine the role that cam morphology and/or symptoms play in worsening joint disease.

8.4.2. Location of cartilage defects and labral tears

Our semiquantitative MRI data support a pathomechanical model of cam impingement, where premature contact between the proximal femoral head-neck junction and the acetabular rim is associated with region-specific cartilage and labral damage.(45) A higher alpha angle was associated with superolateral cartilage defects and superior labral tears, whereby, a 10° increase in the AP alpha angle was associated with a 1.34-fold increase in the odds of having either MRI finding. Mechanical abutment between the femoral head-neck junction and acetabulum may occur throughout the full arc of flexion in hips with a larger cam morphology,(330) which over time, could induce prolonged impingement and resultant damage to chondrolabral structures. Our findings suggest that MRI-defined chondrolabral damage corresponds to the location of cam morphology and that the prevalence of this damage is associated with the size of any cam morphology rather than the presence of symptoms.

8.4.3. Why do some football players with cam morphology and early hip OA features remain asymptomatic and others do not?

Not all football players with cam morphology and early hip OA features had hip/groin pain. The question then emerges, what factors differ in football players with and without pain? For many, their symptoms may emanate from structures external to the hip joint, even in the presence of cam morphology and early hip OA features. For example, clinical groin pain entities, such as adductor-related groin pain are present in close to 70% of players with long-standing symptoms.(202,317) We examined cam morphology in isolation from acetabular morphology. It could be that symptoms are only generated when specific femoral and acetabular bony parameters exist together alongside early OA features.(153,331) However, consideration of structural factors alone fails to appreciate the complex aetiology of pain.(332) Joint injury (e.g., labral tears) may occur without pain(264,293) and pain may persist despite tissue healing.(332) Longstanding hip/groin pain is often accompanied by an altered psychological state, disturbed sleep, and social limitations, which can all modulate pain levels.(332–334) A symptomatic football player with cam morphology and early hip OA features requires a comprehensive assessment that considers the contribution of structural and non-structural factors.

8.4.4. Clinical implications

Young adult football players with cam morphology are likely to display early radiological features of hip OA; however, the severity and extent of structural damage appear to be no greater in football players with symptoms (including a positive FADIR test) and cam morphology than in pain-free football players with cam morphology. Cam morphology is a risk factor for hip OA,(158–160) but not all people with cam morphology develop symptoms(135) or display the progression of joint disease.(158) Therefore, it is currently unknown if treatments designed to change cam morphology (e.g., surgery) are needed to slow the progression of joint disease in football players, without prospective studies.

8.4.5. Limitations

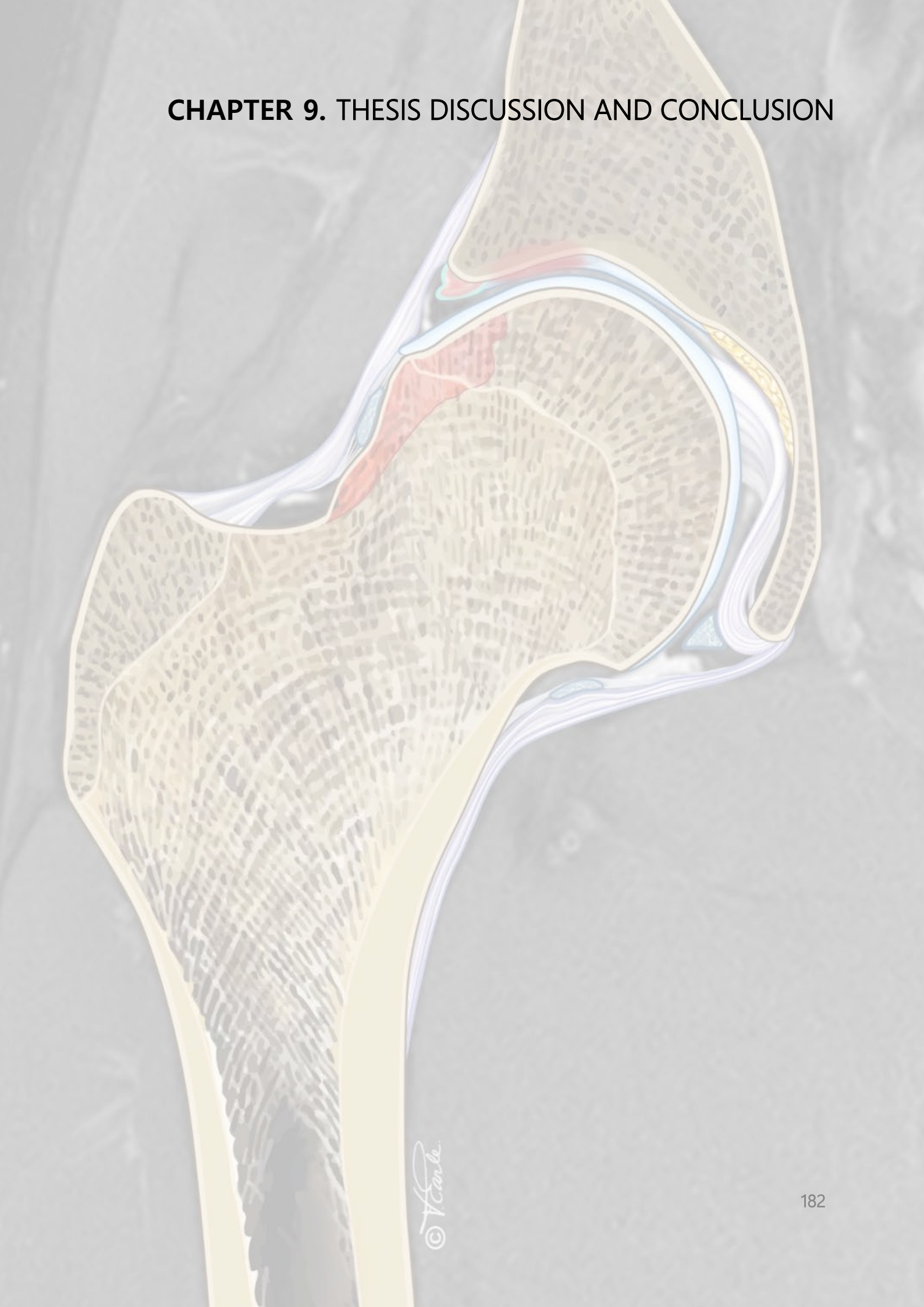
First, several different clinical entities may elicit symptoms in football players.(11) We did not evaluate our football players for the presence of specific clinical entities, including adductor-, iliopsoas-, pubic- or inguinal-related groin pain, and some football players may have had coexisting conditions that contributed to their symptoms. The FADIR test is sensitive, but not specific to intra-articular hip conditions.(12) Some football players might not have had pain

generated by intra-articular conditions. The SHOMRI system is a reliable and valid tool for assessing the morphology of intra-articular structures involved in the pathogenesis of hip OA.(123) However, it does not enable assessment of cartilage volume or composition, which can be altered in hips with cam morphology.(156,327,335) We only presented two of the eight SHOMRI features. While other features, such as bone marrow lesions may play an important role in symptom genesis and disease progression, they were present in very few football players in our study (<10%). A single musculoskeletal radiologist completed the SHOMRI scoring for all hips and we did not determine inter-rater reliability. As a result, we may over or under-report the severity of early hip OA features. The accuracy of contrast-enhanced MRI is superior to unenhanced MRI for assessment of cartilage and labral conditions,(92,111) but high-resolution, unenhanced 3-Tesla MRI can provide comparable accuracy to contrast-enhanced approaches.(95,96,304) Furthermore, contrast-enhanced MRI is invasive and not appropriate for asymptomatic populations.(89) We did not stratify our cohort by sex due to the low number of women. As male sex is a risk factor for cam morphology(64) and cartilage defects,(85,88) it should be considered in future studies of athletes. Our cohort may not be representative of all young adults participating in football since participants responded to study adverts or participated in information sessions. The case-control design of this study precludes inferences of a cause-and-effect relationship between cam morphology and early hip OA features.

8.5. Conclusion

In football players, cam morphology was associated with early radiological features of hip OA, specifically cartilage defects and labral tears. This relationship was no greater in football players with symptoms than without, suggesting a complex relationship between cam morphology, early hip OA features, and symptoms.

CHAPTER 9. THESIS DISCUSSION AND CONCLUSION



Hip/groin pain is a common problem in football players and is associated with impaired sports performance and lower quality of life.(1,7) Hip/groin pain can emanate from intra- and extra-articular structures.(11,41,204) There is growing interest in the role that hip-related conditions (e.g., FAI syndrome, labral tears) play in the genesis of hip/groin pain and the pathogenesis of early hip OA in athletes. Hip-related pain is the recommended term to describe non-arthritic hip disease in young and middle-aged active adults and encompasses three intra-articular conditions: i) FAI syndrome, ii) acetabular dysplasia and/or hip instability, and iii) other disorders without distinct osseous morphology, which can include labral, chondral and ligamentum teres conditions.(12) Imaging findings of altered bony morphology and/or intra-articular structures are used alongside patient symptoms and clinical examination findings to assist in diagnosing the cause of hip-related pain.(12) However, the relationship between hip joint imaging findings and symptoms has been debated.(280) If structural features are associated with hip/groin pain it may allow for the provision of targeted treatments.

Hip-related pain may precede hip OA.(45) The pathogenesis of hip OA involves the complex interplay of genetic, biological, environmental, and biomechanical factors.(145) Football players are a population of interest, as they are subjected to repetitive high-impact activity, which over time may lead to joint overload and development of hip OA.(172) Subtle alterations in bony anatomy, such as cam morphology could play a role in the pathogenesis of early hip OA. While several studies have reported cam morphology prevalence,(79,224,309–311,314) its relationship with early hip OA has yet to be studied in detail in football players.

This thesis aimed to evaluate the relationship of hip joint imaging findings and hip/groin pain and to understand the link between cam morphology and early hip OA in football players. This chapter provides an overview of the findings of this thesis, implications for clinical practice, strengths and limitations, and future research directions. The key findings are outlined in **Figure 9.1**.

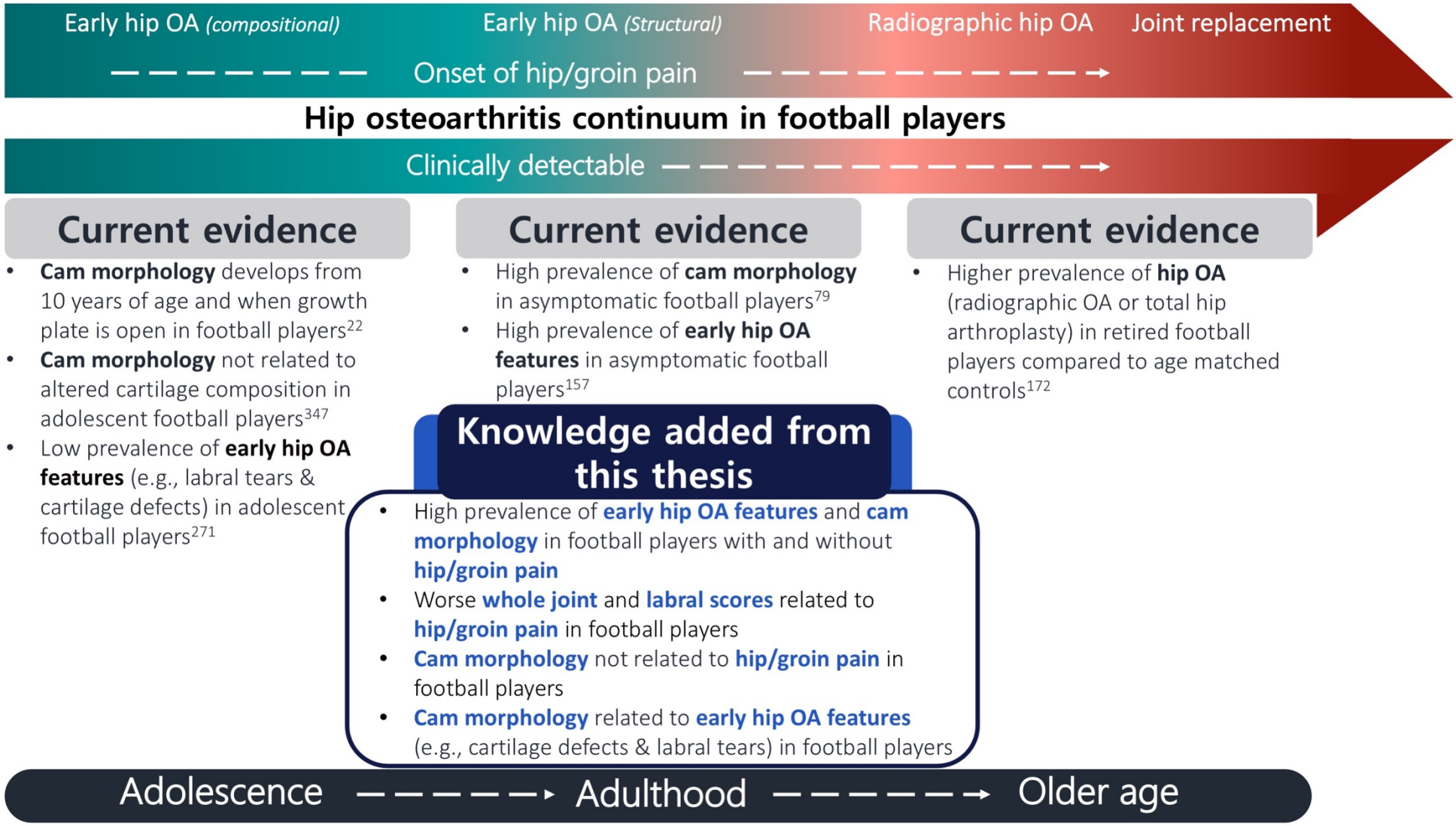


Figure 9.1. Knowledge added from this thesis.

9.1. The prevalence of intra-articular hip conditions

In chapter 4 (study 1) a systematic review evaluated the prevalence of imaging-defined intra-articular hip conditions in people with and without hip/groin pain. A higher prevalence of cartilage defects was observed in people with hip/groin pain (64%) than without (12%). A high and similar prevalence of labral tears was noted in people with (62%) and without pain (54%). The prevalence of herniation pits and paralabral cysts was similar in people with and without pain. In contrast, a higher prevalence of BML and ligamentum teres tears was found in people with pain. The reported cartilage defect and labral tear prevalence were supported by limited to moderate strength evidence in people with pain and moderate strength evidence in those without pain, requiring further, high-quality investigations.

The prevalence of intra-articular hip conditions in people with and without hip/groin pain was outlined in chapter 4, which provided foundation knowledge for the studies in this thesis but did not specifically evaluate the prevalence of intra-articular conditions in athletes. Therefore, in chapter 5 (study 2) the literature was systematically reviewed to report the prevalence of imaging-defined intra-articular hip conditions and radiographic hip OA in active athletes with and without hip/groin pain. The included studies examined athletes from a range of sports, including American football, football (soccer), ice hockey, ballet, rugby, golf, track and field, skiing, and capoeira. This review revealed a similar, but varied prevalence of cartilage defects in the hips of athletes with (7 to 40%) and without hip/groin pain (2 to 36%). A higher prevalence of cartilage defects was found in athletes with pain from flexibility sports, but not asymmetrical or cutting sports. For labral tears, a higher prevalence was identified in the hips of athletes without pain (33%) when compared to those with pain (20%). Furthermore, a higher prevalence of labral tears was also observed in athletes without pain participating in flexibility, asymmetrical, and cutting sports. There was a higher prevalence of BML, herniation pits, and ligamentum teres tears, but not effusion-synovitis or labral degeneration in athletes with pain, than those without. In general, a low prevalence of radiographic hip OA was observed in all athletes. In athletes with pain, the reported labral tear prevalence was supported by moderate evidence. The strength of evidence for cartilage defect and labral tear prevalence was limited to moderate in athletes without pain. In athletes with hip/groin pain, no analysis could be performed at a per person level for cartilage defects or labral tears.

Combined, the systematic reviews (chapters 4 and 5) suggest that imaging-defined intra-articular hip conditions are present in people with and without hip/groin pain. The limited to moderate

strength of evidence for the findings of cartilage defect and labral tear prevalence reflects the HR of the included studies. Both reviews identified several key limitations in the existing literature. For instance, study participants were not representative of the target populations (community (chapter 4) and/or athletes (chapter 5)), heterogenous taxonomy was used to classify hip/groin pain, sex-based differences were not reported, and few studies directly compared prevalence in people with and without hip/groin pain. No included studies evaluated imaging-defined intra-articular conditions in football players with hip/groin pain. Therefore, further high-quality studies were needed to understand the relationship between intra-articular hip conditions and hip/groin pain in football players.

9.2. Hip joint imaging findings in football players

Chapter 6 (study 3) described the severity and prevalence of intra-articular hip conditions (early hip OA features) on MRI in all football players (men and women combined), and men and women separately. In each of these groups, the severity and prevalence of OA features in those with and without hip/groin pain was compared, and the relationship between these features and hip/groin specific PROMs was examined. In all football players and men, higher total SHOMRI scores were present in symptomatic and other hips when compared to control hips. By comparison, total SHOMRI scores were similar between symptom groups in women. In men only, higher cartilage scores were present in symptomatic and other hips than in control hips. Labral scores were also higher in symptomatic and other hips than control hips in football players and men, but not women. In all football players, differences in BML and ligamentum teres scores between symptom groups were inconclusive. For men, differences in BML, ligamentum teres, and subchondral cyst scores between symptomatic, other, and control hips were also inconclusive. Differences in ligamentum score between symptom groups were inconclusive in women. A sex by symptom group interaction was only found for total SHOMRI and cartilage score, whereby higher scores were present in men but not women in symptomatic and other hips relative to control hips.

To establish the prevalence of early hip OA features, each imaging feature was scored as present or absent. In all football players, a similarly high prevalence of cartilage defects (partial or full thickness) was found in symptomatic (50%), other (51%), and control hips (47%). Sex-based differences for cartilage defect prevalence were inconclusive. The prevalence of full-thickness defects was higher in symptomatic (17% and 19%) and other hips (7 to 24%) relative to control hips (0% and 2%) in football players, men, and women. A high prevalence of labral tears was

found across all hips regardless of symptoms or sex (symptomatic (68 to 73%), other (51 to 61%), and control hips (63 to 75%)). A low prevalence of BML (≤10%), subchondral cysts (<15%), paralabral cysts (<30%), and intra-articular loose bodies (<5%) were found in all symptom groups in football players, men, and women. In all football players, a lower prevalence of effusion-synovitis was identified in symptomatic (23%) and other hips (20%) than in control hips (40%). In men and women, symptomatic and other hips also had a lower prevalence of effusion-synovitis. A low prevalence of ligamentum teres tears (≤5%) was found across symptom groups in all football players, men, and women. No sex by symptom group interaction was found for individual OA features. The total SHOMRI and individual OA features scores (cartilage, BML, subchondral cyst, labral, and ligamentum teres) were not associated with iHOT33 or HAGOS symptoms and pain subscale scores in all football players, nor men or women. In conclusion, the findings of Chapter 6 (study 3) suggest that most features of early hip OA observed on MRI do not discriminate football players with hip/groin pain from those without pain.

Chapter 7 (study 4) compared the size and prevalence of bony hip morphology in all football players, men, and women with and without hip/groin pain, and the relationship between the size of bony hip morphology, iHOT33, and HAGOS pain and symptom subscales. Anteroposterior pelvis and Dunn 45° alpha angle values did not differ between symptomatic, other and control hips in all football players or men. In women, higher alpha angle values were found in symptomatic relative to control hips on the Dunn 45° view, but not AP pelvis view. In all football players and men, a high and similar prevalence of cam morphology (alpha angle >60°) was found in symptomatic (71% and 78%), other (66% and 75%), and control hips (63% and 76%). A lower prevalence of cam morphology was found in women (25 to 42%), with no difference between symptom groups. The prevalence of large cam morphology (alpha angle >78°) was similar in symptomatic (16 to 44%), other (7 to 55%), and control hips (18 to 43%) in football players, men, and women. Lateral-centre-edge-angle values did not differ between symptom groups and a low prevalence of pincer morphology (<20%) and acetabular dysplasia (<15%) was found in all football players, men, or women. There was no correlation between the size of alpha angles and iHOT 33 or HAGOS pain and symptom subscales in all football players, men or women. In women, we found higher LCEA values (indicating greater acetabular coverage) were associated with lower HAGOS pain scores (worse hip/groin pain) (r = -0.374, 95% CI: -0.70, -0.05).

9.3. Cam morphology and early hip osteoarthritis in football players

Chapter 8 (study 5) evaluated the relationship between cam morphology and early hip OA features (cartilage defects and labral tears) and whether the relationship was stronger in football players with hip/groin pain than those without. Larger cam morphology was associated with the presence, location, and severity of cartilage and labral damage, but this relationship was no stronger in football players with hip/groin pain when compared to those without pain. Specifically, hips with cam and large cam morphology had a higher prevalence of cartilage defects than hips without cam morphology. In contrast, hips with large cam morphology, but not cam morphology had a higher prevalence of labral tears than hips without. When analysed as a continuous variable, greater AP and Dunn 45° alpha angles were associated with cartilage defects. Greater AP and Dunn 45° alpha angles were associated with labral tears. Larger cam morphology was associated with the location (superolateral cartilage defects and superior labral tears) and severity of early hip OA features. No cam morphology by symptom group interaction was found for cartilage or labral damage (presence, location or severity).

9.4. Clinical implications of thesis findings

The overall results of this thesis suggest that the relationship between most hip joint imaging findings and hip/groin pain is imprecise and an association exists between cam morphology and cartilage and labral damage in football players, irrespective of pain. The specific implications of this thesis are discussed below and where appropriate, study findings will be compared to the existing literature.

9.4.1. Don't be hip-notised by imaging findings

Advancement of imaging techniques has enabled the assessment of a constellation of intra-articular structures.(180,192) While this has improved our understanding of hip-related conditions, it may have led to an over-reliance on imaging findings.(212,280) Imaging can exclude serious pathology (i.e., red flags),(336) but is increasingly used to identify structural conditions(41,56,107,111) that are assumed to be related to pain and to inform treatment decisions.(212)

The findings of this thesis suggest that most hip joint imaging findings do not discriminate football players with hip/groin pain from those without pain (Figure 9.2). In particular, a high and similar

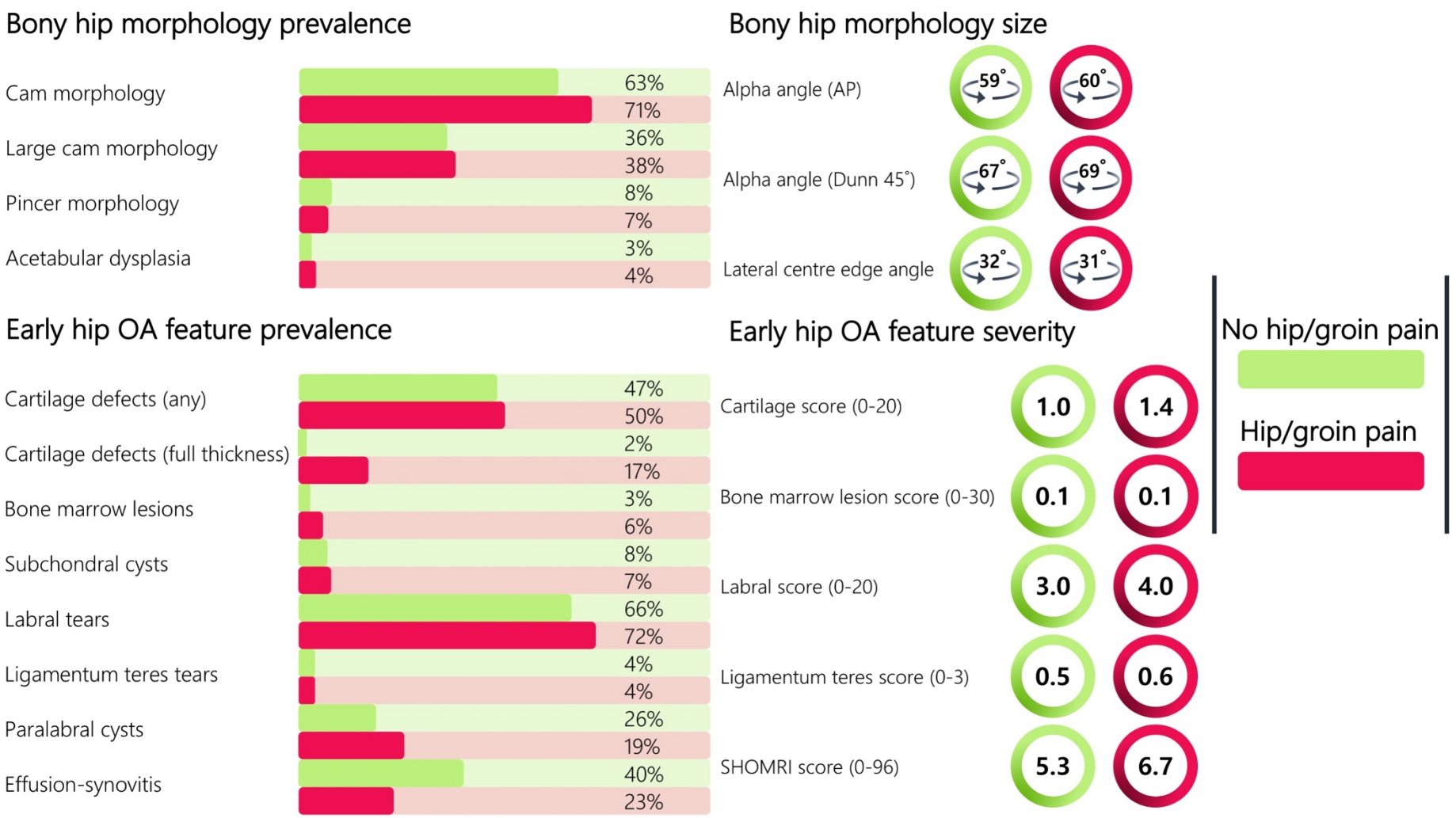


Figure 9.2. An overall summary of hip joint imaging findings in football players with and without hip/groin pain.

prevalence of labral tears, cartilage defects, and cam morphology were found in asymptomatic football players. While the severity of select imaging findings (whole joint damage, cartilage, labrum, and alpha angle in women) was associated with the presence of hip/groin pain (**Figure 9.2**), they had either no or a limited relationship with patient relevant domains (e.g., pain, symptoms, quality of life), as determined by the IHOT33 and HAGOS. The long-term implications of these imaging findings are also unknown. They may lead to the development, persistence, and/or worsening of symptoms or the progression of structural damage in football players. Long-term follow-up studies will assist in answering that important question.

Imaging should form one part of a comprehensive assessment.(12,280) Hip joint imaging findings should be considered alongside injury history (acute vs chronic), patient characteristics (e.g., age, sex, activity level), clinical examination, and wider physiological, psychological, and social factors. Hip joint imaging findings that exist alongside symptoms and clinical findings may be relevant and influence treatment decisions. Several studies have outlined demographic, radiographic, and intra-operative findings that are associated with unfavourable outcomes after hip arthroscopy or surgical hip dislocation.(303,337–339) While MRI findings may not always relate to symptoms, clinicians need to be aware of hip joint imaging findings that are associated with unfavourable outcomes and educate patients appropriately if they are present.

The way that medical information is communicated can influence patients' understanding of their diagnosis and treatment preferences. In a recent scoping review, hip joint imaging findings characteristic of FAI syndrome (e.g., cam morphology, pincer morphology) were the main criterion for surgery, despite the prognostic influence of these findings still being unclear.(212,340) Patients often believe their hip/groin pain and associated disability is caused by damaged intra-articular joint structures present on imaging.(341) These unhelpful beliefs are often developed through information provided by health care practitioners.(341) Conceptualising hip/groin pain solely through a pathoanatomical lens may lead patients to seek interventions that "cure" structural joint damage, such as hip arthroscopy. Therefore, when communicating hip joint imaging findings, clinicians should use the CLEAR principle(280):

- **C**onsistent **L**anguage: The terminology used by clinicians to describe imaging can affect patient thoughts and actions.(342) Clinicians should avoid using threatening language. For example, "labral tear" denotes something that is damaged and requires fixing, where "labral changes or alterations" may reduce pain-related behaviour and anxiety.

- **E**pidemiological information: Patients should be provided with age, sex and activity matched imaging findings of asymptomatic populations as this will assist to provide context and enable discussion about relevance (Figure 9.2).
- **A**ssessment of **R**elevance: Clinicians should be honest with patients about the relevance of imaging findings. This discussion should address the limitations and strengths of different imaging techniques, the imprecise relationship with pain, limitations of clinical examination findings to identify tissue-based pathology, and the prognostic ability of imaging features if known.

Adoption of these strategies can assist in providing context for imaging findings and may improve the management of football players with hip/groin pain.

9.4.2. One in every two football players had cartilage damage

While OA is a disease of the whole synovial joint, cartilage damage is considered a hallmark feature.(145,192) A concerning finding was the high proportion (47 to 51%) of young football players that displayed cartilage damage in chapter 6. This might partially explain the link between high-impact sports and the development of hip OA.(172) However, the relevance and natural history of cartilage defects, especially the partial thickness defects in young athletes as found in our study, is unknown. In prior reports, cartilage damage of the hip seen on MRI progresses slowly over time,(194,343,344) and is rarely associated with symptom worsening.(194,343,344) It is unclear if hip cartilage defects develop into radiographic OA. In the knee, full thickness cartilage damage is associated with the development of radiographic knee OA.(345) While the aetiology of hip OA differs to that of knee OA,(153,346) it is conceivable that full thickness cartilage damage (found in 17% of football players with hip/groin pain) present in early adulthood could expedite the development of hip OA. Cartilage defects are preceded by changes in the collagen-proteoglycan matrix and cartilage water content.(144,282) In football players, these compositional changes commence early in adolescence,(347) and may predispose them to cartilage damage in later life. As compositional changes may be reversible, adolescence may be a time where cartilage quality can be improved by the monitoring of training loads and substituting high-impact activities with football-specific skill training.

Cartilage defects may not always generate symptoms.(104,123,124,194,240,287) Intact articular cartilage is aneural (i.e., cannot provide nociception), but can contribute to symptoms through secondary mechanisms as damage progresses.(83,348) For example, exposure of nociceptors within the underlying subchondral bone, the release of inflammatory mediators or cartilage

debris that act on the synovium and initiate synovitis and chondrocyte driven release of nerve growth factor.(83,84) While the optimal load for cartilage health is unclear, over and under loading may be detrimental.(349) In football players, modification of high or low training loads may slow cartilage defect progression and reduce associated symptoms.

9.4.3. Labral tears are present in football players with and without hip/groin pain

An intact acetabular labrum may enhance joint stability and maintain cartilage homeostasis.(17,18,108) As the labrum contains nociceptors,(131,239) hip/groin pain is often attributed to labral damage present on MRI. However, labral tears can also be present in people without pain. For instance, two out of every three pain-free football players (66%) had labral changes on MRI in chapter 6. This high prevalence of incidental labral findings is consistent with studies of ice hockey(185–187), skiing(186), rugby(228) and ballet athletes(142). Although labral damage of greater severity was observed in football players with hip/groin pain, it was not associated with patient relevant domains (evaluated with the IHOT33 and HAGOS). It is unclear why some football players with labral tears have hip/groin pain and others do not. The anatomical location and/or concomitant intra-articular pathology (e.g., synovitis, cam morphology) may be different in football players with symptoms. However, the findings of chapter 8 suggest that labral tear prevalence and location is similar in symptomatic and asymptomatic football players with cam morphology. We recommend that clinicians use imaging findings in combination with patient symptoms and clinical findings.(12) It may also be prudent to consider the effect that age and radiographic hip OA has on labral tear prevalence.(102,124,230) For example, people over 30 years are eight times more likely to have a labral tear than those 30 years or younger,(124,230) and prevalence increases with the severity of radiographic hip OA.(124,230)

History of joint injury is a risk factor for the development of hip OA.(167) Whilst injuries can occur to both intra and extra-articular structures, the findings of chapters 4, 5 and 6 suggest that labral tears are common hip joint injury. Although labral damage may not always result in symptom genesis, it may have a deleterious effect on other joint tissues. For instance, cross-sectional investigations show that people with labral tears are more likely to have cartilage defects(99,102,142,350); however, further studies are needed to understand if this is a causal relationship. Although surgical techniques can restore labral mechanics, improve patient function and reduce pain,(276–278) it remains uncertain if such approaches slow the progression of structural joint disease. Joint injury can also result in altered muscle function (e.g., strength,

endurance) and change in movement biomechanics.(281) Together, these secondary consequences of joint injury might lead to irregular joint loading and further structural deterioration. Clinicians need to be cognisant of the role that hip joint injuries play in the pathogenesis of hip OA. However, clinical treatments for labral tears must always be considered carefully considering their high prevalence in asymptomatic individuals.

9.4.4. Cam morphology and early hip OA in football players

An association between cam morphology (size and presence) and early hip OA features (specifically cartilage and labral damage) was found in chapter 8. A modest dose-response relationship existed, where for every 1° increase in alpha angle a 3% greater odds of cartilage damage was found. For instance, an increase in AP alpha angle from 40° to 78° was associated with a 3-fold (95% CI 1.46 to 4.44) increase in the odds of having a cartilage defect. It is unclear if a change of this magnitude is of clinical relevance or if this association gets stronger or weaker over time. Football players with cam morphology also exhibited specific patterns of joint damage. Those with cam morphology were more likely to have superolateral cartilage defects and superior labral tears (Figures 9.3 and 9.4). This aligns with the proposed pathomechanical model of cam impingement, where bony abutment between cam morphology and acetabular structures may lead to region-specific damage.(86,327,328,351)

The aetiology of FAI syndrome is complex.(44) Why some people with cam morphology remain asymptomatic while others develop the clinical entity of FAI syndrome remains unclear. One explanation could be that symptoms are generated when cam morphology exists alongside joint damage of a certain severity or specific location. However, in chapter 8 we found that the severity and location of cartilage and labral damage did not differ in football players with pain (that included a positive FADIR test) and cam morphology when compared to those without pain and cam morphology. While a triad of symptoms, clinical signs, and imaging findings is used to diagnose FAI syndrome,(44) we suggest caution when interpreting the presence of this triad as a sign of more extensive joint disease.

Cam morphology increases the risk of hip OA, but not all people with this bony alteration have joint damage or progress through the OA continuum. Only 53% of people with large cam morphology and reduced internal rotation developed end-stage hip OA within 5 years.(158) Progression of hip OA may involve the complex interplay between demographic, systemic, radiologic, genetic and dynamic parameters (hip and/or pelvic biomechanics and muscle

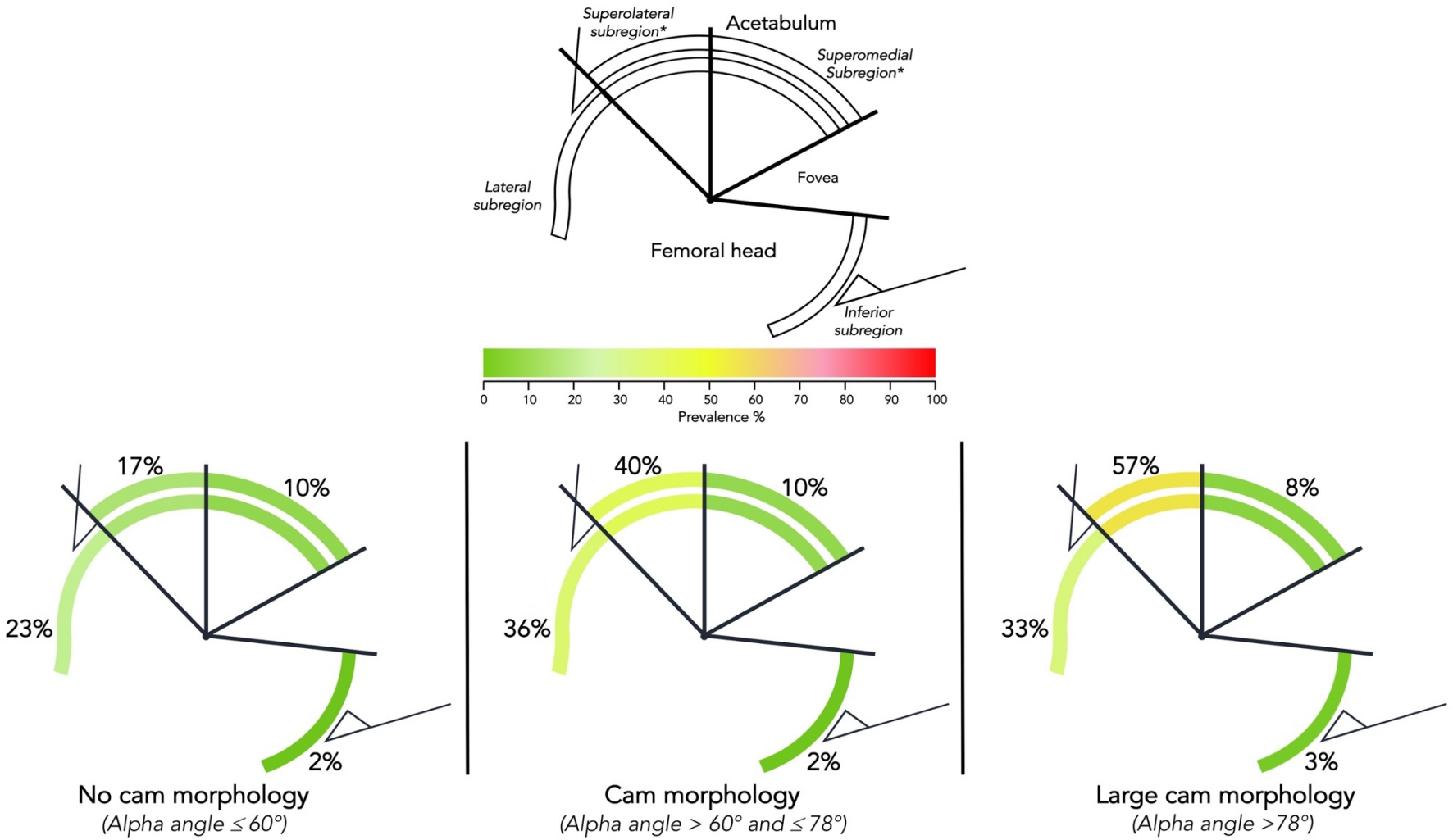


Figure 9.3. Location of cartilage defects in football players with and without cam morphology.

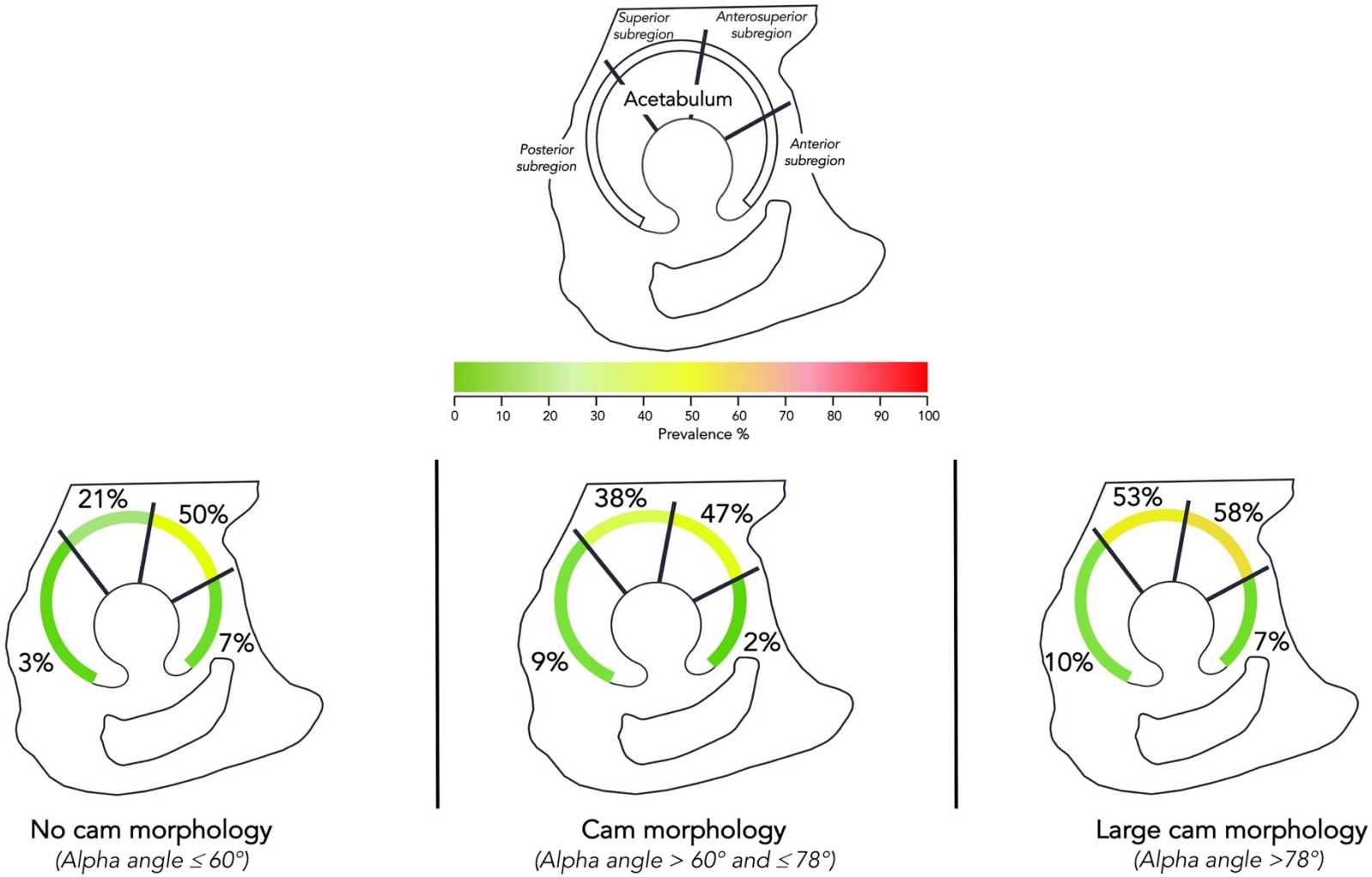


Figure 9.4. Location of labral tears in football players with and without cam morphology.

function).(159) While surgical resection of cam morphology can improve patient symptoms and function,(352–356) there is little evidence to support its long-term efficacy for slowing the development of hip OA.(357) Until prospective studies demonstrate that football players with cam morphology are at greater risk of developing hip OA, treatments targeting this bony feature and surrounding intra-articular soft-tissues should be considered carefully.

9.4.5. The prevalence of early hip OA features is sex-dependent

Irrespective of symptom status, sex-dependent differences were evident for certain early hip OA features in chapter 6. Specifically, we found a higher prevalence of cartilage defects, BML and subchondral cysts in men than women. For cartilage defects, this may be explained by the presence of larger cam morphology in men, as shown in chapter 7. However, male sex is a risk factor for cartilage defects, independent of cam morphology.(85,88) When compared to women, adolescent men exhibit altered cartilage composition which may predispose them to developing cartilage defects in adulthood.(347) Men and women exhibited a similar prevalence of labral tears in chapter 6, despite the higher prevalence of cam morphology in men. This is consistent with existing studies(102,103,142) and suggests a multifactorial aetiology, where joint trauma, congenital hip conditions, hip joint degeneration, capsular laxity, and altered bony morphology all contribute to the development of labral tears.(107,108) Clinicians should be mindful that the prevalence of specific early hip OA features may differ between men and women who are actively participating in football.

9.5. Research implications and future directions

The findings of this thesis raise questions about the link between hip joint imaging findings and hip/groin pain. While select imaging findings were associated with pain, most were found to a similar extent in pain-free football players. It is unclear if imaging findings lead to symptoms and/or structural worsening during the lifespan of football players. The longitudinal arm of the FORCe study(188) will assist in understanding this relationship. Future studies may also consider if different imaging profiles exist within the population of football players with hip/groin pain.

Articular cartilage is a tissue of particular interest in OA research.(144,145,348) Most people exhibit cartilage damage with ageing,(124) but not all people develop radiographic and/or symptomatic OA.(148) The MRI protocol used in chapter 8 enabled the observation of a high prevalence of cartilage defects in football players with cam morphology.(91,282) By comparison,

cartilage composition measured with advanced MRI did not differ in adolescent soccer players with and without cam morphology.(347) This suggests that cartilage damage might begin towards the end of skeletal growth through into early adulthood in football players with cam morphology. Advanced MRI techniques, such as dGEMRIC, T2 or T1 rho mapping could be used to understand when football players first develop altered cartilage structure(91,282) and if these changes are can be altered with targeted interventions. Future studies investigating measures to slow cartilage damage could investigate younger football players than were included in this thesis and if early signs of altered cartilage morphology (i.e., partial thickness defects) seen on MRI are reversible.

Studies of athletes report conflicting results for the association between cam morphology and hip/groin pain.(139,140,272,273,358,359) This may reflect the inadequacies of specific imaging techniques or that cam morphology is not associated with hip/groin pain. While recommended for assessing cam morphology,(44,56) radiographs do not provide a detailed three-dimensional assessment of the femoral head that is afforded by MRI or CT techniques.(180) Cam morphology is often examined in isolation from other bony parameters.(153) This approach fails to reflect the dynamic interplay between femoral and acetabular anatomy in FAI syndrome. Bouma et al. (331) developed a single imaging metric that combines femoral and acetabular bony anatomy. Three-dimensional imaging techniques and combined femoral/acetabular imaging measures could be useful in future studies investigating the link between cam morphology and hip/groin pain.

The SHOMRI system is a reliable and valid semi-quantitative MRI measure that can characterise and monitor disease burden in young and older adults.(123,194,302) While the total SHOMRI score is used to measure whole joint degeneration,(123,194) the relative weights that should be assigned to each feature are unknown. For example, a total SHOMRI score of eight could be derived through two different patterns of structural damage: i) paralabral cyst (1 point), full-thickness ligamentum teres tear (3 points), effusion-synovitis (1 point), and labral tear with chondrolabral separation (3 points); or ii) cartilage defects in 3 subregions (6 points) and simple labral tear (2 points). Until the importance of each OA feature to whole joint disease is established, studies should present the total SHOMRI alongside individual feature scores.

Movement and muscle impairments exist in people with hip-related pain.(170,360) Despite the absence of longitudinal studies, it is conceivable that these impairments may be associated with the development and worsening of joint structure (e.g., cartilage defects, labral tears). As movement and muscle impairments are modifiable with rehabilitation approaches, future studies

should explore their role in the progression of joint structural damage and functional decline in football players.

When researchers evaluate the relationship between imaging findings and hip/groin pain they need to consider current or past levels of physical activity. For example, high levels of physical activity were associated with cam morphology development in adolescence(22,261) and cartilage damage found at hip arthroscopy in older adults.(85) In chapters 6 to 8, groups are matched by sex, age, and level of activity, which may account for the minimal differences in prevalence and severity of hip joint findings in those with and without pain. A relationship between imaging findings and hip/groin pain may exist in football players competing in elite-level competitions. Further large-scale studies are needed to confirm our findings.

Football players in this thesis were not evaluated for known extra-articular causes of hip/groin pain (i.e., clinical entities).(11) Extra-articular clinical entities are common in football players and can co-exist with hip-related pain.(37,202) Their role in the progression of intra-articular conditions is unclear and warrants further investigation.

9.6. Strengths and limitations of the research design

9.6.1. Systematic review

Two systematic reviews provided level one evidence of the prevalence of imaging-defined intra-articular hip conditions. However, most studies had a moderate to HR, which should be considered when interpreting our findings. The systematic reviews were registered prospectively on PROSPERO and followed PRISMA reporting guidelines.(223) Two independent researchers conducted the literature search, data extraction, and risk of bias assessment in each review. We excluded HR studies from meta-analyses(219) and undertook sensitivity analysis to determine the influence of MRI field strength on prevalence findings. We also assigned a strength of evidence to the pooled results that took into account the study risk of bias and statistical heterogeneity.

Limitations include the use of a single summary score that did not provide a domain-based risk of bias assessment. This approach does not provide sufficient detail of methodological limitations that can affect study outcomes.(361,362) Furthermore, the previously used cut-off threshold to determine the risk of bias (low, medium, or high) for each study(216) does not consider the independent effect of each item included in a risk of bias assessment.(361,362) There was

considerable variability in the prevalence of intra-articular conditions in both MRI and MRA studies. This was evidenced by the wide CIs surrounding the prevalence estimates and high I^2 values. Further work is needed to understand what factors (clinical and methodological) contribute to this observed variation. Nine of 16 meta-analyses contained two studies and displayed statistical heterogeneity (i.e., high I^2 values), which can affect the validity of pooled findings. We did not undertake statistical hypothesis testing in either systematic review. This approach could be considered in future studies evaluating prevalence of intra-articular hip conditions. While not a limitation of our research design, both systematic reviews included highly selective populations that limit the generalisability of the findings.

9.6.2. Imaging techniques and assessment

Recommended radiographic views were used to assess bony hip morphology.(56,180) While radiographs are the first-line imaging technique for assessment of the femoral head-neck junction and acetabulum,(56,180,336) techniques such as MRI or CT may have provided a superior assessment of bony morphology size and/or orientation.(56,180) The semi-quantitative methods used to measure bony morphology were consistent with large epidemiological studies and have superior reproducibility compared with other measurement techniques.(59,158,162,321) We used bony morphology as a continuous and dichotomous variable. This overcomes the problems associated with dichotomisation of continuous variables, such as loss of statistical power and characterisation of bony hip morphology as an all-or-nothing event (i.e., considering an individual with an alpha angle of 61° as clinically different to someone with an alpha angle of 59°).(323) The alpha angle was used to determine the presence of cam morphology, which is a commonly used measure.(56,138,180) Several other measures can assess femoral head asphericity and orientation,(138,180) but were not used in our study. Future studies of the FORCe cohort will investigate if these other measures are associated with hip/groin pain or early hip OA. A single radiographic view and measure of acetabular coverage was used in chapter 7, possibly leading to under reporting of pincer morphology and acetabular dysplasia. However, subjective measures of depth and/or orientation exhibit poor reliability and may over-estimate prevalence.(322)

A high-resolution, unenhanced 3-T MRI protocol was used in chapters 6 and 8. For key intra-articular features, such as cartilage defects, labral tears, ligamentum teres tears, and synovitis, contrast-enhanced MRI may be more accurate than unenhanced MRI.(92,94,111,119,192) However, contrast-enhanced MRI is associated with risk and not appropriate for asymptomatic populations.(89) Furthermore, high-resolution 3-T MRI protocols (as used in our study) may

provide comparable accuracy to contrast enhanced techniques for articular cartilage and labrum.(95,96,302,304)

The SHOMRI system evaluates eight different intra-articular features.(123) The SHOMRI scoring was completed by a single trained musculoskeletal radiologist and we did not establish inter-observer reliability. The intra-observer values were good to excellent for most OA features, but for select features (cartilage, ligamentum teres, and subchondral cysts) there was modest reliability. Therefore, we may under- or over-report the severity of certain imaging features and subsequently their relationship with symptoms.

We combined acetabular and femoral cartilage defects into a singular outcome which may explain our findings of no association between this feature and hip/groin pain. Either acetabular or femoral cartilage might relate to symptoms in football players, as in a previous study.(240) However, our approach of combining cartilage defects into a composite score is recommended in studies using unenhanced MRI.(124) Future studies could explore if cartilage defects within particular anatomical subregions relate to symptoms in young adult football players.

The findings of this thesis (chapters 4, 5, 6 and 8) suggest that a large proportion of people with MRI evidence of early hip OA do not report hip/groin pain. In future, it is important to distinguish between MRI-defined OA and symptomatic hip OA.

9.6.3. Study design and population

The case-control study design precludes assumptions being made about a causal relationship between hip joint imaging findings and hip/groin pain. The longitudinal arm of the FORCe study will enable us to understand if imaging findings are associated with worsening of symptoms and if the presence of altered bony morphology is associated with progression of OA features over the 2-year study period.

Chapters 6 to 8 used baseline data from a prospective cohort study of 184 football players with hip/groin pain, powered to evaluate changes in hip joint structure on MRI over 2 years; and determine if baseline measures of potentially modifiable factors (cam morphology, hip contact force, strength, and range of motion) predict structural decline over 2 years.(188) The control participant sample size (n=55) was limited by personnel and budgetary constraints. As a result, a formal *a priori* power analysis was not undertaken for the studies included in this thesis. However, Chapters 6 to 8 of this thesis include the largest sample of football players (n=239 (476

hips)) with comprehensive hip joint imaging ever investigated, which is a strength of this research. Further, when evaluated using the risk of bias tool (used in chapters 4 and 5) the studies presented in chapters 6 and 7 would be considered at LR, with only two of 10 criteria scored as HR.

Football players with and without hip/groin pain were actively participating in sub-elite competitions in Melbourne or Brisbane, Australia. The inclusion of active football players increases the generalisability of our findings. The studies in this thesis may be at risk of selection bias as participants were recruited through online or print advertising and information sessions conducted at sporting clubs or organisations. Study participants may not reflect all football players with and without hip/groin pain. The level of sub-elite football in Australia may differ to other countries and this should be considered when interpreting our study findings. Football players were engaged in the same number of training and/or competition sessions per week, but we did not establish the intensity or duration of these sessions and if these metrics differed between groups. The frequency and level of football during skeletal growth have been linked to cam morphology development.(22,313) We did not establish these factors in this study and differing values between groups may influence the prevalence of cam morphology in each of the study groups.

Hip/groin pain can emanate from intra- and extra-articular conditions.(11,41,204) We included football players with self-reported hip/groin pain and did not assess clinical entities known to be present in football players, such as adductor-, iliopsoas-, pubic- and inguinal-related groin pain. These conditions may have been present in football players with hip/groin pain in our study and contributed to their symptoms. The relationship between these conditions and hip joint imaging findings should be the focus of future studies. Football players with hip/groin pain had a positive FADIR test. The FADIR test is a recommended clinical test for FAI syndrome and other causes of hip-related pain.(12,44,204) However, its limited specificity means that some football players might have had hip/groin pain that did not originate from an intra-articular condition.

Although this study was a predominately male cohort (80% in symptomatic and 75% in control group), we are the first to report the prevalence of hip joint imaging findings in female football players with hip/groin pain. The lower number of females may have prevented us from determining differences between symptom groups. Further large-scale studies of women are needed to understand the relationship between imaging findings and pain.

9.6.4. Hip/groin pain-specific patient-reported outcome measures

The HAGOS and iHOT33 are recommended PROMs for young and middle-aged people with hip and/or groin complaints.(189,298) Despite this, the construct and content validity of the iHOT33 in a non-surgical cohort is still to be clarified.(189) A relationship may possibly exist between hip joint imaging findings and PROMs that measure different dimensions (e.g., intensity and unpleasantness) of hip/groin pain and/or symptoms.

9.7. Final summary and thesis conclusions

Hip/groin pain is a common complaint in football players. Hip joint imaging findings are used alongside symptoms and clinical signs to diagnose hip-related pain. Hip-related pain may represent a precursor to hip OA in football players. Before this thesis, the relationship between hip joint imaging findings and hip/groin pain was unknown in active football players.

Football players both with and without hip/groin pain had a high prevalence of early hip OA features. Higher SHOMRI and labral scores and cartilage damage of greater severity were found in football players with hip/groin pain, but there was no a relationship between OA features and iHOT33 or HAGOS.

The size and prevalence of bony hip morphology did not differ in football players with and without hip/groin pain. In female football players, higher alpha angle values were present in those with hip/groin pain, and greater acetabular coverage was related to HAGOS-P. The size of the alpha angle did not correlate with iHOT33 or HAGOS responses.

Cam morphology (size and presence) was associated with early hip OA features, specifically cartilage defects and labral tears. The association between cam morphology and early hip OA features (severity or location) was no greater in football players with hip/groin pain than those without pain. This suggests a complex relationship between cam morphology, early hip OA, and hip/groin pain in football players. The long-term implications of cam morphology on joint structure need to be further investigated in longitudinal studies.

THESIS APPENDICES

Appendix 1. Ethics approval letter for football players with hip/groin pain (La Trobe University).

LA TROBE UNIVERSITY

University Human Ethics Committee

RESEARCH OFFICE

MEMORANDUM

To: **Dr Kay Crossley, School of Allied Health, College of Science, Health and Engineering**

From: **Senior Human Ethics Officer, La Trobe University Human Ethics Committee**

Subject: **Review of Human Ethics Committee Application No. 15-019**

Title: **Femoroacetabular impingement and early osteoarthritis**

Date: **4 June 2015**

Thank you for your recent correspondence in relation to the research project referred to above. The project has been assessed as complying with the *National Statement on Ethical Conduct in Human Research*. I am pleased to advise that your project has been granted ethics approval and you may commence the study now.

The project has been approved from the date of this letter until 1 June 2020.

Please note that your application has been reviewed by a sub-committee of the University Human Ethics Committee (UHEC) to facilitate a decision before the next Committee meeting. This decision will require ratification by the UHEC and it reserves the right to alter conditions of approval or withdraw approval at that time. You will be notified if the approval status of your project changes. The UHEC is a fully constituted ethics committee in accordance with the National Statement under Section 5.1.29.

The following standard conditions apply to your project:

- **Limit of Approval.** Approval is limited strictly to the research proposal as submitted in your application while taking into account any additional conditions advised by the UHEC.

- **Variation to Project.** Any subsequent variations or modifications you wish to make to your project must be formally notified to the UHEC for approval in advance of these modifications being introduced into the project. This can be done using the appropriate form: *Modification to Project – Human Ethics* which is available on the Human Ethics website at http://www.latrobe.edu.au/researchers/ethics/human-ethics If the UHEC

considers that the proposed changes are significant, you may be required to submit a new application form for approval of the revised project.

- **Adverse Events.** If any unforeseen or adverse events occur, including adverse effects on participants, during the course of the project which may affect the ethical acceptability of the project, the Chief Investigator must immediately notify the UHEC Executive Officer. An *Adverse Event Form – Human Ethics* is available at the Research Services website (see above address). Any complaints about the project received by the researchers must also be referred immediately to the UHEC Executive Officer.

- **Withdrawal of Project.** If you decide to discontinue your research before its planned completion, you must advise the UHEC and clarify the circumstances.

- **Monitoring.** All projects are subject to monitoring at any time by the University Human Ethics Committee.

- **Annual Progress Reports.** If your project continues for more than 12 months, you are required to submit a Progress Report annually, **on or just prior to 12 February**. The form is available on the Research Office website (see above address). Failure to submit a Progress Report will mean approval for this project will lapse.

- **Auditing**. An audit of the project may be conducted by members of the UHEC.

- **Final Report.** A Final Report (see above address) is required within six months of the completion of the project or by **1 December 2020.**

If you have any queries on the information above or require further clarification please email: **humanethics@latrobe.edu.au** or contact me by phone.

On behalf of the University Human Ethics Committee, best wishes with your research!

Kind regards,

Ms Sara Paradowski
Senior Human Ethics Officer
Executive Officer – University Human Ethics Committee
Ethics and Integrity / Research Office
La Trobe University Bundoora, Victoria 3086
P: (03) 9479 – 1443 / F: (03) 9479 - 1464
http://www.latrobe.edu.au/researchers/ethics/human-ethics

Appendix 2. Ethics approval letter for football players without hip/groin pain (La Trobe University).

Application HEC16-045 - Application finalised as Approved

Dear Kay Crossley,

The following project has been assessed as complying with the National Statement on Ethical Conduct in Human Research. I am pleased to advise that your project has been granted ethics approval and you may commence the study.

Application ID: HEC16-045

Application Status/Committee: Finalised - Approved

Project Title: Normative Lower Limb Biomechanics Study

Chief Investigator: Kay Crossley
Other Investigators: Harvi Hart, Kate Croft, Peter Lawrenson, Joshua Heerey, Dr Anthony Schache, Joanne Kemp, Adam Semciw, Ebonie Rio, Sean Docking, Tania Pizzari, Jade Tan, Kane Middleton, Ms Brooke E Howells, Mr Matthew King, Hylton Menz, Denise Jones

Date of Approval: **13/07/2016**
Date of Ethics Approval Expiry: **31/12/2018**

The following standard conditions apply to your project:

- **Limit of Approval.** Approval is limited strictly to the research proposal as submitted in your application.

- **Variation to Project.** Any subsequent variations or modifications you wish to make to your project must be formally notified for approval in advance of these modifications being introduced into the project.

- **Adverse Events.** If any unforeseen or adverse events occur the Chief Investigator must immediately notify the UHEC immediately. Any complaints about the project received by the researchers must also be referred immediately to the UHEC.

- **Withdrawal of Project**. If you decide to discontinue your research before its planned completion, you must inform the relevant committee and complete a Final Report form.

- **Monitoring**. All projects are subject to monitoring at any time by the University Human Ethics Committee.

- **Annual Progress Reports**. If your project continues for more than 12 months, you are required to submit a Progress Report annually**, on or just prior to 12 February**. The form is available on the Research Office website. Failure to submit a Progress Report will mean approval for this project will lapse.

- **Auditing**. An audit of the project may be conducted by members of the UHEC.

- **Final Report**. A Final Report (see above address) is required within six months of the completion of the project.

You may log in to Research Master (https://rmenet.latrobe.edu.au) to view your application.

If you have any further questions, please contact the:
UHEC at humanethics@latrobe.edu.au
SHE College Human Ethics Sub-Committee at chesc.she@latrobe.edu.au
ASSC College Human Ethics Sub-Committee at chesc.assc@latrobe.edu.au

Appendix 3. Ethics approval letter for football players with hip/groin pain (The University of Queensland).

THE UNIVERSITY OF QUEENSLAND

Institutional Human Research Ethics Approval

Project Title:	Femoroacetabular Impingement and Early Osteoarthritis
Chief Investigator:	Prof Kay Crossley
Supervisor:	None
Co-Investigator(s):	Dr Adam Semciw, Dr Joanne Kemp, Prof Marcus Pandy, Dr Anthony Schache
School(s):	School of Allied Health, College of Science, Health and Engineering, La Trobe University; UQ School of Health and Rehabilitation Sciences
Approval Number:	2015000916
Granting Agency/Degree:	NHMRC
Duration:	1st June 2020

Comments/Conditions:

Expedited review on the basis of approval from La Trobe University HREC dated 04/06/2015

Note: if this approval is for amendments to an already approved protocol for which a UQ Clinical Trials Protection/Insurance Form was originally submitted, then the researchers must directly notify the UQ Insurance Office of any changes to that Form and Participant Information Sheets & Consent Forms as a result of the amendments, before action.

Name of responsible Committee:
Medical Research Ethics Committee
This project complies with the provisions contained in the *National Statement on Ethical Conduct in Human Research* and complies with the regulations governing experimentation on humans.

Name of Ethics Committee representative:
Professor Bill Vicenzino
Chairperson
Medical Research Ethics Committee

Signature _____ Date 12 JAN 2015

Appendix 4. Ethics approval letter for football players without hip/groin pain (The University of Queensland).

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

Human Ethics Research Office

Cumbrae-Stewart Building #72
The University of Queensland
St Lucia, QLD 4072

CRICOS PROVIDER NUMBER 00025B

30 January 2017

Prof Kay Crossley, Peter Lawrenson

Dear Peter,

Clearance Number: 2016001694 / HEC16-045
Project Title: "Normative Lower Limb Biomechanics Study"

Following administrative review of the human research ethics approval from the La Trobe University Human Research Ethics Committee, I am pleased to advise that, as the University of Queensland's authorised delegate for the University of Queensland's Human Research Ethics Committees A & B, approval is granted for this project.

The approved documents include:

Document	Version	Date
La Trobe University Human Research Ethics Approval		17/05/2016
Appendix 1 Research Study Radiation Dose and Risk Assessment report		10/04/2015
Appendix 2 Participant Information Statement		No date
Appendix A Participant Information Statement		No date
Appendix B La Trobe University Participant Consent Form		No date
La Trobe University Application		14/07/2016
La Trobe University Human Research Ethics Modification Approval		12/09/2016
La Trobe University Modification Form		No date

This project has been approved to 31st December 2018.

We would like to take this opportunity to remind you that, should any modifications be made to this project, they will need to be approved by the lead human research ethics committee

Address: Human Research Ethics Office
Cumbrae-Stewart Building #72
The University of Queensland
St Lucia, QLD 4072
E humanethics@research.uq.edu.au
W www.uq.edu.au/research/integrity-compliance/human-ethics

Appendix 5. Patient information statement used for football players with hip/groin pain (La Trobe University).

School of Allied Health
College of Science, Health and Engineering
La Trobe University

Participant Information Statement

Project Title: **FEMOROACETABULAR IMPINGEMENT AND EARLY OSTEOARTHRITIS.**

Investigators:

1. Prof Kay Crossley School of Allied Health. College of Science, Health and Engineering. La Trobe University. k.crossley@latrobe.edu.au

2. Dr Adam Semciw School of Health and Rehabilitation Sciences, The University of Queensland. A.semciw@uq.edu.au

3. Dr Joanne Kemp The Australian Centre for Research into Injury in Sport and its Prevention, Federation University, j.kemp@federation.edu.au

4. Prof Marcus Pandy Melbourne School of Engineering, The University of Melbourne, pandym@uunimelb.edu.au

5. Dr Anthony Schache Melbourne School of Engineering, The University of Melbourne a.schache@unimelb.edu.au

6. Josh Heerey School of Allied Health. College of Science, Health and Engineering. La Trobe University j.heerey@latrobe.edu.au

7. Matthew King School of Allied Health. College of Science, Health and Engineering. La Trobe University m.king@latrobe.edu.au

8. Denise Jones School of Allied Health. College of Science, Health and Engineering. La Trobe University 18772915@students.latrobe.edu.au

9. Mark Scholes School of Allied Health. College of Science, Health and Engineering. La Trobe University M.Scholes@latrobe.edu.au

We invite you to participate in our research project "Femoroacetabular impingement and early osteoarthritis". This project is collaboration between La Trobe University, The University of Queensland and The University of Melbourne. We would like to give you some background information on why we think this project is important and on what we would like you to do if you decide to participate.

What is this study about and why is it important?

Femoroacetebular impingement (FAI) is a common cause of hip and groin pain in active young adults and affects up to 25% of the general population. It is characterised by extra bone formation at the edge of the hip and is known as a cam-deformity. During motion, the cam deformity can cause further damage to the hip. The aims of this study are to (i) evaluate changes in hip joint structure over 2 years; and (ii) determine if factors such as hip joint force, hip muscle strength and hip joint range predict worsening of hip structure over 2 years in people with FAI. This knowledge may help to develop targeted intervention strategies for managing this condition in the future.

What does the research involve?

Once screened for eligibility, you will have an X-ray and MRI of your pelvis and hip and attend either La Trobe University or The University of Queensland for your baseline clinical assessment. This assessment process will be completed again 2 years later (excluding the x-ray). At the completion of each testing session, you will be partially reimbursed $100 for time and travel expenses. The total time commitment will be approximately 4hrs at base line and 3-4hrs at the follow up assessment. In addition, you will be asked to complete a series of mini questionnaires each month. These will be sent via text or email and will be less than 5minutes in duration.

The baseline and follow-up assessment will be performed at no cost to you. Both consist of:

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CRICOS Provider 00115M

- Questionnaires, including:
  - Age, gender, occupational and sporting history, mechanism of injury, symptom duration, rehabilitation, medication use, and family history of OA.
  - Previous treatment for hip pain including (i) use of treatment modalities to increase joint range (may include massage, other soft tissue treatments, joint mobilisation, acupuncture and dry needling); (ii) exercise programs to improve hip muscle strength (may include home programs, gym programs or other).
  - Your expectations and values regarding your condition and its management.
  - Physical activity (type, frequency and dosage)
  - Age that you started playing sport
  - Type and level of sport you have played previously
  - Hip-related pain and quality of life.
  - Area of pain will be determined through drawing on a high resolution body chart (navigate pain software).
- Physical testing- Tests of hip muscle strength and range of motion and area pain
  - The maximal strength of your lower limb muscles will be measured using a special hand-held device and an isometric pulling device. The examiner will ask you to push or pull against it, as hard as you can, in up to eight directions. Following the assessment, you will be asked via email to complete the questionnaires outlined above. You may ask for a copy of your assessment results.
  - Range of motion of your lower limb will be measured using a special hand held device. You will be asked to move your leg in different direction while the examiner holds it on different sections of your leg. You may ask for a copy of your assessment results.
  - The maximal power of you lower limb muscles will be measured using a counter movement jump. The examiner will ask you to perform a jump of maximal height from a semi-squatting position. You may ask for a copy of you assessment results
  - Assessment of the hip muscles, tendons and bony areas of the pelvis will be undertaken to determine the location of pain. This will require the examiner to palpate specific muscles and joints around the hip and pelvis to determine if they are painful. You may ask for a copy of the assessment results.
- Biomechanics testing- Measures of hip joint force
  - Measurements of hip joint force during tasks such as walking, jogging, squatting, going up and down steps will be taken. For the measurements, you will be required to change into shorts and singlet. You may either bring your own shorts or we can provide you with some. Reflective skin markers and electrodes will be attached to your skin at various sites such as the ankle, knee, hip and trunk as well as over the muscles of your leg, and will aid in the visualisation of joint movement while you walk. You may be videoed during these tasks.
- Magnetic resonance imaging (MRI) and X-ray scans:
  - You will undergo the x-ray and MRI assessment at Imaging at Olympic Park (Melbourne) or Queensland X-Ray (Brisbane). This will take approximately one hour of your time. The X-ray will be completed at baseline only.

The physical and biomechanical testing will be completed at the physiotherapy department of either La Trobe University in Melbourne, or the University of Queensland in Brisbane. These measures will be completed at baseline and the 2-year follow up, and will take approximately 2-3 hours of your time.

Why were you chosen for this research?

You can participate in this study if you are aged between 18 and 50 years of age, have symptoms indicative of impingement, which may include gradual onset of hip pain (may radiate to outside of your leg or groin), that is aggravated by prolonged sitting or hip movements (such as squatting, twisting, stair climbing, running).

You are not eligible to participate in this study if you (i) are not fluent in written and spoken English; or (ii) have planned to have lower-limb surgery in the following 2 years (e.g. arthroscopy); or (iii) have another significant hip condition (e.g. trauma, rheumatoid arthritis, congenital dislocation of the hip Perthes disease, subluxation, osteochondritis dissecans, fracture, septic arthritis, bursitis or tendinitis); or (iv) have any contraindications to magnetic resonance (MR) imaging; or (v) have a physical inability to undergo physical testing procedures; or (vi) are pregnant, might be pregnant or are breast feeding (as you will need to have an X-ray).

Consenting to participate in the project and withdrawing from the research

Before you can participate in the study you will be asked to read this participant information statement and sign a consent form indicating you have understood what the study is about and that you agree to participate. You have a right to withdraw from further participation at any stage without disadvantages, penalties or adverse consequences. Specifically, this is will not impact upon any relationships with the University or and affiliated clinics/sporting clubs.

What are the possible risks of participating in this study?

X-ray- You will be asked to have an X-ray of your hip to confirm eligibility. This involves exposure to a very small amount of radiation from X-Ray imaging. As part of everyday living, everyone is exposed to naturally occurring background radiation and receives a dose of about 2 millisieverts (mSv) each year. The effective dose from the x-rays of your hip is about 0.7 mSv. At this dose level, no harmful effects of radiation have been demonstrated, as any effect is too small to measure. The risk is believed to be very low.

MRI- There is a side effect related to the use of MRI in individuals with some metal in their body. Thus it is imperative that you inform the investigator of your full medical history and of previous surgical procedures and any metal implants. You will be given a safety screening form to complete to ensure that it is safe for you to be scanned by the MRI machine. If the practitioner who is assessing your MRI scan believes that you have an abnormal finding that is potentially significant, you will be notified and referred to an appropriate practitioner for further management and investigation. There is no exposure to radiation with MRI scans.

It is important to be aware that with any imaging investigation there is a small chance of a previously unknown medical condition being detected. In the unlikely event that this occurs, we will contact you directly and inform you of the findings. Should you require further medical review, we will also organise a referral to your chosen GP. It must be emphasized that the purpose of this study is to investigate the progression of Femoroacetabular impingement over time and not to identify other potential medical conditions. The investigators will ensure the participant is made aware of any incidental findings reported on by the consulting radiologist, which are outside of the primary scope of the study. However neither they, the radiologist, nor the Universities involved, will be held accountable if a medical condition exists that is not detected during the process.

Physical and biomechanical testing- The physical tests are routinely performed by physiotherapists and are not associated with any risks. You may experience a small amount of discomfort in the joints or muscles during the physical examination. Please report to the researcher any undue discomfort or pain experienced during the testing. If the pain or discomfort is deemed to be excessive by yourself or the investigators, testing will cease.

If required, emergency procedures will be used to deal with any medical event that arises during the testing. The physiotherapy departments and on-call security have documented procedures for emergencies. This includes annual St John's ambulance CPR training and appropriate management of fire for all staff.

School of Allied Health
College of Science, Health and Engineering
La Trobe University

What are the possible benefits of participating in this study?

There are no direct benefits in completing this study. However your participation will inform researchers and clinicians of possible risk factors that may predict deterioration of this condition. This information can be used to direct targeted treatment in future.

What will happen to the results?

The results of this project will appear in journal publications and in conference presentations, but you will not be able to be identified in any of these reports. With the participants consent, still and video images may be taken during aspects of the biomechanical and physical testing procedures. These images may be used in future for professional training purposes at Universities, or presentations at conferences related to the testing procedures used in this study. All images will be edited to prevent facial recognition for de-identification purposes. Data may also be used by members of this research team in future projects to compare with results from similar studies relating to the same testing procedures.

Results from the study will be confidential and only accessible by the researchers named above. No-one other than the investigators will have access to the data. No findings that could identify you will be published and access to individual results is restricted to the investigators. All data and results will be handled in a strictly confidential manner, under guidelines set out by the National Health and Medical Research Council. Data will be kept in a password protected computer located at La Trobe University Health Sciences 3 building, gait laboratory. Hard copies of questionnaires will be kept in a locked filing cabinet in the office of Prof Kay Crossley (room 521; 5th Floor, Health Sciences 3) at La Trobe University. Data will be stored for at least 5 years after completion of the study in the Health Sciences storage vault, Building 3, level 1.

Furthermore, results of the experiment will be made available to you upon request. This may entail a mailing of results to your home residence, or if you prefer, a discussion with one of the investigators in person. If a participant choses to withdraw from the study they may opt to have their data deleted, irrespective of the timing of their withdrawal.

Funding

Funding for this project has been kindly provided by the National Health and Medical Research Council of Australia (NHMRC).

Who can I contact if I have any questions?

Questions concerning the procedure and/or rationale used in this investigation are welcome at any time. Please ask for clarification of any point, which you feel, is not explained to your satisfaction. Your initial contact is the person conducting the experiment (Professor Kay Crossley, 9479 3902 or k.crossley@latrobe.edu.au).

Complaints

If you have any complaints or queries that the researcher has not been able to answer to your satisfaction, you may contact the Ethics Liaison Officer, Faculty of Health Sciences Ethics Committee, La Trobe University, Victoria, 3086, (ph: 94791443, email: humanethics@latrobe.edu.au). FHEC reference number 15-019

Thank you

Prof Kay Crossley, Dr Adam Semciw, Dr Joanne Kemp, Prof Marcus Pandy, Dr Anthony Schache

Appendix 6. Patient information statement used for football players without hip/groin pain (La Trobe University).

LA TROBE UNIVERSITY
School of Allied Health
College of Science, Health and Engineering
La Trobe University

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

THE UNIVERSITY OF MELBOURNE

Participant Information Statement

Project Title:	NORMATIVE LOWER LIMB BIOMECHANICS STUDY.
Chief Investigator:	**Prof Kay Crossley** School of Allied Health. College of Science, Health and Engineering. La Trobe University. k.crossley@latrobe.edu.au
Investigators:	Pros Hylton Menz, Dr Anthony Schache, Dr Joanne Kemp, Dr Adam Semciw, Dr Harvi Hart, Dr Ebonie Rio, Dr Sean Docking, Dr Kane Middleton, Dr Tania Pizzari, Dr Jodie McClelland, Matthew King, Joshua Heerey, Peter Lawrenson, Kate Croft, Jade Tan, Denise Jones, Brooke Howells and Mark Scholes

We invite you to participate in our research project "Normative Lower Limb Biomechanics Study". This project is collaboration between La Trobe University, The University of Queensland and The University of Melbourne. We would like to give you some background information on why we think this project is important and on what we would like you to do if you decide to participate.

What is this study about and why is it important?

The way in which the human body moves during different daily activities has been shown to contribute to the development and exacerbation of different of different lower limb musculoskeletal conditions (such as arthritis). The main aim of this study is to develop a data base of information of biomechanics, strength and range of motion of the lower limb, in adults with no pathology of their lower limbs. This data will be used to compare against the biomechanics of adults with known lower limb pathology (such as hip or knee arthritis) to determine their differences and similarities.

What does the research involve?

Once screened for eligibility, you will have an MRI of your pelvis and hip or your knee and attend either La Trobe University or The University of Queensland for your baseline clinical assessment. At the completion of the testing session, you will be partially reimbursed $50 for time and travel expenses. The total time commitment will be approximately 4hrs.

This assessment will comprise of:

- Questionnaires, including:
  - Age, gender, occupational and sporting history, injury history, medication use, and family history of OA.
  - Physical activity (type, frequency and dosage)
  - Age that you started playing sport
  - Type and level of sport you have played previously
- Physical testing- Tests of hip and lower limb muscle strength and range of motion
  - The maximal strength of your lower limb muscles will be measured using a special hand-held device and an isometric pulling device. The examiner will ask you to push or pull against it, as hard as you can. You may ask for a copy of your assessment results.
  - Range of motion of your lower limb will be measured using a special hand held device. You will be asked to move your leg in different direction while the examiner holds it on different sections of your leg. You may ask for a copy of your assessment results.
  - The maximal power of you lower limb muscles will be measured using a counter movement jump. The examiner will ask you to perform a jump of maximal height from a semi-squatting position. You may ask for a copy of you assessment results.

- Biomechanics testing-
  - Measurements of your lower limb biomechanics such as walking, jogging, squatting, hopping, changing direction and going up and down steps will be taken. For the measurements, you will be required to change into shorts and singlet. You may either bring your own shorts or we can provide you with some. Reflective skin markers and electrodes will be attached to your skin at various sites such as the ankle, knee, hip and trunk as well as over the muscles of your leg, and will aid in the visualisation of joint movement while you walk. You may be videoed during these tasks
  - You may be asked to wear a fit bit for 30 days after the initial day of testing at the University. This it to gain information on your participation and exercise habits, exercise intensity, sleep habits, steps taken per day and calories burnt. You will be asked to post the fitbit back to the researchers at the conclusion of the 30 days in a reply paid envelope.
- Magnetic resonance imaging (MRI):
  - You may be asked to undergo an MRI of either your hip or your knee at Imaging at Olympic Park (Melbourne) or Q-Scan (Brisbane). This will take approximately one hour of your time.
- *X-ray-*
  - You will be asked to have an X-ray of your hip to confirm eligibility. This involves exposure to a very small amount of radiation from X-Ray imaging. As part of everyday living, everyone is exposed to naturally occurring background radiation and receives a dose of about 2 millisieverts (mSv) each year. The effective dose from the x-rays of your hip is about 0.7 mSv. At this dose level, no harmful effects of radiation have been demonstrated, as any effect is too small to measure. The risk is believed to be very low.

The physical and biomechanical testing will be completed at the physiotherapy department of either La Trobe University in Melbourne, or the University of Queensland in Brisbane. These measures will take approximately 3 hours of your time.

Why were you chosen for this research?

You can participate in this study if you are aged between 18 and 50 years of age and you have not have a major injury or trauma to your lower limbs or back. You are not eligible to participate in this study if you (i) are not fluent in written and spoken English; or (ii) have significant lower limb condition (e.g. trauma, rheumatoid arthritis, congenital dislocation of the hip, Perthes disease, subluxation, osteochondritis dissecans, fracture, septic arthritis, bursitis or tendinitis); or (iv) have any contraindications to magnetic resonance (MR) imaging; or (v) have a physical inability to undergo physical testing procedures; or (vi) are pregnant, might be pregnant or are breast feeding.

Consenting to participate in the project and withdrawing from the research

Before you can participate in the study you will be asked to read this participant information statement and sign a consent form indicating you have understood what the study is about and that you agree to participate. You have a right to withdraw from the research at any time, up to four weeks following the completion of your participation iin the research, without disadvantages, penalties or adverse consequences. Specifically, this is will not impact upon any relationships with the University or and affiliated clinics/sporting clubs.

What are the possible risks of participating in this study?

MRI- There is a side effect related to the use of MRI in individuals with some metal in their body. Thus it is imperative that you inform the investigator of your full medical history and of previous surgical procedures and any metal implants. You will be given a safety screening form to complete to ensure that it is safe for you to be scanned by the MRI machine. If the practitioner who is assessing your MRI scan believes that you have an abnormal finding that is potentially significant, you will be notified and referred to an appropriate practitioner for further management and investigation. There is no exposure to radiation with MRI scans.

It is important to be aware that with any imaging investigation there is a small chance of a previously unknown medical condition being detected. In the unlikely event that this occurs, we will contact you directly and inform you of the findings. Should you require further medical review, we will also organise a referral to your chosen GP. It must be emphasized that the purpose of this study is to investigate the lower limb biomechanics and not to identify other potential medical conditions. While we will ensure that you are made aware of any incidental findings reported on by the consulting radiologist, neither the radiologist, nor the Universities involved, will be held accountable if a medical condition exists that is not detected during the process.

Physical and biomechanical testing- The physical tests are routinely performed by physiotherapists and are not associated with any risks. You may experience a small amount of discomfort in the joints or muscles during the physical examination. Please report to the researcher any undue discomfort or pain experienced during the testing. If the pain or discomfort is deemed to be excessive by yourself or the investigators, testing will cease.

If required, emergency procedures will be used to deal with any medical event that arises during the testing. The physiotherapy departments and on-call security have documented procedures for emergencies. This includes annual St John's ambulance CPR training and appropriate management of fire for all staff.

What are the possible benefits of participating in this study?

There are no direct benefits in completing this study. However your participation will inform researchers and clinicians of the biomechanics of different tasks in individuals with no lower limb pathology. This information will assist in identifying risk factors in different conditions of the lower limb and can be used to direct targeted treatment in future.

What will happen to the results?

The results of this project will appear in journal publications and in conference presentations, but you will not be able to be identified in any of these reports. With your consent, still and video images may be taken during aspects of the biomechanical and physical testing procedures. These images may be used in future for professional training purposes at Universities, or presentations at conferences related to the testing procedures used in this study. All images will be edited to prevent facial recognition for de-identification purposes. Data will held and preserved indefinitely by the research team for use in future projects to compare with results from similar studies relating to the same testing procedures.

Results from the study will be confidential and only accessible by the researchers named above. No-one other than the investigators will have access to the data. No findings that could identify you will be published and access to individual results is restricted to the investigators. All data and results will be handled in a strictly confidential manner, under guidelines set out by the National Health and Medical Research Council. Data will be kept in a password protected computer located at La Trobe University Health Sciences 3 building, gait laboratory. Hard copies of questionnaires will be kept in a locked filing cabinet in the office of Prof Kay Crossley (room 508, 5th Floor, Health Sciences 3) at La Trobe University. Data will be stored for at least 5 years after completion of the study in the Health Sciences storage vault, Building 3, level 1.

Furthermore, the data which is collected on you and the results of the experiment will be made available to you upon request. This may entail a mailing of results to your home residence, or if you prefer, a discussion with one of the investigators in person." If you chose to withdraw from the study, within four weeks of the conclusion of your participation, your data will be deleted.

Funding
Funding for this project has been kindly provided by the National Health and Medical Research Council of Australia (NHMRC).

Who can I contact if I have any questions?

Questions concerning the procedure and/or rationale used in this investigation are welcome at any time. Please ask for clarification of any point, which you feel, is not explained to your satisfaction. Your initial contact is the person conducting the experiment (Professor Kay Crossley, 9479 3902 or k.crossley@latrobe.edu.au).

Complaints

School of Allied Health
College of Science, Health and Engineering
La Trobe University

If you have any complaints or queries that the researcher has not been able to answer to your satisfaction, you may contact the Ethics Liaison Officer, Faculty of Health Sciences Ethics Committee, La Trobe University, Victoria, 3086, (ph: 94791443, email: humanethics@latrobe.edu.au). HEC reference number HEC16-045

Thank you

Prof Kay Crossley

Appendix 7. Patient information statement used for football players with hip/groin pain (The University of Queensland).

School of Allied Health
College of Science, Health and Engineering
La Trobe University

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

THE UNIVERSITY OF MELBOURNE

Participant Information Statement

Project Title: **FEMOROACETABULAR IMPINGEMENT AND EARLY OSTEOARTHRITIS (FORCe).**

Investigators:

1. Prof Kay Crossley, School of Allied Health. College of Science, Health and Engineering. La Trobe University. k.crossley@latrobe.edu.au

2. Dr Adam Semciw, School of Health and Rehabilitation Sciences, The University of Queensland. A.semciw@uq.edu.au

3. Dr Joanne Kemp, The Australian Centre for Research into Injury in Sport and its Prevention, Federation University, j.kemp@federation.edu.au

4. Prof Marcus Pandy, Melbourne School of Engineering, The University of Melbourne, pandym@uunimelb.edu.au

5. Dr Anthony Schache, Melbourne School of Engineering, The University of Melbourne a.schache@unimelb.edu.au

6. Prof Paul Hodges, School of Health and Rehabilitation Sciences, The University of Queensland. p.hodges@uq.edu.au

7. Prof Bill Vicenzino, School of Health and Rehabilitation Sciences, The University of Queensland. b.vicenzino@uq.edu.au

8. Mr Peter Lawrenson, School of Health and Rehabilitation Sciences, the University of Queensland. p.lawrenson@uq.edu.au

We invite you to participate in our research project "Femoroacetabular impingement and early osteoarthritis". This project is collaboration between La Trobe University, The University of Queensland and The University of Melbourne. We would like to give you some background information on why we think this project is important and on what we would like you to do if you decide to participate.

What is this study about and why is it important?

Femoroacetebular impingement (FAI) is a common cause of hip and groin pain in active young adults and affects up to 25% of the general population. It is characterised by extra bone formation at the edge of the hip and is known as a cam-deformity. During motion, the cam deformity can cause further damage to the hip. The aims of this study are to (i) evaluate changes in hip joint structure over 2 years; and (ii) determine if factors such as hip joint force, hip muscle strength and hip joint range predict worsening of hip structure over 2 years in people with FAI. This knowledge may help to develop targeted intervention strategies for managing this condition in the future.

What does the research involve?

Once screened for eligibility, you will have an X-ray and MRI of your pelvis and hip and attend either La Trobe University or The University of Queensland for your baseline clinical assessment. This assessment process will be completed again 2 years later (excluding the x-ray). At the completion of each testing session, you will be partially reimbursed for time and travel expenses. The total time commitment will be approximately 4hrs at base line and 3-4hrs at the follow up assessment. In addition, you will be asked to complete a series of mini questionnaires each month. These will be sent via text or email and will be less than 5minutes in duration.

The baseline and follow-up assessment will be performed at no cost to you. Both consist of:

- Questionnaires, including:
  - Age, gender, occupational and sporting history, mechanism of injury, symptom duration, rehabilitation, medication use, and family history of osteoarthritis (OA).
  - Previous treatment for hip pain including (i) use of treatment modalities to increase joint range (may include massage, other soft tissue treatments, joint mobilisation, acupuncture

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CRICOS Provider 00115M

and dry needling); (ii) exercise programs to improve hip muscle strength (may include home programs, gym programs or other).
    - Your expectations and values regarding your condition and its management.
    - Physical activity (type, frequency and dosage)
    - Age that you started playing sport
    - Type and level of sport you have played previously
    - Hip-related pain and quality of life.

- Physical testing- Tests of hip muscle strength and range of motion
    - The maximal strength of your lower limb muscles will be measured using a special hand-held device. The examiner will ask you to push against it, as hard as you can, in up to eight directions. Following the assessment, you will be asked via email to complete the questionnaires outlined above. You may ask for a copy of your assessment results.
- Biomechanics testing- Measures of hip joint force
    - Measurements of hip joint force during tasks such as walking, jogging, squatting, going up and down steps will be taken. For the measurements, you will be required to change into shorts and singlet. You may either bring your own shorts or we can provide you with some. Reflective skin markers and electrodes will be attached to your skin at various sites such as the ankle, knee, hip and trunk as well as over the muscles of your leg, and will aid in the visualisation of joint movement while you walk. You may be videoed during these tasks.
- Magnetic resonance imaging (MRI) and X-ray scans:
    - You will undergo the x-ray and MRI assessment at Imaging at Olympic Park (Melbourne) or Queensland X-Ray (Brisbane). This will take approximately one hour of your time. The X-ray will be completed at baseline only.

The physical and biomechanical testing will be completed at the physiotherapy department of either La Trobe University in Melbourne, or the University of Queensland in Brisbane. These measures will be completed at baseline and the 2-year follow up, and will take approximately 2-3 hours of your time.

- Intramuscular Electromyographic testing of muscles of the hip joint
    - Following baseline testing and imaging, participants who demonstrate positive radiological findings for Femoroacetabular impingement will be eligible for a one off additional testing session at the physiotherapy department of the University of Queensland. This will involve intramuscular electromyographic testing of the deep hip muscles. Fine wire electrodes will be inserted into the skin to ascertain the electrical activity of deep muscles close to the hip joint. Testing will take approximately three hours of your time and will involve the completion of tasks such as walking, squatting and lunging.

Why were you chosen for this research?

You can participate in this study if you are aged between 18 and 50 years of age, have symptoms indicative of impingement, which may include gradual onset of hip pain (may radiate to outside of your leg or groin), that is aggravated by prolonged sitting or hip movements (such as squatting, twisting, stair climbing, running).

You are not eligible to participate in this study if you (i) are not fluent in written and spoken English; or (ii) have planned to have lower-limb surgery in the following 2 years (e.g. arthroscopy); or (iii) have another significant hip condition (e.g. trauma, rheumatoid arthritis, congenital dislocation of the hip Perthes disease, subluxation, osteochondritis dissecans, fracture, septic arthritis, bursitis or tendinitis); or (iv) have any contraindications to magnetic resonance (MR) imaging; or (v) have a physical inability to undergo physical testing procedures; or (vi) are pregnant, might be pregnant or are breast feeding (as you will need to have an X-ray); (vii) have other musculoskeletal conditions or pain that has required assessment or management by a health practitioner in the last 3 months; or (vii) have had intra-articular joint injections for the purpose of diagnosis or pain reduction in the last 3 months

Consenting to participate in the project and withdrawing from the research

Before you can participate in the study you will be asked to read this participant information statement and sign a consent form indicating you have understood what the study is about and that you agree to participate. You have a right to withdraw from further participation at any stage without disadvantages, penalties or adverse consequences. Specifically, this is will not impact upon any relationships with the University or and affiliated clinics/sporting clubs.

What are the possible risks of participating in this study?

X-ray- You will be asked to have an X-ray of your hip to confirm eligibility. This involves exposure to a very small amount of radiation from X-Ray imaging. As part of everyday living, everyone is exposed to naturally occurring background radiation and receives a dose of about 2 millisieverts (mSv) each year. The effective dose from the x-rays of your hip is about 0.7 mSv. At this dose level, no harmful effects of radiation have been demonstrated, as any effect is too small to measure. The risk is believed to be very low.

MRI- There is a side effect related to the use of MRI in individuals with some metal in their body. Thus it is imperative that you inform the investigator of your full medical history and of previous surgical procedures and any metal implants. You will be given a safety screening form to complete to ensure that it is safe for you to be scanned by the MRI machine. If the practitioner who is assessing your MRI scan believes that you have an abnormal finding that is potentially significant, you will be notified and referred to an appropriate practitioner for further management and investigation. It is important to be aware that with any imaging investigation there is a small chance of a previously unknown medical condition being detected. In the unlikely event that this occurs, we will contact you directly and inform you of the findings. Should you require further medical review, we will also organise a referral to your chosen GP. It must be emphasized that the purpose of this study is to investigate the progression of your hip pain over time and not to identify other potential medical conditions. While we will ensure that you are made aware of any incidental findings reported on by the consulting radiologist, neither the investigators, the radiologist, nor the Universities involved, will be held accountable if a medical condition exists that is not detected during the process. There is no exposure to radiation with MRI scans.

Physical and biomechanical testing- The physical tests are routinely performed by physiotherapists and are not associated with any risks. You may experience a small amount of discomfort in the joints or muscles during the physical examination. Please report to the researcher any undue discomfort or pain experienced during the testing. If the pain or discomfort is deemed to be excessive by yourself or the investigators, testing will cease.

If required, emergency procedures will be used to deal with any medical event that arises during the testing. The physiotherapy departments and on-call security have documented procedures for emergencies. This includes annual St John's ambulance CPR training and appropriate management of fire for all staff.

Intramuscular Electromyographic Testing –To measure the activity of the deep hip muscles, fine wire or needle electrodes will be inserted into the muscle through the skin. Real-time ultrasound may be used to ensure accurate positioning of the electrodes. The electrode insertion may be accompanied with minor discomfort similar to that experienced with any hypodermic needle insertion. There is a remote risk of infection and standard sterilization procedures will be carried out at all times. Occasionally individuals feel light headed or dizzy after the insertion of the electrode. If this happens please let us know so that we can lie you down to prevent fainting. There is an extremely rare risk that a small piece of the electrode may remain in the muscle however this is harmless.

What are the possible benefits of participating in this study?

There are no direct benefits in completing this study. However your participation will inform researchers and clinicians of possible risk factors that may predict deterioration of this condition. This information can be used to direct targeted treatment in future.

School of Allied Health
College of Science, Health and Engineering
La Trobe University

What will happen to the results?

The results of this project will appear in journal publications and in conference presentations, but you will not be able to be identified in any of these reports. With the participants consent, still and video images may be taken during aspects of the biomechanical and physical testing procedures. These images may be used in future for professional training purposes at Universities, or presentations at conferences related to the testing procedures used in this study. All images will be edited to prevent facial recognition for de-identification purposes. Data may also be used by members of this research team in future projects to compare with results from similar studies relating to the same testing procedures.

Results from the study will be confidential and only accessible by the researchers named above. No-one other than the investigators will have access to the data. No findings that could identify you will be published and access to individual results is restricted to the investigators. All data and results will be handled in a strictly confidential manner, under guidelines set out by the National Health and Medical Research Council. Data will be kept in a password protected computer located at La Trobe University Health Sciences 3 building, gait laboratory. Hard copies of questionnaires will be kept in a locked filing cabinet in the office of Prof Kay Crossley (room 521; 5th Floor, Health Sciences 3) at La Trobe University. Data will be stored for at least 5 years after completion of the study in the Health Sciences storage vault, Building 3, level 1.

Furthermore, results of the experiment will be made available to you upon request. This may entail a mailing of results to your home residence, or if you prefer, a discussion with one of the investigators in person. If a participant choses to withdraw from the study they may opt to have their data deleted, irrespective of the timing of their withdrawal.

*"I (the participant) have read (or, where appropriate, have had read to me) and understood the **participant information statement and consent form**, and any questions I have asked have been answered to my satisfaction. I understand that even though I agree to be involved in this project, I can withdraw from the study at any time, up to four weeks following the completion of my participation in the research. Further, in withdrawing from the study, I can request that no information from my involvement be used. I agree that research data provided by me or with my permission during the project may be included in a thesis, presented at conferences and published in journals on the condition that neither my name nor any other identifying information is used."*

Funding
Funding for this project has been kindly provided by the National Health and Medical Research Council of Australia (NHMRC).

Who can I contact if I have any questions?

Questions concerning the procedure and/or rationale used in this investigation are welcome at any time. Please ask for clarification of any point, which you feel, is not explained to your satisfaction. Your initial contact is the person conducting the experiment (Dr Adam Semciw, contactable on 336 54592 or a.semciw@uq.edu.au).

This study adheres to the Guidelines of the ethical review process of The University of Queensland and the *National Statement on Ethical Conduct in Human Research*. Whilst you are free to discuss your participation in this study with project staff (Dr Adam Semciw, contactable on 336 54592 or a.semciw@uq.edu.au), if you would like to speak to an officer of the University not involved in the study, you may contact the Ethics Coordinator on 3365 3924 (also contactable on humanethics@research.uq.edu.au).

Thank you

Prof Kay Crossley, Dr Adam Semciw, Dr Joanne Kemp, Prof Marcus Pandy, Dr Anthony Schache, Prof Paul Hodges, Prof Bill Vicenzino, Mr Peter Lawrenson

Appendix 8. Patient information statement used for football players without hip/groin pain (The University of Queensland).

Participant Information Statement

Project Title:	NORMATIVE LOWER LIMB BIOMECHANICS STUDY**.**
Chief Investigator:	**Prof Kay Crossley** School of Allied Health. College of Science, Health and Engineering. La Trobe University. k.crossley@latrobe.edu.au
Investigators:	Pros Hylton Menz, Dr Anthony Schache, Dr Joanne Kemp, Dr Adam Semciw, Dr Harvi Hart, Dr Ebonie Rio, Dr Sean Docking, Dr Kane Middleton, Dr Tania Pizzari, Dr Jodie McClelland, Matthew King, Joshua Heerey, Peter Lawrenson, Kate Croft, Jade Tan, Denise Jones and Brooke Howells

We invite you to participate in our research project "Normative Lower Limb Biomechanics Study". This project is collaboration between La Trobe University, The University of Queensland and The University of Melbourne. We would like to give you some background information on why we think this project is important and on what we would like you to do if you decide to participate.

What is this study about and why is it important?

The way in which the human body moves during different daily activities has been shown to contribute to the development and exacerbation of different of different lower limb musculoskeletal conditions (such as arthritis). The main aim of this study is to develop a data base of information of biomechanics, strength and range of motion of the lower limb, in adults with no pathology of their lower limbs. This data will be used to compare against the biomechanics of adults with known lower limb pathology (such as hip or knee arthritis) to determine their differences and similarities.

What does the research involve?

Once screened for eligibility, you will have an MRI of your pelvis and hip or your knee and attend either La Trobe University or The University of Queensland for your baseline clinical assessment. At the completion of the testing session, you will be partially reimbursed $50 for time and travel expenses. The total time commitment will be approximately 4hrs.

This assessment will comprise of:

- Questionnaires, including:
    - Age, gender, occupational and sporting history, injury history, medication use, and family history of OA.

- Physical activity (type, frequency and dosage)
- Age that you started playing sport
- Type and level of sport you have played previously

- Physical testing- Tests of hip and lower limb muscle strength and range of motion
  - The maximal strength of your lower limb muscles will be measured using a special hand-held device. The examiner will ask you to push against it, as hard as you can. You may ask for a copy of your assessment results.
  - Range of motion of your lower limb will be measured using a special hand held device. You will be asked to move your leg in different direction while the examiner holds it on different sections of your leg. You may ask for a copy of your assessment results.

- Biomechanics testing-
  - Measurements of your lower limb biomechanics such as walking, jogging, squatting, hopping, changing direction and going up and down steps will be taken. For the measurements, you will be required to change into shorts and singlet. You may either bring your own shorts or we can provide you with some. Reflective skin markers and electrodes will be attached to your skin at various sites such as the ankle, knee, hip and trunk as well as over the muscles of your leg, and will aid in the visualisation of joint movement while you walk. You may be videoed during these tasks
  - You may be asked to wear a fit bit for 30 days after the initial day of testing at the University. This it to gain information on your participation and exercise habits, exercise intensity, sleep habits, steps taken per day and calories burnt. You will be asked to post the fitbit back to the researchers at the conclusion of the 30 days in a reply paid envelope.
- Magnetic resonance imaging (MRI):
  - You may be asked to undergo an MRI of either your hip or your knee at Imaging at Olympic Park (Melbourne) or Q-Scan (Brisbane). This will take approximately one hour of your time.
- *X-ray*-
  - You will be asked to have an X-ray of your hip to confirm eligibility. This involves exposure to a very small amount of radiation from X-Ray imaging. As part of everyday living, everyone is exposed to naturally occurring background

radiation and receives a dose of about 2 millisieverts (mSv) each year. The effective dose from the x-rays of your hip is about 0.7 mSv. At this dose level, no harmful effects of radiation have been demonstrated, as any effect is too small to measure. The risk is believed to be very low.

The physical and biomechanical testing will be completed at the physiotherapy department of either La Trobe University in Melbourne, or the University of Queensland in Brisbane. These measures will take approximately 3 hours of your time.

Why were you chosen for this research?

You can participate in this study if you are aged between 18 and 50 years of age and you have not have a major injury or trauma to your lower limbs or back. You are not eligible to participate in this study if you (i) are not fluent in written and spoken English; or (ii) have significant lower limb condition (e.g. trauma, rheumatoid arthritis, congenital dislocation of the hip, Perthes disease, subluxation, osteochondritis dissecans, fracture, septic arthritis, bursitis or tendinitis); or (iv) have any contraindications to magnetic resonance (MR) imaging; or (v) have a physical inability to undergo physical testing procedures; or (vi) are pregnant, might be pregnant or are breast feeding.

Consenting to participate in the project and withdrawing from the research

Before you can participate in the study you will be asked to read this participant information statement and sign a consent form indicating you have understood what the study is about and that you agree to participate. You have a right to withdraw from the research at any time, up to four weeks following the completion of your participation iin the research, without disadvantages, penalties or adverse consequences. Specifically, this is will not impact upon any relationships with the University or and affiliated clinics/sporting clubs.

What are the possible risks of participating in this study?

MRI- There is a side effect related to the use of MRI in individuals with some metal in their body. Thus it is imperative that you inform the investigator of your full medical history and of previous surgical procedures and any metal implants. You will be given a safety screening form to complete to ensure that it is safe for you to be scanned by the MRI machine. If the

practitioner who is assessing your MRI scan believes that you have an abnormal finding that is potentially significant, you will be notified and referred to an appropriate practitioner for further management and investigation. There is no exposure to radiation with MRI scans.

It is important to be aware that with any imaging investigation there is a small chance of a previously unknown medical condition being detected. In the unlikely event that this occurs, we will contact you directly and inform you of the findings. Should you require further medical review, we will also organise a referral to your chosen GP. It must be emphasized that the purpose of this study is to investigate the lower limb biomechanics and not to identify other potential medical conditions. While we will ensure that you are made aware of any incidental findings reported on by the consulting radiologist, neither the radiologist, nor the Universities involved, will be held accountable if a medical condition exists that is not detected during the process.

Physical and biomechanical testing- The physical tests are routinely performed by physiotherapists and are not associated with any risks. You may experience a small amount of discomfort in the joints or muscles during the physical examination. Please report to the researcher any undue discomfort or pain experienced during the testing. If the pain or discomfort is deemed to be excessive by yourself or the investigators, testing will cease.

If required, emergency procedures will be used to deal with any medical event that arises during the testing. The physiotherapy departments and on-call security have documented procedures for emergencies. This includes annual St John's ambulance CPR training and appropriate management of fire for all staff.

What are the possible benefits of participating in this study?

There are no direct benefits in completing this study. However your participation will inform researchers and clinicians of the biomechanics of different tasks in individuals with no lower limb pathology. This information will assist in identifying risk factors in different conditions of the lower limb and can be used to direct targeted treatment in future.

What will happen to the results?

The results of this project will appear in journal publications and in conference presentations, but you will not be able to be identified in any of these reports. With your consent, still and

video images may be taken during aspects of the biomechanical and physical testing procedures. These images may be used in future for professional training purposes at Universities, or presentations at conferences related to the testing procedures used in this study. All images will be edited to prevent facial recognition for de-identification purposes. Data will held and preserved indefinitely by the research team for use in future projects to compare with results from similar studies relating to the same testing procedures.

Results from the study will be confidential and only accessible by the researchers named above. No-one other than the investigators will have access to the data. No findings that could identify you will be published and access to individual results is restricted to the investigators. All data and results will be handled in a strictly confidential manner, under guidelines set out by the National Health and Medical Research Council. Data will be kept in a password protected computer located at La Trobe University Health Sciences 3 building, gait laboratory. Hard copies of questionnaires will be kept in a locked filing cabinet in the office of Prof Kay Crossley (room 508, 5th Floor, Health Sciences 3) at La Trobe University. Data will be stored for at least 5 years after completion of the study in the Health Sciences storage vault, Building 3, level 1.

Furthermore, the data which is collected on you and the results of the experiment will be made available to you upon request. This may entail a mailing of results to your home residence, or if you prefer, a discussion with one of the investigators in person." If you chose to withdraw from the study, within four weeks of the conclusion of your participation, your data will be deleted.

Funding

Funding for this project has been kindly provided by the National Health and Medical Research Council of Australia (NHMRC).

Who can I contact if I have any questions?

Questions concerning the procedure and/or rationale used in this investigation are welcome at any time. Please ask for clarification of any point, which you feel, is not explained to your satisfaction. Your initial contact is the person conducting the experiment (Dr Adam Semciw, contactable on 336 54592 or a.semciw@uq.edu.au)

Complaints

If you have any complaints or queries that the researcher has not been able to answer to your satisfaction, you may contact the Ethics Coordinator on 3365 3924 (also contactable on humanethics@research.uq.edu.au)

Thank you

Prof Kay Crossley,

Appendix 9. Informed consent for football players with hip/groin (La Trobe University).

School of Allied Health
College of Science, Health and Engineering
La Trobe University

La Trobe University Human Ethics Committee Participant Consent Form

Project Title: FEMOROACETABULAR IMPINGEMENT AND OSTEOARTHRITIS.

Investigator no.1 **Prof Kay Crossley**
Investigator no.2 **Dr Adam Semciw**
Investigator no.3 **Dr Joanne Kemp**
Investigator no.4 **Prof Marcus Pandy**
Investigator no.5 **Dr Anthony Schache**
Investigator no.6 **Josh Heerey**
Investigator no.7 **Matthew King**
Investigator no.8 **Denise Jones**
Investigator no.9 **Mark Scholes**

I _____ have read and understood the **participant information statement and consent form**, and any questions I have asked have been answered to my satisfaction. I understand that even though I agree to be involved in this project, I can withdraw from the study at any time, up to four weeks following the completion of my participation in the research. Further, in withdrawing from the study, I can request that no information from my involvement be used. I agree that research data provided by me or with my permission during the project may be included in a thesis, presented at conferences and published in journals on the condition that neither my name nor any other identifying information is used.

	Yes	No
I am willing to have photographs and/ or videos taken during the testing session and consent for these images or videos to be used solely for education and research purposes at physiotherapy schools at other universities in Australia and when presentations are made at conferences / workshops in National and International Settings.	☐	☐

Last Name: Given Name:

DOB: Age: Contact Phone number:

Address:

Signature: Date:

Witness name: Date:

Investigator: Date:

Name and phone number of contact person in case of an emergency:

Name: Phone:

Family Doctor: Phone:

	Yes	No
I am willing for the study investigators to arrange a referral to my chosen medical practitioner in the unlikely event of a previously unknown medical condition being discovered during radiological imaging	☐	☐

Subject Signature: Date:

ABN 64 804 735 313
CRICOS Provider 00115M

Appendix 10. Informed consent for football players without hip/groin (La Trobe University and The University of Queensland).

School of Allied Health
College of Science, Health and Engineering
La Trobe University

La Trobe University Human Ethics Committee Participant Consent Form

Project Title: NORMATIVE LOWER LIMB BIOMECHANICS STUDY.

Chief Investigator **Prof Kay Crossley**

Investigators: Prof Hylton Menz, Dr Anthony Schache, Dr Joanne Kemp, Dr Adam Semciw, Dr Harvi Hart, Dr Ebonie Rio, Dr Sean Docking, Dr Kane Middleton, Dr Tania Pizzari, Dr Jodie McClelland, Matthew King, Joshua Heerey, Peter Lawrenson, Kate Croft, Jade Tan, Denise Jones, Brooke Howells and Mark Scholes.

I_____ have read (or, where appropriate, have had read to me) and understood the **participant information statement and consent form**, and any questions I have asked have been answered to my satisfaction. I understand that even though I agree to be involved in this project, I can withdraw from the study at any time, and can withdraw my data up to four weeks following the completion of my participation in the research. Further, in withdrawing from the study, I can request that no information from my involvement be used. I agree that research data provided by me or with my permission during the project may be included in a thesis, presented at conferences and published in journals on the condition that neither my name nor any other identifying information is used.

	Yes	No
I am willing to have photographs and/ or videos taken during the testing session and consent for these images or videos to be used solely for education and research purposes at physiotherapy schools at other universities in Australia and when presentations are made at conferences / workshops in National and International Settings.	☐	☐
I consent for the the information obtained from my involvement in the study be used in future research.	☐	☐

Last Name:		Given Name:
DOB:	Age:	Contact Phone number:
Address:		
Signature:		Date:
Witness name:		

Name and phone number of contact person in case of an emergency:

Name:		Phone:
Family Doctor:		Phone:

	Yes	No
I am willing for the study investigators to arrange a referral to my chosen medical practitioner in the unlikely event of a previously unknown medical condition being discovered during radiological imaging	☐	☐

Subject Signature: Date:

Appendix 11. Informed consent for football players with hip/groin (The University of Queensland).

School of Allied Health
College of Science, Health and Engineering
La Trobe University

The University of Queensland Human Ethics Committee Participant Consent Form

Project Title: FEMOROACETABULAR IMPINGEMENT AND OSTEOARTHRITIS (FORCe)

Investigator no.1 **Prof Kay Crossley**
Investigator no.2 **Dr Adam Semciw**
Investigator no.3 **Dr Joanne Kemp**
Investigator no.4 **Prof Marcus Pandy**
Investigator no.5 **Dr Anthony Schache**
Investigator no.6 **Prof Paul Hodges**
Investigator no.7 **Prof Bill Vicenzino**
Investigator no.8 **Mr Peter Lawrenson**

I _____ have read and understood the **participant information statement and consent form**, and any questions I have asked have been answered to my satisfaction. I understand that even though I agree to be involved in this project, I can withdraw from the study at any time, up to four weeks following the completion of my participation in the research. Further, in withdrawing from the study, I can request that no information from my involvement be used. I agree that research data provided by me or with my permission during the project may be included in a thesis, presented at conferences and published in journals on the condition that neither my name nor any other identifying information is used.

	Yes	No
I am willing to have photographs and/ or videos taken during the testing session and consent for these images or videos to be used solely for education and research purposes at physiotherapy schools at other universities in Australia and when presentations are made at conferences / workshops in National and International Settings.	☐	☐

	Yes	No
I am willing to undertake intramuscular electromyographic investigation of the deep hip muscles. This component of the study will only involve participants who have demonstrated radiological signs of Femoroacetabular impingement with imaging. I have been made aware of the anticipated length of time it will take, and have been informed of the possible risks which may be expected. I can withdraw my consent for this aspect of the study without affecting my involvement in the rest of the study	☐	☐

Last Name:		Given Name:
DOB:	Age:	Contact Phone number:
Address:		
Signature:		Date:
Witness name:		

Name and phone number of contact person in case of an emergency:

Name:		Phone:	
Family Doctor:		Phone:	
I am willing for the study investigators to arrange a referral to my nominated medical practitioner in the unlikely event of a previously unknown medical condition being discovered during radiological imaging		Yes ☐	No ☐
Subject Signature:		Date:	

Appendix 12. International Hip Outcome Tool.

APPENDIX 1

International Hip Outcome Tool (iHOT-33).

QUALITY OF LIFE QUESTIONNAIRE FOR YOUNG, ACTIVE PEOPLE WITH HIP PROBLEMS

INSTRUCTIONS

- These questions ask about the problems you may be experiencing in your hip, how these problems affect your life, and the emotions you may feel because of these problems.
- Please indicate the severity by marking the line below each question with a slash.
  - » If you put a mark on the far **left**, it means that you **feel you are significantly impaired**. For example:

SIGNIFICANTLY IMPAIRED / _____ NO PROBLEMS AT ALL

  - » If you put a mark on the far **right**, it means that you **do not think that you have any problems** with your hip. For example:

SIGNIFICANTLY IMPAIRED _____ / NO PROBLEMS AT ALL

  - » If the mark is placed in the middle of the line, this indicates that you are moderately disabled, or in other words, between the extremes of 'significantly impaired' and 'no problems at all'. It is important to put your mark at either end of the line if the extreme descriptions accurately reflect your situation.

TIP If you don't do an activity, imagine how your hip would feel if you had to try it.

- Please let your answers describe the typical situation in the last **month**.

SECTION 1 | SYMPTOMS AND FUNCTIONAL LIMITATIONS

The following questions ask about symptoms that you may experience in your hip and about the function of your hip with respect to daily activities. Please think about how you have felt most of the time over the past month and answer accordingly.

Q01 How often does your hip/groin ache?

CONSTANTLY _____ NEVER

Q02 How stiff is your hip as a result of sitting/resting during the day?

EXTREMELY STIFF _____ NOT STIFF AT ALL

Q03 How difficult is it for you to walk long distances?

EXTREMELY DIFFICULT _____ NOT DIFFICULT AT ALL

Q04 How much pain do you have in your hip while sitting?

EXTREME PAIN _____ NO PAIN AT ALL

Q05 How much trouble do you have standing on your feet for long periods of time?

SEVERE TROUBLE _____ NO TROUBLE AT ALL

Q06 How difficult is it for you to get up and down off the floor/ground?

EXTREMELY DIFFICULT _____ NOT DIFFICULT AT ALL

Q07 How difficult is it for you to walk on uneven surfaces?

EXTREMELY DIFFICULT _____ NOT DIFFICULT AT ALL

Q08 How difficult is it for you to lie on your affected hip side?

EXTREMELY DIFFICULT _____ NOT DIFFICULT AT ALL

Q09 How much trouble do you have with stepping over obstacles?

SEVERE TROUBLE _____ NO TROUBLE AT ALL

Q10 How much trouble do you have with climbing up/down stairs?

SEVERE TROUBLE _____ NO TROUBLE AT ALL

Q11 How much trouble do you have with rising from a sitting position?

SEVERE TROUBLE _____ NO TROUBLE AT ALL

Q12 How much discomfort do you have with taking long strides?

EXTREME DISCOMFORT _____ NO DISCOMFORT AT ALL

Q13 How much difficulty do you have with getting into and/or out of a car?

EXTREME DIFFICULTY _____ NO DIFFICULTY AT ALL

Q14 How much trouble do you have with grinding, catching or clicking in your hip?

SEVERE TROUBLE _____ NO TROUBLE AT ALL

Q15 How much difficulty do you have with putting on/taking off socks, stockings or shoes?

EXTREME DIFFICULTY _____ NO DIFFICULTY AT ALL

Q16 Overall, how much pain do you have in your hip/groin?

EXTREME PAIN _____ NO PAIN AT ALL

SECTION 2 | SPORTS AND RECREATIONAL ACTIVITIES

The following questions ask about your **hip** when you participate in sports and recreational activities. Please think about how you have felt most of the time over the past **month** and answer accordingly.

Q17 How concerned are you about your ability to maintain your desired fitness level?

EXTREMELY CONCERNED _____ NOT CONCERNED AT ALL

Q18 How much pain do you experience in your hip after activity?

EXTREME PAIN _____ NO PAIN AT ALL

Q19 How concerned are you that the pain in your hip will increase if you participate in sports or recreational activities?

EXTREMELY CONCERNED _____ NOT CONCERNED AT ALL

Q20 How much has your quality of life deteriorated because you cannot participate in sport/recreational activities?

EXTREMELY DETERIORATED _____ NOT DETERIORATED AT ALL

Q21 How concerned are you about cutting/changing directions during your sport or recreational activities?

☐ I do not do this action in my activities

EXTREMELY CONCERNED _____ NOT CONCERNED AT ALL

Q22 How much has your performance level decreased in your sport or recreational activities?

EXTREMELY DECREASED _____ NOT DECREASED AT ALL

SECTION 3 | JOB RELATED CONCERNS

The following questions relate to your hip with respect to your current work. Please think about how you have felt most of the time over the past month and answer accordingly.

☐ I do not work because of my hip *(please skip section)*

☐ I do not work for reasons other than my hip *(please skip section)*

Q23 How much trouble do you have pushing, pulling, lifting or carrying heavy objects at work?

☐ I do not do these actions in my activities

SEVERE TROUBLE _____ NO TROUBLE AT ALL

Q24 How much trouble do you have with crouching/squatting?

SEVERE TROUBLE _____ NO TROUBLE AT ALL

Q25 How concerned are you that your job will make your hip worse?

EXTREMELY CONCERNED _____ NOT CONCERNED AT ALL

Q26 How much difficulty do you have at work because of reduced hip mobility?

EXTREME DIFFICULTY _____ NO DIFFICULTY AT ALL

SECTION 4 | SOCIAL, EMOTIONAL AND LIFESTYLE CONCERNS

The following questions ask about social, emotional and lifestyle concerns that you may feel with respect to your hip problem. Please think about how you have felt most of the time over the past month and answer accordingly.

Q27 How frustrated are you because of your hip problem?

EXTREMELY FRUSTRATED _____ NOT FRUSTRATED AT ALL

Q28 How much trouble do you have with sexual activity because of your hip?

☐ This is not relevant to me

SEVERE TROUBLE _____ NO TROUBLE AT ALL

Q29 How much of a distraction is your hip problem?

EXTREME DISTRACTION _____ NO DISTRACTION AT ALL

Q30 How difficult is it for you to release tension and stress because of your hip problem?

EXTREMELY DIFFICULT _____ NOT DIFFICULT AT ALL

Q31 How discouraged are you because of your hip problem?

EXTREMELY DISCOURAGED _____ NOT DISCOURAGED AT ALL

Q32 How concerned are you about picking up or carrying children because of your hip?

☐ I do not do this action in my activities

EXTREMELY CONCERNED _____ NOT CONCERNED AT ALL

Q33 How much of the time are you aware of the disability in your hip?

CONSTANTLY AWARE _____ NOT AWARE AT ALL

Appendix 13. The Copenhagen Hip and Groin Outcome Score.

HAGOS

Questionnaire concerning hip and/or groin problems

Today's date: _____/_____/_____ Date of birth: _____/_____/_____

Name: _____

INSTRUCTIONS: This questionnaire asks for your view about your hip and/or groin problem. The questions should be answered considering your hip and/or groin function during the **past week**.This information will help us keep track of how you feel, and how well you are able to do your usual activities.

Answer **every** question by ticking the appropriate box. Tick only one box for each question. If a question does not pertain to you or you have not experienced it in the past week please make your "best guess" as to which response would be the most accurate.

Symptoms

These questions should be answered considering your hip and/or groin **symptoms** and difficulties during the **past week**.

S1 Do you feel discomfort in your hip and/or groin?

Never	Rarely	Sometimes	Often	Always
☐	☐	☐	☐	☐

S2 Do you hear clicking or any other type of noise from your hip and/or groin?

Never	Rarely	Sometimes	Often	All the time
☐	☐	☐	☐	☐

S3 Do you have difficulties stretching your legs far out to the side?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

S4 Do you have difficulties taking full strides when you walk?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

S5 Do you experience sudden twinging/stabbing sensations in your hip and/or groin?

Never	Rarely	Sometimes	Often	All the time
☐	☐	☐	☐	☐

Stiffness

The following questions concern the amount of stiffness you have experienced during the **past week** in your hip and/or groin. Stiffness is a sensation of restriction or slowness in the ease with which you move your hip and/or groin.

S6 How severe is your hip and/or groin stiffness after first awakening in the morning?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

S7 How severe is your hip and/or groin stiffness after sitting, lying or resting **later in the day**?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Pain

P1 How often is your hip and/or groin painful?

Never	Monthly	Weekly	Daily	Always
☐	☐	☐	☐	☐

P2 How often do you have pain in areas other than your hip and/or groin that you think may be related to your hip and/or groin problem?

Never	Monthly	Weekly	Daily	Always
☐	☐	☐	☐	☐

The following questions concern the amount of pain you have experienced during the **past week** in your hip and/or groin. **What amount of hip and/or groin pain have you experienced during the following activities?**

P3 Straightening your hip fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P4 Bending your hip fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P5 Walking up or down stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P6 At night while in bed (pain that disturbs your sleep)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P7 Sitting or lying

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

The following questions concern the amount of pain you have experienced during the **past week** in your hip and/or groin. **What amount of hip and/or groin pain have you experienced during the following activities?**

P8 Standing upright

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P9 Walking on a hard surface (asphalt, concrete, etc.)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P10 Walking on an uneven surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Physical function, daily living

The following questions concern your physical function. **For each of the following activities please indicate the degree of difficulty you have experienced in the past week due to your hip and/or groin problem.**

A1 Walking up stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A2 Bending down, e.g. to pick something up from the floor

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A3 Getting in/out of car

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A4 Lying in bed (turning over or maintaining the same hip position for a long time)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A5 Heavy domestic duties (scrubbing floors, vacuuming, moving heavy boxes etc)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Function, sports and recreational activities

The following questions concern your physical function when participating in higher-level activities. Answer **every** question by ticking the appropriate box. If a question does not pertain to you or you have not experienced it in the past week please make your "best guess" as to which response would be the most accurate. **The questions should be answered considering what degree of difficulty you have experienced during the following activities in the past week due to problems with your hip and/or groin.**

SP1 Squatting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP2 Running

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP3 Twisting/pivoting on a weight bearing leg

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP4 Walking on an uneven surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP5 Running as fast as you can

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP6 Bringing the leg forcefully forward and/or out to the side, such as in kicking, skating etc.

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP7 Sudden explosive movements that involve quick footwork, such as accelerations, decelerations, change of directions etc.

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP8 Situations where the leg is stretched into an outer position (such as when the leg is placed as far away from the body as possible)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Participation in physical activities

The following questions are about your ability to participate in your preferred physical activities. Physical activities include sporting activities as well as all other forms of activity where you become slightly out of breath. **When you answer these questions consider to what degree your ability to participate in physical activities during the past week has been affected by your hip and/or groin problem.**

PA1 Are you able to participate in your preferred physical activities for as long as you would like?

Always	Often	Sometimes	Rarely	Never
☐	☐	☐	☐	☐

PA2 Are you able to participate in your preferred physical activities at your normal performance level?

Always	Often	Sometimes	Rarely	Never
☐	☐	☐	☐	☐

Quality of Life

Q1 How often are you aware of your hip and/or groin problem?

Never	Monthly	Weekly	Daily	Constantly
☐	☐	☐	☐	☐

Q2 Have you modified your life style to avoid activities potentially damaging to your hip and/or groin?

Not at all	Mildly	Moderately	Severely	Totally
☐	☐	☐	☐	☐

Q3 In general, how much difficulty do you have with your hip and/or groin?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Q4 Does your hip and/or groin problem affect your mood in a negative way?

Not at all	Rarely	Sometimes	Often	All the time
☐	☐	☐	☐	☐

Q5 Do you feel restricted due to your hip and/or groin problem?

Not at all	Rarely	Sometimes	Often	All the time
☐	☐	☐	☐	☐

Thank you very much for completing all the questions in this questionnaire.

Review

What is the prevalence of imaging-defined intra-articular hip pathologies in people with and without pain? A systematic review and meta-analysis

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ABSTRACT

Background Intra-articular hip pathologies are thought to be associated with the development of hip and groin pain. A better understanding of the relationship between symptoms and imaging findings may improve the management of individuals with intra-articular hip pathologies.

Objective To undertake a systematic review and meta-analysis to determine the prevalence of intra-articular hip pathologies in individuals with and without pain.

Methods Seven electronic databases were searched in February 2017 for studies investigating the prevalence of intra-articular hip pathologies using MRI, MRA or CT. Two independent reviewers conducted the search, study selection, quality appraisal and data extraction. Meta-analysis was performed when studies were deemed homogenous, with a strength of evidence assigned to pooled results.

Results In general, studies were moderate to high risk of bias, with only five studies adjudged to be low risk of bias. The 29 studies reporting on the prevalence of intra-articular hip pathologies identified limited evidence of a labral tear prevalence of 62% (95% CI 47% to 75%) in symptomatic individuals, with moderate evidence identifying a labral tear prevalence of 54% (95% CI 41% to 66%) in asymptomatic individuals. Limited evidence demonstrated a cartilage defect prevalence of 64% (95% CI 25% to 91%) in symptomatic individuals, compared with moderate evidence of a cartilage defect prevalence of 12% (95% CI 7% to 21%) in asymptomatic individuals.

Conclusion The prevalence of intra-articular hip pathologies is highly variable in both symptomatic and asymptomatic populations. The prevalence of intra-articular hip pathologies appears to be higher in symptomatic individuals. However, imaging-defined intra-articular hip pathologies are also frequently seen in asymptomatic individuals, highlighting a potential discordant relationship between imaging pathology and pain.

PROSPERO registration number CRD42016035444.

INTRODUCTION

Hip and groin pain is a common cause of loss of function in young and middle-aged adults.[1 2] The prevalence of hip and groin pain is known to be as high as 49% in athletes and 21% in population cohorts.[1 3] The occurrence of hip and/or groin pain increases with age,[3–5] and its impact often extends beyond activity reduction, to reduction in participation in work and family activities.[1 6–9] Many different structures, sometimes referred to as clinical entities, may contribute to the development of hip and groin pain.[10–14] Imaging is often used to assist in the diagnosis of intra-articular and extra-articular hip pathology.[15–17] With the advent of higher-quality imaging, the understanding and implications of commonly seen hip morphology and pathology requires attention.[18]

Surgical management for morphological and articular pathologies has increased dramatically,[19 20] with Montgomery *et al*[20] highlighting a 365% increase between 2004 and 2009. However, some of the articular pathologies targeted by surgical management may exist within the 'normal spectrum' related to age, gender and activity exposure. This concept is evident in a number of other anatomical regions, including the knee, shoulder and spine.[21–25] With imaging findings of intra-articular hip pathology in the presence of prolonged symptoms being the catalyst for surgical interventions,[26 27] it seems prudent to explore the relationship of imaging findings and symptoms. Recent reviews have highlighted normal variants of the acetabular labrum,[28] as well as a high prevalence of labral tears in symptomatic and asymptomatic subjects.[29 30] However, none of these reviews aimed to report the prevalence of all intra-articular hip pathologies. In addition, a number of relevant studies have been published subsequent to these reviews. Therefore, the aim of this review was to determine the prevalence of intra-articular hip pathologies in symptomatic and asymptomatic individuals irrespective of their sex, age, level of activity and presence or absence of radiographic hip osteoarthritis (OA).

METHODS

This systematic review was undertaken using the preferred reporting guidelines for systematic reviews and meta-analysis (PRISMA). The review protocol was registered on the PROSPERO international prospective register of systematic reviews (http://www.crd.york.ac.uk/PROSPERO) on 16 February 2016. Registration number: CRD42016035444.

Eligibility criteria

Prespecified inclusion criteria were (1) studies written in English language that used cross-sectional, case–control, case series and cohort designs; (2) studies that included participants with and without hip, groin and buttock pain; (3) studies that performed magnetic resonance imaging

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(MRI), magnetic resonance arthrography (MRA) or computed tomography (CT) with or without contrast to investigate the presence of intra-articular pathology; and (4) studies that had a primary outcome to determine the prevalence of intra-articular pathologies (including labral tears, cartilage defects, bone marrow lesions (BML), ligamentum teres tears and herniation pits) or a primary aim to report femoroacetabular impingement (FAI) prevalence and intra-articular pathology prevalence. No restrictions were placed on the age of study participants. Studies were excluded if they (1) reported prevalence of intra-articular pathology, but it was not the primary aim of the study; (2) investigated intra-articular pathology in the following hip conditions: slipped capital femoral epiphysis or Legg-Calve-Perthes disease; (3) used other forms of imaging to determine prevalence including X-ray, isotopic bone scans and ultrasound; (4) determined prevalence by arthroscopy or open surgery; (5) included less than five participants; (6) were systematic reviews, abstracts or unpublished data; and (7) were not published in the English language.

Search strategy

A systematic search was undertaken using MEDLINE, PubMed, CINAHL, EMBASE, SPORTDiscus, Scopus and Cochrane databases from inception to 19 May 2016; the search was then repeated in its entirety on 27 February 2017. In addition, reference lists of included articles were screened, and citation tracking using Google Scholar was undertaken. The search strategy was independently undertaken by two authors (JJH and DMJ) using database-specific controlled vocabulary and keyword terms. The search strategy for each respective database can be found in online supplementary appendix 1.

At completion of database searching, all potentially eligible articles were exported into Endnote X7 (Thomson Reuters, Carlsbad, California, USA) and duplicates removed. The specified inclusion/exclusion criteria were independently applied to the yield achieved from database and secondary searching by two authors (JJH, DMJ). Full-text articles were subsequently retrieved and screened independently by each author for eligibility. Final inclusion was determined by each author (JJH, DMJ) independently and then a consensus meeting was held to determine the final list of included articles. If disagreements arose in relation to the study's eligibility, a third reviewer (JLK) was consulted to determine eligibility.

Risk of bias

Two authors (JJH, DMJ), independently evaluated each eligible study for risk of bias using a tool designed for prevalence papers.[31] This tool consists of 10 'yes' or 'no' questions that evaluate both external (four questions) and internal validity (six questions) (table 4), a 'yes' is associated with low risk of bias (LR) and a 'no' with high risk of bias (HR). An article that fails to report sufficient detail to enable scoring for an item is given a 'no' which equates to HR.[31] Modification was made to question seven which evaluated the reliability of the imaging modality, with an intraclass correlation coefficient >0.40 and Cohen's kappa (κ) >40% considered to be LR. At the completion of scoring, each article receives an overall risk of bias score based on the number of items that demonstrate HR. The articles were then grouped into LR (0–3 items), moderate risk (MR) (4–5 items) and HR (≥6 items) derived from literature using the same tool for risk of bias appraisal.[32] If disagreements arose in relation to a study's risk of bias, a third independent reviewer (JLK) resolved the discrepancy. Inter-rater reliability was evaluated with κ, with values >80% considered excellent agreement, between 60% and 80% substantial agreement, 40% and 60% moderate agreement and <40% poor to fair agreement.[33]

Data extraction

Data from all 29 articles were independently extracted by two authors (JJH, ABM). Consensus meetings were held following data extraction of the first 10 articles, and after the completion of the 29 articles, to discuss discrepancies in extraction and to reach consensus. A third author (KMC) was used to reach consensus if discrepancies in data extraction occurred between the two authors. If additional data were required, the corresponding authors were contacted. Where two articles reported the same data set, the studies were examined for discrepancies and the author was contacted if required to seek clarity. The extracted data included author, study design, number of study participants (and hips), demographics, imaging modality and study findings (intra-articular pathology) (tables 1–3).

Data synthesis and analysis

In relation to this systematic review, as none of the included studies investigated community-based populations, the term prevalence was used to define the frequency of intra-articular pathologies in each study's included population. The prevalence of intra-articular hip pathology was determined by dividing the number of cases by the total number of participants in the specified population. Comprehensive Meta-Analysis Software (V.3.0, Biostat, USA) was used to determine prevalence and 95% CIs. Prevalence was presented at a per person level, and if the study did not present sufficient information to enable per person analysis, prevalence was reported per hip (if the request for per person data was not successful). In the event that a study used two or more radiologists to evaluate the presence of intra-articular pathologies, an average prevalence score was determined for each of the pathologies reported. Additional intra-articular hip pathologies that were only reported in one symptomatic and asymptomatic study were displayed in supplementary content. Pooled data were presented in per person format, with per hip analysis summarised in text, and details presented in the supplementary content.

Primary subgroup analysis occurred on the presence or absence of pain. Secondary group analysis was completed on the basis of the method used to report prevalence (per person or per hip) and imaging modality (MRI, MRA or CT).

Pathology was recorded as present or absent, due to the variation in assessment, and grading of pathology in the included studies. In relation to cartilage defects, only studies that reported femoral and acetabular defects together were considered for primary analysis. Where studies reported femoral and acetabular defects independently, qualitative analysis was undertaken.

Meta-analyses were undertaken only with studies adjudged to be LR and MR using a random effects model. High risk of bias studies were not included in meta-analyses in line with recent recommendations.[34 35] Qualitative analyses were undertaken when pooling of data was precluded because of clinical heterogeneity or if adjudged to be HR. The level of statistical heterogeneity for the pooled data was evaluated with Q and I^2 statistics.[34] An I^2 ≤25% represented low levels of statistical heterogeneity, 25%–≤50% moderate and ≥75% high heterogeneity.[36] Sensitivity analysis was undertaken first with removal of studies using a MRI field strength <1.5 tesla (T) and second in only studies using 3 T MRI.

Table 1 Included studies involving asymptomatic participants only

Author	Study design	Study population	Participants (hips, n)	Demographics	Imaging modality	Findings (intra-articular pathology)
Ayeni *et al*[40]	Cross-sectional	*Subjects* Ice hockey players *Controls* Non-athletic individuals	*Subjects* 20 (20) *Controls* 20 (20)	*Subjects* Age*: 20.6 Sex: 9 F/11 M *Controls* Age*: 20.1 Sex: 9 F/11 M	1.5T MRI	*Subjects* Labral tear: 12/20; acetabular cartilage defect: 0/20; femoral cartilage defect: 2/20; herniation pit: 2/20; osseous bump: 4/20; paralabral cyst: 0/20 *Controls* Labral tear: 12/20; acetabular cartilage defect: 3/20; femoral cartilage defect: 3/20; herniation pit: 2/20; osseous bump: 4/20; paralabral cyst: 0/20
Farrell *et al*[59]	Cross-sectional	*Subjects* Rugby union academy players *Controls* Moderately active individuals	*Subjects* 20 (40) *Controls* No MRI performed	*Subjects* Age*: 22 (1.5) Sex: 20 M *Controls* Age*: 21.3 (1.7) Sex: 20 M	3T MRI	*Subjects* Labral tear: 17/20†; labral tear right hip: 10/20; labral tear left hip: 15/20; bilateral labral tear: 8/20; cartilage defect: 5/20; cartilage defect right hip: 3/20; cartilage defect left hip: 3/20; bilateral cartilage defect: 1/20
Georgiadis *et al*[60]	Case series	Children	108 (216)	Age*: 11.9 (†2–18)	3T MRI 1.5T MRI	Labral tear per person: 2/108; labral tear per hip: 3/216
Lahner *et al*[42]	Cross-sectional	*Subjects* Semiprofessional soccer players *Controls* Amateur soccer players	*Subjects* 22 (22) *Controls* 22 (22)	*Subjects* Age*: 23.3 (3.3) Sex: 22 M *Controls* Age*: 22.5 (3.5) Sex: 22 M	1.5 T MRI	*Subjects* Labral tear: 3/22; cartilage defect: 2/22 *Controls* Labral tear: 1/22; cartilage defect: 1/22
Lahner *et al*[57]	Cross-sectional	*Subjects* Track and field athletes *Controls* Non-athletes	*Subjects* 22 (44) *Controls* 22 (44)	*Subjects* Age*: 23.7 (3.0) (†18–30) Sex: 11 F/11 M *Controls* Age*: 22.4 (4.2) (†18–32) Sex: 11 F/11 M	1.5T MRI	*Subjects* Labral tear: 2/44; acetabular cartilage defect: 1/44; femoral cartilage defect: 1/44; herniation pit: 3/44; osseous bump: 3/44 *Controls* Labral tear: 1/44; acetabular cartilage defect: 0/44; femoral cartilage defect: 0/44; herniation pit: 1/44; osseous bump: 0/44
Lee *et al*[64]	Cross-sectional	Medical students and allied health professionals	70 (70)	Age*: 26 (†19–41) Sex: 47 F/23 M	3T MRI	Labral tear: 27/70; isolated labral tear: 16/70; sublabral recesses: 10/70; labral ossification: 10/70; paralabral cyst: 1/70; acetabular cartilage delamination 7/70; fibrocystic changes at head-neck junction 4/70; intra-articular pathology with or without labral tear: 32/70
Leunig *et al*[52]	Cross-sectional	*Subjects* Young women *Controls* Young men	*Subjects* 80 (80) *Controls* 244 (244)	*Subjects* Age*: 19.3±1.3 *Controls* Age*: 20.0±0.9	1.5T MRI	*Subjects* Labral tear: 17/80; intra-labral signal alterations: 10/80; labral avulsions: 13/80; labral deformities: 4/80; labral ganglions: 4/80; impingement pits: 0/80 *Controls* Labral tear: 175/244; intra-labral signal alterations: 86/244; labral avulsions: 153/244; labral deformities: 27/244; labral ganglions: 65/244; impingement pits: 41/244
Mineta *et al*[62]	Case series	Individuals who underwent abdominal or pelvic CT	NR (1178)	Age*: 58.2 (†20–89) Sex: 483 F/695 M	CT	Hemiation pit: 164/1178
Panzer *et al*[46]	Case series	Individuals who had CT for polytrauma/pelvic, abdominal or thoracic examinations	200 (400)	Age*: 55.1 (†15–96) Sex: 77 F/123 M	CT	Hemiation pit (per person): 85/200; herniation pit (per hip): 107/400; >1 herniation pit (per hip): 25/400; herniation pit right hip: 65/107; herniation pit left hip: 42/107; bilateral herniation pit: 22/85

Continued

Table 1 Continued

Author	Study design	Study population	Participants (hips, n)	Demographics	Imaging modality	Findings (intra-articular pathology)
Philippon *et al*[53]	Cross-sectional	*Subjects* Youth ice hockey players *Controls* Youth skiers	*Subjects* 61 (61) *Controls* 27 (27)	*Subjects* Age*: 14.5 (2.7) Sex: 61 M *Controls* Age*: 15.2 (2.7) Sex: 27 M	3 T MRI	*Subjects* Labral tear: 42/61; peewee hockey players—labral tear: 13/27; bantam hockey players—labral tear: 5/8; midget hockey players—labral tear: 24/26; cartilage defect: 5/61; peewee hockey players—cartilage defect: 0/27; bantam hockey players—cartilage defect: 0/8; midget hockey players—cartilage defect: 5/26 *Controls* Labral tear: 19/27; skier—labral tear (peewee control): 5/7; skier—labral tear (bantam control): 5/8; skier—labral tear (midget control): 9/12; cartilage defect: 1/27; skier—cartilage defect (peewee control): 0/7; skier—cartilage defect (bantam control): 0/8; skier—cartilage defect (midget control): 1/12
Register *et al*[49]	Cross-sectional	Asymptomatic individuals	45 (45)	Age*: 38 (†18–66) Sex: 17 F/28 M	3 T MRI	Labral tears: 31/45; cartilage defect: 11/45; ligamentum teres tear: 1/45; labral/paralabral cyst: 6/45; acetabular bone oedema: 5/45; fibrocystic changes to the femoral head/neck junction: 10/45; rim fracture: 5/45; subchondral cysts: 7/45; osseous bump of the femoral neck: 9/45
Schmitz *et al*[50]	Case series	US air force personnel on active duty	21 (42)	Age*: 34 (†27–43) Sex: 5 F/16 M	1.5 T MRI	Labral tears: reader 1 35/42; reader 2 33/42 Paralabral cysts: reader 1 11/42; reader 2 9/42
Silvis *et al*[48]	Cross-sectional	Ice hockey players	39 (39)	Age: NR Sex: 39 M	3 T MRI	Hip pathology total findings: 25/39; labral tear: 22/39; cartilage defect: 7/39; hip effusion: 0/39
Yuan *et al*[54]	Cross-sectional	*Subjects* High school student with clinical signs of FAI *Controls* High school students no clinical signs of FAI	*Subjects* 13 (22) *Controls* 13 (26)	*Subjects* Age: NR Sex: 1 F/12 M *Controls* Age: NR Sex: 1 F/12 M	3 T MRI 1.5 T MRI	*Subjects* Any abnormal hip finding: 15/22; labral tear: 14/22; acetabular rim damage: 3/22; cartilage defect: 1/22 *Controls* Any abnormal hip finding: 10/26; labral tear: 10/26; acetabular rim damage: 0/26; cartilage defect: 1/26

*Mean (SD).
†Range.
‡Results from raw data obtained from author.
F, female; FAI, femoroacetabular impingement; M, male; NR, not reported.

Table 2 Included studies involving symptomatic participants only

Author	Study design	Study population	Participants (hips, n)	Demographics	Imaging modality	Findings (intra-articular pathology)
Domb *et al*[55]	Case series	Retired NFL players with hip pain	38 (62)	Age*: 33 (†27–39) Sex: 38 M	1.5T MRI 1.5T MRA	Labral tear: 55/62; cartilage defect (gr 1/2): 61/62; cartilage defect (gr 3): 0/62; ligamentum teres tear (partial to severe): 50/62; osteophyte: 3/62; subchondral bone cyst: 9/62; paralabral cyst: 3/62; bursitis: 0/62; loose bodies: 0/62; transverse ligament tear: 2/62; AVN: 0/62
Jayakar *et al*[61]	Case series	Individuals with hip pain	192 (208)	Age*: 61 (8.9) (†50–92) Sex: 139 F/69 M	MRA	Labral tear: 152/208; labral fraying: 42/208; no labral tearing: 14/208; tonnis gr 0–1—labral tearing: 133/182, labral fraying: 35/182, no labral tearing: 14/182; tonnis gr 2–3 —labral tearing: 19/26, labral fraying: 7/26, no labral tearing: 0/26
Kassarjian *et al*[41]	Case series	Individuals with clinical signs of FAI	40 (42)	Age*: 36.5 (12) (†17–67) Sex: 18 F/22 M	1.5T MRA	Labral tear: 42/42; cartilage defect: 40/42; triad (abnormal AA, anterosuperior cartilage abnormalities, anterosuperior labral tear): 37/42; paralabral cyst: 6/42 (6/6 triad abnormalities); herniation pit: 2/42 (2/2 triad abnormalities); os acetabuli: 17/42 (16/17 triad abnormalities)
Narvani *et al*[44]	Case series	Individuals playing sport with groin pain	18 (18)	Age*: 30.5 (8.5) (17–48) Sex: 5 F/13 M	1T MRA	Labral tear: 4/18
Neiman *et al*[63]	Case series	Individuals with hip pain	229 (229)	Age*: 36.5 (14.2) (†18–67) Sex: 102 F/127 M	1.5T MRA	Labral tear: 146/229; cartilage defect: 64/229; ligamentum teres partial tears: 2/229; ligamentum teres complete tears: 2/229; synovitis: 3/229; transient osteoporosis of the hip: 2/229; PVNS: 1/229; AVN: 1/229
Neumann *et al*[45]	Case series	Individuals with mechanical hip pain	100 (100)	Age*: 39 (13) (†17–76) Sex: 76 F/ 24 M	1.5T MRA	Labral tear: 66/100; cartilage defect: 76/100; BML: 29/100; osteophytes: 32/100; subchondral cysts: 23/100; subchondral sclerosis: 22/100
Pizzolatti *et al*[47]	Case series	Individuals with suspicion of labral tear	96 (108)	Age*: M 39.3 (†18–63) Age*: F 41.3 (†20–73) Sex: 59 F/37 M	0.5T MRA 1.5T MRA	Labral tear (per person): 96/96; labral tear (per hip): 108/108; isolated labral tears: 24/108; completely torn labrum: 43/108 hips; first-degree labral tear: 44/108; second-degree labral tear: 34/108; third-degree labral tear: 30/108; cartilage defect: 88/108; cartilage defect in entire weightbearing zone: 46/108; first-degree cartilage defect: 55/108; second-degree cartilage defect: 14/108; third-degree cartilage defect: 19/108

*Mean (SD).
†Range.
AA, alpha angle; AVN, avascular necrosis; BML, bone marrow lesion; F, female; FAI, femoroacetabular impingement; Gr, grade; M, male; MRA, magnetic resonance arthrography; PVNS, pigmented villonodular synovitis.

The strength of evidence for the pooled results of this review is based on the original methods advocated by van Tulder *et al*[37] and later adapted by Rathleff *et al*.[38]

Strong evidence: pooled results derived from three or more studies, including a minimum of two LR studies, which are statistically homogenous (P>0.05).

Moderate evidence: pooled results derived from multiple studies, including at least one LR study, which are statistically heterogeneous (P<0.05); or from multiple MR and HR studies which are statistically homogenous (P>0.05).

Limited evidence: pooled results from multiple HR or MR studies which are statistically heterogeneous (P<0.05).

RESULTS

Search results

The review used the PRISMA flow diagram (figure 1).[39] In total, 343 citations were identified through the search strategy. At the completion of duplicate removal, 124 citations were screened based on title and abstract. The full-text versions of 56 articles were retrieved and subsequently assessed for eligibility using the inclusion criteria. Four[40–43] additional articles were added after the screening of reference lists and citation tracking. Thirty-one articles were subsequently excluded (online supplementary appendix 2), and the remaining 29 articles[40–68] were included for data analysis (tables 1–3).

Risk of bias within studies

The two reviewers agreed on risk of bias items on 96% of occasions (278/290 items), with a κ value of 0.84 (95% CI 0.78 to 0.90) representing excellent agreement.[33] Five of the 29 (17%) included articles were adjudged to be of HR, with 19 of MR and 5 of LR. All 29 studies had HR for items 1 and 2, which highlights the disparity of the included study populations compared with a general population and the inadequacies of the sampling frames used within the studies. In addition, inability to demonstrate the reliability of the assessment method used to determine the prevalence of intra-articular pathology, the use of different imaging methods within the one study population and the reporting of prevalence per hip instead of per person were other notable sources of bias (table 4).

Study characteristics

The 29 included studies reported prevalence characteristics on 2573 participants and 4410 hips. Fourteen studies (1069 participants, 2662 hips) included only asymptomatic participants, with 10 of the studies reporting a mean age of <40 years of age (table 1).[40 42 46 48–50 52–54 57 59 60 62 64] Eight studies investigating symptomatic participants used MRA to evaluate the prevalence of intra-articular pathology, with seven studies reporting a mean age of <40 years of age (tables 2 and 3).[41 44 45 47 55 61 63 66] Fifteen studies investigated

Table 3 Included studies involving asymptomatic and symptomatic participants

Author	Study design	Study population	Participants (hips, n)	Demographics	Imaging modality	Findings (intra-articular pathology)
Dickenson *et al*[67]*	Cross-sectional	*Subjects* Male golfers with hip pain *Controls* Male golfers without hip pain	*Subjects* NR (15) *Controls* NR (95)	*Subjects* Age: NR Sex: 15 M *Controls* Age: NR Sex: 95 M	1.5T MRI	*Subjects* Labral tear: 3/15; increased labral signal: 3/15; acetabular cartilage defect 4/15; femoral cartilage defect: 1/15; acetabular subchondral oedema: 3/15; femoral subchondral oedema: 6/15; herniation pit: 4/15; joint effusion: 1/15 *Controls* Labral tear: 22/95; increased labral signal: 21/95; acetabular cartilage defect: 6/95; femoral cartilage defect: 3/95 acetabular subchondral oedema: 10/95; femoral subchondral oedema: 10/95; herniation pit: 9/95; joint effusion: 8/95
Ji *et al*[66]	Case–control	*Subjects* Mechanical symptoms with hip pain *Controls* Pain due to a ureter stone without hip pain	*Subjects* 151 (151) *Controls* 151 (151)	*Subjects* Age†: 46 (12) Sex: 83 F/68 M *Controls* Age†: 46 (12) Sex: 83 F/68 M	CTACT	*Subjects* Herniation pit: 36/151 *Controls* Herniation pit: 5/151
Kolo *et al*[51]	Cross-sectional	*Subjects* Symptomatic/asymptomatic ballet dancers *Controls* Asymptomatic non-dancing individuals	*Subjects* 30 (59) *Controls* 14 (28)	*Subjects* Age†: 24.6 (§18–39) Sex: 30 F *Controls* Age†: 27.1 (§20–34) Sex: 14 F	1.5T MRI	*Subjects* Labral tear: 28/59; hips≥2 labral tears: 12/59; labral degeneration: 24/59; hips≥2 labral degenerative tears: 11/59; labral ossification: 2/59; hips≥2 ossified lesions: 2/59; acetabular cartilage defect≤5 mm: 12/59; acetabular cartilage defect≥5 mm: 17/59 herniation pit: 31/59 *Controls* Labral tear: 8/28; hips≥2 labral tears: 1/28; labral degeneration: 12/28; hips≥2 labral degenerative tears: 1/28; labral ossification: 4/28; hips≥2 ossified lesions: 0/28; acetabular cartilage defect≤5 mm: 4/28; acetabular cartilage defect≥5 mm: 2/28; herniation pit: 5/28
Mayes *et al*[68]*	Case-control	*Subjects* Hip pain last 3 months¶ *Controls* No hip pain¶	*Subjects* NR (40) *Controls* NR (156)	*Subjects* Age**††: 30 (IQR 24) Age**‡‡: 34.5 (IQR 24) Sex¶: 24 F/9 M *Controls* Age**††: 30.5 (IQR 20) Age**‡‡: 28 (IQR 20) Sex¶: 32 F/33 M	3 T MRI	*Subjects* Labral tear: 16/40 *Controls* Labral tear: 83/156
Mayes *et al*[43]*	Case–control	*Subjects* Hip pain last 3 months¶ *Controls* No hip pain¶	*Subjects* NR (40) *Controls* NR (156)	*Subjects* Age**††: 30 (IQR 24) Age**‡‡: 34.5 (IQR 24) Sex¶: 24 F/9 M *Controls* Age**††: 30.5 (IQR 20) Age**‡‡: 28 (IQR 20) Sex¶: 32 F/33 M	3T MRI	*Subjects* Ligamentum teres tear: 20/40 *Controls* Ligamentum teres tear: 38/156
Mayes *et al*[65]*	Case–control	*Subjects* Hip pain last 3 months¶ *Controls* No hip pain¶	*Subjects* NR (40) *Controls* NR (156)	*Subjects* Age**††: 30 (IQR 24) Age**‡‡: 34.5 (IQR 24) Sex¶: 24 F/9 M *Controls* Age**††: 30.5 (IQR 20) Age**‡‡: 28 (IQR 20) Sex¶: 32 F/33 M	3 T MRI	*Subjects* Cartilage defect: 18/40 *Controls* Cartilage defect: 66/156

Continued

Table 3 Continued

Author	Study design	Study population	Participants (hips, n)	Demographics	Imaging modality	Findings (intra-articular pathology)
Teichtahl *et al*[68]	Cross-sectional	*Subjects* Hip pain with radiographic hip OA *Controls* No hip pain	*Subjects* 19 (19) *Controls* 141 (141)	*Subjects* Age‡: 59.2 (7.6) Sex: 11 F/8 M *Controls* Age‡: 66.8 (7.3) Sex: 78 F/63 M	3 T MRI	*Subjects* Femoral head cartilage defect: central superolateral 17/19; central inferomedial 10/19; anterior: 12/19; posterior 14/19; acetabular cartilage defects: central superolateral 17/19; anterior 18/19; posterior 15/19; femoroacetabular cartilage defect: central superolateral 18/19; anterior 18/19; posterior 16/19; femoral head BML: central superolateral 10/19; central inferomedial 6/19; anterior 7/19; posterior 5/19; acetabular BML: central superolateral 13/19; central inferomedial 2/19; anterior 13/19; posterior 11/19; femoroacetabular BML: central superolateral 14/19; central inferomedial 6/19; anterior 14/19; posterior 13/19 *Controls* Femoral head cartilage defect: central superolateral 45/141; central inferomedial 67/141; anterior 5/141; posterior 25/141; acetabular cartilage defects: central superolateral 37/141; anterior 26/141; posterior 50/141; femoroacetabular cartilage defect: central superolateral 64/141; anterior 27/141; posterior 57/141; femoral head BML: central superolateral 7/141; central inferomedial 6/141; anterior 2/141; posterior 4/141; acetabular BML: central superolateral 22/141; central inferomedial 3/141; anterior 28/141; posterior 18/141; femoroacetabular BML : central superolateral 27/141; central inferomedial 8/141; anterior 29/141; posterior 20/141
Tresch *et al*[66]	Cross-sectional	*Subjects* Individuals with FAI *Controls* Asymptomatic individuals	*Subjects* 63 (63) *Controls* 63 (63)	*Subjects* Age‡: 35.3 (§20–50) *Controls* Age‡: 34.4 (§20–50)	1.5 T MRA 1.5 T MRI	*Subjects* Labral tears: reader 1 37/63; reader 2 40/63; degenerated labrum: reader 1 6/63; reader 2 9/63; normal labrum: reader 1 20/63; reader 2 14/63; acetabular cartilage defect (superficial): reader 1 9/63; reader 2 21/63; acetabular cartilage defect (deep): reader 1 17/63; reader 2 12/63; normal acetabular cartilage: reader 1 37/63; reader 2 30/63 femoral cartilage defect (superficial): reader 1 13/63; reader 2 13/63; femoral cartilage defect (deep): reader 1 7/63; reader 2 5/63; normal femoral cartilage: reader 1 43/63; reader 2 45/63 *Controls* Labral tears: reader 1 23/63; reader 2 33/63; degenerated labrum: reader 1 4/63; reader 2 8/63; normal labrum: reader 1 36/63; reader 2 22/63; acetabular cartilage defect (superficial): reader 1 5/63; reader 2 11/63; acetabular cartilage defect (deep): reader 1 0/63; reader 2 2/63; normal acetabular cartilage: reader 1 58/63; reader 2 50/63 femoral cartilage defect (superficial): reader 1 2/63; reader 2 3/63; femoral cartilage defect (deep): reader 1 0/63; reader 2 2/63; normal femoral cartilage: reader 1 61/63; reader 2 58/63

*Authors provided additional results not presented in original article.
†Median (SD).
‡Mean (SD).
§Range.
¶Includes dancers and athletes.
**Median (IQR).
††Dancers.
‡‡Athletes.
BML, bone marrow lesion; CTA, CT arthrography; F, female; FAI, femoroacetabular impingement; M, male; MRA, magnetic resonance arthrography; NR, not reported; OA, osteoarthritis.

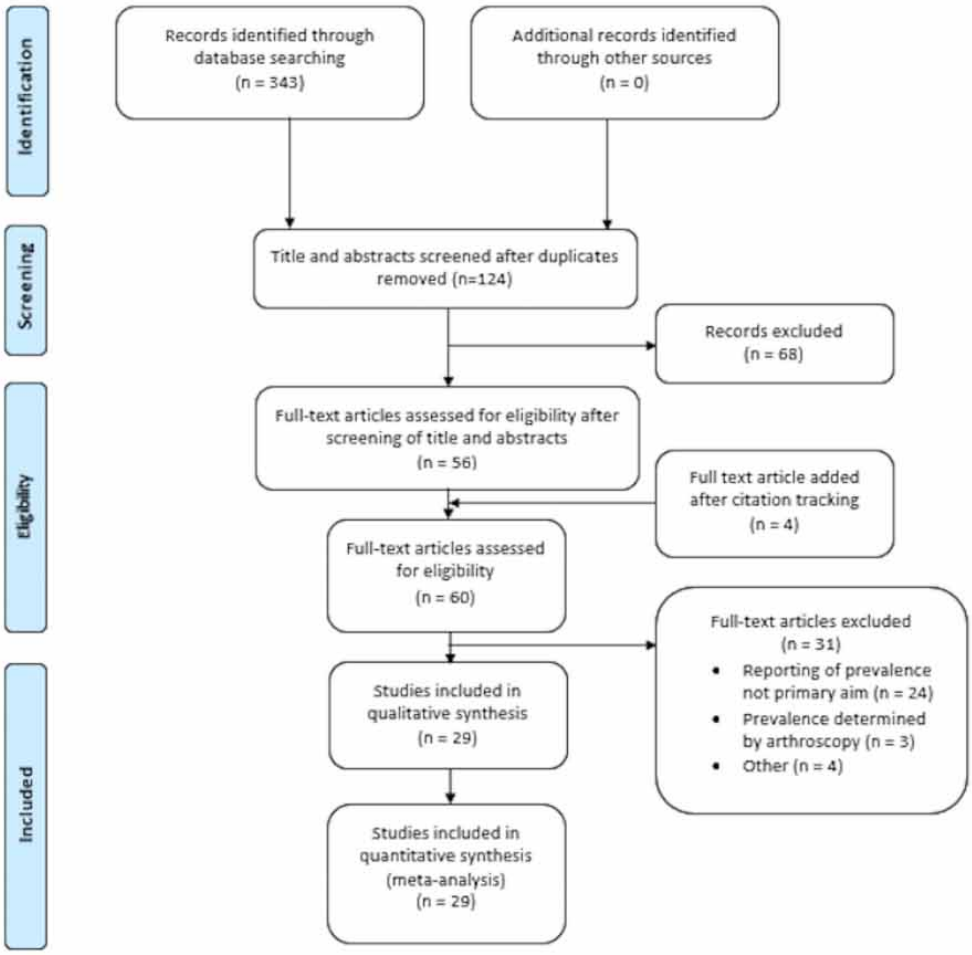

Figure 1 Preferred reporting guidelines for systematic reviews and meta-analysis flow diagram of search results and study selection.

athletic participants,[40 42–44 48 51 53–55 57–59 64 65 67] with the remaining studies investigating non-athletic participants or not reporting participant activity level. Two studies[61 68] included participants with radiographic hip OA, with 25 of the remaining 27 studies not identifying if participants had radiographically confirmed hip OA[40–53 55–60 63–67] (online supplementary appendix 3 tables 2-4). Magnetic resonance imaging was used in 20 studies.[40 42 43 48–55 57–60 64–68] Three studies[46 56 62] evaluated prevalence with CT (one of the three studies[56] used a case–control design and CT arthrography (CTA) in a symptomatic group). The MRI field strength used in the included studies varied between 0.5 to 3.0 T, with one study[61] using MRA not reporting the field strength used.

Heterogeneity of included studies

Heterogeneity ranged between 46%–83% and 87%–93% in pooled studies investigating the prevalence of labral tears in symptomatic and asymptomatic participants, respectively. In the studies investigating symptomatic participants with cartilage defects, high levels of heterogeneity were observed (98%). In studies investigating asymptomatic participants, moderate (62%) to high levels (76%) were observed.

Prevalence of labral tears

Twenty-three studies (1911 participants, 2370 hips) reported the prevalence of labral tears.[40–42 44 45 47–55 57–61 63 64 66 67] Eleven studies reported prevalence per person,[40 42 44 45 48 49 52 53 63 64 66] whereas six studies[50 51 55 57 61 67] reported prevalence per hip. Six studies[41 47 54 58–60] reported prevalence per person and per hip.

Symptomatic participants

There was limited evidence of a pooled labral tear prevalence of 62% (95% CI 47% to 75%) per person from five studies (five MR)[44 45 47 63 66] using MRA (figure 2). Six studies (one HR, four MR and one LR)[41 51 55 58 61 67] reported prevalence of labral tears per hip in symptomatic participants. There was limited evidence of a pooled labral tear prevalence of 92% (95% CI 29% to 100%) per hip from two (two MR)[41 61] MRA studies, with moderate evidence of a pooled labral tear prevalence of 32% (95% CI 16%

Table 4 Included studies risk of bias

Author	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Overall risk of bias
	External validity				Internal validity						
Ayeni *et al*[40]	HR	HR	HR	LR	LR	HR	HR	LR	LR	LR	MR
Dickenson *et al*[67]	HR	HR	HR	LR	LR	HR	LR	LR	LR	HR	MR
Domb *et al*[55]	HR	HR	HR	LR	LR	LR	HR	HR	LR	HR	HR
Farrell *et al*[59]	HR	HR	HR	LR	LR	HR	HR	LR	LR	LR	MR
Georgiadis *et al*[60]	HR	HR	HR	LR	LR	HR	HR	HR	LR	LR	HR
Jayakar *et al*[61]	HR	HR	HR	LR	LR	LR	HR	LR	LR	HR	MR
Ji *et al*[56]	HR	HR	HR	LR	LR	LR	LR	HR	LR	LR	MR
Kassarjian *et al*[41]	HR	HR	HR	LR	LR	LR	HR	LR	LR	HR	MR
Kolo *et al*[51]	HR	HR	HR	LR	LR	LR	HR	LR	LR	HR	MR
Lahner *et al*[42]	HR	HR	HR	LR	LR	HR	HR	LR	LR	LR	MR
Lahner *et al*[57]	HR	HR	HR	LR	LR	HR	HR	LR	LR	HR	HR
Lee *et al*[64]	HR	HR	HR	LR	LR	LR	LR	LR	LR	LR	LR
Leunig *et al*[52]	HR	HR	LR	LR	LR	LR	LR	LR	LR	LR	LR
Mayes *et al*[58]	HR	HR	HR	LR	LR	LR	LR	LR	LR	LR	LR
Mayes *et al*[43]	HR	HR	HR	LR	LR	LR	LR	LR	LR	LR	LR
Mayes *et al*[65]	HR	HR	HR	LR	LR	LR	LR	LR	LR	LR	LR
Mineta *et al*[62]	HR	HR	HR	LR	LR	LR	LR	LR	LR	HR	MR
Narvani *et al*[44]	HR	HR	HR	LR	LR	HR	HR	LR	LR	LR	MR
Neiman *et al*[63]	HR	HR	HR	LR	LR	HR	HR	LR	LR	LR	MR
Neumann *et al*[45]	HR	HR	HR	LR	LR	LR	HR	LR	LR	LR	MR
Panzer *et al*[46]	HR	HR	HR	LR	LR	LR	LR	HR	LR	LR	MR
Philippon *et al*[53]	HR	HR	HR	LR	LR	HR	HR	LR	LR	LR	MR
Pizzolatti *et al*[47]	HR	HR	HR	LR	LR	LR	HR	HR	LR	LR	MR
Register *et al*[49]	HR	HR	HR	LR	LR	HR	HR	LR	LR	LR	MR
Schmitz *et al*[50]	HR	HR	HR	LR	LR	LR	LR	LR	LR	HR	MR
Silvis *et al*[48]	HR	HR	HR	HR	LR	HR	HR	LR	LR	LR	HR
Teichtahl *et al*[68]	HR	HR	HR	LR	LR	LR	LR	LR	HR	LR	MR
Tresch *et al*[66]	HR	HR	HR	LR	LR	LR	HR	HR	LR	LR	MR
Yuan *et al*[54]	HR	HR	HR	HR	LR	HR	HR	HR	LR	HR	HR

Risk of bias items.
1. Was the study's target population a close representation of the national population in relation to relevant variables, for example, age, sex, occupation?
2. Was the sample frame a true or close representation of the target population?
3. Was some form of random selection used to select the sample, or, was a census taken?
4. Was the likelihood of non-response bias minimal?
5. Were data collected directly from the subjects (as opposed to a proxy)?
6. Was an acceptable case definition used in the study?
7. Was the study instrument that measured the parameter of interest (eg, prevalence of low back pain) shown to have reliability and validity (if necessary)?
8. Was the same mode of data collection used for all subjects?
9. Was the length of the shortest prevalence period for the parameter of interest appropriate?
10. Were the numerator(s) and denominator(s) for the parameter of interest appropriate?
HR, high risk of bias; LR, low risk of bias; MR, moderate risk of bias.

to 54%) from two (one MR and one LR)[58 67] studies using MRI (online supplementary appendix 3 figure 1). The remaining two studies (one HR and one MR) reported a labral tear prevalence of 89%[55] and 48%[51] per hip, respectively.

Asymptomatic participants

There was moderate evidence of a pooled labral tear prevalence of 54% (95% CI 41% to 66%) per person from eight studies (six MR and two LR)[40 42 49 52 53 59 64 66] using MRI (figure 2). Three studies (three HR)[48 54 60] not included in the meta-analysis reported a labral tear prevalence per person in children of 1.9%,[60] high school athletes (85%)[54] and ice hockey players (56%).[48]

Six studies (two HR, three MR and one LR)[50 51 54 57 58 67] reported prevalence of labral tears per hip in asymptomatic participants. Moderate evidence from four studies (three MR and one LR) using MRI demonstrated a pooled prevalence of 46% (95% CI 24% to 70%) per hip (online supplementary appendix 3 figure 1). The remaining two studies (two HR)[54 57] reported a labral tear prevalence per hip of 38% and 3%, respectively. No studies used MRA in asymptomatic participants.

Sensitivity analysis

In symptomatic participants, sensitivity analysis demonstrated a pooled labral tear prevalence of 64% (95% CI 59% to 69%; Q=0.3; P=0.861; I^2=0%) per person in studies using an MRI field strength of ≥1.5 T. Sensitivity analysis was unable to be performed for studies using 3 T MRI due to an insufficient number of studies. The labral tear prevalence in asymptomatic participants was 56% (95% CI 45% to 67%; Q=55.0; P<0.001; I^2=84%) per person and 34% (95% CI 17% to 57%; Q=69.8; P<0.001; I^2=93%) per hip when studies using an MRI field strength <1.5 T

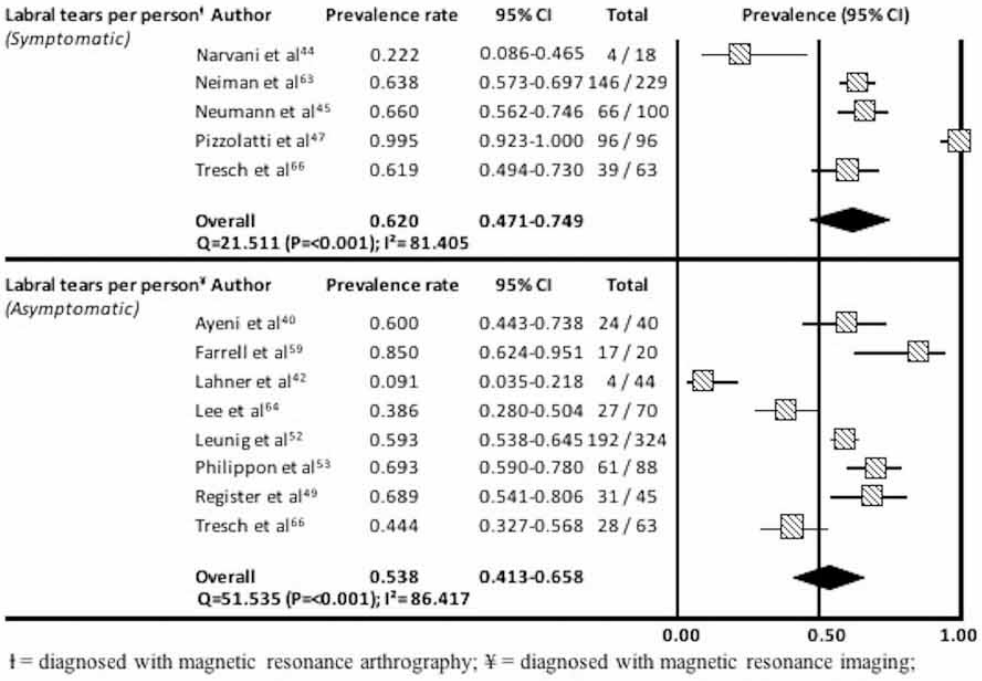

Figure 2 Prevalence and 95% CIs of labral tears in symptomatic and asymptomatic participants among studies that reported prevalence per person.

were removed. In studies only using 3 T MRI in asymptomatic individuals, the labral tear prevalence was 63% (95% CI 47% to 76%; Q=21.9; P=<0.001; I^2=82%) per person, with analysis not undertaken at per hip level due to an insufficient number of studies.

Prevalence of cartilage defects

Nineteen studies (1402 participants, 1722 hips) reported the prevalence of cartilage defects.[40–42 45 47–49 51 53–55 57 59 63–68] Twelve studies analysed prevalence per person[40 42 45 48 49 53 59 63–66 68] and four studies reported prevalence per hip.[51 55 57 67] Three studies reported prevalence using per person and per hip analysis.[41 47 54]

Symptomatic participants

There was limited evidence of a pooled cartilage defect prevalence of 64% (95% CI 25% to 90%) per person from three studies (three MR)[45 47 63] that used MRA (figure 3). Two studies (two MR)[66 68] reported acetabular and femoral cartilage defects independently. One study[68] reported femoral (53%–90%) and acetabular (79%–95%) defects in specified hip joint regions. The remaining study[66] reported acetabular (23% and 24%) and femoral cartilage (10% and 21%) defect prevalence.

Five studies reported prevalence per hip.[41 54 55 58 67] One study (MR)[41] reported a cartilage defect prevalence of 95% in participants with FAI. Three (one HR, one MR and one LR) of the remaining four studies used a combination of MRI and MRA (98%)[55] and MRI in isolation (45% and 49%)[51 58] to identify cartilage defects. The final study (MR)[67] reported on acetabular (27%) and femoral cartilage defects (7%) in golfers with hip pain.

Asymptomatic participants

There was moderate evidence of a pooled cartilage defect prevalence of 12% (95% CI 7% to 21%) per person, from five studies (one LR and four MR)[42 49 53 59 64] using MRI (figure 3). Two studies (two HR)[48 54] reported cartilage defect prevalence per person in ice hockey players (18%)[48] and high school athletes (8%).[54] Moderate evidence of a pooled cartilage defect prevalence of 33% (95% CI 16% to 56%) per hip was demonstrated from two studies (one MR and one LR)[51 65] using MRI (online supplementary appendix 3 figure 2). One study (HR)[54] reported a cartilage defect prevalence per hip of 4%. Five studies (one HR and four MR)[40 57 66–68] reported the prevalence of acetabular and femoral cartilage defects independently. Acetabular cartilage defect prevalence was reported per person (2%–35%)[40 66 68] and per hip (1% and 6%),[57 67] with femoral cartilage defects identified at per person (2%–48%)[40 66 68] and per hip level (1% and 3%).[57 67]

Sensitivity analysis

In symptomatic participants, sensitivity analysis demonstrated a pooled cartilage defect prevalence of 52% (95% CI 12% to 90%; Q=57.6; P<0.001; I^2=98%) per person. No sensitivity analysis was performed for studies using 3 T MRI due to an insufficient number of studies. In asymptomatic participants, a cartilage defect prevalence of 13% (95% CI 8% to 20%; Q=11.7; P=0.070; I^2=49%) per person and 22% (95% CI 7% to 50%; Q=11.5 P=0.003; I^2=83%) per hip was identified in studies using an MRI field strength of ≥1.5 T. In studies only using 3 T MRI, a cartilage defect prevalence of 15% (95% CI 9% to 23%; Q=9.2; P=0.055; I^2=57%) was demonstrated, with no analysis undertaken at per hip level due to an insufficient number of studies.

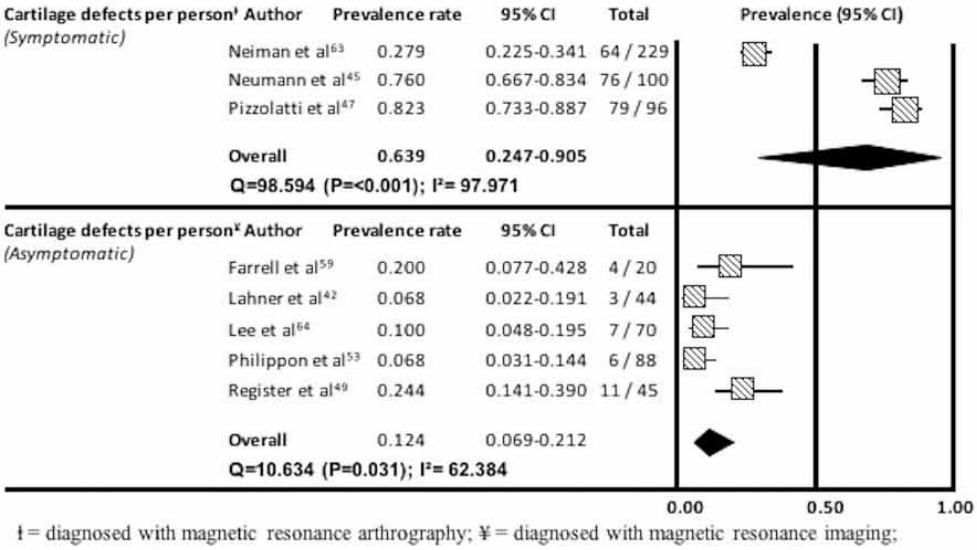

Figure 3 Prevalence and 95% CIs of cartilage defects in symptomatic and asymptomatic participants among studies that reported prevalence per person.

Other pathologies

Symptomatic participants

Bone marrow lesions

Three studies (three MR)[45 67 68] identified the presence of BML in symptomatic participants. One study[45] reported a prevalence of 29%, with the remaining two studies[67 68] evaluating acetabular (11%–68%) and femoral (26%–53%) lesions independently.

Herniation pits

Four studies (four MR)[41 51 56 67] reported the prevalence of herniation pits in symptomatic participants. One study[56] which used CTA reported prevalence per person of 24%. Two studies[51 67] evaluated the prevalence of herniation pits per hip using MRI (27% and 53%). The final study[41] identified a prevalence of 5% in participants with FAI using MRA.

Ligamentum teres tears

Three studies evaluated the prevalence of ligamentum teres tears.[43 55 63] One study (MR)[63] reported prevalence per person (2%). Prevalence was reported per hip (81% and 50%) in two studies (one HR and one LR).[43 55]

Paralabral cysts

Two studies (one HR and one MR)[41 55] reported the prevalence of paralabral cysts per hip (5% and 14%).

Asymptomatic participants

Bone marrow lesions

Three studies (three MR)[49 67 68] evaluated the presence of BML in asymptomatic participants. One study[49] reported acetabular lesions only (11%), with the remaining two studies[67 68] reporting acetabular (2%–20%) and femoral lesions (2%–11%) independently.

Herniation pits

Ten studies (one HR, seven MR and two LR)[40 46 49 51 52 56 57 62 64 67] reported the prevalence of herniation pits in asymptomatic participants. Four (two MR and two LR)[40 49 52 64] of the six studies reporting prevalence per person used MRI (6%–22%). The remaining two studies (two MR)[46 56] used CT (3% and 43%). Four studies reported prevalence per hip, three studies (one HR and two MR)[51 57 67] used MRI (5%–18%) and the remaining study (MR)[62] CT (14%).

Ligamentum teres tears

Two studies (one MR and one LR)[43 49] reported the prevalence of ligamentum teres tears using MRI. One study (LR)[43] reported a prevalence per hip of 24%, with the other (MR)[49] a prevalence per person of 2%.

Paralabral cysts

Four studies (one LR and three MR)[40 49 50 64] identified the prevalence of paralabral cysts in asymptomatic participants. Three studies (one LR and two MR)[40 49 64] reported prevalence per person of between 0% and 13%. One study (MR)[50] reported a prevalence per hip of 24%.

Other pathologies reported in less than two studies

Pathologies that were not reported in symptomatic and asymptomatic populations in two or more studies are presented in online supplementary appendix 3 table 1.

DISCUSSION

Imaging-defined intra-articular hip pathologies are frequently observed in individuals with and without pain. Diagnostic imaging is now readily used to assist in the evaluation of individuals with hip and groin conditions.[10 17] However, there is often a poor association between hip symptoms and structural changes seen on imaging.[69] In total, 29 studies were analysed in this review, with 24 studies adjudged to have moderate to high risk of bias. The external validity of the included studies is generally limited, with no studies investigating large population cohorts. High levels of statistical heterogeneity ($I^2 \geq 75\%$) were consistently observed within MRI and MRA studies highlighting that

considerable variability exists in the prevalence of intra-articular pathologies in the studies included in this review. The results of this review provide a greater understanding of the prevalence of commonly seen hip pathologies in relation to the presence or absence of pain. In summary, labral tears are prevalent in both symptomatic and asymptomatic individuals, although the prevalence is slightly higher in symptomatic groups. Importantly, the prevalence of cartilage defects, BML and ligamentum teres tears was higher in symptomatic than asymptomatic groups.

Labral tears were observed in 62% of individuals with pain and 54% of asymptomatic individuals. The high prevalence of labral tears in asymptomatic individuals is a particularly interesting finding, given the reported nociceptive ability of labral tissue[70 71] and its proposed role in hip joint health.[72 73] The questionable relationship between labral pathology and symptoms identified in this review has been mirrored recently in two papers[74 75] reporting a limited association between labral pathology and self-reported function in a chronic hip pain population and individuals with and without radiographic hip OA. The role that labral tissue plays in the development of symptoms appears more complex than previously thought.

Cartilage defects were evident in 64% of symptomatic individuals, considerably more than the 12% of asymptomatic individuals. Thus, it could be considered that cartilage defects might contribute to hip-related symptoms. However, recent work has highlighted a variable relationship between cartilage defects and pain.[74–76] Moreover, articular cartilage is considered to be aneural under normal physiological conditions.[77 78] Interestingly, of the included studies that reported acetabular and femoral cartilage defects independently, a trend highlighting a greater prevalence of acetabular cartilage defects was observed in symptomatic individuals. Our finding is consistent with studies reporting associations between acetabular cartilage damage and pain, clinical symptoms and reduction in function.[74] The presence of cartilage defects could indicate early stages of the arthritic cascade, and the involvement of other tissues such as periarticular tissues, subchondral bone or synovial tissue.[71 74 78 79]

This review also highlighted variability in prevalence of herniation pits between those with and without pain. Studies using MRI demonstrated a greater prevalence in symptomatic individuals, conversely studies using CT identified a greater prevalence in asymptomatic individuals. Paralabral cysts were identified similarly in symptomatic and asymptomatic individuals in studies using MRA and MRI, respectively. However, akin to cartilage defects, ligamentum teres tears and BML were seen more often in those with pain. Variability has been observed within literature regarding the nociceptive ability of the ligamentum teres.[71 80] This lack of consensus is reflected in our results, with a quarter of asymptomatic individuals having imaging defined pathology. A greater understanding of the role of ligamentum teres in nociception is required to inform management decisions. The greater prevalence of BML observed in symptomatic populations is congruent with recent findings showing the association of such lesions with clinical symptoms and impaired patient-reported outcomes.[74 75 81] In addition, individuals with acetabular and femoral cartilage defects have a greater prevalence of BML, which may demonstrate an association between such defects and early arthritic change.[74]

Two recent reviews[29 30] have reported on the prevalence of intra-articular hip pathologies. The review undertaken by Frank *et al*[30] reported a higher prevalence of labral tears in asymptomatic individuals (68% vs 54%), which likely reflects the 11 new studies published since the completion of their literature search, and our decision to distinguish the prevalence of pathologies by either person or hip. The review by Mascarenhas *et al*[29] reported on labral tears and cartilage defects in symptomatic, asymptomatic and athletic individuals. The prevalence of labral tears in symptomatic individuals was lower than our results (28% vs 62%). The variation in results can be explained through the differences seen in review aims, methods used to combine prevalence figures and the large variation in studies included in each review.

The findings of our review should be interpreted in conjunction with the known limitations of diagnostic imaging. In particular, we highlighted that labral tears were observed on MRI in a high number of asymptomatic individuals (54%). Magnetic resonance imaging across various field strengths with and without the use of contrast agents has variable diagnostic utility to identify labral pathology,[18 82] which may result in overestimation or underestimation of prevalence in asymptomatic individuals. However, 4 of the 8 studies included in meta-analysis used 3 T MRI, which may provide greater accuracy compared with lower field strength systems[83] and increases confidence in our findings. Contrast-enhanced MRA provides the highest diagnostic accuracy in the identification of labral tears. Unfortunately, no studies including MRA on asymptomatic individuals were identified in this review. Further studies are necessary to determine whether MRA findings of labral tears in asymptomatic individuals agree with the current analysis. The disparity in cartilage defects is a notable result, with this trend observed in studies using MRA and MRI. The use of low-field strength MRA protocols across the studies included in meta-analysis increases the possibility of misinterpretation of cartilage defects in symptomatic individuals. Conversely, a number of studies used 3 T MRI for analysis of cartilage defects in symptomatics and consistently demonstrated a higher prevalence. As 3 T MRI provides greater visualisation of acetabular and femoral articular cartilage,[83 84] it may be that the prevalence of cartilage defects is indeed higher in symptomatic individuals.

The decision to dichotomise the imaging findings may have resulted in an overestimation of prevalence. However, this method was deemed necessary due to the variability in methods used to grade intra-articular pathology.[75 76] The recent development of semiquantitative methods for the assessment of hip structural pathologies has shown promise with high levels of reliability and agreement.[75 76] Furthermore, these methods have shown moderate correlation with patient-reported outcome measures.[76] Future research should focus on developing consensus for the grading of intra-articular pathologies as this will provide a better understanding of the true spectrum of pathology.

In total, 5 of the 29 included studies were adjudged to have HR, highlighting poor study methodology in the current literature evaluating the prevalence of intra-articular hip pathologies. Study populations were often attained by convenience and not deemed representative of a wider population, reducing the generalisability of the reviews findings. The reliability and level of agreement for the diagnostic criteria used to evaluate intra-articular pathologies were often not documented in studies, reducing confidence in the reported findings. The method used to determine prevalence was variable across studies. Prevalence by definition should be determined by dividing 'the number of cases of a disease in a population, by the population number'.[85] Our decision to adjudge studies reporting prevalence per hip as high risk of bias was in line with recent literature.[86] Exclusion of HR studies in the meta-analyses may increase confidence in the findings of this review. However, limited to moderate-level evidence was

assigned with our findings, outlining that studies of greater methodological quality are still required.

The high levels of heterogeneity observed in the pooled symptomatic and asymptomatic populations are akin to other prevalence reviews.[24 87] In relation to this review, it likely reflects variability in imaging modalities and parameters used across the included studies. Other sources of heterogeneity may include variations in age, sex and levels of physical activity across the included studies. Interestingly, high levels of heterogeneity were present despite the exclusion of HR studies, which may indicate that study quality and heterogeneity are not directly related in this review.

Limitations

There are a number of limitations relating to the results of this review. First, the decision to exclude studies investigating the prevalence of intra-articular hip pathologies in individuals with slipped capital femoral epiphysis and Legg-Calve-Perthes disease reduces the generalisability of our findings specifically to these conditions. Second, a number of studies were excluded on the basis of not identifying a primary aim of reporting the prevalence of intra-articular hip pathologies.[88–91] While excluded, the results from the aforementioned studies are very similar to those achieved in our review, providing validation of the results of this review. Third, unpublished studies and those not published in the English language were not included in this review which may have excluded some relevant studies. A notable limitation of the studies in this review is the inclusion of participants based on the presence of hip and/or groin pain. Hip and groin-related pain can be caused by a number of different intra-articular and extra-articular conditions,[10 13 14] hence the relevance of imaging-defined intra-articular pathologies may be questionable in some symptomatic individuals.

Importantly, the studies in this review evaluate highly selective populations, meaning the results of this review are not interpretable beyond the inclusion criteria of the included studies. Furthermore, there is limited comparability between the included studies which further reduces the generalisability of the reviews findings. Consideration is needed regarding the use of the term 'prevalence' to describe the findings of this review as none of the included studies evaluated community-based populations. Finally, the intra-articular pathologies identified with imaging in both symptomatic and asymptomatic individuals were not confirmed by hip arthroscopy, which is currently considered the gold standard for diagnosis of intra-articular hip pathologies. Although this is a notable limitation, arthroscopic confirmation of intra-articular pathologies will never be a consideration in asymptomatic populations.

CONCLUSION

This systematic review identified 29 studies. The included studies used MRI, MRA and CT to investigate the prevalence of intra-articular hip pathologies. Most studies had a moderate to high risk of bias with only five low-risk studies. The prevalence of cartilage pathology is higher in people with pain than those without. In contrast, the prevalence of labral pathology is similar in those with and without pain. Bone marrow lesions and ligamentum teres tears appear to be more prevalent in individuals with pain. Paralabral cysts and herniation pits are prevalent in both symptomatic and asymptomatic individuals. This review highlights the uncertainty of the relationship between intra-articular hip joint pathology on imaging and pain. A greater understanding of this relationship may improve the selection and effectiveness of conservative and surgical interventions for intra-articular hip pathologies.

What is already known?

- Diagnostic imaging is used to evaluate the cause of symptoms in individuals with hip, groin or buttock pain.
- Intra-articular hip pathologies found on imaging are often a catalyst for surgical interventions in those with hip, groin or buttock pain.
- The prevalence of pathological findings has been shown to be high in those with and without pain in other anatomical regions.

What are the new findings?

- Labral tear prevalence is high in those with and without hip, groin or buttock pain.
- Cartilage defects are seen more often in individuals with pain.
- Bone marrow lesions and ligamentum teres tears are more prevalent in individuals with pain.
- Herniation pits and paralabral cysts are seen at similar rates in individuals with and without pain.
- Uncertainty surrounds the relationship between imaging-defined intra-articular pathology and pain.
- Studies evaluating true community-based populations are needed to better understand the true prevalence of intra-articular hip pathologies in asymptomatic and symptomatic individuals.

Contributors JJH, JLK and KMC were responsible for the creation and planning of the review. JJH and JLK were responsible for the search strategy used. JJH, JLK and DMJ developed the strategy to evaluate study quality. JJH, ABM and KMC were involved in the data extraction process. JJH wrote the final manuscript with all authors assisting in revising content.

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Appendix 15. Search strategy for Study 1 (Chapter 4).

MEDLINE.

(Hip[Mesh] OR hip$1 kw OR Hip joint[Mesh] OR hip joint$1 kw OR coxofemoral joint$1 kw OR Acetabulum[Mesh] OR acetabulum kw OR acetabular fossa kw OR Femur head[Mesh] OR fem* head$1 kw OR Femoracetabular impingement[Mesh] OR femor?acetabular impingement kw OR femoral acetabular impingement kw OR FAI kw) AND (labr$2 kw OR labr$2 tear$1 kw OR Cartilage, Articular[Mesh] OR articular cartilage kw OR chondral damage kw OR chondropath* kw OR cartilage delamination kw OR internal derangement kw OR ligamentum teres kw OR foveal ligament$1 kw OR Round ligament of femur[Mesh] OR herniation pit$1 kw OR paralabral cyst$1 kw) AND (Magnetic Resonance Imaging[Mesh] OR magnetic resonance imaging kw OR MRI kw OR magnetic resonance arthrogra* kw OR MRA kw OR Tomography, X-ray Computed[Mesh] OR computed tomography kw OR CT kw OR c?t scan* kw OR computed tomography arthrogra* kw OR CTA kw) AND (Prevalence[Mesh] OR prevalen* kw OR Epidemiology[Mesh] OR epidemiology kw)

CINAHL.

(Hip[Mesh] OR hip# kw OR Hip joint[Mesh] OR "hip joint#" kw OR "coxofemoral joint#" kw OR Acetabulum[Mesh] OR acetabulum kw OR "acetabular fossa" kw OR Femur head[Mesh] OR "fem* head#" kw OR Femoracetabular impingement[Mesh] OR "femor#acetabular impingement" kw OR "femoral acetabular impingement" kw OR FAI kw) AND (Hip labram tear[Mesh] OR labr* kw OR "labr* tear#" kw OR Cartilage, Articular[Mesh] OR "articular cartilage" kw OR "chondral damage" kw OR chondropath* kw OR "cartilage delamination" kw OR "internal derangement" kw OR "ligamentum teres" kw OR "foveal ligament#" kw OR "herniation pit#" kw OR "paralabral cyst#" kw) AND (Magnetic resonance imaging[Mesh] OR "magnetic resonance imaging" kw OR MRI kw OR "magnetic resonance arthrogra*" kw OR MRA kw OR Tomography, X-ray Computed[Mesh] OR "computed tomography" kw OR CT kw OR "c#t scan*" kw OR "computed tomography arthrogra*" kw OR CTA kw) AND (Prevalence[Mesh] OR prevalence kw OR Cross sectional studies[Mesh] OR Epidemiology[Mesh] OR epidemiolog* kw)

EMBASE.

(Hip[Mesh] OR hip$1 kw OR hip joint$1 kw OR coxofemoral joint$1 kw OR Acetabulum[Mesh] OR acetabulum kw OR acetabular fossa kw OR Femur head[Mesh] OR fem* head$1 OR Femoracetabular impingement[Mesh] OR femor?acetabular impingement OR femoral acetabular impingement OR FAI) AND (labr$2 kw OR labr$2 tear$1 kw OR Articular cartilage[Mesh] OR articular cartilage kw OR chondral damage kw OR Chondropathy[Mesh] OR chondropath* kw OR cartilage delamination kw OR internal derangement kw OR ligamentum teres kw OR foveal ligament$1 kw OR herniation pit$1 kw OR paralabral cyst$1 kw) AND (Nuclear magnetic resonance

imaging[Mesh]ORmagneticresonanceimaging kw OR MRI kw OR magnetic resonance arthrogra* OR MRA kw OR Computer assisted tomography[Mesh]ORcomputedtomographykwORCTkwORc?tscan*kwOR computedtomography arthrogra*kwORCTAkw)AND(Prevalence[Mesh]ORprevalen*kwOR Epidemiology[Mesh]OR epidemiolog* kw)

SPORTdiscus.

(hip kw OR Hip joint de OR "hip joint#" kw OR "coxofemoral joint#" kw OR acetabulum kw OR "acetabular fossa" kw OR "fem* head#" kw OR "femor#acetabular impingement" OR "femoral acetabularimpingement"OR"FAI")AND(labr*kwOR"labr*tear#"kwORarticularcartilagedeOR "articular cartilage" kw OR "chondral damage" kw OR chondropath* kw OR "cartilage delamination" kw OR"internal derangement"kwOR"ligamentumteres"kwOR"fovealligament"kwOR"herniationpit*" kwOR"paralabral cyst*" kw) AND (Magnetic resonance imaging de OR "magnetic resonance imaging" kw OR MRI kw OR "magnetic resonance arthrogra*" kw OR MRA kw OR Computed tomography de OR "computedtomography"kwORCTkw OR"c#tscan*"kwOR"computedtomographyarthrogra*"OR CTAkw)AND("Diseaseprevalence"deOR prevalen*kwOREpidemiologydeORepidemiolog*)

Cochrane library.

(Hip[Mesh] OR "hip" ti.ab.kw OR Hip joint[Mesh] OR "hip joint" ti.ab.kw OR "coxofemoral joint*" ti.ab.kw OR Acetabulum[Mesh] OR "acetabular fossa" ti.ab.kw OR Femur head[Mesh] OR fem* NEXT head ti.ab.kw OR Femoracetabular impingement[Mesh] OR "femoracetabular impingement" ti.ab.kw OR "femoral acetabular impingement" ti.ab.kw OR "FAI" ti.ab.kw) AND ("labral" ti.ab.kw OR "labrum" ti.ab.kw OR labral NEXT tear ti.ab.kw OR Articular cartilage[Mesh] OR "articular cartilage" ti.ab.kw OR "chondral damage" ti.ab.kw OR chondropath* ti.ab.kw OR "cartilage delamination" ti.ab.kw OR "internal derangement" ti.ab.kw OR "ligamentum teres" ti.ab.kw OR "foveal ligament" ti.ab.kw OR herniation NEXT pit* ti.ab.kw OR paralabral NEXT cyst* ti.ab.kw) AND (Magnetic resonance imaging[Mesh] OR "magnetic resonance imaging" ti.ab.kw OR MRI ti.ab.kw OR magnetic NEXT resonance NEXT arthrogra* ti.ab.kw OR MRA ti.ab.kw OR Tomography, X-ray Computed[Mesh] OR "computed tomgraphy" ti.ab.kw OR CT ti.ab.kw OR "cat scan" ti.ab.kw OR "ct scan" ti.ab.kw OR computed NEXT tomography NEXT arthrogra* ti.ab.kw OR CTA ti.ab.kw) AND (Prevalence[Mesh] OR Prevalence ti.ab.kw OR Epidemiology[Mesh] OR epidemiolog* ti.ab.kw)

Pubmed.

(hip OR hip joint OR coxofemoral joint OR acetabulum OR acetabular fossa OR femur head OR femoral head OR femoracetabular impingement OR femoral acetabular impingement OR FAI) AND (labral OR labrum OR labral tear OR labrum tear OR articular cartilage OR chondral damage OR chondropathy OR cartilage delamination OR internal derangement OR ligamentum teres OR foveal ligament OR herniation pit OR paralabral cyst) AND (magnetic resonance imaging OR MRI OR magnetic resonance arthrogra* OR MRA OR computed tomography OR CT OR ct scan OR cat scan OR computed tomography arthrogra* OR CTA) AND (prevalence OR prevalen* OR epidemiology OR epidemiolog*)

Scopus.

(hip ti.ab.kw OR "hip joint" ti.ab.kw OR "coxofemoral joint" ti.ab.kw OR acetabulum ti.ab.kw OR "acetabular fossa" ti.ab.kw OR "fem* head" ti.ab.kw OR "femoracetabular impingement" ti.ab.kw OR "femoroacetabular impingement" ti.ab.kw OR "femoral acetabular impingement" ti.ab.kw OR FAI ti.ab.kw) AND (labr* ti.ab.kw OR "labr* tear" ti.ab.kw OR "articular cartilage" ti.ab.kw OR "chondral damage" ti.ab.kw OR chondropath* ti.ab.kw OR "cartilage delamination" ti.ab.kw OR "internal derangement" ti.ab.kw OR "ligamentum teres" ti.ab.kw OR "foveal ligament" ti.ab.kw OR "herniation pit" ti.ab.kw OR "paralabral cyst" ti.ab.kw) AND ("magnetic resonance imaging" ti.ab.kw OR MRI ti.ab.kw OR "magnetic resonance arthrogra*" ti.ab.kw OR MRA ti.ab.kw OR "computed tomography" ti.ab.kw OR CT ti.ab.kw OR "ct scan" ti.ab.kw OR "cat scan" ti.ab.kw OR computed tomography arthrogra* ti.ab.kw OR CTA ti.ab.kw) AND (prevalen* ti.ab.kw OR epidemiolog* ti.ab.kw)

Appendix 16. Studies excluded from Study 1 (Chapter 4).

Author	Title	Reason excluded
Abe, 2001[1]	Acetabular labrum: abnormal findings at MR imaging in asymptomatic hips.	Reported signal intensity and shape only.
Ahedi, 2013[2]	The association between hip bone marrow lesions and bone mineral density: a cross-sectional and longitudinal population-based study.	Reporting of intra-articular hip pathology prevalence not the primary aim.
Anderson, 2009[3]	Acetabular cartilage delamination in femoroacetabular impingement. Risk factors and magnetic resonance imaging diagnosis.	Reporting of intra-articular hip pathology prevalence not primary aim.
Angioi, 2014[4]	Early signs of osteoarthritis in professional ballet dancers: A preliminary study.	Less than 5 subjects evaluated for intra-articular hip pathology.
Bellaiche, 2010[5]	Imaging data in a prospective series of adult hip pain in under-50 year-olds.	Reporting of intra-articular hip pathology prevalence not the primary aim.
Botser, 2011[6]	Tears of the ligamentum teres: prevalence in hip arthroscopy using 2 classification Systems.	Prevalence of intra-articular hip pathology determined at Arthroscopy.
Cheng, 2013[7]	Correlation between the prevalence of herniation pits and the alpha angle of the hip: Computed tomography evaluation in healthy Chinese adults.	Reporting of intra-articular hip pathology prevalence not the primary aim.
Corten, 2011[8]	Bone apposition of the acetabular rim in deep hips: A distinct finding of global pincer impingement.	Reporting of intra-articular hip pathology prevalence not the primary aim.
Dinauer, 2004[9]	Sublabral sulcus at the posteroinferior acetabulum: A potential pitfall in MR arthrography diagnosis of acetabular labral tears.	Reporting of intra-articular hip pathology prevalence not the primary aim.
Dolan, 2011[10]	CT reveals a high incidence of osseous abnormalities in hips with labral tears.	Reporting of intra-articular hip pathology prevalence not the primary aim.
Frank, 2015[11]	Prevalence of femoroacetabular impingement imaging findings in asymptomatic volunteers: A systematic review.	Systematic review.
Guo, 2013[12]	Correlation between the prevalence of herniation pits and the alpha angle of the hip: computed tomography evaluation in healthy Chinese adults.	Reporting of intra-articular hip pathology prevalence not the primary aim/duplicate.

Ha, 2017[13]	Prevalence and clinical significance of hypertrophic labrum in non-dysplastic Hips.	Reporting of intra-articular hip pathology prevalence not the primary aim.
Kang, 2010[14]	Computed tomography assessment of hip joints in asymptomatic individuals in relation to femoroacetabular impingement.	Reporting of intra-articular hip pathology prevalence not the primary aim.
Kassarjian, 2009[15]	Obturator externus bursa: Prevalence of communication with the hip joint and associated intra-articular findings in 200 consecutive hip MR arthrograms.	Reporting of intra-articular hip pathology prevalence not the primary aim.
Khanna, 2014[16]	Hip arthroscopy: Prevalence of intra-articular pathologic findings after traumatic injury of the hip.	Reporting of intra-articular hip pathology not the primary aim.
Kubicki, 2015[17]	The acetabular fossa hot spot on 18F-FDG PET/CT: epidemiology, natural history, and proposed aetiology.	Reporting of intra-articular hip pathology not the primary aim.
Kwee, 2013[18]	Normal anatomical variants of the labrum of the hip at magnetic resonance imaging: a systematic review.	Systematic review.
Lee, 2015[19]	Associations between alpha angle and herniation pit on MRI revisited in 185 asymptomatic hip joints.	Reporting of intra-articular hip pathology not the primary aim.
Magee, 2015[20]	Comparison of 3.0-T MR vs 3.0-T MR arthrography of the hip for detection of acetabular labral tears and chondral defects in the same patient population.	Reporting of intra-articular hip pathology not the primary aim.
Magerkurth, 2015[21]	Prevalence of the acetabular sublabral sulcus at MR arthrography in patients under 17 years of age: Does it exist?	Reporting of intra-articular hip pathology not the primary aim.
Mimura, 2017[22]	Prevalence of pincer, cam, and combined deformities in Japanese hip joints evaluated with the Japanese Hip Society. diagnostic guideline for femoroacetabular impingement: A CT-based study.	Reporting of intra-articular hip pathology not the primary aim.
Nishii, 1998[23]	Articular cartilage evaluation in osteoarthritis of the hip with mr imaging under continuous leg traction.	Reporting of intra-articular hip pathology not the primary aim.
Nishii, 2001[24]	Articular cartilage abnormalities in dysplastic hips without joint space Narrowing.	Reporting of intra-articular hip pathology not the primary aim.
Parmar, 2010[25]	The multifaceted aetiology of acetabular labral tears.	Reporting of intra-articular hip pathology not the primary.aim.

Pfirrmann,2008[26]	MR arthrography of acetabular cartilage delamination in femoroacetabular cam Impingement.	Prevalence of intra-articular hip pathology determined at Arthroscopy.
Saddik, 2006[27]	Prevalence and location of acetabular sublabral sulci at hip arthroscopy with retrospective MRI review.	Prevalence of intra-articular hip pathology determined at arthroscopy.
Scheyerer, 2014[28]	Radiographic markers of femoroacetabular impingement: correlation of herniation pit and femoral bump with a positive cross-over ratio.	Reporting of intra-articular hip pathology not the primary aim.
Sink, 2008[29]	Clinical presentation of femoroacetabular impingement in adolescents.	Reporting of intra-articular hip pathology not the primary aim.
Stelzeneder, 2012[30]	Patterns of joint damage seen on MRI in early hip osteoarthritis due to structural hip deformities.	Reporting of intra-articular hip pathology not the primary aim.
Tamura, 2013[31]	Differences in the locations and modes of labral tearing between dysplastic hips and those with femoroacetabular impingement.	Reporting of intra-articular hip pathology not the primary aim.

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Appendix 17. Additional study population characteristics for studies investigating asymptomatic participants in Study 1 (Chapter 4).

Author	Study population	Level of activity				Radiographic osteoarthritis			Cam morphology	Pincer Morphology
		Elite athlete	Non- elite athlete	Non-athlete	Not reported	Present (%)	Absent (%)	Not reported	Prevalence (%)	Prevalence (%)
Ayeni et al.	Subjects	x						x	AA >50°: 55%¥	LCEA >40°: 10%¥ Acetabular depth ≤0.0mm: 0%¥ Cranial AV <15°: 25%¥
	Controls			x				x	AA >50°: 25%¥	LCEA >40°: 10%¥; Acetabular depth ≤0.0mm: 10%¥; Cranial AV <15°: 25%¥
Farrell et al.	Subjects	x						x	AA ≥50.5°: 55%¥	Not reported
	Controls		x					x	Not reported	Not reported
Georgiadis et al.	Subjects				x			x	Not reported	Not reported
Lahner et al.	Subjects		x					x	AA >55°: 59%¥	Not reported
	Controls		x					x	AA >55°: 40%¥	Not reported
Lahner et al.	Subjects	x						x	AA >55°: 34%¥	LCEA >40°: 0%¥
	Controls				x			x	AA >55°: 2.7%¥	LCEA >40°: 4.5%¥
Lee et al.	Subjects		x					x	Not reported	Not reported
Leunig et al.	Subjects				x			x	Gr ≥1: 22%¥; Gr ≥2: 0%¥	Acetabular depth ≤ 3mm: 10%¥
	Controls				x			x	Gr ≥1: 71%¥; Gr ≥2: 24%¥	Acetabular depth ≤3mm: 6%¥
Mineta et al.	Subjects				x		x⋕ 100%		AA >55° or FHNO ratio <0.15: 45%ᶠ	LCEA >40° or AI <0° or central AV <15° or cranial AV <0°: 37%ᶠ
Panzer et al.	Subjects				x			x	Not reported	Not reported
Philippon et al.	Subjects		x					x	AA ≥55°: 75%¥	Not reported
	Controls		x					x	AA ≥55°: 42%¥	Not reported
Register et al.	Subjects				x			x	Not reported	Not reported
Schmitz et al.	Subjects				x			x	Not reported	Not reported
Silvis et al.	Subjects	x	x					x	AA >55°: 39%¥	Not reported
Yuan et al.	Subjects		x				x‡ 100%		AA >55°: 68%ƛ AA >55°: 55%¥	+ve crossover sign: 32%ƛ +ve ischial spine sign: 41%ƛ
	Controls		x					x	AA >55°: 8%¥	Not reported

AA = alpha angle; ¥ = determined with magnetic resonance imaging; LCEA = lateral-centre-edge-angle; mm = millimetres; AV = acetabular version; Gr = grade; ⋕ = Kellgren and Lawrence grade 0 and 1; FHNO = femoral head-neck offset; ᶠ = determined with computed tomography; AI = acetabular index; AV = acetabular version; ‡ = Tonnis grade 0; ƛ = determined with x-ray

Appendix 18. Additional study population characteristics for studies investigating symptomatic participants in Study 1 (Chapter 4).

Author	Study population	Symptoms	Level of activity				Radiographic osteoarthritis			Cam morphology	Pincer Morphology
			Elite athlete	Non-elite athlete	Non-athlete	Not reported	Present (%)	Absent (%)	Not reported	Prevalence	Prevalence
Domb et al.	Subjects	Hip pain	x						x	AA >55°: 73%[¥†]	Not reported
Jayakar et al.	Subjects	Hip pain				x	x[∓] 35.6%	x[‡] 64.4%		AA >55°: 28%[†]	Not reported
Kassarjian et al.	Subjects	Clinical signs of FAI syndrome				x			x	AA >55°: 93%[†]	Not reported
Narvani et al.	Subjects	Groin pain	x	x					x	Not reported	Not reported
Neiman et al.	Subjects	Hip pain				x			x	Not reported	Not reported
Neumann et al.	Subjects	Mechanical symptoms of the hip				x			x	Not reported	Not reported
Pizzolatti et al.	Subjects	Suspicion of labral tear				x			x	33%*	12%**

AA = alpha angle; ¥ = determined with magnetic resonance imaging; † = determined with magnetic resonance arthrography; ∓ = Tonnis grade 1-3; ‡ = Tonnis grade 0; FAI = femoroacetabular impingement; * = no quantitative measure reported for determining cam morphology; ** = no quantitative measure reported for determining pincer morphology

Appendix 19. Additional study population characteristics for studies investigating symptomatic and asymptomatic participants in Study 1 (Chapter 4).

Author	Study population	Symptoms	Level of activity				Radiographic osteoarthritis			Cam morphology	Pincer Morphology
			Elite athlete	Non-elite athlete	Non-athlete	Not reported	Present (%)	Absent (%)	Not reported	Prevalence (%)	Prevalence (%)
Dickenson et al.	Subjects	Hip pain	x						x	Not reported[§]	Not reported[§]
	Controls	No hip pain	x						x	Not reported[§]	Not reported[§]
Ji et al.	Subjects	Mechanical hip pain for 3/12 +ve clinical examination			x				x	AA >50°: 7%[∫]	LCEA >39° or central AV <10° or cranial AV <0°: 59%[∫]
	Controls	No hip pain			x				x	AA >50°: 14%[f]	LCEA >39° or central AV <10° or cranial AV <0°: 37%
Kolo et al.	Subjects	Hip pain and no hip pain	x						x	AA >55°: 2%[¥]	Acetabular depth *(+ve/normal if centre of femoral head is lateral to line connecting ant/post acetabular rim*)/Acetabular version (*determined by the angle between the sagittal direction and lines drawn between the ant/post acetabular rim; +ve when inclined medially/-ve when inclined laterally*): 0%

	Controls	No hip pain			x			x	AA >55°: 0%¥	Acetabular depth *(+ve/normal if centre of femoral head is lateral to line connecting ant/post acetabular rim*)/Acetabular version (*determined by the angle between the sagittal direction and lines drawn between the ant/post acetabular rim; +ve when inclined medially/-ve when inclined laterally*): 4%
Mayes et al.	**Subjects**	Hip pain in last 3 months	x	x				x	Not reported	Not reported
	Controls	No hip pain	x	x				x	Not reported	Not reported
Mayes et al.	**Subjects**	Hip pain in last 3 months	x	x				x	Not reported	Not reported
	Controls	No hip pain	x	x				x	Not reported	Not reported
Mayes et al.	**Subjects**	Hip pain in last 3 months	x	x				x	Not reported	Not reported
	Controls	No hip pain	x	x				x	Not reported	Not reported
Teichtahl et al.	**Subjects**	Hip pain with radiographic hip OA			x	x‡ 100%			Not reported	Not reported
	Controls	No hip pain			x		x‡ 100%		Not reported	Not reported

Tresch et al.	**Subjects**	Symptomatic individuals (groin pain >3/12, +ve FADIR test and hip int rot <20°) with FAI Syndrome	x		x	52%†*	16%†**
	Controls	Asymptomatic individuals (-ve FADIR test and hip int rot >25°)	x		x	Not reported	Not reported

§ = information regarding prevalence of morphology relative to symptoms not reported in original data paper; AA = alpha angle; ∫ = determined with computed tomography arthrography; ƒ = determined with computed tomography; ¥ = determined with magnetic resonance imaging; OA = osteoarthritis; ǂ = Kellgren and Lawrence grade 2 to 4; ǂ = never had a diagnosis of hip osteoarthritis made by a medical or allied health professional; FADIR = flexion adduction internal rotation; int rot = internal rotation; FAI = femoroacetabular impingement; † = determined with magnetic resonance arthrography; * = no quantitative measure reported for determining cam morphology; ** = no quantitative measure reported for determining pincer morphology

Appendix 20. Prevalence of other pathologies not reported in ≥2 symptomatic and asymptomatic studies in Study 1 (Chapter 4).

Participant group	Per person	Per hip
Symptomatic	Neiman et al. *(MR)*: avascular necrosis: 0%; pigmented villonodular synovitis: 0%; synovitis: 1%; transient osteoporosis of the hip: 1% Neumann et al. *(MR)*: diffuse signal increase in labrum: 6%; diminutive signal increase in labrum: 2%; labral intrasubstance degeneration: 13% osteophytes: 32%; subchondral bone cysts: 23%; subchondral sclerosis: 22% Tresch et al. *(MR)*: degenerated labrum: 12%	Dickenson et al. (*HR)*: joint effusion: 7%; increased labral signal: 20% Domb et al. *(HR)*: avascular necrosis: 0%; bursitis: 0%; osteophytes: 5%; subchondral bone cysts: 14.5%; transverse ligament tears: 3% Jayakar et al. *(MR)*: labral fraying: 20% Kassarjian et al. *(MR)*: os ascetabuli: 40% Kolo et al. *(MR)*: labral degeneration: 41%¥; Labral ossification: 3%¥
Asymptomatic	Lee et al. *(LR)*: Labral ossification: 14% Leunig et al. *(LR)*: labral deformity: 10%; labral ganglions: 21% Register et al. *(MR)*: osseous bumps: 20%; rim fracture: 11%; Subchondral bone cysts: 16% Silvis et al. *(HR)*: hip effusion: 0% Tresch et al. *(MR)*: degenerated labrum: 10% Yuan et al. *(HR)*: acetabular rim damage: 15%†	Dickenson et al. (*HR)*: joint effusion: 8%; increased labral signal: 22% Kolo et al. *(MR)*: labral degeneration: 43%; Labral ossification: 14% Lahner et al. *(HR)*: osseous bumps: 3% Yuan et al. *(HR)*: Acetabular rim damage: 0%ǂǂ

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SYSTEMATIC REVIEW

What is the Prevalence of Hip Intra-Articular Pathologies and Osteoarthritis in Active Athletes with Hip and Groin Pain Compared with Those Without? A Systematic Review and Meta-Analysis

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Published online: 10 April 2019

Abstract

Background In athletes, hip and groin pain is considered to be associated with hip intra-articular pathologies and hip osteoarthritis (OA). A greater understanding of the relationship between hip and groin pain and imaging findings is required.

Objective Our objective was to undertake a systematic review and meta-analysis to determine the prevalence of hip intra-articular pathologies and hip OA in athletes with and without hip and groin pain.

Methods Seven electronic databases were searched on 29 January 2018 for studies investigating the prevalence of hip intra-articular pathologies and hip OA using X-ray, magnetic resonance imaging, magnetic resonance arthrography or computed tomography. The search, study selection, quality appraisal and data extraction were performed by two independent reviewers. When studies were considered homogenous, meta-analysis was undertaken. A strength of evidence was given to pooled results.

Results Twenty studies reporting on the prevalence of hip intra-articular pathologies and hip OA in athletes were identified. Included studies were considered moderate to high risk of bias, with only three studies adjudged as low risk of bias. In asymptomatic athletes, limited evidence identified a labral tear prevalence of 54% per person and moderate evidence of 33% per hip. In symptomatic athletes, moderate evidence of a labral tear prevalence of 20% per hip was found. Moderate evidence of a cartilage defect prevalence of 10% per person was reported in asymptomatic athletes. In symptomatic athletes, cartilage defect prevalence was 7–40%. In asymptomatic athletes, the prevalence of hip OA was 0–17%, compared with 2% in symptomatic athletes.

Conclusion The prevalence of hip intra-articular pathologies and hip OA in symptomatic and asymptomatic athletes is variable. Labral tears and cartilage defects appear to be seen often in athletes with and without pain. Hip OA is rarely seen in athletes either with or without hip and groin pain.

Study Registration PROSPERO registration CRD42017082457.

Key Points

Hip intra-articular pathologies are seen in athletes with and without pain.

Labral tears were identified in up to one in every two athletes without pain, highlighting a potential discordant relationship between labral tears and pain in athletes.

Cartilage defects, bone marrow lesions, herniation pits, hip joint effusion, labral degeneration and ligamentum teres tears were observed in symptomatic and asymptomatic athletes.

A complex relationship exists between structural hip conditions identified with imaging and pain in athletes.

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1 Introduction

Hip and groin pain is common in athletes [1–11], particularly those participating in football codes [1, 3, 8, 10–12], ice hockey [5] and dancing [9]. Hip and groin pain constitutes up to 18% of all time loss injuries in professional football (soccer) [1, 13]. Moreover, in football 59% of men and 45% of women will experience groin pain/injury during a competitive season [6]. Many athletes will experience long-standing symptoms [3], with one in three sub-elite football players with hip and groin pain having symptoms for greater than 6 weeks. Chronicity of symptoms is associated with greater difficulties in activities of daily living, reduced quality of life and impaired athletic performance [3].

A number of different and often coexisting clinical entities are proposed to cause hip and groin pain in athletes [14–17]. Hip-related groin pain in athletes often results from femoroacetabular impingement (FAI) syndrome and labral tears [15, 18–20]. The bony morphology associated with FAI syndrome is characterised as cam and/or pincer morphology [21]. Cam morphology is present in up to 66% of athletes [22–24], with male athletes eight times more likely to have cam morphology than non-athletes [24]. In athletes, the combination of bony morphology with the repetitive end of range hip movements performed during sporting activities may predispose to mechanical abutment and the development of symptoms and pain [18–20]. Over time, cam morphology may result in intra-articular hip conditions, including hip osteoarthritis (OA). Cam morphology is associated with intra-articular pathology including labral tears in individuals with and without pain [25–27], and increases the odds of developing OA by up to ten times in older adults [28]. However, little is known about the risk of developing hip OA in athletic populations with cam morphology [16, 28].

Imaging is used to evaluate the presence of intra-articular hip conditions in athletes with hip and groin pain [29, 30]. Our recent review of studies evaluating athletes and non-athletes highlighted similar prevalence of select intra-articular hip pathologies in individuals with and without pain, regardless of level of athletic activity [31]. However, our review did not provide a detailed understanding of the prevalence of such pathologies specifically in athletes. Additional reviews on the prevalence of intra-articular hip conditions including bony morphology, labral tears and cartilage defects in athletes [22, 23] have not described all frequently reported intra-articular pathologies. The prevalence of hip OA in retired athletes is known [32, 33], but the prevalence in athletes currently playing sport is not. Therefore, the aim of this review was to determine the prevalence of intra-articular hip pathologies such as labral tears, cartilage defects, ligamentum teres tears, bone marrow lesions (BML), synovitis and hip OA in athletes with and without hip and groin pain who are currently playing sport.

2 Methods

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used in this systematic review. The protocol for this review was registered on the PROSPERO international prospective register of systematic reviews (http://www.crd.york.ac.uk/PROSPERO) on 11 December 2017 (registration number CRD42017082457).

2.1 Eligibility Criteria

We included studies if they (1) were written in the English language; (2) were cross-sectional, case-control, case series or cohort designs; (3) included current amateur, semi-professional or elite athletes with and without hip and groin pain; (4) utilised X-ray, magnetic resonance imaging (MRI), magnetic resonance arthrography (MRA) and/or computed tomography (CT) to determine the presence of intra-articular hip pathologies or OA; (5) had a primary aim of reporting the prevalence intra-articular hip pathologies or OA in athletes; and (6) evaluated the presence of FAI (including bony morphology) or hip dysplasia and the prevalence of intra-articular hip pathologies or OA. We did not place any restrictions on the age of athletes included in the studies. We excluded studies if they (1) reported on the prevalence of intra-articular hip pathologies or OA in athletes but this was not listed as the primary aim of the study; (2) reported on the prevalence of intra-articular hip pathologies or OA in retired athletes; (3) evaluated the prevalence of FAI (including bony morphology) and hip dysplasia but did not report the presence of intra-articular hip pathologies or OA; (4) identified the presence of intra-articular hip pathologies or OA in athletes with Legg–Calvé–Perthes disease or slipped capital femoral epiphysis; (5) used ultrasound or isotopic bone scan to determine the prevalence of intra-articular hip pathologies or OA; (6) used hip arthroscopy or open hip surgery to determine the prevalence of intra-articular hip pathologies or OA in athletes; (7) included fewer than five athletes; or (8) were unpublished data, abstracts or systematic reviews and/or were studies not published in the English language

2.2 Search Strategy

Two independent authors (JJH and MJS) undertook a comprehensive search using the OVID MEDLINE, PubMed, CINAHL, EMBASE, SPORTDiscus, SCOPUS and Cochrane databases from inception to 29 January 2018. Citation tracking using Google Scholar and the screening of reference lists of included articles was undertaken by one

author (JJH). Database-specific controlled vocabulary and keyword terms were used for each database (Electronic Supplementary Material Online Resource 1).

Endnote X7 (Thomson Reuters, Carlsbad, CA, USA) was used for management of the identified articles. Two authors (JJH, MJS) applied the specified inclusion/exclusion criteria to the articles identified during the search process. Each author (JJH, MJS) independently selected the articles eligible for final inclusion in the review. At the completion of this process, consensus was achieved between the two authors on the articles to be included in the review. A third reviewer (JLK) was utilised when the two authors could not agree upon the inclusion of an article.

2.3 Risk of Bias

Risk of bias was independently assessed by two authors (JJH, DMJ). A tool designed to determine the risk of bias in prevalence literature was utilised in the review [34]. The external validity (four questions) and internal validity (six questions) of each included article was evaluated. Each of the ten questions is scored as low risk of bias (LR) or high risk of bias (HR). If an article did not provide adequate information for a question to be scored, a score of HR was given. In relation to question one, an article was scored as LR if it was considered that the athletes were representative of a wider population of athletes playing the selected sport. In line with a recent review [31], question seven was modified, where an article was considered LR if it reported an intra-class correlation coefficient (ICC) greater than 0.40 and/or Cohen's kappa (κ) greater than 40% for the method used to assess the prevalence of specific intra-articular hip pathologies and/or OA. Each included article was provided with an overall risk of bias score, as determined by the number of HR items. Articles were considered LR if they had 0–3 HR items, moderate risk of bias (MR) if they had 4–5 HR items and HR if they had ≥ 6 HR items [35]. In the event of author disagreement, a third author (JLK) was consulted. The inter-rater agreement was evaluated with κ: excellent agreement was achieved with κ values above 80%, substantial agreement with 60–80%, moderate agreement with 40–60% and, finally, poor to fair agreement with values below 40% [36].

2.4 Data Extraction

Two authors (JJH, ABM) independently extracted data from all 20 included articles. The data extracted from each article included author, study design, sport, number of athletes, number of hips, sex, age, imaging method used and prevalence of intra-articular hip pathologies and/or OA. In the event of disagreement between the authors on the data extracted, a third author (KMC) was consulted to reach consensus. Authors of the included articles were contacted if additional data were required. Authors from nine of the 20 included articles were contacted and provided additional data upon request.

2.5 Data Synthesis and Analysis

For this review, athletes were defined as individuals who competed and trained in a specific sport [37]. The athletic populations investigated in this review were not representative of community-based populations; hence, the reported prevalence of intra-articular hip pathologies and/or OA is representative of the frequency of such pathologies in athletic individuals with and without pain. To determine the prevalence of intra-articular hip pathologies and/or OA, the number of athletes (cases) was divided by the total athlete population included in the article. We used Comprehensive Meta-Analysis software (version 3.0, Biostat Inc., Englewood, NJ, USA) to determine overall prevalence and 95% confidence intervals (CIs). The prevalence of intra-articular hip pathologies and OA was either reported as per person or per hip depending on the method used in the included article. Data deemed eligible for pooling were presented in either per person or per hip format. Primary subgrouping was undertaken based on the presence or absence of hip and groin pain. Secondary grouping included the type of mechanical loading placed on the hip by the sport [38, 39] and imaging modality (MRI, MRA or CT) used for each specific intra-articular hip pathology.

In line with our recent review [31], intra-articular hip pathologies were reported as being present or absent. Cartilage defects were reported in the primary analysis when femoral and acetabular defects were reported together. Studies that reported acetabular and femoral cartilage separately were analysed qualitatively. A Tonnis grade of ≥ 2 or a joint space width (JSW) of ≤ 2.0 mm was used to define the presence of hip OA [40, 41]. A Tonnis grade of 1 was used to define minor or early features of hip OA [42]. Studies reporting prevalence of intra-articular hip pathologies in fewer than five athletes were not included in secondary analysis. Studies adjudged to be HR were not considered for meta-analysis [43]. LR and MR studies were included in meta-analyses using a random effects model. Where articles were HR or deemed clinically heterogenous, qualitative analysis was undertaken. The statistical heterogeneity present in the pooled analysis was evaluated using Q and I^2 statistics [44, 45] and classified in accordance with Higgins et al. [45]. A strength of evidence was assigned to the pooled results, using previously described modified criteria [31, 46, 47] as follows:

- *Strong evidence*: pooled results derived from three or more studies, including a minimum of two LR studies, which are statistically homogenous ($p > 0.05$).

- *Moderate evidence*: pooled results derived from multiple studies, including at least one LR study, which are statistically heterogeneous (<0.05); or from multiple MR and HR studies which are statistically homogenous ($p>0.05$).
- *Limited evidence*: pooled results from multiple HR or MR studies which are statistically heterogeneous ($p<0.05$).

3 Results

3.1 Search Results

At the completion of database searching, 847 articles were identified (Fig. 1). Removal of duplicates left 470 articles for screening by title and abstract, and 69 full-text articles that were evaluated for eligibility using the listed inclusion criteria. In total, six additional articles [48–53] were retrieved and evaluated for inclusion after the completion of reference list searching and citation tracking. Fifty-five articles were excluded (Electronic Supplementary Material Online Resource 2), with a total of 20 articles [48–67] included in the review for qualitative and quantitative analysis (Tables 1, 2, 3).

3.2 Risk of Bias Within Studies

Agreement between the two authors occurred on 91% of occasions (182/200 items). A κ-value of 0.82 (95% CI 0.74–0.90) was determined, indicating excellent agreement between authors [36]. In total, five of the 20 (25%) included articles were considered HR, 12 were considered MR and three were LR. In summary, all of the 20 included articles had HR for items 1 and 2, outlining that no study included participants that were considered representative of a wider sporting population and that participants were often selected by convenience. Thirteen of the studies (65%) did not report the reliability of the method used to determine the presence of either hip intra-articular pathology or OA [48–51, 53, 55–58, 60–63]. Finally, ten (50%) of the studies reported

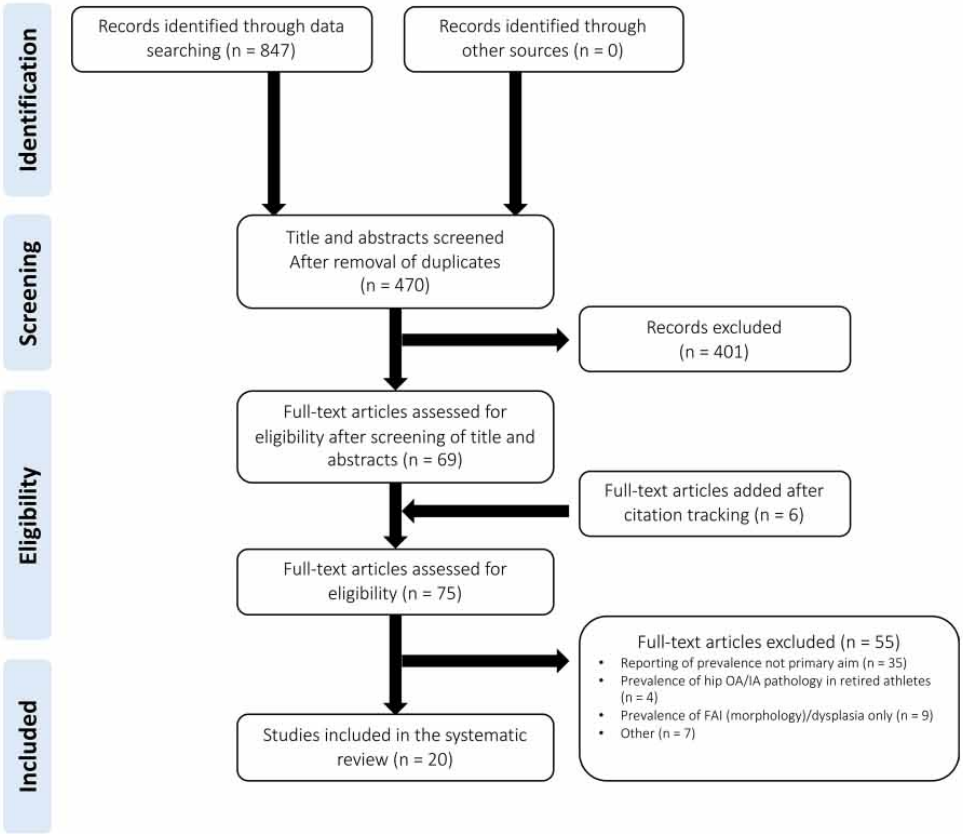

Fig. 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow chart

Table 1 Included studies involving asymptomatic athletes only

Study	Study design	Study population	Number of participants (hips)	Demographics	Imaging modality	Findings (intra-articular hip pathology/osteoarthritis)
Anderson et al. [54][a]	Cross-sectional	*Subjects* Senior athletes	*Subjects* 547 (1081)	*Subjects* Age[b]: 67 (8) Sex: 246 (45%) F/301 (55%) M	X-ray	*Subjects* Tonnis grade 3: 30/1081; Tonnis grade 2: 156/1081; Tonnis grade 1: 352/1086; Tonnis grade 0: 543/1081; Tonnis grade 2/3: 186/1081; Tonnis grade 0/1: 895/1081
Ayeni et al. [48]	Cross-sectional	*Subjects* Ice hockey players	*Subjects* 20 (20)	*Subjects* Age[b]: 20.6 Sex: 9 (45%) F/11 (55%) M	1.5 T MRI	*Subjects* Labral tear: 12/20; acetabular cartilage defect: 0/20; femoral cartilage defect: 2/20; herniation pit: 2/20; osseous bump: 4/20; paralabral cyst: 0/20
Farrell et al. [55]	Cross-sectional	*Subjects* Rugby union academy players	*Subjects* 20 (40)	*Subjects* Age[b]: 22 (1.5) Sex: 20 (100%) M	3 T MRI	*Subjects* Labral tear: 17/20[c]; labral tear right hip: 10/20; labral tear left hip: 15/20; bilateral labral tear: 8/20; cartilage defect: 4/20[c]; cartilage defect right hip: 3/20; cartilage defect left hip: 3/20; bilateral cartilage defect: 1/20
Kapron et al. [49]	Cross-sectional	*Subjects* Collegiate American football players	*Subjects* 67 (134)	*Subjects* Age[b]: 21 (1.9) Sex: 67 (100%) M	X-ray	*Subjects* Tonnis grade 0: 112/134; Tonnis grade 1: 22/134; Tonnis grade 2: 0/134; Tonnis grade 3: 0/134
Lahner et al. [57]	Cross-sectional	*Subjects* Semi-professional soccer players *Controls* Amateur soccer players	*Subjects* 22 (22) *Controls* 22 (22)	*Subjects* Age[b]: 23.3 (3.3) Sex: 22 (100%) M *Controls* Age[b]: 22.5 (3.5) Sex: 22 (100%) M	1.5 T MRI	*Subjects* Labral tear: 3/22; cartilage defect: 2/22 *Controls* Labral tear: 1/22; cartilage defect: 1/22
Lahner et al. [56]	Cross-sectional	*Subjects* Track and field athletes	*Subjects* 22 (44)	*Subjects* Age[b]: 23.7 (3.0) (18–30[d]) Sex: 11 (50%) F/11 (50%) M	1.5 T MRI	*Subjects* Labral tear: 2/44; acetabular cartilage defect: 1/44; femoral cartilage defect: 1/44; herniation pit: 3/44; osseous bump: 3/44

Table 1 (continued)

Study	Study design	Study population	Number of participants (hips)	Demographics	Imaging modality	Findings (intra-articular hip pathology/osteoarthritis)
Philippon et al. [58]	Cross-sectional	*Subjects* Youth ice hockey players *Controls* Youth skiers	*Subjects* 61 (61) *Controls* 27 (27)	*Subjects* Age[b]: 14.5 (2.7) Sex: 61 (100%) M *Controls* Age[b]: 15.2 (2.7) Sex: 27 (100%) M	3 T MRI	*Subjects* Labral tear: 42/61; peewee hockey players—labral tear: 13/27; bantam hockey players—labral tear: 5/8; midget hockey players—labral tear: 24/26; cartilage defect: 5/61; peewee hockey players—cartilage defect: 0/27; bantam hockey players—cartilage defect: 0/8; midget hockey players—cartilage defect: 5/26 *Controls* Labral tear: 19/27; skier—labral tear (peewee control): 5/7; skier—labral tear (bantam control): 5/8; skier—labral tear (midget control): 9/12; cartilage defect: 1/27; skier—cartilage defect (peewee control): 0/7; skier—cartilage defect (bantam control): 0/8; skier—cartilage defect (midget control): 1/12
Silvis et al. [59]	Cross-sectional	*Subjects* Ice hockey players	*Subjects* 39 (39)	*Subjects* Age: NR Sex: 39 (100%) M	3 T MRI	*Subjects* Hip pathology total findings: 25/39; labral tear: 22/39; cartilage defect: 7/39; hip effusion: 0/39
Yépez et al. [53]	Cross-sectional	*Subjects* Youth soccer players	*Subjects* 56 (112)	*Subjects* Age[b]: 15.3 (13–18[d]) Sex: 56 (100%) M	1.5 T MRI	*Subjects* Labral tear: 10/112; degenerative labral tear: 2/112; cartilage defect: 3/112; herniation pit: 4/112; BML: 24/112; acetabular osteitis: 10/112; osseous bump 49/112
Yuan et al. [60]	Cross-sectional	*Subjects* High school student with clinical signs of FAI *Controls* High school students no clinical signs of FAI	*Subjects* 13 (22) *Controls* 13 (26)	*Subjects* Age: NR Sex: 1 (8%) F/12 (92%) M *Controls* Age: NR Sex: 1 (8%) F/12 (92%) M	3 T MRI 1.5 T MRI	*Subjects* Any abnormal hip finding: 15/22; labral tear: 14/22; acetabular rim damage: 3/22; cartilage defect: 1/22; Tonnis grade 0: 22/22; Tonnis grade 1: 0/22; Tonnis grade 2: 0/22; Tonnis grade 3: 0/22 *Controls* Any abnormal hip finding: 10/26; labral tear: 10/26; acetabular rim damage: 0/26; cartilage defect: 1/26

BML bone marrow lesion, *FAI* femoroacetabular impingement, *F* female, *M* male, *MRI* magnetic resonance imaging, *NR* not reported, *T* Tesla

[a]Author provided additional results not presented in original Article

[b]Mean (standard deviation)

[c]Results from raw data obtained from author

[d]Range

Table 2 Included studies involving symptomatic athletes only

Study	Study design	Study population	Number of participants (hips)	Demographics	Imaging modality	Findings (intra-articular hip pathology/osteoarthritis)
Narvani et al. [61]	Case series	*Subjects* Individuals playing sport with groin pain	*Subjects* 18 (18)	*Subjects* Age[a]: 30.5 (8.45) (17–48[b]) Sex: 5 (28%) F/13 (72%) M	*Subjects* 1 T MRA	*Subjects* Labral tear: 4/18
Nepple et al. [62]	Case series	*Subjects* American football athletes at scouting combine	*Subjects* 107 (123)	*Subjects* Age[c]: 22.7 (20–25) Sex: 107 (100%) M	*Subjects* X-ray	*Subjects* Tonnis grade 0–1: 121/123; Tonnis grade 2: 2/123; Tonnis grade 3: 0/123

F female, *M* male, *MRA* magnetic resonance arthrography, *T* Tesla

[a]Mean (standard deviation)

[b]Range

[c]Mean (range)

the prevalence at a per hip level and not a per person level [49–51, 53, 54, 56, 60, 62, 64, 67] (Table 4).

3.3 Heterogeneity of Included Studies

Heterogeneity was considered low for pooled studies investigating the prevalence of labral tears in symptomatic athletes, and high in the studies of asymptomatic athletes. For prevalence of cartilage defects, only studies reporting in asymptomatic athletes were combined in meta-analysis. These studies displayed moderate levels of heterogeneity (I^2 43%). When categorised by mechanical hip load, the heterogeneity observed in pooled data evaluating the prevalence of labral tears and cartilage defects ranged from low (I^2 0%) to high (I^2 96%).

3.4 Deviation from PROSPERO

The categorisation of sports as either linear or multi-planar was included in the original protocol submitted to PROSPERO. During the review process a previously used method to categorise based on the mechanical load placed on the hip joint by the particular sport was identified [38, 39]. This method was used to improve the generalisability of the reviews findings.

3.5 Study Characteristics

In total, the prevalence of intra-articular hip pathologies and OA was evaluated in 1335 participants and 2352 hips. Twelve studies (315 participants, 637 hips) reported the prevalence of intra-articular hip pathologies in asymptomatic athletes using MRI [48, 52, 53, 55–60, 65–67]. Three studies (627 participants, 1237 hips) investigated the prevalence of hip OA in asymptomatic athletes using X-ray [49, 54, 60]. Four studies (40 hips) [52, 65–67] investigated the prevalence of intra-articular hip pathologies in symptomatic athletes with MRI. One study (18 participants, 18 hips) utilised MRA to determine the presence of intra-articular hip pathologies in symptomatic athletes [61]. One study investigated intra-articular pathology in a combined population of ballet dancers with and without pain [50]. Three studies evaluated the prevalence of OA in symptomatic and asymptomatic athletes [51, 63, 64] and one study reported OA prevalence in only symptomatic athletes [62]. No studies evaluated symptomatic or asymptomatic athletes with CT. In total, 375 (28%) of the athletes were women and 960 were men. The included studies investigated different sports, including American football ($n=174$) [49, 62], soccer ($n=100$) [53, 57], ice hockey ($n=179$) [48, 58, 59, 64], ballet ($n=110$) [50, 52, 63, 65, 66], rugby ($n=20$) [55], golf ($n=55$) [67], skiing ($n=27$) [58], track and field ($n=22$) [56], capoeira ($n=24$) [51] and mixed sports ($n=624$) [52, 54, 60, 61, 65, 66]. The level of play reported in the included studies included professional [50, 52, 59, 61, 63–65], elite [48, 49, 54–56, 59, 62, 67], semi-professional [57], amateur or recreational [52, 57, 61, 65, 66], and youth/high school level [53, 58]. Athletes participated in cutting ($n=6$) [52, 53, 57, 58, 65, 66], flexibility ($n=6$) [50–52, 63, 65, 66], impingement ($n=4$) [48, 58, 59, 64], asymmetrical ($n=5$) [52, 56, 65–67] and endurance sports ($n=1$) [56] (Table 5).

3.6 Prevalence of Labral Tears

Twelve studies (484 participants, 754 hips) reported the prevalence of labral tears [48, 50, 53, 55–61, 65, 67]. Five studies reported prevalence per person [48, 57–59, 61], with four studies [50, 53, 56, 67] reporting prevalence per hip and the remaining three studies [55, 60, 65] reporting prevalence per person and per hip.

Table 3 Included studies involving asymptomatic and symptomatic athletes

Study	Study design	Study population	Number of participants (hips)	Demographics	Imaging modality	Findings (intra-articular hip pathology/osteoarthritis)
Dickenson et al. [67][a]	Cross-sectional	*Subjects* Male golfers with hip pain *Controls* Male golfers without hip pain	*Subjects* NR (15) *Controls* NR (95)	*Subjects* Age: NR Sex: 15 (100%) M *Controls* Age: NR Sex: 95 (100%) M	1.5 T MRI	*Subjects* Labral tear: 3/15; increased labral signal: 3/15; acetabular cartilage defect 4/15; femoral cartilage defect: 1/15; acetabular subchondral oedema: 3/15; femoral subchondral oedema: 6/15; herniation pit: 4/15; joint effusion: 1/15 *Controls* Labral tear: 22/95; increased labral signal: 21/95; acetabular cartilage defect: 6/95; femoral cartilage defect: 3/95 acetabular subchondral oedema: 10/95; femoral subchondral oedema: 10/95; herniation pit: 9/95; joint effusion: 8/95
Harris et al. [63]	Cross-sectional	*Subjects* Symptomatic/asymptomatic ballet dancers	*Subjects* 47 (94)	*Subjects* Age[b]: 23.8 (5.4) (18–39[c]) Sex: 26 (55%) F/21 (45%) M	X-ray	*Subjects* Tonnis grade 0 left hip: 40/47; Tonnis grade 1 left hip: 7/47; Tonnis grade 2 left hip: 0/47; Tonnis grade 3 left hip: 0/47; Tonnis grade 0 right hip: 42/47; Tonnis grade 1 right hip: 5/47; Tonnis grade 2 right hip: 0/47; Tonnis grade 3 right hip: 0/47; medial joint space male[b]: 3.64 [0.54]; medial joint space female[b]: 3.51 [0.65]; middle joint space male[b]: 3.93 [0.37]; middle joint space female[b]: 3.86 [0.57]; lateral joint space male[b]: 4.39 [0.55]; lateral joint space female[b]: 4.39 [0.59]; total joint space male[b]: 3.98 [0.39]; total joint space female[b]: 3.92 [0.54]
Kolo et al. [50]	Cross-sectional	*Subjects* Symptomatic/asymptomatic ballet dancers	*Subjects* 30 (59)	*Subjects* Age[d]: 24.6 (18–39) Sex: 30 (100%) F	1.5 T MRI	*Subjects* Labral tear: 28/59; hips ≥ 2 labral tears: 12/59; labral degeneration: 24/59; hips ≥ 2 labral degenerative tears: 11/59; labral ossification: 2/59; hips ≥ 2 ossified lesions: 2/59; acetabular cartilage defect ≤ 5 mm: 12/59; acetabular cartilage defect: ≥ 5 mm: 17/59; herniation pit: 31/59
Larson et al. [64]	Cross-sectional	*Subjects* Symptomatic/asymptomatic ice hockey players	*Subjects* 59 (118)	*Subjects* Age[b]: 24.2 (4.6) Sex: 59 (100%) M	X-ray	*Subjects* Joint space[b]: 4.13 (0.62)
Mariconda et al. [51]	Cross-sectional	*Subjects* Symptomatic/asymptomatic capoeira players	*Subjects* 24 (48)	*Subjects* Age[b]: 31.5 (4.5) (25–42[c]) Sex: 10 (42%) F/14 (58%) M	X-ray	*Subjects* Tonnis grade 3: 0/48; Tonnis grade 2: 3/48; Tonnis grade 1: 9/48; Tonnis grade 0 36/48

Table 3 (continued)

Study	Study design	Study population	Number of participants (hips)	Demographics	Imaging modality	Findings (intra-articular hip pathology/osteoarthritis)
Mayes et al. [65][a]	Case-control	*Subjects* Mixed sporting population/ballet dancers with hip pain last 3 months[e,f] *Controls* Mixed sporting population/ballet dancers without hip pain[e,f]	*Subjects* NR (25) *Controls* NR (107)	*Subjects* Age[b,e]: 27.9 (4.6) Age[b,f]: 29 (5) Sex[e,f]: 18 (72%) F/7 (28%) M *Controls* Age[b,e]: 25.4 (4.7) Age[b,f]: 28.3 (5.6) Sex[e,f]: 54 (50%) F/53 (50%) M	3 T MRI	*Subjects* Labral tear: 5/25 *Controls* Labral tear: 48/107
Mayes et al. [52][a]	Case-control	*Subjects* Mixed sporting population/ballet dancers with hip pain last 3 months[e,f] *Controls* Mixed sporting population/ballet dancers without hip pain[e,f]	*Subjects* NR (25) *Controls* NR (107)	*Subjects* Age[b,e]: 27.9 (4.6) Age[b,f]: 29 (5) Sex[e,f]: 18 (72%) F/7 (28%) M *Controls* Age[b,e]: 25.4 (4.7) Age[b,f]: 28.3 (5.6) Sex[e,f]: 54 (50%) F/53 (50%) M	3 T MRI	*Subjects* Ligamentum teres tear: 11/25 *Controls* Ligamentum teres tear: 22/107
Mayes et al. [66][a]	Case-control	*Subjects* Mixed sporting population/ballet dancers with hip pain last 3 months[e,f] Controls Mixed sporting population/ballet dancers without hip pain[e,f]	*Subjects* NR (25) *Controls* NR (107)	*Subjects* Age[b,e]: 27.9 (4.6) Age[b,f]: 29 (5) Sex[e,f]: 18 (72%) F/7 (28%) M *Controls* Age[b,e]: 25.4 (4.7) Age[b,f]: 28.3 (5.6) Sex[e,f]: 54 (50%) F/53 (50%) M	3 T MRI	*Subjects* Cartilage defect: 10/25 *Controls* Cartilage defect: 38/107

F female, *M* male, *MRI* magnetic resonance imaging, *NR* not reported, *T* Tesla

[a]Author provided additional results not presented in original article

[b]Mean (standard deviation)

[c]Range

[d]Mean (range)

[e]Male dancers and male mixed athletes

[f]Female dancers and female mixed athletes

3.6.1 Symptomatic Participants

One study (MR) [61] reported a labral tear prevalence of 22% per person, while two studies (one LR and one MR) [65, 67] reported labral tear prevalence per hip in symptomatic athletes. There was moderate evidence of a labral tear prevalence of 20% (95% CI 10–35) per hip from two studies (one LR and one MR) [65, 67] (Fig. 2).

3.6.2 Asymptomatic Participants

Five studies (four MR and one HR) [48, 55, 57–59] reported the prevalence of labral tears per person in asymptomatic athletes. Limited evidence from four studies (four MR) [48, 55, 57, 58] identified a labral tear prevalence of 54% (95% CI 22–83) per person (Fig. 3). The remaining study (HR) [59] reported a labral tear prevalence of 56% in ice hockey players competing at professional and collegiate level.

Five studies (three HR, one MR and one LR) [53, 56, 60, 65, 67] evaluated labral tear prevalence per hip in athletes using MRI. Moderate evidence from two studies [65, 67] identified a labral tear prevalence of 33% (95% CI 16–57) per hip in asymptomatic athletes (Fig. 2). The three HR studies [53, 56, 60] not included in meta-analysis reported labral tear prevalence per hip in high school athletes (50%) [60], Brazilian youth soccer players (9%) [53], and track and field athletes (5%) [56].

3.6.3 Mixed Participants

One study (MR) [50] evaluated symptomatic and asymptomatic ballet dancers and reported a labral tear prevalence per hip of 47%.

3.6.4 Mechanical Hip Load of the Various Sports

3.6.4.1 Symptomatic Participants One study (LR) [65] reported a labral tear prevalence of 33% in symptomatic athletes participating in flexibility sports. Two studies (one MR and one LR) [66, 67] reported on the prevalence of labral tears in symptomatic athletes participating in asymmetrical sports. One study (MR) [67] of golfers identified a labral tear prevalence of 20%. The remaining study (LR) [66] included fewer than five symptomatic hips and was not included in analysis. In symptomatic basketball players (cutting sport), a labral tear prevalence of 0% was identified (LR) [65]. No studies investigated the prevalence of labral tears in symptomatic athletes participating in contact, endurance or impingement sports.

3.6.4.2 Asymptomatic Participants One study (MR) [55] reported a labral tear prevalence of 85% in athletes participating in a contact sport. Three studies (one HR and two MR) reported the prevalence of labral tears in impingement sports. Two studies (two MR) [48, 58] found moderate evidence of a labral tear prevalence of 67% (95% CI 56–76) in asymptomatic ice hockey players (Fig. 4). The remaining study (HR) [59] identified labral tears in 56% of ice hockey players without pain. One study (LR) [65] reported a labral tear prevalence of 43% in asymptomatic ballet dancers (flexibility sport). Limited evidence from two studies (two MR) [57, 58] found a labral tear prevalence of 33% (95% CI 2–92) per person in athletes participating in cutting sports (Fig. 4). The remaining two studies (one HR and one LR) [53, 65] investigating asymptomatic athletes reported a labral tear prevalence per hip of 9% and 45%, respectively. Three studies (one HR, one MR and one LR) [56, 65, 67] evaluated athletes competing in sports that place asymmetrical loads on the hip joint. Moderate evidence from two studies (one MR and one LR) [65, 67] identified a labral tear prevalence of 33% (95% CI 13–61) in asymptomatic athletes (Fig. 4). The remaining study (HR) [56] in track and field athletes did not provide sufficient information to determine the labral tear prevalence in athletes performing asymmetrical sports, nor in endurance athletes.

3.6.4.3 Mixed Participants One study (MR) [50] reported a labral tear prevalence of 47% in ballet dancers (flexibility sport) with and without pain.

3.7 Prevalence of Cartilage Defects

Eleven studies (466 participants, 736 hips) evaluated the prevalence of cartilage defects [48, 50, 53, 55–60, 66, 67]. In total, four studies analysed prevalence per person [48, 57–59] and five studies reported prevalence per hip [50, 53, 56, 60, 67]. Finally, cartilage defect prevalence was reported per person and per hip in two studies [55, 66].

3.7.1 Symptomatic Participants

Cartilage defect prevalence was not reported per person but reported per hip by two studies (one MR and one LR) [66, 67] in symptomatic athletes. Acetabular (27%) and femoral cartilage defects (7%) were reported independently in golfers (MR) [67], while hip cartilage defects were reported in ballet dancers and mixed sports athletes (40%) (LR) [66].

3.7.2 Asymptomatic Participants

Five studies (one HR and five MR) [48, 55, 57–59] reported cartilage defect prevalence per person in asymptomatic

Table 4 Included studies' risk of bias

Study	External validity				Internal validity						Overall risk of bias for study
	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	
Anderson et al. [54]	HR	HR	HR	LR	LR	LR	LR	LR	LR	HR	MR
Ayeni et al. [48]	HR	HR	HR	LR	LR	HR	HR	LR	LR	LR	MR
Dickenson et al. [67]	HR	HR	HR	LR	LR	HR	LR	LR	LR	HR	MR
Farrell et al. [55]	HR	HR	HR	LR	LR	HR	HR	LR	LR	LR	MR
Harris et al. [63]	HR	HR	HR	LR	LR	LR	HR	LR	LR	LR	MR
Kapron et al. [49]	HR	HR	HR	HR	LR	LR	HR	LR	LR	HR	HR
Kolo et al. [50]	HR	HR	HR	LR	LR	LR	HR	LR	LR	HR	MR
Lahner et al. [56]	HR	HR	HR	LR	LR	HR	HR	LR	LR	LR	MR
Lahner et al. [57]	HR	HR	HR	LR	LR	HR	HR	LR	LR	HR	HR
Larson et al. [64]	HR	HR	HR	LR	LR	HR	LR	LR	LR	HR	MR
Mariconda et al. [51]	HR	HR	HR	LR	LR	LR	HR	LR	LR	HR	MR
Mayes et al. [65]	HR	HR	HR	LR	LR	LR	LR	LR	LR	LR	LR
Mayes et al. [52]	HR	HR	HR	LR	LR	LR	LR	LR	LR	LR	LR
Mayes et al. [66]	HR	HR	HR	LR	LR	LR	LR	LR	LR	LR	LR
Narvani et al. [61]	HR	HR	HR	LR	LR	HR	HR	LR	LR	LR	MR
Nepple et al. [62]	HR	HR	HR	LR	LR	LR	HR	LR	LR	HR	MR
Philippon et al. [58]	HR	HR	HR	LR	LR	HR	HR	LR	LR	LR	MR
Silvis et al. [59]	HR	HR	HR	HR	LR	HR	HR	LR	LR	LR	HR
Yépez et al. [53]	HR	HR	HR	LR	LR	HR	HR	LR	LR	HR	HR
Yuan et al. [60]	HR	HR	HR	HR	LR	HR	HR	HR	LR	HR	HR
Overall risk of bias for item	20 HR 0 LR	20 HR 0 LR	20 HR 0 LR	3 HR 17 LR	0 HR 20 LR	11 HR 9 LR	14 HR 6 LR	1 HR 19 LR	0 HR 20 LR	10 HR 10 LR	

HR high risk of bias, *MR* moderate risk of bias, *LR* low risk of bias

Risk of bias items:

1. Was the study's target population a close representation of the national sporting population in relation to relevant variables, e.g. age, sex, competition level?
2. Was the sample frame a true or close representation of the target population?
3. Was some form of random selection used to select the sample *OR* was a census taken?
4. Was the likelihood of non-response bias minimal?
5. Were data collected directly from the subjects (as opposed to a proxy)?
6. Was an acceptable case definition used in the study?
7. Was the study instrument that measured the parameter of interest (e.g. prevalence of low back pain) shown to have reliability and validity (if necessary)?
8. Was the same mode of data collection used for all subjects?
9. Was the length of the shortest prevalence period for the parameter of interest appropriate?
10. Were the numerator(s) and denominator(s) for the parameter of interest appropriate?

athletes. Moderate evidence from three studies (three MR) [55, 57, 58] identified a cartilage defect prevalence of 10% (95% CI 5–19) (Fig. 5). The two remaining studies (one HR and one MR) [48, 59] reported acetabular (0%), femoral (10%) and a combined cartilage defect prevalence of 18% in ice hockey players.

Five studies (three HR, one MR and one LR) [53, 56, 60, 66, 67] evaluated cartilage defect prevalence per hip. One study (LR) [66] reported a cartilage defect prevalence of 36% in professional ballet dancers and mixed sport athletes. Two studies (two HR) [53, 60] reported on athletes competing in high school sport (4%) and youth soccer players (3%). The remaining two studies (one HR and one MR) [56, 67] evaluated acetabular and femoral cartilage defects independently in elite track and field athletes [56] (2% and 2%, respectively) and asymptomatic golfers [67] (6% and 3%, respectively).

3.7.3 Mixed Participants

One study (MR) [50] reported a cartilage defect prevalence of 49% in ballet dancers with and without pain.

Table 5 Mechanical load placed on hip joint by sport

Athlete sports category [39]	Study
Cutting (soccer, basketball, lacrosse, field hockey, downhill skiing, snowboarding)	Lahner et al. [57] Mayes et al. [52, 65, 66] Philippon et al. [58] Yepez et al. [53]
Flexibility (dancing, gymnastics, yoga, cheerleading, figure skating, synchronised swimming, martial arts, rock climbing)	Harris et al. [63] Kolo et al. [50] Mariconda et al. [51] Mayes et al. [52, 65, 66]
Contact (football, rugby, wrestling)	Farrell et al. [55] Kapron et al. [49] Nepple et al. [62]
Impingement (ice hockey, crew/rowing, baseball catching, water polo, equestrian polo, breaststroke swimming, weight lifting, bobsled, CrossFit, horseback riding)	Ayeni et al. [48] Philippon et al. [58] Silvis et al. [59] Larson et al. [64]
Asymmetric/overhead (baseball, softball, tennis, golf, volleyball, athletic field events, fencing, badminton, cricket, squash, racquetball, handball)	Lahner et al. [56] Dickenson et al. [67] Mayes et al. [52, 65, 66]
Endurance (track, cross-country, other running, cycling, swimming [not breaststroke], cross-country skiing, biathlon, aerobics)	Lahner et al. [56]
Not reported	Anderson et al. [54] Yuan et al. [60] Narvani et al. [61]

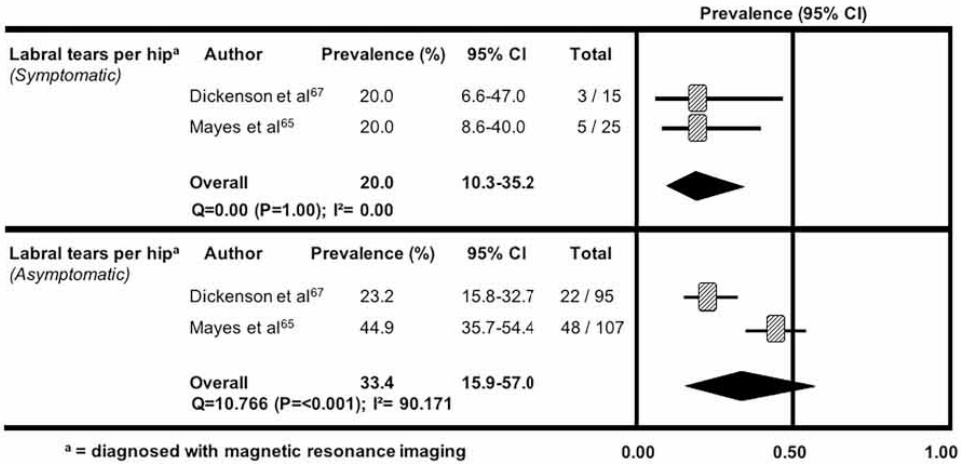

Fig. 2 Prevalence and 95% confidence interval (CI) of labral tears per hip in symptomatic and asymptomatic athletes

3.7.4 Mechanical Hip Load of the Various Sports

3.7.4.1 Symptomatic Participants One study (LR) [66] reported a cartilage defect prevalence of 53% in symptomatic athletes participating in a flexibility sport. Two studies (one MR and one LR) [65, 67] evaluated the prevalence of cartilage defects in sports that cause asymmetrical hip loading. One study (MR) [67] in symptomatic golfers reported the prevalence of cartilage defects on the acetabulum (27%) and femur (7%) separately. The final study (LR) [66] included fewer than five symptomatic hips and was not included in the final analysis. One study (LR) [66] reported a cartilage defect prevalence of 17% per hip in basketball athletes (cutting sport) with hip pain. None of the included studies reported the prevalence of cartilage defects in symp-

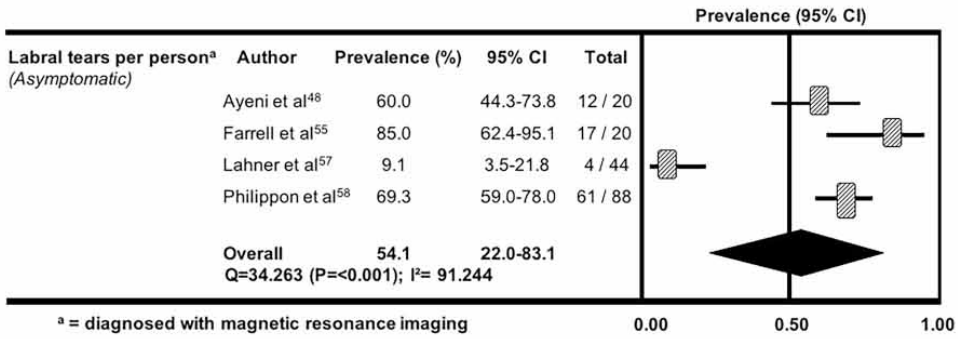

Fig. 3 Prevalence and 95% confidence interval (CI) of labral tears per person in asymptomatic athletes

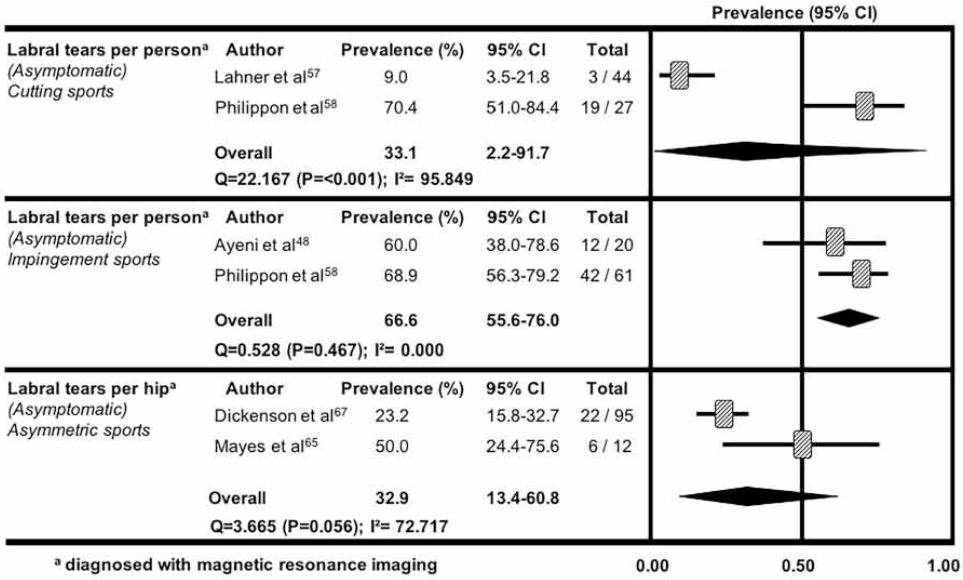

Fig. 4 Prevalence and 95% confidence interval (CI) of labral tears per person and per hip in asymptomatic athletes in cutting, impingement and asymmetrical sports

tomatic athletes participating in contact, impingement or endurance sports.

3.7.4.2 Asymptomatic Participants Three studies (one HR, one MR and one LR) [56, 66, 67] reported the prevalence of cartilage defects in athletes participating in sports that place an asymmetrical load on the hip joint. One study (LR) [66] reported a cartilage defect prevalence per hip of 50% in tennis players without pain. One (MR) [67] of the remaining two studies evaluated acetabular (6%) and femoral cartilage defects (3%) independently in golfers without hip pain. The remaining study (HR) [56] was not included in analysis as it combined information on athletes performing asymmetrical and endurance sports. One study (LR) [66] in ballet dancers (flexibility sport) reported a cartilage defect prevalence of 33%. In contact athletes, one study (MR) [55] identified a cartilage defect prevalence of 20%. In asymptomatic cutting athletes, moderate evidence from two studies (two MR) [57, 58] identified a cartilage defect prevalence of 5.8% (95% CI 2–15) (Fig. 6). Two additional studies (one HR and one LR) [53, 66] reported a cartilage defect prevalence per hip in asymptomatic cutting athletes of 34% (basketball players) and 3% (youth soccer players). Three studies (one HR and two MR) [48, 58, 59] evaluated the prevalence of carti-

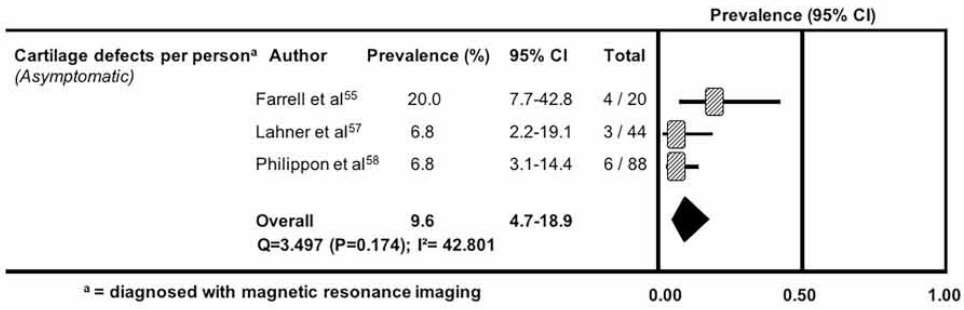

Fig. 5 Prevalence and 95% confidence interval (CI) of cartilage defects per person in asymptomatic athletes

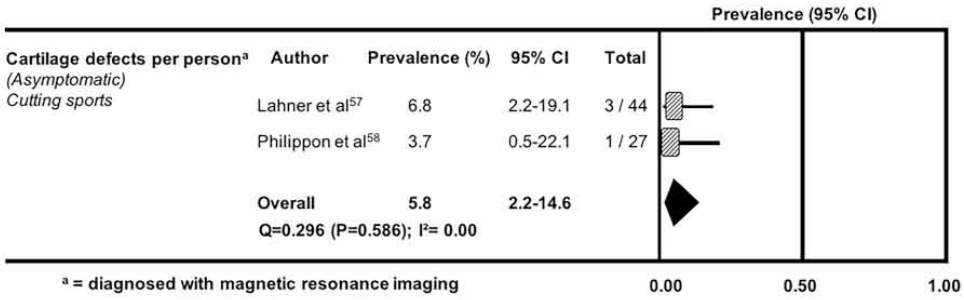

Fig. 6 Prevalence and 95% confidence interval (CI) of cartilage defects per person in asymptomatic athletes in cutting sports

lage defects in athletes participating in impingement sports (ice hockey players). Two of the three studies (one HR and one MR) [58, 59] identified a cartilage defect prevalence of 8% and 18%, respectively. The remaining study reported acetabular (0%) and femoral cartilage defects (10%) independently. One study (HR) [56] reported the prevalence of cartilage defects in a combined population of endurance and asymmetrical/overhead athletes, which resulted in the study not being included in analysis.

3.7.4.3 Mixed Participants One study (MR) [50] found a cartilage defect prevalence of 49% per hip in a population of ballet dancers (flexibility sport) with and without pain.

3.8 Prevalence of Hip Osteoarthritis

Seven studies (877 participants, 1646 hips) reported the prevalence of hip OA [49, 51, 54, 60, 62–64]. Five studies (804 participants, 1504 hips) reported prevalence per hip [49, 51, 54, 62, 64], with two studies reporting hip OA prevalence per person and per hip [60, 63].

3.8.1 Symptomatic Participants

One study (MR) [62] reported the prevalence of hip OA per hip in symptomatic athletes. A hip OA (Tonnis grade ≥ 2/JSW of ≤ 2.0 mm) prevalence of 2% was reported in National Football League (NFL) athletes attending the NFL scouting combined with a history of pain or injury around the hip [62].

3.8.2 Asymptomatic Participants

Three studies (two HR and one MR) evaluated asymptomatic athletes for hip OA using X-ray [49, 54, 60]. One study (HR) [60] reported hip OA prevalence per person in high school athletes (0%). Two studies (one HR and one MR) [49, 54] reported early hip OA (Tonnis grade 1) and hip OA per hip. In a group of mixed senior athletes [54] the prevalence of early hip OA and hip OA was 32% and 17%, respectively. The remaining study [49] reported a prevalence of early hip OA of 16%, with no collegiate NFL players having hip OA.

3.8.3 Mixed Participants

Three studies (three MR) reported early hip OA and hip OA prevalence in athletes with and without pain [51, 63, 64]. One study [63] reported prevalence per person and per hip in professional ballet dancers. Hip OA was not found in any ballet dancer using Tonnis grade and mean joint space. However, early hip OA was present in 13% of ballet dancers hips [63]. Two studies (two MR) [51, 64] reported hip OA per hip. One study [51] evaluating capoeira players reported hip OA (6%) and early hip OA (19%) using Tonnis grade, with the remaining study [64] reporting a mean minimum joint space of 4.1 mm in ice hockey players.

3.9 Other Pathologies

3.9.1 Symptomatic Participants

3.9.1.1 Bone Marrow Lesions One study (MR) [67] identified the presence of acetabular (20%) and femoral head BML (40%) in golfers with hip pain.

3.9.1.2 Herniation Pits One study (MR) [67] evaluated the prevalence of herniation pits in golfers with hip pain (27%).

3.9.1.3 Hip Joint Effusion One study (MR) [67] reported a prevalence of hip joint effusion per hip of 7% in golfers with hip pain.

3.9.1.4 Labral Degeneration One study [67] reported a prevalence of labral degeneration per hip of 20% in golfers with hip pain.

3.9.1.5 Ligamentum Teres Tears One study (LR) [52] reported the prevalence of ligamentum teres tears per hip (44%) in symptomatic ballet dancers and mixed athletes.

3.9.2 Asymptomatic Participants

3.9.2.1 Bone Marrow Lesions Two studies (one HR and one MR) [53, 67] reported the prevalence of BML per hip in asymptomatic athletes. One study [53] evaluated youth soccer players (21%), with the remaining study [67] reporting acetabular (11%) and femoral BML (11%) independently in asymptomatic golfers.

3.9.2.2 Herniation Pits Four studies (two HR and two MR) [48, 53, 56, 67] evaluated the prevalence of herniation pits in asymptomatic athletes. One study (MR) [48] reported a herniation pit prevalence per person in ice hockey athletes of 10%. The remaining three studies (two HR and one MR) [53, 56, 67] reported prevalence per hip in track and field athletes (7%), youth soccer players (4%) and golfers (9%).

3.9.2.3 Hip Joint Effusion Two studies (one HR and one MR) [59, 67] identified the prevalence of hip joint effusion in asymptomatic athletes. One study (MR) [67] reported a prevalence of 8% in asymptomatic golfers. The remaining study (HR) [59] in ice hockey players identified a prevalence of 0%.

3.9.2.4 Labral Degeneration Two studies (one HR and one MR) [53, 67] reported a labral degeneration prevalence of 2% and 22% in asymptomatic youth soccer players and golfers, respectively.

3.9.2.5 Ligamentum Teres Tears One study (LR) [52] reported a prevalence of ligamentum teres tears per hip of 21% in a mixed population of athletes.

3.10 Other Pathologies Reported in Fewer than Two Studies

Intra-articular hip pathologies that were reported in less than one symptomatic and one asymptomatic study are presented in Electronic Supplementary Material Online Resource 3.

4 Discussion

This systematic review highlights that imaging defined intra-articular hip pathologies are observed in athletes with and without pain. Across the included studies, considerable heterogeneity existed in regard to the methods used to evaluate the presence of intra-articular hip pathologies. Moreover, athletes participated in a wide range of sports and competition levels, resulting in limited comparability between the included studies. Hence, caution should be taken when comparing differences in prevalence of intra-articular pathologies between studies and in athletes with and without pain. In particular, we identified that labral tears on MRI are observed in up to 54% of athletes without pain and 22% of athletes with pain. Cartilage defects were identified in symptomatic (7–40%) and asymptomatic athletes (0–36%). Qualitative analysis identified that bone marrow lesions, herniation pits, labral degeneration, ligamentum teres tears and joint effusion appear to be prevalent in athletes with and without pain. Our review identified that features associated with early radiographic hip OA (Tonnis grade 1) appear more frequently than radiographic hip OA (Tonnis grade $\geq$ 2/JSW of $\leq$ 2.0 mm) in athletes currently playing sport regardless of pain.

4.1 Review Findings

Labral tears have long been considered a cause of hip and groin pain in athletes [68–70]. A combination of the dynamic movements performed in sport and the high prevalence of bony hip morphology, in particular cam morphology, is believed to place athletes at greater risk of labral tears. In athletes without pain, we identified moderate evidence of a labral tear prevalence per hip of 33%, while in athletes with pain there was moderate evidence of a labral tear prevalence per hip of 20%. These findings provide further evidence of the complex relationship between labral tears and experience of pain [27, 31, 71, 72]. Furthermore, it appears that athletes do not have a higher prevalence of labral tears than non-athletic individuals, regardless of pain status [22, 23, 31]. Debate exists around the optimal management of labral tears [73–75]. It is proposed that the integrity of the labrum is important for joint function and maintenance of tissue homeostasis [73, 74]. Restoration of labral tissue integrity might be achieved with surgical approaches, and this may result in improved patient function and pain [73–75]. However, such approaches are supported by low levels of evidence [73–75], and may result in varied return to sport and/or performance rates in athletes [76]. Our findings highlight that up to one in every two asymptomatic athletes can be active in sport with a labral tear, ultimately questioning the clinical significance of labral tears in some athletes with pain. Moreover, it highlights the importance of considering 'non-structural' factors in an athlete with hip and groin pain [77]. Future work should focus on gaining a greater understanding of the long-term implications for symptomatic and asymptomatic athletes with labral tears, in order to provide appropriate management of these athletes.

Cartilage defects were seen in symptomatic and asymptomatic athletes. The prevalence of cartilage defects in symptomatic athletes ranged from 7% to 40%, with three of the four studies reporting a prevalence greater than 25%. Our pooled data identified moderate evidence of a prevalence of 10% in asymptomatic athletes with a mean age of less than 25 years. In addition, five of the remaining studies not included in the meta-analysis reported a cartilage defect prevalence of less than 10%. The high prevalence of cartilage defects seen in symptomatic athletes in this review is similar to that seen in older individuals with and without pain [71, 78], but lower than in our previous review [31]. Injury to the articular cartilage affects joint homeostasis, in addition to biomechanical and neuromuscular function [79]. This alteration in joint function combined with athletic activity may accelerate hip joint degenerative change, which is known to occur more frequently in retired athletes [33, 80]. However, longitudinal studies confirming this causation are currently lacking and should be a focus of future work. Importantly, articular cartilage is deficient of neural and vascular supply, rendering it unable to produce pain [81]. This understanding is reflected in the variable relationship seen between cartilage defects and pain [71, 72, 78, 82]. In relation to our findings, it is likely that the presence of cartilage defects in symptomatic athletes indicates the involvement of inflammatory mediators, subchondral bone and peri-articular tissues, which are all capable of causing nociception [81]. This suggests that cartilage defects are likely to be a precursor to OA in susceptible individuals.

Our review highlights that hip OA is not commonly seen in athletes who are currently competing at an elite or professional level, even if they have hip and groin pain. This finding is of particular interest, as elite male athletes have a greater prevalence of OA [33] and likelihood of undergoing hip arthroplasty (odds ratio = 2.5) after they have retired from sport than age-matched controls [80]. The prevalence of hip OA in asymptomatic senior athletes appears similar to that of older non-athletic populations (17% vs. 15%) [54, 83]. In addition, our review indicates that radiographic features associated with early hip OA are seen in younger athletes regardless of the presence or absence of pain [49, 51, 63]. Our findings highlight a discordant relationship between radiographic features associated with early hip OA and pain in athletes currently playing sport, which is consistent with previous work in older populations [84]. In the included studies, OA was measured using X-ray, whilst other pathologies were measured using MRI or MRA. Since radiographic measures are insensitive to early changes in articular cartilage integrity [85], our findings may underestimate the true disease prevalence in athletes. The use of imaging methods with greater sensitivity to early features of OA may be important for identifying athletes at risk of progression to hip OA.

Bone marrow lesions, herniation pits, labral degeneration, ligamentum teres tears and hip joint effusions were seen in symptomatic and asymptomatic athletes. These findings are congruent with our recent review [31]. Bone marrow lesions were reported in up to 40% of athletes with pain. This relationship between pain and BML has been demonstrated previously, albeit in older non-athletic populations [71, 72]. The prevalence of BML identified in this review is lower than in our previous review [31]. However, BML are known to be seen more frequently in individuals with OA [71, 78, 86], which was seen in very few athletes included in this review. In relation to ligamentum teres tears, debate currently exists regarding its role in both joint stability and pain generation [87–91]. The only study that reported on the prevalence of ligamentum teres tears in ballet dancers and mixed sport athletes described a high prevalence in those with hip pain (44%) [52]. The high prevalence of ligamentum teres tears observed in athletes may reflect the demands placed on this ligament during sporting activity, particularly those sports requiring large ranges of hip motion. Hip joint effusion was present in athletes with and without pain. Hip joint effusion

is often considered a surrogate marker of synovitis when evaluated by MRI without contrast [92]. However, optimal evaluation of synovitis requires contrast-enhanced MRI [78, 92], which was not used in the two studies reporting hip joint effusion in our review. The prevalence rates identified appear similar to older populations with and without pain [72], but lower than individuals with radiographic hip OA or MRI-defined cartilage defects [78, 93]. The association between pain, symptoms and effusion appears variable [72, 78] and requires greater understanding in athletic individuals to enable appropriate intervention.

Athletes competing in sports that place contact, impingement and flexibility loads on the hip joint appear to have a high prevalence of labral tears. In relation to cartilage defects, there appears to be less variation between sports when categorised by mechanical hip load. However, athletes performing flexibility, cutting and asymmetrical sports appear to have a high prevalence of cartilage defects. None of the included studies in our review reported the prevalence of labral tears in symptomatic athletes competing in impingement or contact sports. However, existing work not included in our review highlights that labral tears appear in similar rates in athletes with and without pain competing in impingement (67% vs. 69%) [48, 58, 70] and contact sports (85% vs. 89%) [55, 94]. In athletes participating in flexibility sports, labral tears (33% and 43%) and cartilage defects (53% and 33%) are commonly seen in symptomatic and asymptomatic athletes, respectively. This review has highlighted the large variation in the prevalence of labral tears and cartilage defects in athletes with and without pain, particularly when sports are categorised by mechanical load placed on the hip joint. As such, a combination of bony morphology, which is seen in a high percentage of athletes [22, 23, 95, 96], and specific hip load may be related to the development of specific intra-articular hip pathologies in athletes.

The diagnostic accuracy of the imaging techniques used to evaluate the presence of intra-articular pathology may have influenced the findings of this review. Magnetic resonance imaging without contrast has known limitations in relation to the identification of labral tears [97–99]. In particular, the moderate sensitivity and specificity of MRI with 1.5 (1.5 T) and 3 Tesla (3 T) field strengths may result in the over- and/or underestimation of the prevalence of labral tears. Since only one of the included studies used contrast-enhanced MRI, the prevalence of labral tears reported in this review may have been underestimated [97–99]. Similarly, the diagnostic accuracy of MRI without contrast for chondral defects has been shown to be variable across two reviews [99, 100]. We identified a higher prevalence of cartilage defects in athletes with pain than in those without pain in studies using MRI without contrast. Five of the 11 studies used 3 T MRI to evaluate cartilage defects [55, 58–60, 66]. The evaluation of cartilage defects with 3 T MRI has shown superiority for the recognition of cartilage defects compared with lower field strength approaches [101, 102]. Importantly, six of the remaining 11 studies used 1.5 T MRI, which provides only limited sensitivity for the identification of cartilage defects [99, 100]; this may have resulted in the under-reporting of cartilage defects in some athletes included in our review.

Seventeen of the 20 included studies were considered to be MR to HR. In particular, the included studies evaluated athletes that were selected by convenience or from specific competitions or organisations, and not deemed representative of wider athletic populations. Future work should focus on evaluating athletes from a larger range of clubs/organisations to improve generalisability. Of the included studies, only six (30%) reported the reliability or extent of agreement for the methods used to determine each of the imaging-defined pathologies. This finding should be considered when interpreting the prevalence of intra-articular pathologies in this review. Our decision to exclude HR studies from our meta-analyses is in line with recent recommendations [43].

Moderate to high levels of heterogeneity were observed in most pooled analyses performed in this review, which may be related to the observed variability across studies in relation to sport and competition level. In addition, athlete sex, age, variation in the imaging type and specific imaging parameters should be considered. Interestingly, when data were pooled based on the mechanical hip load, two of the four pooled analyses demonstrated low levels of heterogeneity, indicating that intra-articular hip pathology prevalence may be influenced by the specific physical requirements of a sport.

4.2 Limitations

A number of limitations need to be considered when interpreting the findings of our review. First, a number of clinical entities may be associated with hip and groin pain in athletes [14–17]. In this review, we evaluated athletes based on the subjective presence or absence of pain, rather than with more objective measures [14]. In light of this, many of the imaging-defined intra-articular hip pathologies may indeed be incidental findings and unrelated to an athlete's hip and groin pain. Second, careful consideration is needed when generalising the findings of our review. The included studies investigated athletes from a broad range of sports and competition levels, meaning that our findings can only be extrapolated to athletes competing at similar levels of competition and sport. The exclusion of studies investigating athletes with other hip conditions, including slipped capital femoral epiphysis and Legg–Calvé–Perthes disease, reduces the generalisability of our findings to athletes with such conditions. Importantly, none of the athletes had their intra-articular pathologies or hip OA confirmed by open or arthroscopic hip surgery. The authors acknowledge that

surgery is considered the gold standard for the identification of intra-articular hip conditions. However, such an approach is not considered reasonable for athletes without hip pain. Finally, not including studies published in languages other than English may have resulted in some relevant studies not being included in this review.

4.3 Future Directions/Research Priorities

Future work should establish a greater understanding of the prevalence of intra-articular hip pathologies in both symptomatic and asymptomatic athletes. To correctly select athletes for surgical interventions it would seem prudent that we understand the relevance of imaging-defined intra-articular hip pathologies in athletes with hip and groin pain. Future studies may choose to compare intra-articular findings between athletes of varying ages and/or competition levels in order to understand the impact of age and level of play on the prevalence of findings in athletes. Using recommended clinical entities [14] to categorise an athlete with hip and groin pain may allow a greater understanding of prevalence of intra-articular hip conditions in athletes with specific clinical presentations. Finally, longitudinal studies are required to provide evidence supporting the relationship between intra-articular pathologies and OA development or progression in athletes [103].

5 Conclusion

Our systematic review identified that imaging-defined intra-articular hip pathologies are seen in athletes with and without pain. In particular, labral tears were identified in one in every two athletes without pain, highlighting a complex, poorly understood and potentially arbitrary (at least in some cases) relationship between labral tears and pain in athletes. Cartilage defects are seen in athletes with and without pain. Importantly, hip OA was rarely seen in athletes, regardless of whether they had pain or not. Bone marrow lesions, herniation pits, hip joint effusion, labral degeneration and ligamentum teres tears were observed in symptomatic and asymptomatic athletes. Two out of three asymptomatic athletes competing in impingement sports had imaging-defined labral tears. In summary, our findings highlight the complex relationship between structural hip conditions identified with imaging and pain in athletes.

Author contributions JJH, JLK, ABM, DMJ, TP, MJS, RA and KMC were responsible for the creation and planning of the review. JJH and JLK were responsible for the search strategy utilised. JJH, JLK and DMJ developed the strategy to evaluate study quality. JJH, ABM and KMC were involved in the data extraction process. JJH wrote the final manuscript, with all authors assisting in revising content.

Compliance with Ethical Standards

Conflict of interest Joshua J. Heerey, Joanne L. Kemp, Andrea B. Mosler, Denise M. Jones, Tania Pizzari, Mark J. Scholes and Rintje Agricola declare they have no competing interests. Kay Crossley is a recipient of an NHMRC (National Health and Medical Research Council; Australia) Project Grant (GNT1088683), which provided funding to support this research.

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Appendix 22. Search strategy for Study 2 (Chapter 5).

MEDLINE.

(Hip[Mesh] OR hip$1 kw OR Hip joint[Mesh] OR hip joint$1 kw OR coxofemoral joint$1 kw OR Acetabulum[Mesh] OR acetabulum kw OR acetabular fossa kw OR Femur head[Mesh] OR fem* head$1 kw OR Femoracetabular impingement[Mesh] OR femor?acetabular impingement kw OR femoral acetabular impingement kw OR FAI kw) AND (labr$2 kw OR labr$2 tear$1 kw OR Cartilage, Articular[Mesh] OR articular cartilage kw OR chondral damage kw OR chondropath* kw OR cartilage delamination kw OR internal derangement kw OR ligamentum teres kw OR foveal ligament$1 kw OR Round ligament of femur[Mesh] OR herniation pit$1 kw OR paralabral cyst$1 kw) AND (Magnetic Resonance Imaging[Mesh] OR magnetic resonance imaging kw OR MRI kw OR magnetic resonance arthrogra* kw OR MRA kw OR Tomography, X-ray Computed[Mesh] OR computed tomography kw OR CT kw OR c?t scan* kw OR computed tomography arthrogra* kw OR CTA kw) AND (Prevalence[Mesh] OR prevalen* kw OR Epidemiology[Mesh] OR epidemiology kw)

CINAHL.

(Hip[Mesh] OR hip# kw OR Hip joint[Mesh] OR "hip joint#" kw OR "coxofemoral joint#" kw OR Acetabulum[Mesh] OR acetabulum kw OR "acetabular fossa" kw OR Femur head[Mesh] OR "fem* head#" kw OR Femoracetabular impingement[Mesh] OR "femor#acetabular impingement" kw OR "femoral acetabular impingement" kw OR FAI kw) AND (Hip labram tear[Mesh] OR labr* kw OR "labr* tear#" kw OR Cartilage, Articular[Mesh] OR "articular cartilage" kw OR "chondral damage" kw OR chondropath* kw OR "cartilage delamination" kw OR "internal derangement" kw OR "ligamentum teres" kw OR "foveal ligament#" kw OR "herniation pit#" kw OR "paralabral cyst#" kw) AND (Magnetic resonance imaging[Mesh] OR "magnetic resonance imaging" kw OR MRI kw OR "magnetic resonance arthrogra*" kw OR MRA kw OR Tomography, X-ray Computed[Mesh] OR "computed tomography" kw OR CT kw OR "c#t scan*" kw OR "computed tomography arthrogra*" kw OR CTA kw) AND (Prevalence[Mesh] OR prevalence kw OR Cross sectional studies[Mesh] OR Epidemiology[Mesh] OR epidemiolog* kw)

EMBASE.

(Hip[Mesh] OR hip$1 kw OR hip joint$1 kw OR coxofemoral joint$1 kw OR Acetabulum[Mesh] OR acetabulum kw OR acetabular fossa kw OR Femur head[Mesh] OR fem* head$1 OR Femoracetabular impingement[Mesh] OR femor?acetabular impingement OR femoral acetabular impingement OR FAI) AND (labr$2 kw OR labr$2 tear$1 kw OR Articular cartilage[Mesh] OR articular cartilage kw OR chondral damage kw OR Chondropathy[Mesh] OR chondropath* kw OR cartilage delamination kw OR internal derangement kw OR ligamentum teres kw OR foveal ligament$1 kw OR herniation pit$1 kw OR paralabral cyst$1 kw) AND

(Nuclear magnetic resonance imaging[Mesh] OR magnetic resonance imaging kw OR MRI kw OR magnetic resonance arthrogra* OR MRA kw OR Computer assisted tomography[Mesh] OR computed tomography kw OR CT kw OR c?t scan* kw OR computed tomography arthrogra* kw OR CTA kw) AND (Prevalence[Mesh] OR prevalen* kw OR Epidemiology[Mesh] OR epidemiolog* kw)

SPORTdiscus.

(hip kw OR Hip joint de OR "hip joint#" kw OR "coxofemoral joint#" kw OR acetabulum kw OR "acetabular fossa" kw OR "fem* head#" kw OR "femor#acetabular impingement" OR "femoral acetabular impingement" OR "FAI") AND (labr* kw OR "labr* tear#" kw OR articular cartilage de OR "articular cartilage" kw OR "chondral damage" kw OR chondropath* kw OR "cartilage delamination" kw OR "internal derangement" kw OR "ligamentum teres" kw OR "foveal ligament" kw OR "herniation pit*" kw OR "paralabral cyst*" kw) AND (Magnetic resonance imaging de OR "magnetic resonance imaging" kw OR MRI kw OR "magnetic resonance arthrogra*" kw OR MRA kw OR Computed tomography de OR "computed tomography" kw OR CT kw OR "c#t scan*" kw OR "computed tomography arthrogra*" OR CTA kw) AND ("Disease prevalence" de OR prevalen* kw OR Epidemiology de OR epidemiolog*)

Cochrane library.

(Hip[Mesh] OR "hip" ti.ab.kw OR Hip joint[Mesh] OR "hip joint" ti.ab.kw OR "coxofemoral joint*" ti.ab.kw OR Acetabulum[Mesh] OR "acetabular fossa" ti.ab.kw OR Femur head[Mesh] OR fem* NEXT head ti.ab.kw OR Femoracetabular impingement[Mesh] OR "femoracetabular impingement" ti.ab.kw OR "femoral acetabular impingement" ti.ab.kw OR "FAI" ti.ab.kw) AND ("labral" ti.ab.kw OR "labrum" ti.ab.kw OR labral NEXT tear ti.ab.kw OR Articular cartilage[Mesh] OR "articular cartilage" ti.ab.kw OR "chondral damage" ti.ab.kw OR chondropath* ti.ab.kw OR "cartilage delamination" ti.ab.kw OR "internal derangement" ti.ab.kw OR "ligamentum teres" ti.ab.kw OR "foveal ligament" ti.ab.kw OR herniation NEXT pit* ti.ab.kw OR paralabral NEXT cyst* ti.ab.kw) AND (Magnetic resonance imaging[Mesh] OR "magnetic resonance imaging" ti.ab.kw OR MRI ti.ab.kw OR magnetic NEXT resonance NEXT arthrogra* ti.ab.kw OR MRA ti.ab.kw OR Tomography, X-ray Computed[Mesh] OR "computed tomgraphy" ti.ab.kw OR CT ti.ab.kw OR "cat scan" ti.ab.kw OR "ct scan" ti.ab.kw OR computed NEXT tomography NEXT arthrogra* ti.ab.kw OR CTA ti.ab.kw) AND (Prevalence[Mesh] OR Prevalence ti.ab.kw OR Epidemiology[Mesh] OR epidemiolog* ti.ab.kw)

Pubmed.

(hip OR hip joint OR coxofemoral joint OR acetabulum OR acetabular fossa OR femur head OR femoral head OR femoracetabular impingement OR femoral acetabular impingement OR FAI) AND (labral OR labrum OR labral tear OR labrum tear OR articular cartilage OR chondral damage OR chondropathy OR cartilage delamination OR internal derangement OR ligamentum teres OR foveal ligament OR herniation pit OR paralabral cyst) AND (magnetic resonance imaging OR MRI OR magnetic resonance arthrogra* OR MRA OR computed tomography OR CT OR ct scan OR cat scan OR computed tomography arthrogra* OR CTA) AND (prevalence OR prevalen* OR epidemiology OR epidemiolog*)

Scopus.

(hip ti.ab.kw OR "hip joint" ti.ab.kw OR "coxofemoral joint" ti.ab.kw OR acetabulum ti.ab.kw OR "acetabular fossa" ti.ab.kw OR "fem* head" ti.ab.kw OR "femoracetabular impingement" ti.ab.kw OR "femoroacetabular impingement" ti.ab.kw OR "femoral acetabular impingement" ti.ab.kw OR FAI ti.ab.kw) AND (labr* ti.ab.kw OR "labr* tear" ti.ab.kw OR "articular cartilage" ti.ab.kw OR "chondral damage" ti.ab.kw OR chondropath* ti.ab.kw OR "cartilage delamination" ti.ab.kw OR "internal derangement" ti.ab.kw OR "ligamentum teres" ti.ab.kw OR "foveal ligament" ti.ab.kw OR "herniation pit" ti.ab.kw OR "paralabral cyst" ti.ab.kw) AND ("magnetic resonance imaging" ti.ab.kw OR MRI ti.ab.kw OR "magnetic resonance arthrogra*" ti.ab.kw OR MRA ti.ab.kw OR "computed tomography" ti.ab.kw OR CT ti.ab.kw OR "ct scan" ti.ab.kw OR "cat scan" ti.ab.kw OR computed tomography arthrogra* ti.ab.kw OR CTA ti.ab.kw) AND (prevalen* ti.ab.kw OR epidemiolog* ti.ab.kw)

Appendix 23. Studies excluded from Study 2 (Chapter 5).

Author	Title	Reason excluded
Adeoye, 2013[1]	Anterior inferior iliac spine and hip abnormalities in high level soccer players: A 3-dimensional CT analysis.	Conference abstract.
Adkins, 2000[2]	Hip pain in athletes.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Agricola, 2012[3]	The development of cam-type deformity in adolescent and young male soccer players.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Angioi, 2014[4]	Early signs of osteoarthritis in professional ballet dancers: a preliminary study.	Less than 5 subjects evaluated for intra-articular hip pathology.
Browne, 2011[5]	The mature athlete with hip arthritis.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Corsini, 2015[6]	Athletic pubalgia: Does it really exist?	Conference abstract.
Croft, 1992[7]	Osteoarthritis of the hip and occupational activity.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Dickenson, 2016[8]	Professional golfers' hips: prevalence and predictors of hip pain with clinical and MR examinations.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Diesel, 2015[9]	The prevalence of femoroacetabular impingement in radiographs of asymptomatic subjects: A cross-sectional study.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Domb, 2014[10]	Magnetic resonance imaging findings in symptomatic hips of younger retired national football league players.	Reported prevalence of intra-articular hip pathologies in retired athletes'.
Economopoulos, 2014[11]	Radiographic evidence of femoroacetabular impingement in athletes with athletic pubalgia.	Reported prevalence of FAI (including bony morphology) but did not report prevalence of hip OA/intra-articular hip pathologies.
Epstein, 2013[12]	Intra-articular hip injuries in national hockey league players: a descriptive epidemiological study.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Feeley, 2008[13]	Hip injuries and labral tears in the national football league.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Fukushima, 2016[14]	Prevalence of radiological findings related to femoroacetabular impingement in professional baseball players in Japan.	Reported prevalence of FAI (including bony morphology) but did not report prevalence of hip OA/intra-articular hip pathologies.

Gallo, 2013[15]	Hip labral tears among asymptomatic professional hockey players identified on MRI: Four-year follow-up study.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Hammoud, 2012[16]	High incidence of athletic pubalgia symptoms in professional athletes with symptomatic femoroacetabular impingement.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Holmich, 2015[17]	Injuries in the pelvis, groin, hip and thigh.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Ji, 2014[18]	Herniation pits as a radiographic indicator of pincer-type femoroacetabular impingement in symptomatic patients.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Jonasson, 2011[19]	Prevalence of joint-related pain in the extremities and spine in five groups of top athletes.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Kang, 2009[20]	Acetabular labral tears in patients with sports injury.	Prevalence of intra-articular hip pathology determined at arthroscopyv
Kern-Scott, 2011[21]	Review of acetabular labral tears in dancers.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Konradsen, 1990[22]	Long distance running and osteoarthrosis.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Kopec, 2015[23]	Relationship between physical activity and hip pain in persons with and without femoroacetabular impingement: A population based case-control study.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Kornaat, 2014[24]	Bone marrow edema lesions in the professional runner.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Kujala, 1999[25]	Heart attacks and lower-limb function in master endurance athletes.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Lane, 1999[26]	Recreational physical activity and the risk of osteoarthritis of the hip in elderly women.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Langhout, 2015[27]	Association between low back pain and hip osteoarthritis in elderly and hip dysfunction in athletes.	Conference abstract.
Larson, 2013[28]	Increasing alpha angle is predictive of athletic-related "hip" and "groin" pain in collegiate national football league prospects.	Reported prevalence of FAI (including bony morphology) but did not report prevalence of hip OA/intra-articular hip pathologies.
Lee, 2016[29]	Descriptive epidemiology of symptomatic femoroacetabular impingement in young athlete: Single centre study.	Reported prevalence of FAI (including bony morphology) but did not report prevalence of hip OA/intra-articular hip pathologies.

Author	Title	Reason excluded
Lerch, 2018[30]	Prevalence of femoral and acetabular version abnormalities in patients with symptomatic hip disease: A controlled study of 538 hips.	Reported prevalence of FAI (including bony morphology) but did not report prevalence of hip OA/intra-articular hip pathologies.
Lindberg, 1993[31]	Prevalence of coxarthrosis in former soccer players: 286 players compared with matched controls.	Reported prevalence of hip OA/intra-articular hip pathology in retired athletes.
Liszewski, 2011[32]	Running and osteoarthritis of the hip: Is there an association.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Michaelsson, 2011[33]	Risk of severe knee and hip osteoarthritis in relation to level of physical exercise: a prospective cohort study of long distance skiers in Sweden.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Monckeberg, 2016[34]	Prevalence of FAI radiographic hip abnormalities in elite soccer players: Are there differences related to skeletal maturity.	Reported prevalence of FAI (including bony morphology) but did not report prevalence of hip OA/intra-articular hip pathologies.
Mosler, 2016[35]	Ethnic differences in bony hip morphology in a cohort of 445 professional male soccer players.	Reported prevalence of FAI (including bony morphology) but did not report prevalence of hip OA/intra-articular hip pathologies.
Murray, 1971[36]	Athletic activity in adolescence as an etiological factor in degenerative hip disease.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Nogier, 2010[37]	Descriptive epidemiology of mechanical hip pathology in adults under 50 years of age. Prospective series of 292 cases: Clinical and radiological aspects and physiopathological review.	Reported prevalence of FAI (including bony morphology)/dysplasia but did not report prevalence of hip OA/intra-articular hip pathologies.
Panush, 1986[38]	Is running associated with degenerative joint disease?	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Philippon, 2007[39]	Hip instability in the athlete.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Puranen, 1975[40]	Running and primary osteoarthritis of the hip.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Rankin, 2015[41]	Hip joint pathology as a leading cause of groin pain in the sporting population.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Robell, 2013[42]	Incidence of femoral acetabalur impingement syndrome at one collegiate athletics program: A two-year, single institution study.	Conference abstract.

Author	Title	Reason excluded
Robinson, 2015[43]	Incidence of femoral acetabular impingement syndrome at one collegiate athletics program: A two-year, single institution study.	Used other forms of imaging to determine the prevalence of hip OA or intra-articular hip pathologies.
Ross, 2015[44]	Characterisation of symptomatic hip impingement in butterfly ice hockey goalies.	Reported prevalence of FAI (including bony morphology)/dysplasia but did not report prevalence of hip OA/intra-articular hip pathologies.
Siebenrock, 2011[45]	The cam-type deformity of the proximal femur arises in childhood in response to vigorous sporting activity.	Reported prevalence of FAI (including bony morphology)/dysplasia but did not report prevalence of hip OA/intra-articular hip pathologies.
Siebenrock, 2013[46]	Prevalence of cam-type deformity and hip pain in elite ice hockey players before and after the end of growth.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Sohn, 1985[47]	The effect of running on the pathogenesis of osteoarthritis of the hips and knees.	Reported prevalence of hip OA/intra-articular hip pathology in retired athletes.
Teitz, 1998[48]	Premature osteoarthrosis in professional dancers.	Reported prevalence of hip OA/intra-articular hip pathology in retired athletes.
Todd, 2017[49]	No difference in prevalence of spine and hip pain in young Elite skiers.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Vingard, 1993[50]	Sports and osteoarthritis of the hip: an epidemiologic study.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
White, 1993[51]	Relationships between habitual physical activity and osteoarthrosis in ageing women.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Williams, 2013[52]	Effects of running and walking on osteoarthritis and hip replacement risk.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Willick, 2010[53]	Running and osteoarthritis.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Yoo, 2017[54]	No difference in prevalence of radiographic subspinal impingement of the hip between symptomatic and asymptomatic subjects.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.
Author not reported[55]	Running and Osteoarthritis: Does Recreational or Competitive Running Increase the Risk?.	Reporting of hip OA/intra-articular hip pathology prevalence in current athletes' not the primary aim.

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Appendix 24. Prevalence of intra-articular hip pathologies reported in less than one symptomatic and asymptomatic study in Study 2 (Chapter 5).

Participant group	Per person	Per hip
Symptomatic	No study reported additional intra-articular hip pathologies at a per person level.	No study reported additional intra-articular hip pathologies at a per hip level.
Asymptomatic	Yuan et al *(HR)*[a]: Acetabular rim damage: 15% Ayeni et al *(MR)*: Osseous bumps: 20%*;* Paralabral cysts: 0% *(MR)*[48].	Yepez et al.*(HR)*: Acetabular Osteitis: 9%. Yuan et al.*(HR)*[b]: Acetabular rim damage: 0%. Lahner et al.*(HR)*: Osseous bumps: 7%.
Mixed		Kolo et al.*(MR)*: *Herniation* pits: 53%; Labral degeneration: 41%; Labral ossification: 3%.

[a] Included study group only [b] Included control group only

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Prevalence of early hip OA features on MRI in high-impact athletes. The femoroacetabular impingement and hip osteoarthritis cohort (FORCe) study

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SUMMARY

Objective: To compare early hip osteoarthritis (OA) features on magnetic resonance imaging (MRI) in high-impact athletes with and without hip and/or groin pain, and to evaluate associations between early hip OA features, the International Hip Outcome Tool (iHOT33) and Copenhagen Hip and Groin Outcome Score (HAGOS).

Design: This case-control study evaluated data of the femoroacetabular impingement and hip osteoarthritis cohort (FORCe). One hundred and eighty-two symptomatic (hip and/or groin pain >6 months and positive flexion-adduction-internal-rotation (FADIR) test) and 55 pain-free high-impact athletes (soccer or Australian football (AF)) without definite radiographic hip OA underwent hip MRI. The Scoring Hip Osteoarthritis with MRI (SHOMRI) method quantified and graded the severity of OA features. Each participant completed the iHOT33 and HAGOS.

Results: Hip and/or groin pain was associated with higher total SHOMRI (0–96) (mean difference 1.4, 95% CI: 0.7–2.2), labral score (adjusted incidence rate ratio (aIRR) 1.33, 95% CI: 1.1–1.6). Differences in prevalence of cartilage defects, labral tears and paralabral cysts between symptomatic and pain-free participants were inconclusive. There was a lower prevalence of effusion-synovitis in symptomatic participants when compared to pain-free participants (adjusted odds ratio (aOR) 0.46 (95% CI: 0.3–0.8). Early hip OA features were not associated with iHOT33 or HAGOS.

Conclusions: A complex and poorly understood relationship exists between hip and/or groin pain and early hip OA features present on MRI in high-impact athletes without radiographic OA. Hip and/or groin pain was associated with higher SHOMRI and labral scores.

Introduction

Hip osteoarthritis (OA) is associated with substantial personal and societal burden[1], with its pathogenesis involving genetic, biological, biomechanical and environmental factors[1–3]. Mechanical joint overload may represent one disease pathway[1,4], with subtle alterations in bony anatomy (i.e., cam morphology) also related to hip OA development[5–8]. Repetitive high-impact physical activity (such as football) might even increase the risk for hip OA[9,10], with many young adults experiencing hip-related pain with sports participation[11]. Once established, the radiological joint changes

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seen in OA are irreversible[12]. Identifying early disease may be important, as this may represent a point in time where interventions aimed at slowing disease progression could be effective[12].

Radiographs are often used to evaluate hip OA but are insensitive to the soft-tissue findings seen in the early stages of OA[10]. Magnetic resonance imaging (MRI) provides superior soft-tissue contrast, enabling assessment of articular cartilage, labrum and other joint features[10,13,14]. Semi-quantitative MRI measures enable structured evaluation of soft-tissues involved in the pathogenesis of OA, with such approaches recommended for use in clinical studies of hip OA[13]. The Scoring of Hip Osteoarthritis with MRI (SHOMRI) is a reliable and valid semi-quantitative measure, which has been used to characterise and monitor the burden of hip OA[15].

Little is known about hip OA features on MRI in younger people participating in high-impact physical activity who are free from radiographic OA, and who have or do not have hip and/or groin pain[16]. Evaluating early OA features in younger active symptomatic individuals, may aid in the understanding of early hip joint degeneration and assist in establishing the relationship between specific OA features and symptoms. The aims of this study were: 1) to compare early hip OA features on MRI between people with and without hip and/or groin pain participating in high-impact physical activity (i.e., soccer or Australian football (AF)); 2) to compare early hip OA features separately in men and women; and 3) to evaluate the relationship between early hip OA features, the International Hip Outcome Tool (iHOT33) and Copenhagen Hip and Groin Outcome Score (HAGOS) symptom and pain subscales.

Methods

Study design

This case-control study used baseline data of the femoroacetabular impingement and hip osteoarthritis cohort (FORCe). The FORCe study is an ongoing prospective study investigating changes to hip joint structures in 184 symptomatic men and women (cases) participating in high-impact physical activity (soccer or AF)[17]. A convenience sample of 55 pain-free men and women participating in high-impact physical activity were recruited to match the mean age and sex distribution of the 184 symptomatic participants of the FORCe study and serve as a control group. Symptomatic and control participants were participating in the same league/competition level and were recruited between August 2015 and October 2018 from sporting clubs or organisations and via online or print advertising in Melbourne and Brisbane, Australia. This study had ethics approval (La Trobe University Human Ethics Committee [HEC 15–019 and HEC 16-045] and the University of Queensland Human Ethics Committee [2015000916 & 2016001694] and all participants provided written informed consent. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines were followed[18].

	Symptomatic group	Control group
Inclusion criteria	• Age: 18–50 years • Playing in a sub-elite football competition • Undertaking at least two sessions (games or training) of football (soccer/Australian football (AF)) per week • Self-reported hip (anterior/lateral/posterior) and/or groin pain which fulfilled criteria one to 3 1. Gradual onset 2. Greater than 6 months in duration 3. >3 and < 8 on an 11-point Numerical Pain Rating Scale* with football or football specific movements (squatting, kicking or cutting/change of direction)+ or - symptoms including clicking, giving way, locking or catching • Positive flexion-adduction-internal-rotation (FADIR) test in at least one hip	• Age: 18–50 years • Playing in a sub-elite football competition • Undertaking at least two sessions (games or training) of football (soccer/AF) per week • Negative FADIR test in both hips
Exclusion criteria	• Self-reported history of significant hip or groin condition, specifically: ◦ Bursitis, congenital dislocation of the hip, fractures, osteochondritis dissecans, Legg-Calvé-Perthes disease, septic or rheumatoid arthritis, slipped capital femoral epiphysis or subluxations/dislocations • Previous hip, groin or pelvic surgery • Kellgren and Lawrence (KL) grade two or greater on anteroposterior (AP) pelvis radiograph • Any lumbar spine or lower limb injury/complaint in the previous 3 months (i.e., hamstring muscle injury or sprained ankle) that resulted in the inability to weight-bear fully or undertake testing procedures • Contra-indications to radiographs (i.e., pregnancy) or magnetic resonance imaging (MRI) (i.e., claustrophobia) • Received intra-articular hip injection (of any type) in the previous 3 months • Unable to understand spoken and written English	• Self-reported history of hip and/or groin pain, or significant hip or groin condition (see exclusion criteria for symptomatic participants) • Past history of lower limb surgery (e.g., anterior cruciate ligament reconstruction) • KL grade two or greater on AP pelvis radiograph • Any lumbar spine or lower limb injury/complaint in the previous 3 months (e.g., hamstring muscle injury or sprained ankle) that resulted in the inability to weight-bear fully or undertake testing procedures • Contra-indications to radiographs (i.e., pregnancy) or MRI (i.e., claustrophobia) • Unable to understand spoken and written English

*Use of the numerical pain rating scale is a deviation from the original femoroacetabular impingement and hip osteoarthritis cohort study protocol (Crossley *et al.*, 2018).

Table I Participant inclusion and exclusion criteria

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Participants

The eligibility criteria for symptomatic and control participants are described in Table I. For symptomatic participants, each hip was classified as either 1) symptomatic or 2) other. The contralateral hip was classified as other if 1) no hip and/or groin was reported; or 2) hip and/or groin pain was reported but the participant had a negative FADIR test (Appendix (A), Table I). Control participants had no history of hip and/or groin pain and a negative FADIR test in both hips.

Radiographs

Each participant underwent a supine anteroposterior (AP) pelvis radiograph using a standardised protocol (Appendix (A)). Features of radiographic hip OA were evaluated using the OARSI atlas[19] by a blinded registrar orthopaedic surgeon (RA) with more than 10 years' experience reading pelvic radiographs. This resulted in a Kellgren and Lawrence (KL) classification (KL) (grade 0–4), with hip OA defined as a KL grade of 2 or greater[20]. Intra-observer reliability for KL classification had a kappa of 0.87 (95% CI: 0.71,1.0)[21].

Magnetic resonance imaging

Each participant underwent an unenhanced 3.0 T MRI (Phillips Ingenia, The Netherlands). Participants were positioned in supine with patient positioning aids used to maintain each hip in internal rotation and neutral abduction/adduction, with a 32-channel torso coil placed over the hips and pelvis, with right and left hips imaged independently. The MRI protocol included the following sequences: coronal proton density (PD) spectral attenuated inversion recovery (SPAIR), sagittal PD SPAIR and oblique axial PD SPAIR (Appendix (A), Table II).

SHOMRI scoring

All MRI scans were evaluated by one musculoskeletal radiologist (RS) with 8 years of experience, who was blinded to radiographic and clinical findings. The SHOMRI scoring system has been defined previously[15]. Briefly, eight different OA features were evaluated including: articular cartilage (graded 0–2), bone marrow edema pattern (BMEP) (graded 0–3), subchondral cysts (graded 0–2), labrum (graded 0–5), paralabral cysts (present or absent), intra-articular bodies (present or absent), effusion-synovitis (present or absent) and ligamentum teres (graded 0–3). Articular cartilage, BMEP and subchondral cysts were evaluated in six femoral and four acetabular subregions, with the labrum evaluated in four acetabular subregions[15]. Intra-observer reliability was determined in 20 randomly selected hips, re-read 2 weeks after the initial scoring.

OA feature scoring

For cartilage, acetabular and femoral subregions were combined, providing a total cartilage score (0–20). BMEP and subchondral cysts were evaluated in 10 subregions, with a total feature score ranging from 0 to 30 and 0 to 20, respectively. The labrum was scored in four subregions (0–20). Ligamentum teres was scored from 0 to 3. The remaining features (paralabral cysts, intra-articular bodies and effusion-synovitis) were scored as present or absent. To be consistent with previous studies[22,23], the total SHOMRI score (0–96) was calculated for each hip by adding the scores for each of the eight OA features, with a higher score indicating more severe whole joint degenerative change.

	Symptomatic group (n = 182)	Control group (n = 55)
Demographic characteristics		
Age, y	26.0 (23, 30)	26.0 (23, 31)
Sex, % women	20%	25%
Height, m	1.79 (1.73, 1.85)	1.79 (1.72, 1.85)
Weight, kg	77.9 (72, 86)	78.7 (67, 89)
BMI, kg/m^2	24.2 (23, 26)	24.3 (22, 27)
Football code, % soccer	50%	55%
Training/competition (per week), %		
2 to 3 sessions	89	82
≥4 sessions	11	18
Duration of symptoms, months*	24 (18, 49)	–
Radiographic measures		
KL grade, hips (%)		
Grade 0	347 (96%)	105 (95%)
Grade 1	15 (4%)	5 (5%)
Patient reported outcome measures		
iHOT33	64 (50, 74)	98 (97, 100)
HAGOS–Symptoms†	61 (51, 68)	100 (93, 100)
HAGOS–Pain†	75 (65, 83)	100 (100, 100)

Values are presented as %, or median (interquartile range).
* 181symptomatic participants.
† 176 symptomatic participants/54 control participants.

Table II Demographic characteristics, radiographic and patient reported outcome measures for symptomatic and control participants

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Dichotomous scoring

Cartilage defects were scored as present if cartilage loss was evident in at least one acetabular or femoral subregion and were defined as: any cartilage defect (grade one or grade two) or full-thickness defect (grade two only). A labral tear was scored as present if a grade two or above finding was reported in one or more subregions. For BMEP and subchondral cysts, acetabular and femoral subregions were combined, with the feature scored as present if a grade one or above was scored in at least one subregion. Ligamentum teres tears were scored as present if a partial (grade two) or full-thickness tear (grade three) was reported. Finally, paralabral cysts, intra-articular bodies and effusion-synovitis were scored as present or absent.

Patient reported outcome measures

Demographic information (age, sex, height, weight, football code participation and training/competition frequency) was collected. Each participant completed the iHOT33[24] and the HAGOS[25], which are recommended patient reported outcome measures (PROM) in young to middle-aged people with hip and/or groin conditions[26].

Statistical analysis

Data analyses were performed with SPSS version 25 (SPSS Inc, Chicago, Illinois, USA) and Stata/IC 15.0 for Windows (StataCorp LC, College Station, Texas, USA). Intra-observer reliability for OA feature scores (including total SHOMRI) were determined with intra-class correlation coefficients (ICC) using a two-way mixed-effects model with absolute agreement[27]. Intra-observer reliability for individual OA features (dichotomous scoring) was determined with kappa and prevalence adjusted bias adjusted kappa (PABAK). The kappa statistic conveys the proportion of agreement greater than expected by chance; however, the magnitude of the kappa coefficient is affected by the prevalence of a finding and bias between observers. The PABAK adjusts for differences in prevalence of each hip OA feature and bias between observers; therefore, providing a more complete assessment of observer agreement[28].

Linear regression models utilising generalised estimating equations (GEE) to account for within-person correlation between right and left hip data were used to evaluate differences in total SHOMRI score between symptom groups, with 95% confidence intervals (CI) and associated *P* values estimated using bootstrapping (1,000 repetitions) to account for right skew in total SHOMRI scores[29]. Differences between groups in individual OA feature scores (cartilage, BMEP, subchondral cysts, labral and ligamentum teres) were evaluated using negative binomial regression utilising GEE, with group differences reported as incidence rate ratios (IRR) with associated 95% CI and *P*-values. For the presence of individual OA features (dichotomous scoring), the prevalence of each feature was reported per hip for primary analysis, with per-person prevalence reported descriptively (Appendix (A), Table III). Differences between groups in feature prevalence were evaluated using logistic binomial regression utilising GEE, with group differences reported as odds ratios (ORs) with associated 95% CI and *P*-values. For the first study aim, data from men and women were pooled and analyses adjusted for sex, age and body mass index (BMI). For the second aim of the study, differences between symptom groups were estimated in men and women separately by including an interaction term between sex and symptom group in the statistical analyses described above (total SHOMRI score, individual OA feature scores and prevalence of OA features), adjusted for age and BMI.

For the third aim of the study, Spearman's rank correlation was used to evaluate the relationship between individual OA feature scores (including total SHOMRI score) and hip and/or groin pain specific PROMs (iHOT33 and HAGOS symptoms and pain subscales) in football players overall with hip and/or groin pain, and in men and women with hip and/or groin pain separately. For all analyses, the total SHOMRI and individual OA features scores were taken from the most symptomatic hip, as defined by the iHOT33, with the HAGOS subscale scores applied to this hip. The absence of non-linear relationships were evaluated graphically using a locally weighted smoothing filter.

	% agreement	Kappa (95%CI)	PABAK (95%CI)	ICC (95%CI)‡
SHOMRI feature*				
Cartilage defect *any* ($n = 200$)	88	0.66 (0.54, 0.78)	0.76 (0.67, 0.85)	0.66 (0.28, 0.85)
Cartilage defect *full thickness* ($n = 200$)	98	−0.01 (−0.27, 0.01)	0.96 (0.91, 1.00)	
BMEP ($n = 200$)	100	0.89 (0.67, 1.00)	0.99 (0.97, 1.00)	0.91 (0.80, 0.97)
Subchondral cysts ($n = 200$)	98	0.59 (0.22, 0.96)	0.96 (0.92, 1.00)	0.65 (0.30, 0.84)
Labral tear ($n = 80$)	90	0.77 (0.62, 0.92)	0.80 (0.67, 0.93)	0.77 (0.51, 0.90)
Ligamentum teres tear ($n = 20$)	80	0.60 (0.24, 0.95)	0.60 (0.25, 0.95)	0.61 (0.23, 0.83)
Paralabral cyst (n-20)	95	0.89 (0.67, 1.00)	0.90 (0.71, 1.00)	–
Intra-articular bodies ($n = 20$)†	100	–	–	–
Effusion-synovitis ($n = 20$)	95	0.83 (0.50, 1.00)	0.90 (0.71, 1.00)	–
Total SHOMRI	-	–	–	0.84 (0.62, 0.93)

PABAK, prevalence adjusted bias adjusted kappa.
* n describes the number of subregions scored in 20 hips.
† Feature not present in 20 hips assessed for reliability.
‡ Intra-class coefficient values only used for features that provided a total score (including total SHOMRI score).

Table III Intra-observer reliability of SHOMRI features (20 hips)

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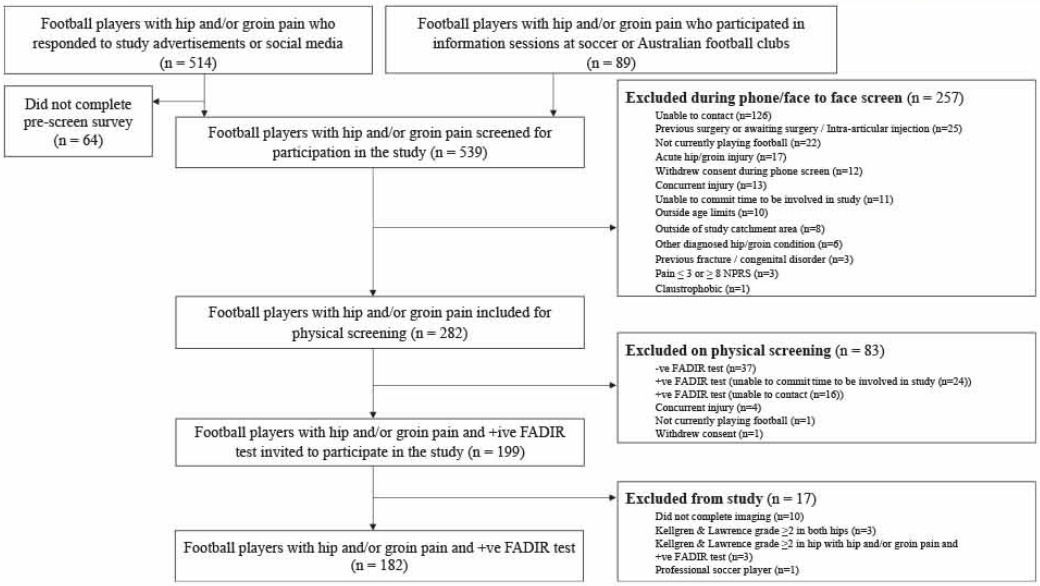

Fig. 1 Flowchart of symptomatic participants.

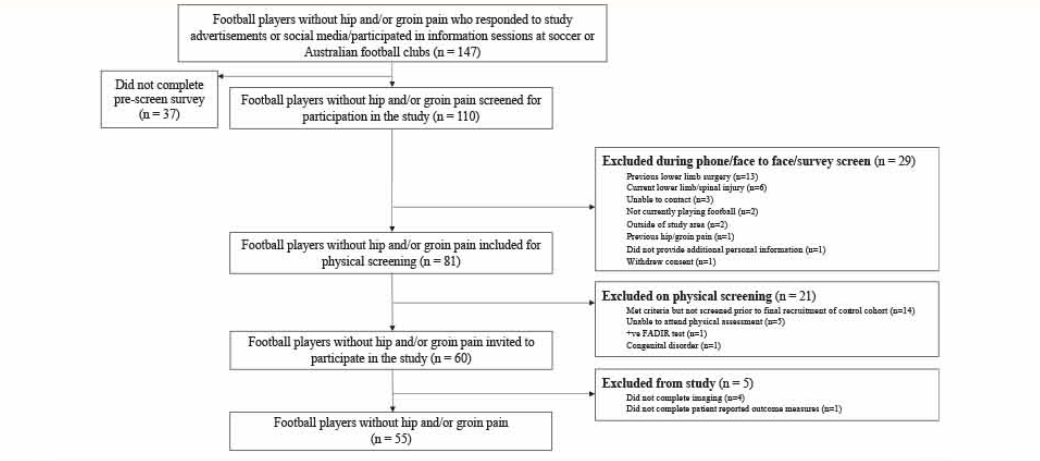

Fig. 2 Flowchart of control participants.

Results

Participants

A total of 539 football players with hip and/or groin pain were screened eligibility, with 182 (symptomatic group) included (Fig. 1). In two symptomatic participants, one hip was excluded due to the presence of hip OA (KL ≥ 2), with the remaining 362 hips included for these analyses. One hundred and forty-seven asymptomatic football players were evaluated for eligibility, with 55 participants (110 hips) included in the control group (Fig. 2). Symptomatic and control participant characteristics are presented in Table II. The

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prevalence of KL grade one was low in both symptomatic (4%) and control (5%) participants. Symptomatic participants had a median symptom duration of 24 months (interquartile range 18–49 months).

Reliability

Percent agreement ranged from 80 (ligamentum teres tears) to 100% (BMEP). For OA feature scores, ICCs ranged from 0.66 to 0.91. For individual features (dichotomous scoring) kappa values ranged from −0.01 to 0.89, with PABAK 0.60 to 0.99 (Table III).

Total SHORMI score

In football players, higher total SHOMRI scores were observed in symptomatic [mean difference (MD) = 1.4 (95% CI: 0.7, 2.2)] and other [MD = 1.2 (95% CI: 0.1, 2.2)] hips than in control hips (Table IV). When stratified by sex, a similar finding was observed in men, with symptomatic [MD = 1.8 (95% CI: 1.0, 2.7)] and other [MD = 1.7 (95% CI: 0.4, 2.9)] hips having higher total SHOMRI scores. In contrast, symptomatic [MD = 0.1 95% CI: −1.0, 1.2)] and other [MD = −0.4 (95% CI: −2.2, 1.4)] hips had similar total SHOMRI scores to control hips in women (Table IV). Unadjusted total SHOMRI scores are presented in Appendix (A), Table IV. An interaction between sex and symptom group was found for total SHOMRI score, whereby higher scores were found in men but not women in both symptomatic and other hips when compared to control hips (Table IV).

Individual osteoarthritis feature scores

In all football players, results for differences in cartilage score between symptomatic, other and control hips were inconclusive (Table V). For men, higher cartilage scores were found in symptomatic [adjusted incidence rate ratio (aIRR) = 1.60 (95% CI: 1.15, 2.22)] and other hips [aIRR = 1.61 (95% CI: 1.09, 2.39)] relative to control hips. In women, differences in cartilage score between symptom groups were inconclusive (Table V).

In all football players, labral scores were higher in symptomatic [aIRR = 1.33 (95% CI: 1.08, 1.64)] and other hips [aIRR = 1.32 (95% CI: 1.03, 1.68)] than in control hips. A similar finding was observed in men, with higher labral scores in symptomatic [aIRR = 1.38 (95% CI: 1.08, 1.76)] and other [aIRR = 1.40 (95% CI: 1.06, 1.85)] hips when compared to control hips. In women, results for differences in labral score between symptomatic, other and control hips were inconclusive (Table V).

In all football players, differences in BMEP and ligamentum teres scores between symptomatic, other and control hips were inconclusive (Table V). For men, results for BMEP, ligamentum teres and subchondral cyst scores between symptom groups were inconclusive. For women, differences in ligamentum score between symptom groups were inconclusive (Table V).

Of the individual OA feature scores, an interaction between sex and symptom group was only found for cartilage, whereby higher scores were observed for men but not women in both symptomatic and other hips versus control hips (Table V).

Prevalence of osteoarthritis features

In all football players, and in men and women, results for differences in cartilage defect and labral tear prevalence between symptomatic, other and control hips were inconclusive (Table VI).

In all football players, symptomatic [aOR = 0.46 (95% CI: 0.26, 0.81)] and other [aOR = 0.38 (95% CI: 0.18, 0.77)] hips had a lower prevalence of effusion-synovitis relative to control hips. In men, a lower prevalence of effusion-synovits was also observed in symptomatic [aOR = 0.49 (95% CI: 0.25, 0.96)] and other [aOR = 0.36 (95% CI: 0.15, 0.83)] than in control hips. For women, results for differences in effusion-synovitis prevalence between symptom groups were inconclusive (Table VI).

In all football players, differences in paralabral cyst prevalence between symptomatic, other and control hips were inconclusive (Table VI). In men, differences in subchondral cyst, ligamentum teres tear and paralabral cyst prevalence between symptom groups were inconclusive. Lastly in women, differences in paralabral cyst prevalence between symptom groups were inconclusive. The prevalence of all OA features (including features not compared statistically due to low prevalence) in football players are presented in Fig. 3, with men and women presented in Appendix (A), Figs. 1 and 2.

No interaction was found between sex and symptom group for cartilage, labral tears, paralabral cysts or effusion-synovitis.

	Mean (95%CI) total SHOMRI score			Between group comparisons	
	Control (ref)	Symptomatic	Other	Symptomatic vs control	Other vs control
				Mean difference (95% CI)‡	Mean difference (95% CI)‡
All football players, hips*	110	288	74		
Mean (95% CI)	5.3 (4.7, 5.8)	6.7 (6.2, 7.2)	6.5 (5.6, 7.4)	1.4 (0.7, 2.2)	1.2 (0.1, 2.2)
Men, hips†	82	229	59		
Mean (95%CI)	5.4 (4.7, 6.0)	7.2 (6.6, 7.8)	7.0 (6.0, 8.1)	1.8 (1.0, 2.7)	1.7 (0.4, 2.9)
Women, hips†	28	59	15		
Mean (95%CI)	4.7 (4.1, 5.4)	4.8 (3.8, 5.8)	4.3 (2.6, 6.0)	0.1 (−1.0, 1.2	−0.4 (−2.2, 1.4)

* Football players adjusted for sex, age and BMI.
† Men and women adjusted for age and BMI.
‡ Normal based 95%CI.

Table IV Differences in total SHOMRI score between control, symptomatic and other hips

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OA feature	Mean (95%CI) OA feature score			Incidence rate ratios (IRR)			
	Control (ref)	Symptomatic	Other	Symptomatic vs control		Other vs control	
				Unadjusted IRR (95%CI)	Adjusted IRR (95CI)	Unadjusted IRR (95%CI)	Adjusted IRR (95CI)
All football players, hips* ‡	110	288	74				
Cartilage	1.0 (0.7, 1.3)	1.4 (1.1, 1.6)	1.3 (1.0, 1.6)	1.38 (1.01, 1.88)	1.34 (0.98,1.83)	1.38 (0.95, 2.00)	1.30 (0.89, 1.88)
BMEP	0.1 (0.0, 0.1)	0.1 (0.0, 0.1)	0.1 (0.0, 0.2)	1.72 (0.40, 7.44)	1.75 (0.42, 7.26)	1.98 (0.40, 9.73)	1.89 (0.39, 9.30)
Labrum	3.0 (2.5, 3.6)	4.0 (3.6, 4.5)	4.0 (3.3, 4.7)	1.30 (1.04, 1.62)	1.33 (1.08, 1.64)	1.29 (1.00, 1.67)	1.32 (1.03, 1.68)
Ligamentum teres	0.5 (0.4, 0.6)	0.6 (0.5, 0.7)	0.6 (0.5, 0.8)	1.19 (0.90, 1.56)	1.20 (0.92, 1.57)	1.26 (0.92, 1.73)	1.26 (0.93, 1.71)
Men, hips†	82	229	59				
Cartilage	1.0 (0.7, 1.2)	1.5 (1.3, 1.8)	1.6 (1.1, 2.0)	1.50 (1.07, 2.11)	1.60 (1.15, 2.22)	1.56 (1.04, 2.33)	1.61 (1.09, 2.39)
BMEP	0.1 (0.0, 0.1)	0.1 (0.0, 0.2)	0.1 (0.0, 0.2)	1.65 (0.31, 8.84)	1.81 (0.36, 9.22)	2.21 (0.37, 13.23)	2.27 (0.38, 13.69)
Subchondral cysts	0.1 (0.0, 0.2)	0.1 (0.1, 0.2)	0.1 (0.0, 0.3)	1.10 (0.51, 2.41)	1.22 (0.56, 2.65)	1.46 (0.55, 3.87)	1.41 (0.54, 3.70)
Labrum	3.2 (2.5, 3.8)	4.3 (3.8, 4.9)	4.4 (3.6, 5.2)	1.28 (1.00, 1.64)	1.38 (1.08, 1.76)	1.30 (0.98, 1.74)	1.40 (1.06, 1.85)
Ligamentum teres	0.5 (0.3, 0.6)	0.6 (0.5, 0.7)	0.6 (0.5, 0.8)	1.24 (0.88, 1.74)	1.28 (0.93, 1.78)	1.29 (0.88, 1.90)	1.31 (0.91, 1.90)
Women, hips† §	28	59	15				
Cartilage	1.0 (0.4, 1.5)	0.7 (0.4, 1.0)	0.4 (0.1, 0.8)	0.79 (0.37, 1.67)	0.73 (0.36, 1.49)	0.49 (0.18, 1.35)	0.43 (0.15, 1.22)
Labrum	2.5 (1.7, 3.3)	3.0 (2.2, 3.8)	2.6 (1.4, 3.9)	1.30 (0.84, 2.00)	1.19 (0.81, 1.74)	1.11 (0.63, 1.97)	1.05 (0.60, 1.83)
Ligamentum teres	0.6 (0.3, 0.8)	0.5 (0.4, 0.7)	0.6 (0.4, 0.9)	1.03 (0.66, 1.61)	0.98 (0.61, 1.56)	1.19 (0.70, 2.02)	1.14 (0.66, 1.97)

* Football players adjusted for sex, age and BMI.
† Men and women adjusted for age and BMI.
‡ Subchondral cysts not analysed in football players.
§ Subchondral cysts and BMEP not analysed in women.

Table V Differences in individual osteoarthritis (OA) feature scores between control, symptomatic and other hips

Osteoarthritis and Cartilage

Correlation between scoring of hip osteoarthritis with MRI feature scores, International Hip Outcome Tool and Hip and Groin Outcome Score

The total SHOMRI and individual OA features scores were not associated with iHOT33 or HAGOS symptoms and pain subscale scores in all football players, or in men or women separately (Appendix (A), Table V).

Discussion

Football players frequently exhibited MRI-defined early hip OA features. The high prevalence of early hip OA features, irrespective of symptomatic status, suggests a complex and poorly understood relationship between pain and most OA features. Football players with longstanding hip and/or groin pain exhibited higher total SHOMRI, labral and cartilage scores. There was no relationship between OA feature scores (including total SHOMRI) and the iHOT33 or HAGOS.

Cartilage defects were present in 47–51% of football players hips without definite radiographic hip OA, regardless of whether they had hip and/or groin pain or not. A higher prevalence of full thickness cartilage defects was found in symptomatic hips than control hips, with more extensive cartilage damage (i.e., higher cartilage scores) present in symptomatic hips in men. Overall, there was a low prevalence of full-thickness defects in football players (17%), suggesting that this feature is unlikely to be the primary driver of nociception. The severity of cartilage damage was not associated with either the iHOT33 or HAGOS. Osteoarthritis is an active disease that affects nearly all joint tissues, with structural changes evident in articular cartilage, synovium, subchondral bone and surrounding muscles[1–3,12]. The discordant relationship between pain and cartilage damage is consistent with our earlier systematic review[16] and the knowledge that articular cartilage is deficient of neural supply, and incapable of nociception in early disease[30]. Evaluation of cartilage damage with MRI is challenging due to the closely apposed and curved joint surfaces and thin layer of acetabular and femoral articular cartilage[13,31]. Despite this, the SHOMRI system may provide accurate grading (when compared to hip arthroscopy) of cartilage damage if performed with high resolution, unenhanced 3-T MRI, as in our study[32]. While the use of contrast-enhanced MRI might provide superior assessment of cartilage damage[33], such approaches are not without risk[13] and not appropriate in people without pain. Imaging-defined cartilage damage is associated with poor surgical outcomes[34]. As such, further work is needed to establish factors associated with progressive cartilage damage, and the role that altered cartilage structure plays in expediating whole joint disease.

Labral findings were observed in symptomatic (68–73%) and control (63–75%) football players. The high prevalence of incidental labral findings in pain-free football players is consistent with our earlier systematic review showing labral changes on MRI in over 50% of active individuals without pain[16]. In general, higher labral scores were observed in symptomatic participants. However, there was not a relationship between more extensive labral pathology and pain or symptom severity, consistent with earlier studies using semi-quantitative MRI measures[15,31,35]. We did not evaluate for extra-articular causes of hip and/or groin pain[36]. It is possible that an interrelationship may exist between labral tear severity and PROMs in football players without coexisting extra-articular conditions. High-resolution, unenhanced 3-T MRI may afford similar accuracy to contrast-enhanced approaches for the assessment of labral abnormalities[37,38]. Despite this, existing literature supports the use of contrast-enhanced over unenhanced MRI[33,39–41]. Therefore, the prevalence and/or severity of labral abnormalities may be underreported in both groups. Labral damage may increase cartilage loading[42,43], possibly initiating cartilage degradation and

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OA feature	Number of hips with OA feature (%)			Odds Ratios (OR)			
	Control (ref)	Symptomatic	Other	Symptomatic vs control		Other vs control	
				Unadjusted OR (95%CI)	Adjusted OR (95CI)	Unadjusted OR (95%CI)	Adjusted OR (95CI)
All football players, hips* ‡	110	288	74				
No. of hips (%)							
Cartilage defect (any)	52 (47)	144 (50)	38 (51)	1.13 (0.67, 1.91)	1.12 (0.65, 1.92)	1.15 (0.62, 2.14)	1.11 (0.58, 2.09)
Labral tear	73 (66)	206 (72)	54 (73)	1.32 (0.77, 2.26)	1.34 (0.78, 2.30)	1.21 (0.62, 2.34)	1.21 (0.62, 2.35)
Paralabral cysts	21 (19)	74 (26)	12 (16)	1.48 (0.80, 2.71)	1.49 (0.81, 2.74)	0.80 (0.36, 1.81)	0.79 (0.35, 1.78)
Effusion-synovitis	44 (40)	67 (23)	15 (20)	0.46 (0.26, 0.81)	0.46 (0.26, 0.81)	0.37 (0.18, 0.75)	0.38 (0.18, 0.77)
Men, hips† §	82	229	59				
No. of hips (%)							
Cartilage defects (any)	39 (48)	125 (55)	36 (61)	1.38 (0.76, 2.52)	1.49 (0.81, 2.74)	1.51 (0.74, 3.07)	1.55 (0.75, 3.18)
Subchondral cysts	8 (10)	24 (11)	8 (14)	1.12 (0.45, 2.76)	1.29 (0.51, 3.23)	1.36 (0.46, 4.04)	1.30 (0.43, 3.95)
Labral tear	52 (63)	166 (73)	46 (78)	1.59 (0.86, 2.93)	1.66 (0.90, 3.08)	1.71 (0.80, 3.69)	1.75 (0.81, 3.79)
Ligamentum teres tear	4 (5)	8 (4)	3 (5)	0.78 (0.18, 3.33)	0.85 (0.22, 3.35)	0.74 (0.13, 4.26)	0.78 (0.14, 4.20)
Paralabral cysts	17 (21)	63 (28)	11 (19)	1.45 (0.74, 2.85)	1.53 (0.78, 3.00)	0.88 (0.37, 2.11)	0.89 (0.37, 2.14)
Effusion-synovitis	30 (37)	52 (23)	10 (17)	0.51 (0.27, 0.98)	0.49 (0.25, 0.96)	0.36 (0.16, 0.83)	0.36 (0.15, 0.83)
Women, hips† ‖	28	59	15				
Cartilage defects (any)	13 (46)	19 (32)	2 (13)	0.48 (0.16, 1.45)	0.44 (0.14, 1.32)	0.34 (0.08, 1.43)	0.32 (0.07, 1.35)
Labral tear	21 (75)	40 (68)	8 (53)	0.70 (0.22, 2.23)	0.67 (0.21, 2.15)	0.39 (0.10, 1.55)	0.38 (0.10, 1.52)
Paralabral cysts	4 (14)	11 (19)	1 (7)	1.42 (0.36, 5.62)	1.36 (0.34, 5.36)	0.35 (0.03, 4.15)	0.35 (0.03, 4.14)
Effusion-synovitis	14 (50)	15 (25)	5 (33)	0.36 (0.12, 1.10)	0.37 (0.12, 1.14)	0.42 (0.11, 1.65)	0.43 (0.11, 1.71)

* Football players adjusted for sex, age and BMI.
† Men and women adjusted for age and BMI.
‡ Full thickness cartilage defects, BMEP, subchondral cysts, ligamentum teres tears and intra-articular loose bodies not analysed in football players.
§ Full thickness cartilage defects, BMEP and intra-articular loose bodies not analysed in men.
‖ Full thickness cartilage defects, BMEP, subchondral cysts, ligamentum teres tears and intra-articular loose bodies not analysed in women.

Table VI Differences in prevalence of individual osteoarthritis (OA) features (present or absent definition) between control, symptomatic and other hips

Osteoarthritis and Cartilage

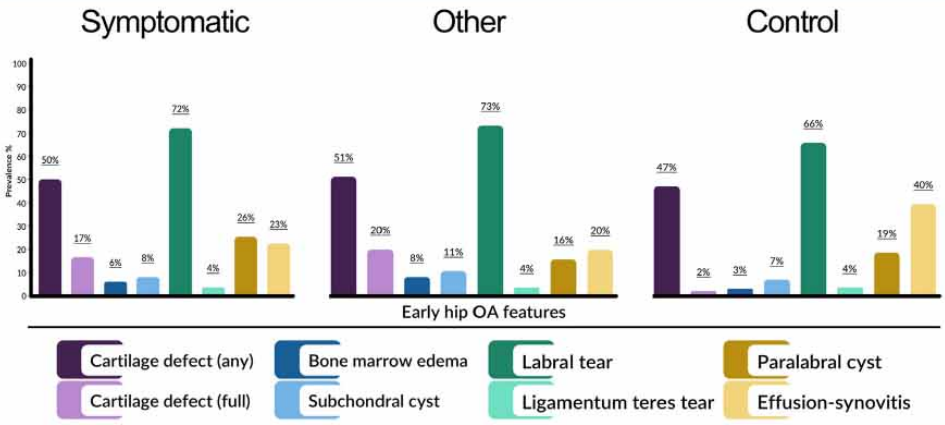

Fig. 3 **Prevalence of individual osteoarthritis (OA) features in symptomatic, other and control hips in football players.** Intra-articular loose bodies not included in figure due to low prevalence in symptom groups (symptomatic 1%, other and control hips feature absent).

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other soft tissue changes, which may lead to the genesis of symptoms[44]. Our findings suggest that labral abnormalities might represent a normal anatomical variant in some, but not all people participating in high-impact sports. Further work is needed to understand if the location or severity of labral abnormalities is associated with the development of symptoms and/or progression of early hip OA. Clinical treatments that target labral tears require

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careful consideration as they may not be appropriate in some high-impact athletes.

We observed a low prevalence of BMEP, subchondral cysts, paralabral cysts and ligamentum teres tears. While studies in older people have described associations between BMEP, subchondral cysts and pain severity[15,35], in our younger cohort of active individuals there was inconclusive evidence of a higher prevalence. Longitudinal studies are needed to establish if BMEP or subchondral cysts are associated with symptom and/or disease progression in high-impact athletes. Ligamentum teres tears can be a source of hip and/or groin pain[45]. We did not observe a higher prevalence of ligamentum teres tears in football players with symptoms or an association between tear severity and PROMs. Reliable and accurate grading of ligamentum teres tears is challenging with unenhanced MRI[46]. Therefore, we may under-report the presence and severity of ligament teres tears, and subsequently the relationship between such findings and symptoms. The role that effusion-synovitis plays in the genesis of hip symptoms and progression of joint disease is unclear. Hip and/or groin pain was associated with a lower prevalence of effusion-synovitis in all football players, men and women. Our findings are consistent with prior work using unenhanced MRI[15,47], but differ to those observed in female ballet dancers[47]. By using unenhanced MRI we could not differentiate effusion from synovitis[48,49]. As such, a relationship may exist between either feature (effusion or synovitis) and symptoms. The SHOMRI has a crude scoring (present or absent), meaning we were unable to determine if the size of effusion-synovitis was associated with symptoms. Further work is required to understand the role that the presence and/or size of effusion-synovitis plays in the pathogenesis of hip OA, in particular the progression of cartilage degradation.

In football players and men without definitive radiographic hip OA, longstanding hip and/or groin pain was associated with higher total SHOMRI scores, indicating a greater number and/or severity of MRI hip OA features, than pain-free controls. However, total SHOMRI scores were not associated with the iHOT33 or HAGOS, suggesting that more extensive 'whole joint' disease may be associated with the presence, but not the level of pain or symptoms. The similarity in SHOMRI scores with those of older individuals[22], suggests that early hip joint disease may be evident in young high-impact athletes. The SHOMRI score has been used as a measure of whole joint disease[23]; however, the relative importance of each specific OA feature remains unknown. Future studies may investigate if specific SHOMRI profiles exist in people who display symptom and/or disease progression.

Our finding of no substantive relationship between the severity of hip OA features and PROMs may be influenced by the reliability of the SHOMRI measure. Intra-observer reliability values were good to excellent for most OA features. For select features (cartilage, ligamentum teres and subchondral cysts) we found only modest reliability (0.61–0.66). Therefore, we may under or over-report the extent of early hip OA and subsequently the relationship between certain features and symptoms. Although recommended for people with hip and/or groin conditions, the construct and content validity of the iHOT33 and HAGOS is still to be clarified[50]. A relationship may exist between hip OA features and PROMs that measure different dimensions (e.g., intensity and unpleasantness) of hip and/or groin pain and/or symptoms.

An interaction between sex and hip and/or groin symptoms was only evident for total SHOMRI and cartilage score, whereby higher scores were seen in symptomatic and other hips relative to control hips in men, but not women. Future studies evaluating the relationship between symptoms and features of early hip OA should consider our findings.

We recognise that there are number of limitations that require consideration when interpreting our findings. First, hip and/or groin pain can originate from pathologies present in bony and musculotendinous structures around the hip joint, as well the lumbar spine and pelvis[51]. Symptomatic participants were not evaluated for other clinical entities observed in high-impact athletes[36], meaning such conditions may have contributed the generation of symptoms. The FADIR test is sensitive but not specific for intra-articular hip conditions[52], which prevents us from concluding that hip and/groin symptoms were being generated from intra-articular hip pathologies alone. The SHOMRI scoring was completed by a single trained musculoskeletal radiologist and we did not establish inter-observer reliability. Our cohort consisted of soccer and AF players, and not those participating in other high-impact physical activities (e.g., ice hockey and handball). This should be considered when generalising our findings to other groups of athletes. Nonetheless, the high prevalence of OA features on MRI observed in our cohort is comparable to earlier studies of other high-impact athletes[53–55], suggesting that high-impact athletes exhibit MRI-defined OA features to a similar extent. Unenhanced MRI provides variable accuracy relative to contrast-enhanced approaches for both cartilage and non-osteochondral features (labrum, ligamentum teres and synovium)[33,40,46,49]. We used an optimised 3-T MRI protocol which increases confidence in our findings, as such approaches have comparable accuracy to contrast-enhanced MRI[37,56]. Further, the SHOMRI scoring system has demonstrated precision for identification of cartilage and labral conditions when compared to hip arthroscopy[32]. We have previously reported the prevalence of bony morphology in our cohort of football players[21]. The relationship between bony morphology and early hip OA is still to be established in active high-impact athletes and will be the focus of future studies. The present case-control study precludes assumptions about causal relationships between OA features present on MRI and hip and/or groin pain.

Conclusion

Early hip OA features on MRI were prevalent in a high number of football players without radiographic OA. Our findings suggest a complex relationship between self-reported symptoms and most hip OA features observed on MRI. Hip and/or groin pain was associated with more extensive cartilage loss and higher total SHOMRI and labral scores. Labral findings were present in over 60% of football players with and without pain, questioning the clinical relevance of this specific feature. Further work is required to establish the natural history of early hip OA features and the identification of factors associated with the progression of structural disease in high-impact athletes.

Contributions

JH contributed to conception and design of the study, acquisition of data, analysis and interpretation of data, writing and revising the manuscript and final approval of the article.

RS contributed to scoring of MRIs and interpretation of data, revision of the manuscript and final approval of the article. AS contributed to conception and design of the study, statistical analysis and interpretation of data, revision of the manuscript and final approval of the article. RA, JK, RS, TP, TL and SM contributed to conception and design of the study, revision of the manuscript and final approval of the article. MK, PL and MS contributed to conception and design of the study, acquisition of data, revising the manuscript and final approval of the article. KC contributed to conception and design of the study, obtaining funding, analysis and interpretation of data, revision of the manuscript and final approval of the article.

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Competing interests
The authors declare they have no competing interests.

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Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.joca.2020.12.013.

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Appendix 26. Prevalence per person of individual osteoarthritis features (dichotomous scoring) in control and symptomatic participants in Study 3 (Chapter 6).*

	Number of people with OA feature (%)	
	Control	Symptomatic
OA feature		
All football players, (no. of people).	55	180
Cartilage defect (any).	34 (62)	113 (63)
Cartilage defects (full).	2 (4)	42 (23)
Bone marrow edema.	3 (6)	21 (12)
Subchondral cysts.	8 (15)	25 (14)
Labral tear.	43 (78)	155 (86)
Ligamentum teres tear.	2 (4)	11 (6)
Paralabral cysts.	18 (33)	65 (36)
Effusion-synovitis.	29 (53)	56 (31)
Men, (no. of people).	41	143
Cartilage defect (any).	26 (63)	98 (69)
Cartilage defects (full).	2 (5)	33 (23)
Bone marrow edema.	2 (5)	20 (14)
Subchondral cysts.	8 (20)	25 (18)
Labral tear.	32 (78)	125 (87)
Ligamentum teres tear.	2 (5)	9 (6)
Paralabral cysts.	15 (37)	54 (38)
Effusion-synovitis.	20 (49)	44 (31)
Women, (no. of people).	14	37
Cartilage defect (any).	8 (57)	15 (41)
Cartilage defects (full.)	0 (0)	9 (24)
Bone marrow edema.	1 (7)	1 (3)
Subchondral cysts.	0 (0)	0 (0)
Labral tear.	11 (79)	30 (81)
Ligamentum teres tear.	0 (0)	2 (5)
Paralabral cysts.	3 (21)	11 (30)
Effusion-synovitis.	9 (64)	12 (32)

*Only participants who had MRIs of both hips included in per person analyses.

Appendix 27. Differences in total scoring of hip osteoarthritis with MRI (SHOMRI) score between control, symptomatic and other hips, unadjusted (Study 3 (Chapter 6)).

	Symptom group			Between group comparisons	
	Control (ref)	Symptomatic	Other	Symptomatic vs control	Other vs control
				Mean difference (95% CI)[‡‡]	Mean difference (95% CI)[‡‡]
All football players (no. of hips)[†]	110	288	74		
SHOMRI score (mean 95%CI))	5.3 (4.7, 5.9)	6.7 (6.2, 7.2)	6.5 (5.6, 7.4)	1.38 (0.6, 2.1)	1.21 (0.1, 2.3)
Men (no. of hips)[‡]	82	229	59		
SHOMRI score (mean 95%CI)	5.5 (4.8, 6.3)	7.1 (6.5, 7.7)	7.1 (6.0, 8.1)	1.6 (0.6, 2.5)	1.5 (0.2, 2.8)
Women (no. of hips)[‡]	28	59	15		
SHOMRI score (mean 95%CI)	4.6 (4.0, 5.3)	5.0 (3.9, 6.1)	4.4 (2.7, 6.2)	0.4 (-0.9, 1.6)	-0.2 (-2.1, 1.7)

[‡‡] Normal based 95%CI

Appendix 28. Study 4 (Chapter 7) - Original publication, Journal of Orthopaedic and Sports Physical Therapy.

[RESEARCH REPORT]

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The Size and Prevalence of Bony Hip Morphology Do Not Differ Between Football Players With and Without Hip and/or Groin Pain: Findings From the FORCe Cohort

OBJECTIVE: To compare the size and prevalence of bony hip morphology in football players with and without hip and/or groin pain.

DESIGN: Case-control.

METHODS: We recruited 184 soccer and Australian football players with self-reported hip and/or groin pain of greater than 6 months in duration and a positive flexion, adduction, and internal rotation (FADIR) test (290 hips, 21% women), and 55 football players with no pain and a negative FADIR test (110 hips, 26% women) as a control group. Bony hip morphology was identified by the alpha angle and lateral center-edge angle (LCEA) on anteroposterior pelvis and Dunn 45° radiographs. The alpha angle and LCEA were analyzed as continuous measures (size) and dichotomized using threshold values to determine the presence of bony hip morphology (cam, large cam, pincer, and acetabular dysplasia). Regression analyses estimated differences in the size and prevalence of bony hip morphology between football players with and without pain.

RESULTS: In all football players and in men, the size and prevalence of bony hip morphology did not differ between those with and without hip and/or groin pain. Cam morphology was evident in 63% of hips in players without pain and 71% of symptomatic hips in players with hip and/or groin pain. In female football players with hip and/or groin pain compared to those without pain, larger alpha angle values were observed on the Dunn 45° view (5.9°; 95% confidence interval: 1.2°, 10.6°; $P = .014$).

CONCLUSION: The size and prevalence of bony hip morphology appear to be similar in football players with and without hip and/or groin pain. *J Orthop Sports Phys Ther 2021;51(3):115-125. Epub 25 Dec 2020. doi:10.2519/jospt.2021.9622*

KEY WORDS: *Australian football, cam morphology, femoroacetabular impingement, rehabilitation, soccer*

Up to 1 in every 5 time-loss injuries in football (soccer) occurs in the hip and/or groin region,[33,54] and over 50% of men[12,17] and 45% of women[17] report groin problems during a competition season. Hip and groin pain are often chronic in soccer players, with a third of all players reporting symptoms that last longer than 6 weeks,[47] and have been associated with impaired sports performance and lower quality of life across different football codes.[11,36,47]

Hip-related pain encompasses different intra-articular hip conditions.[40] Bony hip morphology associated with femoroacetabular impingement syndrome is characterized as cam and pincer morphology,[16] with the former appearing to develop during skeletal growth.[2,38,52] Over time, repetitive mechanical abutment between the femoral head and acetabulum may lead to hip pain, labral tears, cartilage defects, and eventually hip osteoarthritis (OA).[51]

The prevalence of imaging-defined cam and pincer morphology in male football players with hip pain (62%-94%)[28,34] is similar to that in male football players without hip pain (50%-95%)[14,22,26,28,32]; however, the size of cam morphology appears to be related to symptom prevalence.[28] The size and prevalence of bony hip morphology in male and female football players with hip and/or groin pain and positive clinical special tests (ie, positive flexion, adduction, and internal rotation [FADIR] test) are unclear.

Our primary aim was to compare the size and prevalence of bony hip morphology in football players with and without hip and/or groin pain. Our sec-

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ondary aims were (1) to compare the size and prevalence of bony hip morphology separately in men and women, and (2) to determine the relationship between the size of bony hip morphology and hip- and groin-related symptoms, as determined by patient-reported outcome measures.

METHODS

Study Design and Participants

This study utilized a case-control design. All symptomatic participants were recruited as part of the Femoroacetabular impingement and hip OsteoaRthritis Cohort (FORCe) study,[7] with these data taken from the baseline examination. The FORCe study is an ongoing prospective study investigating changes in hip joint structures in 184 sub-elite football (soccer and Australian football) players.[7] A convenience sample of 55 sub-elite football players who had no self-reported hip and/or groin pain and a negative FADIR test was recruited for the control group. Football players with (symptomatic group) and without (control group) self-reported hip and/or groin pain and a positive FADIR test, who were currently playing sub-elite football (soccer or Australian football), were recruited in Melbourne and Brisbane, Australia, between August 2015 and October 2018. Symptomatic and control football players were recruited from the same league/competition level via social and print media advertising or information sessions conducted at soccer or Australian football clubs.

The eligibility criteria for symptomatic participants were described previously[7] and are reported in **TABLE 1**. Each of the symptomatic participants' hips was classified as (1) symptomatic or (2) other, referring to the hip that had no pain or a negative FADIR test. In the control group (for eligibility criteria, see **TABLE 1**), both hips were asymptomatic (see **TABLE 2**). We followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.[50] The study had ethics approval (La Trobe University Human Ethics Committee [HEC 15-019/HEC 16-045] and The University of Queensland Human Ethics Committee [2015000916/2016001694]), and participants provided informed consent.

Radiographs

Each participant underwent a supine anteroposterior (AP) pelvis and a Dunn 45° radiograph of each hip, taken with standardized protocols in Melbourne and Brisbane, Australia (see **APPENDIX A**, available at www.jospt.org). A physical therapist (J.H.) with 10 years of clinical experience and training in the methodology was blinded to hip classification and analyzed bony hip morphology using quantitative methods.[1] Briefly, a point set was placed on predetermined locations on the surface of the femur and acetabulum, using statistical shape

TABLE 1 Participant Inclusion and Exclusion Criteria

	Symptomatic Group	Control Group
Inclusion criteria	• Age, 18-50 y • Playing in sub-elite football competition • Undertaking at least 2 sessions (games or training) of football (soccer or Australian football) per week • Self-reported hip (anterior/lateral/posterior) and/or groin pain fulfilling criteria 1-3: 1. Gradual onset 2. Greater than 6 mo in duration 3. Average hip and/or groin pain of >3 and <8 on an 11-point NPRS[a] with football-specific movements (squatting, kicking, or cutting/change of direction) and positive or negative symptoms, including clicking, giving way, locking, or catching • Positive FADIR test in at least 1 hip	• Age, 18-50 y • Playing in sub-elite football competition • Undertaking at least 2 sessions (games or training) of football (soccer or Australian football) per week • Negative FADIR test in both hips
Exclusion criteria	• Self-reported history of a significant hip and/or groin condition, specifically bursitis, congenital dislocation of the hip, fracture, osteochondritis dissecans, Legg-Calvé-Perthes disease, septic or rheumatoid arthritis, slipped capital femoral epiphysis, or subluxations/dislocations • Previous hip and/or pelvis surgery • KL grade of ≥2 on AP pelvis radiograph • Any lumbar spine or lower-limb injury/complaint in the previous 3 mo (eg, hamstring muscle injury or sprained ankle) that resulted in the inability to fully bear weight or undertake testing procedures • Contraindications to radiographs (eg, pregnancy) • Received intra-articular hip injection (of any type) in the previous 3 mo • Unable to understand spoken and written English	• Self-reported history of hip and/or groin pain or a significant hip and/or groin condition (see symptomatic group exclusion criteria for details) • Lower-limb surgery (eg, anterior cruciate ligament reconstruction) • KL grade of ≥2 on AP pelvis radiograph • Any lumbar spine or lower-limb injury/complaint in the previous 3 mo (eg, hamstring muscle injury or sprained ankle) that resulted in the inability to fully bear weight or undertake testing procedures • Contraindications to radiographs (eg, pregnancy) • Unable to understand spoken and written English

Abbreviations: AP, anteroposterior; FADIR, flexion, adduction, and internal rotation; KL, Kellgren-Lawrence; NPRS, numeric pain-rating scale.
[a]*Use of the NPRS in symptomatic football players is a deviation from the original study protocol.*[7]

modeling software (active shape model toolkit; The University of Manchester, Manchester, UK). The alpha angle and lateral center-edge angle (LCEA) were then calculated using MATLAB Version 7.1.0 (The MathWorks, Inc, Natick, MA). Radiographic hip OA was classified as a Kellgren and Lawrence[24] (KL) score of 2 or greater by a registrar orthopaedic surgeon (R.A.) with 11 years of experience reading pelvic radiographs. Intraobserver reliability was determined by 1 investigator assessing 20 images twice, 1 week apart for bony hip morphology (J.H.) and 6 months apart for KL classification (R.A.). For bony hip morphology, interobserver reliability was determined by a second investigator (R.A.) assessing 20 images. Moderate to good reliability was found for bony hip morphology, with substantial intraobserver agreement demonstrated for KL classification (**APPENDIX B**, available at www.jospt.org).

Cam Morphology

The alpha angle determined the presence of cam morphology on the AP pelvis and Dunn 45° views (**APPENDIX C**, available at www.jospt.org).[37] Continuous alpha angle was our primary outcome and determined the size of cam morphology. Based on previously proposed threshold values,[1,32] an alpha angle greater than 60° defined cam morphology and an alpha angle greater than 78° defined large cam morphology on either the AP pelvis or Dunn 45° view.

Acetabular Morphology

The LCEA on the AP pelvis view described the superolateral coverage of the femoral head by the acetabulum (**APPENDIX C**).[3] The LCEA was analyzed using continuous and threshold values, with an LCEA of greater than 40° or less than 20° used to define pincer morphology or acetabular dysplasia, respectively.[32]

Patient-Reported Outcome Measures

Participant characteristics (age, sex, height, weight, football code participation, and training/competition frequency) were collected. Participants completed the 33-item International Hip Outcome Tool (iHOT-33)[30] and the Copenhagen Hip and Groin Outcome Score (HAGOS),[46] which are recommended for use in young to middle-aged individuals with hip and/or groin pain.[20,49] The iHOT-33 is a 33-item health-related quality-of-life questionnaire, with a total score of 100 indicating the best quality of life.[30] The HAGOS includes 6 subscales (pain, symptoms, function in daily living, function in sport and recreation, participation in physical activities, and hip- and/or groin-related quality of life), with a total score of 100 for each subscale indicating no hip and/or groin problems.[46] As we were particularly interested in hip and/or groin pain and symptoms, only the pain and symptoms subscales were analyzed.

Sample Size

A sample size of 184 symptomatic and 55 control football players provided 80% power to detect differences in alpha angle between symptomatic and control hips of at least 5.5°, assuming a within-person correlation of 0.7 and a common standard deviation of 14°.

Statistical Analysis

Data analyses were performed using SPSS Version 25 (IBM Corporation, Armonk, NY) and Stata/IC Version 15.0 (StataCorp LLC, College Station, TX). Differences between symptomatic and control football players on the iHOT-33 and on the HAGOS pain and symptoms subscales were evaluated using Mann-Whitney *U* tests. Intraobserver and interobserver reliability values for the alpha angle and LCEA were determined with intraclass correlation coefficients (ICCs), using a 2-way mixed-effects model with absolute agreement. The weighted Cohen kappa was used to establish intraobserver reliability for KL grading. The levels of reliability (ICC) and agreement (kappa) were determined using previously defined criteria.[27,43]

For all analyses, when data from men and women were combined, they were defined as "football players," and when separated by sex they were defined as "men" or "women." For the first and second aims of this study, all analyses were undertaken at a per-hip level. Symptomatic hips were considered as cases. There were 2 control groups: hips classified as other and hips from asymptomatic participants. Differences in continuous radiographic measures between groups were determined with linear regression models and generalized estimating equations to account for the nonindependence of bilateral hip measures. Estimates of difference between symptomatic, other, and control hips are presented with accompanying *P* values and 95% confidence intervals (CIs), estimated with bootstrapped standard error

TABLE 2 Hip Classification for Symptomatic and Control Football Players[a]

	Symptomatic (290 hips)[b]	Other (76 hips)[c]	Control (110 hips)[d]
Clinical assessment findings	The football player reported hip and/or groin pain Positive FADIR test	The football player reported no hip and/or groin pain *or* The football player reported hip and/or groin pain and had a negative FADIR test	The football player reported no hip and/or groin pain Negative FADIR test

Abbreviation: FADIR, flexion, adduction, and internal rotation.
[a]*106 symptomatic football players had symptomatic hips bilaterally, 76 symptomatic football players had 1 symptomatic hip and 1 other hip, and 2 symptomatic football players had 1 symptomatic hip and 1 hip with radiographic hip osteoarthritis (Kellgren-Lawrence grade of 2 or greater).*
[b]*Men, n = 230 hips; women, n = 60 hips.*
[c]*Men, n = 60 hips; women, n = 16 hips.*
[d]*Men, n = 82 hips; women, n = 28 hips.*

(1000 repetitions) to account for departures from normality.[4]

For additional analyses, bony hip morphologies were considered as dichotomous variables (cam, large cam, pincer, or acetabular dysplasia). For cam and large cam, only hips with an AP pelvis and Dunn 45° radiograph were included in analyses. Hips with pincer morphology and acetabular dysplasia were compared to reference hips with an LCEA of 20° or greater and 40° or less.[3] We used logistic regression with generalized estimating equations to estimate differences between symptom groups, with results presented as odds ratios with 95% CIs and *P* values. Pincer morphology in women and hip dysplasia in both men and women were reported descriptively but were not compared, due to the low prevalence of each morphology. The prevalence of bony hip morphology per person is presented descriptively in **APPENDIX D** (available at www.jospt.org).

For the second aim, we evaluated differences between symptom groups in men and women separately, by including an interaction term (symptom group by sex). All analyses in football players (men and women combined) were adjusted for sex.

For the third aim, only data from symptomatic participants were included in analyses. Alpha angle and LCEA values were taken from the most symptomatic hip, as defined by the iHOT-33, and the HAGOS symptoms and pain subscale scores were applied to this hip. The relationships between continuous radiographic measures, iHOT-33 score, and HAGOS symptoms and pain scores were evaluated using Pearson's correlation coefficient. For all analyses, correlation coefficients are presented with accompanying 95% CIs and *P* values. Scatter plots with a locally weighted smoother were fitted to the data to confirm the absence of nonlinear associations or influential outliers.

TABLE 3 Demographic Characteristics for Symptomatic and Control Football Players[a]

	Symptomatic Group (n = 184)	Control Group (n = 55)
Age, y	26.0 (23-30)	26.0 (23-31)
Sex (women), %	21	26
Height, m	1.79 (1.73-1.84)	1.79 (1.72-1.85)
Mean ± SD weight, kg	78.5 ± 12.8	77.9 ± 13.5
Body mass index, kg/m^2	24.1 (23-26)	24.3 (22-27)
Football code, %		
Soccer	50.5	54.5
Australian football	49.5	45.5
Training/competition, %[b]		
2-3 sessions	89	82
≥4 sessions	11	18
Duration of symptoms, mo	24 (18-50)[c]	...

[a]*Values are median (interquartile range) unless otherwise indicated.*
[b]*Combined training and competition sessions per week.*
[c]*183 participants.*

TABLE 4 Patient-Reported Outcome Measures for Symptomatic and Control Football Players[a]

	Symptomatic Group (n = 184)	Control Group (n = 55)	*P* Value
iHOT-33	64 (50-74)	98 (97-100)	<.001
HAGOS symptoms subscale	61 (50-68)[b]	100 (93-100)[c]	<.001
HAGOS pain subscale	75 (65-83)[b]	100 (100-100)[c]	<.001

Abbreviations: HAGOS, Copenhagen Hip and Groin Outcome Score; iHOT-33, 33-item International Hip Outcome Tool.
[a]*Values are median (interquartile range) unless otherwise indicated.*
[b]*178 participants.*
[c]*54 participants.*

RESULTS

Participant Characteristics

Of the 603 sub-elite football players with hip and/or groin pain, 184 football players fulfilled the eligibility criteria for the present study (**FIGURE 1**). Two hips from 2 football players with hip and/or groin pain were excluded due to the presence of hip OA (KL grade, 2 or greater), leaving 366 hips for analysis. In 7 symptomatic men (14 hips), a standing (not supine) AP pelvis radiograph was taken and was included in the overall analyses, with a sensitivity analysis performed by removing the radiographs (see **APPENDICES E** and **F**, available at www.jospt.org). Twelve participants (24 hips) had nonstandardized Dunn radiographs, and their data were excluded. The number of hips classified as symptomatic, other, or control are presented in **TABLE 2**. Fifty-five football players (110 hips) without hip and/or groin pain were recruited as the control group (**FIGURE 2**). Demographic characteristics of symptomatic and control football players are presented in **TABLE 3**. The iHOT-33 scores and the HAGOS symptoms and pain subscale scores for symptomatic and control participants are presented in **TABLE 4**.

Comparison of Bony Hip Morphology Between Symptom Groups in Football Players

There was no difference in alpha angle between symptom groups in the AP or Dunn view (**TABLE 5**). For LCEA, the values

did not differ between groups. The prevalence of cam morphology, large cam morphology, pincer morphology, and acetabular dysplasia was not different between symptom groups (**TABLE 6**).

Comparison of Bony Hip Morphology Between Symptom Groups in Men and Women

In men, the alpha angle on the AP and Dunn views did not differ across the 3 symptom groups (**TABLE 5**). In women, symptomatic hips had a slightly larger alpha angle (5.9°; 95% CI: 1.2°, 10.6°) compared to control hips on the Dunn, but not the AP, view (**TABLE 5**). Regarding the LCEA, symptom groups did not differ in either men or women (**TABLE 5**).

The prevalence of cam and large cam morphology was not different between the 3 symptom groups in either men or women (**TABLE 6**). In men, the prevalence of pincer morphology was not different across symptom groups (**TABLE 6**). Due to low prevalence, statistical analysis was not undertaken in men for acetabular dysplasia or in women for pincer morphology and acetabular dysplasia.

Relationship Between Bony Morphology and iHOT-33 and HAGOS Scores

In all football players, and in men and women separately, there were no associations between alpha angle (AP or Dunn view) and iHOT-33 or HAGOS (symptoms and pain subscales) score (**APPENDIX G**, available at www.jospt.org). In all football players and in men, the LCEA was not associated with scores on the iHOT-33 or HAGOS pain and symptoms subscales. In women, the LCEA was not associated with the iHOT-33 or HAGOS symptoms subscale score, but there was an associa-

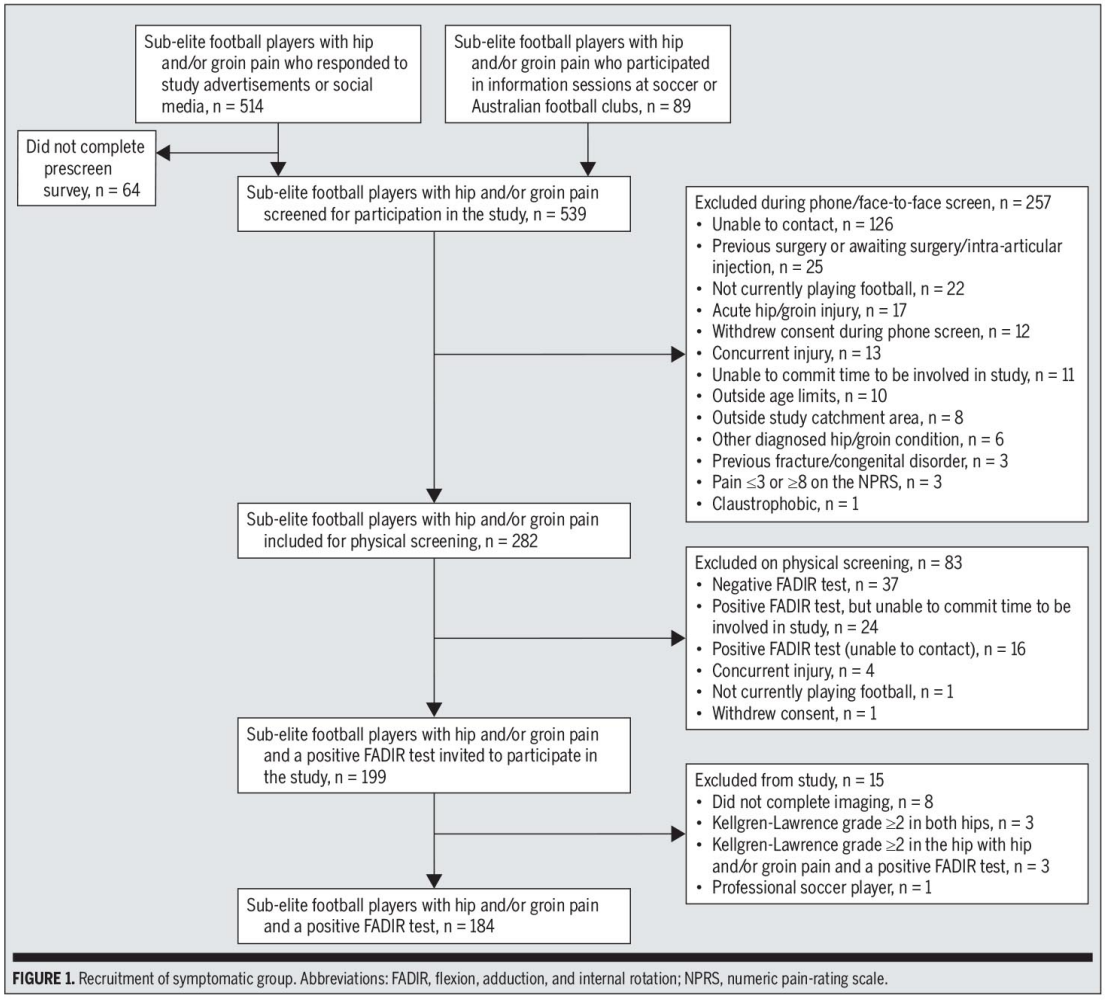

FIGURE 1. Recruitment of symptomatic group. Abbreviations: FADIR, flexion, adduction, and internal rotation; NPRS, numeric pain-rating scale.

tion between the LCEA and HAGOS pain subscale score ($r = -0.37$; 95% CI: −0.70, −0.05; $P = .027$) (**APPENDIX G**).

DISCUSSION

We compared the size and prevalence of bony hip morphology in football players with and without hip and/or groin pain and a positive (symptomatic) or negative (control) FADIR test. In football players, the size and prevalence of bony hip morphology did not differ between symptomatic and pain-free hips. In men and women, the LCEA and prevalence of cam, large cam, and pincer morphology were not different between symptom groups. Women with hip and/or groin pain, but not men, had a larger alpha angle (5.9°; 95% CI: 1.2°, 10.6°) when compared to controls. Acetabular morphologies were not common in football players. There was no relationship between the alpha angle or LCEA and the iHOT-33 or HAGOS pain and symptoms subscale scores in all football players and in men, with only the LCEA associated with the HAGOS pain subscale score in women.

Cam Morphology Is a Common Finding in Football Players With and Without Hip and/or Groin Pain

Our lack of substantive differences in football players may reflect similar activity levels between groups and highlights the importance of considering physical activity when evaluating the link between cam morphology and symptoms. Women had a slightly larger alpha angle (5.9°; 95% CI: 1.2°, 10.6°) in symptomatic hips than in control hips, but the clinical significance of this difference is uncertain. Cam morphology was present in 76% of men and 25% of women without pain, which is consistent with some,[22,28,32] but not all, studies[13,14,21,23,26,31] of men and women participating in football codes. The prevalence of large cam morphology did not differ between symptom groups in all football players, men, and women. In men, 43% to 55% of hips had large cam morphology, which is higher than reports in elite male football players (0%-36%).[32,44] Discrepancies may be explained by different alpha angle threshold values and/or imaging techniques. Consistent with earlier studies,[9,15,18,21,39] men had a higher prevalence of cam and large cam morphology than women. Cam morphology was common in football players; however, the size and prevalence of this bony feature did not differ between those with and without long-standing hip and/or groin pain.

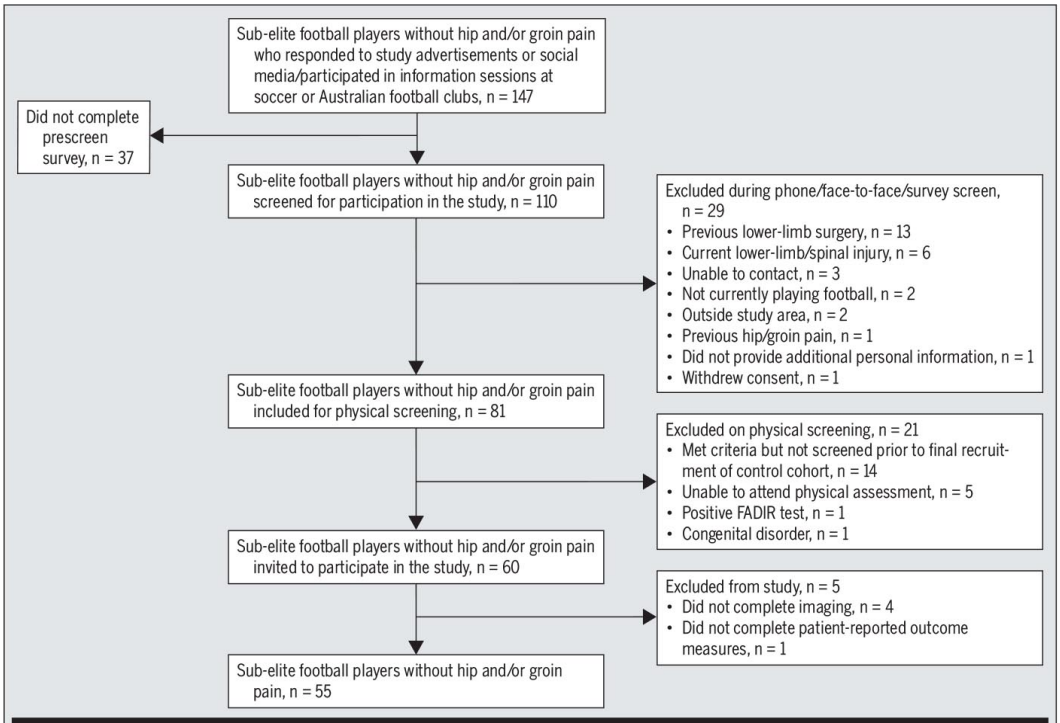

FIGURE 2. Recruitment of the control group. Abbreviation: FADIR, flexion, adduction, and internal rotation.

Pincer Morphology and Acetabular Dysplasia Are Rarely Seen in Football Players

Football players with hip and/or groin pain had similar low prevalences of pincer morphology (7% versus 7%) and acetabular dysplasia (4% versus 3%) to those of controls. Differences in pincer morphology prevalence from prior reports (0%-33%)[13,15,22,23,32] may be explained by the different definition of pincer morphology. We observed a low prevalence of acetabular dysplasia in all football players (3%-8%), men (0%-6%), and women (2%-13%), similar to previous reports.[22,23,32,34]

The Size of Bony Hip Morphology Was Mostly Unrelated to Pain and Symptom Severity

In men and women, higher alpha angles were not associated with symptom or pain severity (ie, lower patient-reported outcome measure scores), in contrast to earlier findings in athletic[8,29] and nonathletic populations.[25] In our large cohort, we evaluated the most symptomatic hip in active football players with long-standing hip and/or groin pain (greater than 6 months) and did not find a relationship between the size of cam morphology and hip- and/or groin-specific patient-reported outcome measures. In women, increasing

TABLE 5 Differences in Size of Bony Hip Morphology Between Symptomatic, Other, and Control Hips[a]

	Alpha Angle, deg					
	AP View	*P* Value	Dunn 45° View	*P* Value	LCEA, deg	*P* Value
All football players[b]						
Control (110 hips)	59.2 (55.9, 62.4)		66.5 (64.3, 68.6)[c]		31.5 (30.4, 32.6)	
Symptomatic (290 hips)	59.9 (58.1, 61.7)		68.8 (67.2, 70.5)[d]		30.8 (30.1, 31.5)	
Other (76 hips)	59.3 (56.8, 61.8)		68.2 (65.6, 70.7)[e]		30.4 (29.1, 31.8)	
Difference						
Symptomatic versus control[f]	0.7 (−3.0, 4.4)	.701	2.4 (−0.3, 5.1)	.085	−0.7 (−2.1, 0.6)	.297
Other versus control[f]	0.1 (−3.9, 4.1)	.963	1.7 (−1.7, 5.1)	.326	−1.1 (−2.9, 0.7)	.217
Symptomatic versus other[f]	0.6 (−1.8, 3.0)	.607	0.7 (−2.2, 3.5)	.648	0.4 (−1.0, 1.8)	.571
Men						
Control (82 hips)	61.3 (57.4, 65.2)		70.3 (67.7, 73.0)[g]		32.4 (31.2, 33.7)	
Symptomatic (230 hips)	62.4 (60.4, 64.5)		71.6 (69.7, 73.4)[h]		31.2 (30.4, 31.9)	
Other (60 hips)	62.2 (59.3, 65.1)		71.3 (68.3, 74.3)[i]		31.0 (29.5, 32.5)	
Difference						
Symptomatic versus control[f]	1.1 (−3.3, 5.5)	.627	1.2 (−2.0, 4.5)	.456	−1.2 (−2.8, 0.3)	.109
Other versus control[f]	0.9 (−3.9, 5.7)	.714	1.0 (−3.0, 5.0)	.621	−1.4 (−3.4, 0.6)	.158
Symptomatic versus other[f]	0.2 (−2.5, 2.8)	.891	0.2 (−3.1, 3.5)	.897	0.2 (−1.4, 1.7)	.827
Women						
Control (28 hips)	51.2 (45.3, 57.1)		53.4 (49.8, 56.9)		28.7 (26.7, 30.6)	
Symptomatic (60 hips)	50.9 (47.1, 54.6)		59.3 (56.0, 62.6)[j]		29.6 (28.1, 31.2)	
Other (16 hips)	48.6 (43.8, 53.4)		57.1 (52.1, 62.0)[k]		28.4 (25.5, 31.2)	
Difference						
Symptomatic versus control[f]	−0.3 (−7.4, 6.8)	.927	5.9 (1.2, 10.6)	.014	1.0 (−1.6, 3.6)	.450
Other versus control[f]	−2.6 (−10.0, 4.8)	.488	3.7 (−2.6, 9.9)	.248	−0.3 (−3.9, 3.3)	.880
Symptomatic versus other[f]	2.3 (−3.2, 7.8)	.418	2.2 (−3.5, 8.0)	.446	1.3 (−1.8, 4.3)	.415

Abbreviations: AP, anteroposterior; LCEA, lateral center-edge angle.
[a]*Values are estimated marginal mean (95% confidence interval) and between-group mean difference (95% confidence interval) unless otherwise indicated.*
[b]*Values were adjusted for sex.*
[c]*n = 108 hips.*
[d]*n = 276 hips.*
[e]*n = 68 hips.*
[f]*Reference group.*
[g]*n = 80 hips.*
[h]*n = 219 hips.*
[i]*n = 53 hips.*
[j]*n = 57 hips.*
[k]*n = 15 hips.*

LCEA values (greater acetabular coverage) were associated with lower HAGOS pain subscale values (higher levels of pain). However, this result needs to be confirmed with larger studies. Future studies might also explore whether bony hip morphology displays a relationship with other patient-reported outcome measures, in particular those measuring different dimensions of pain and symptoms.

Clinical Implications

Two of every 3 pain-free hips had cam morphology, and it is unlikely that bony hip morphology was the sole factor related to the development and/or severity of hip and/or groin symptoms in football players. Careful examination of all potential sources of nociception[42,48,53] and more centrally mediated contributors to symptoms is required in patients with hip and/

TABLE 6 Differences in Prevalence of Bony Hip Morphology Between Symptomatic, Other, and Control Hips

	Cam Morphology				Pincer Morphology		Acetabular Dysplasia	
	Alpha Angle >60°	*P* Value	Alpha Angle >78°	*P* Value	LCEA >40°	*P* Value	LCEA <20°	*P* Value
All football players								
Prevalence, n (%)								
Control[a]	68 (63)		39 (36)		8 (7)		3 (3)	
Symptomatic[b]	195 (71)		106 (38)		20 (7)		11 (4)	
Other[c]	45 (66)		30 (44)		12 (17)		5 (8)	
Odds ratio[d,e]								
Symptomatic versus control[f]	1.34 (0.72, 2.47)	.355	1.06 (0.59, 1.91)	.852	1.05 (0.39, 2.79)	.925	1.36 (0.30, 6.20)	.691
Other versus control[f]	1.12 (0.55, 2.29)	.762	1.23 (0.63, 2.43)	.544	1.87 (0.64, 5.44)	.254	3.38 (0.70, 16.35)	.130
Symptomatic versus other[f]	1.20 (0.73, 1.95)	.471	0.86 (0.56, 1.32)	.486	0.56 (0.27, 1.16)	.118	0.40 (0.15, 1.06)	.064
Men								
Prevalence, n (%)								
Control[g]	61 (76)		34 (43)		7 (9)		0 (0)	
Symptomatic[h]	171 (78)		97 (44)		17 (8)		10 (5)	
Other[i]	40 (75)		29 (55)		11 (19)		3 (6)	
Odds ratio[d]								
Symptomatic versus control[f]	1.13 (0.54, 2.36)	.746	1.10 (0.58, 2.08)	.770	1.02 (0.35, 2.92)	.977	NE	...
Other versus control[f]	0.94 (0.40, 2.19)	.884	1.50 (0.72, 3.12)	.277	1.86 (0.59, 5.86)	.290	NE	...
Symptomatic versus other[f]	1.20 (0.68, 2.11)	.520	0.73 (0.46, 1.16)	.188	0.55 (0.25, 1.17)	.120	NE	...
Women								
Prevalence, n (%)								
Control[j]	7 (25)		5 (18)		1 (4)		3 (11)	
Symptomatic[k]	24 (42)		9 (16)		3 (5)		1 (2)	
Other[l]	5 (33)		1 (7)		1 (7)		2 (13)	
Odds ratio[d]								
Symptomatic versus control[f]	2.09 (0.62, 7.08)	.237	0.90 (0.21, 3.89)	.886	NE	...	NE	...
Other versus control[f]	1.79 (0.43, 7.39)	.423	0.26 (0.03, 2.70)	.260	NE	...	NE	...
Symptomatic versus other[f]	1.17 (0.46, 2.97)	.743	3.43 (0.55, 21.53)	.188	NE	...	NE	...

Abbreviations: LCEA, lateral center-edge angle; NE, not estimated.
[a]*Number of hips: cam morphology, n = 108; pincer morphology, n = 107; acetabular dysplasia, n = 102.*
[b]*Number of hips: cam morphology, n = 276; pincer morphology, n = 279; acetabular dysplasia, n = 270.*
[c]*Number of hips: cam morphology, n = 68; pincer morphology, n = 71; acetabular dysplasia, n = 64.*
[d]*Values in parentheses are 95% confidence interval.*
[e]*Adjusted for sex.*
[f]*Reference group.*
[g]*Number of hips: cam morphology, n = 80; pincer morphology, n = 82; acetabular dysplasia, n = 75.*
[h]*Number of hips: cam morphology, n = 219; pincer morphology, n = 220; acetabular dysplasia, n = 213.*
[i]*Number of hips: cam morphology, n = 53; pincer morphology, n = 57; acetabular dysplasia, n = 49.*
[j]*Number of hips: cam morphology, n = 28; pincer morphology, n = 25; acetabular dysplasia, n = 27.*
[k]*Number of hips: cam morphology, n = 57; pincer morphology, n = 59; acetabular dysplasia, n = 57.*
[l]*Number of hips: cam morphology, n = 15; pincer morphology, n = 14; acetabular dysplasia, n = 15.*

or groin pain. For example, adductor-related groin pain may be present in up to 69% of football players with long-standing symptoms.[19,45]

Limitations and Future Research Directions

We included football players with self-reported hip and/or groin pain and a positive FADIR test. Therefore, the pathoanatomical source of symptoms, if one exists, cannot be truly known. Contributors to long-standing hip and/or groin pain, including adductor-, iliopsoas-, pubic-, and inguinal-related groin pain, might have been associated with the hip and/or groin symptoms.[53] The poor specificity of the FADIR test means that our findings cannot be assumed to be specific to hip-related pain.[5,41]

Radiographs (AP pelvis and Dunn 45°) cannot provide 3-D visualization of femoral anatomy, potentially underreporting the size and prevalence of cam morphology. However, alpha angle values obtained from radiographs, as used in our study, have acceptable correlation with those seen on magnetic resonance imaging[10] and computed tomography.[35]

We might have underestimated pincer morphology prevalence, because we did not assess focal acetabular retroversion (determined by the crossover sign). However, radiographic assessment of focal overcoverage has poor reproducibility[6] and may overestimate the prevalence of such findings.[55]

There is a risk of selection bias, as both symptomatic and control football players responded to study advertisements or participated in information sessions and may not represent all football players. The presence of cam morphology was not established in control football players prior to inclusion, which may reduce the likelihood of oversampling. We did not establish the age when football players started regular training or competitive football, and differences between groups might have influenced our findings.[44] Symptomatic and control football players participated in at least 2 training sessions per week, but training intensity or duration might have differed between groups.

While the structural, construct, and content validity of the iHOT-33 and HAGOS and their utility in nonsurgical populations are unclear,[20] they are recommended for use in young to middle-aged people with hip and/or groin pain.[20,49] The small number of female football players might have prevented us from detecting differences between symptom groups in the size and prevalence of bony morphology.

Future studies evaluating the relationship between pain and cam morphology should consider participants' current and/or past activity levels to ensure that these factors do not influence findings. Long-term prospective studies could confirm or refute our findings and/or establish whether cam morphology is associated with the development or worsening of symptoms or with structural joint deterioration (including hip OA) in football players. Although such studies require considerable resources and time to complete, they are essential to answer prognostic questions.

CONCLUSION

In football players, the size and prevalence of bony hip morphology did not differ between those with and without hip and/or groin pain. Cam morphology was present in 76% of men and 25% of women and was mostly unrelated to the presence or severity of hip and/or groin symptoms. ◉

KEY POINTS

FINDINGS: The size and prevalence of bony hip morphology did not differ between football players with and without self-reported hip and/or groin pain. Larger alpha angle values were found in women with hip and/or groin pain compared to those without hip or groin pain. The size of bony hip morphology was mostly unrelated to hip and/or groin pain and symptoms in football players.

IMPLICATIONS: In football players, interventions should not be based purely on the presence or size of bony hip morphology.

CAUTION: The findings of this study can only be applied to active male and female sub-elite football players (soccer or Australian football) with long-standing hip and/or groin pain and a positive flexion, adduction, and internal rotation test.

STUDY DETAILS

AUTHOR CONTRIBUTIONS: All authors contributed to the study design, analysis and interpretation of data, drafting the article or revising it critically for important intellectual content, and final approval of the article. Joshua Heerey, Mark Scholes, and Drs King, Lawrenson, Kemp, Pizzari, and Crossley recruited participants. Joshua Heerey, Mark Scholes, and Drs King and Lawrenson acquired the data. All authors were involved in the study and preparation of the final manuscript, and all are responsible for the integrity of data and accuracy of results.

DATA SHARING: Data (bony hip morphology and patient-reported outcome measures) are available on request. Suitability of the data request and access to data will be determined by the corresponding author.

PATIENT AND PUBLIC INVOLVEMENT: There was no patient and/or public involvement in this study.

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Appendix 29. Prevalence of bony hip morphology per person in football players, men and women*† in Study 4 (Chapter 7).

	Cam morphology‡§II		Pincer morphology	Acetabular dysplasia
	Alpha angle >60°	Alpha angle >78°	LCEA >40°	LCEA <20°
Football players				
Prevalence (%)				
Control (n=55)	39 (72)	24 (44)	6 (11)	2 (4)
Symptomatic (n=182)	134 (78)	85 (50)	24 (13)	14 (8)
Men				
Prevalence (%)				
Control (n=41)	34 (85)	21 (53)	5 (12)	0 (0)
Symptomatic (n=144)	116 (86)	78 (58)	21 (15)	11 (8)
Women				
Prevalence (%)				
Control (n=14)	5 (36)	3 (21)	1 (7)	2 (14)
Symptomatic (n=38)	18 (50)	7 (19)	3 (8)	3 (8)

Abbreviations: LCEA, lateral-centre-edge-angle.

* Bony morphology prevalence classification: present = bony morphology observed in at least one hip; absent = bony morphology not observed in either hip.

† Only performed in football players with radiographic variables available in both hips (2 symptomatic football players were excluded as one hip had radiographic hip osteoarthritis).

‡ Only in football players with AP and Dunn 45° views in both hips (control = 54; symptomatic = 171).

§ Only in male football players with AP and Dunn 45° views in both hips (control = 40; symptomatic = 135).

II Only in female football players with AP and Dunn 45° views in both hips (control = 14; symptomatic = 36).

Appendix 30. Results of sensitivity analysis (removal of standing AP pelvis radiographs) for differences in size of bony hip morphology between symptomatic, other and control hips in football players and men in Study 4 (Chapter 7).

	Alpha angle (deg)	LCEA (deg)
	AP View	
Football players† (No. of hips)		
Estimated Marginal means (95%CI)†		
Control (n=110)	59.1° (56.0°, 62.2°)	31.5° (30.5°, 32.6°)
Symptomatic (n=282)	59.6° (57.8°, 61.4°)	30.8° (30.0°, 31.5°)
Other (n=70)	59.0° (56.5°, 61.6°)	30.3° (28.9°, 31.6°)
Between Group Differences (95%CI), *P* value		
Symptomatic vs control*	0.5° (-3.2°,4.2°), *P* = .791	-0.7° (-2.0°, 0.5°), *P* = .245
Other vs control*	-0.1° (-4.0°, 3.9°), *P* = .978	-1.3° (-3.0°, 0.5°), *P* = .151
Symptomatic vs other*	0.6° (-1.9°, 3.0°), *P* = .654	0.5° (-0.9°, 1.9°), *P* = .468
Men (No. of hips)		
Estimated Marginal means (95%CI)		
Control (n=82)	61.3° (57.5°, 65.2°)	32.4° (31.2°, 33.6°)
Symptomatic (n=222)	62.2° (60.1°, 64.3°)	31.1° (30.3°, 32.0°)
Other (n=54)	62.1° (59.2°, 65.0°)	30.9° (29.3°, 32.4°)
Between Group Differences (95%CI), *P* value		
Symptomatic vs control*	0.9° (-3.6°, 5.3°), *P* = .701	-1.3° (-2.8°, 0.2°), *P* = .091
Other vs control*	0.8° (-4.0°, 5.5°), *P* = .753	-1.5° (-3.5°, 0.4°), *P* = .123
Symptomatic vs other*	0.1° (-2.5°, 2.7°), *P* = .936	0.3° (-1.4°, 1.9°), *P* = .749

Abbreviations: AP, anteroposterior; LCEA, lateral-centre-edge-angle.
*Referent group.
†Estimated marginal means presented for football players were adjusted for sex.

Appendix 31. Results of sensitivity analysis (removal of standing AP pelvis radiographs) for differences in the prevalence of bony hip morphology between symptomatic, other and control hips in football players and men in Study 4 (Chapter 7).

	Cam morphology		Pincer morphology‡II	Acetabular dysplasia§#
	Alpha angle >60°	Alpha angle >78°	LCEA >40°	LCEA <20°
Football players (No. of hips)				
Prevalence (%).				
Control (n=108)	68 (63)	39 (36)	8 (8)	3 (3)
Symptomatic (n=274)	193 (70)	104 (38)	20 (7)	11 (4)
Other (n=66)	43 (65)	28 (42)	11 (17)	5 (9)
Odds ratio (95%CI), *P* value†.				
Symptomatic vs control*	1.32 (0.72, 2.44), *P* = .374	1.03 (0.57, 1.86), *P* = .915	1.10 (0.41, 2.92), *P* = .856	1.40 (0.31, 6.38), *P* = .665
Other vs control*	1.09 (0.53, 2.23), *P* = .816	1.19 (0.60, 2.34), *P* = .624	1.80 (0.60, 5.38), *P* = .295	3.62 (0.75, 17.56), *P* = .110
Symptomatic vs other*	1.21 (0.74, 1.98), *P* = .442	0.87 (0.56, 1.35), *P* = .539	0.61 (0.29, 1.29), *P* = .196	0.39 (0.15, 1.02), *P* = .055
Men (No. of hips)				
Prevalence (%.)				
Control (n=80)	61 (76)	34 (43)	7 (9)	0 (0)
Symptomatic (n=217)	169 (78)	95 (44)	17 (8)	10 (5)
Other (n=51)	38 (75)	27 (53)	10 (20)	3 (7)
Odds ratio (95%CI), *P* value.				
Symptomatic vs control*	1.11 (0.53, 2.32), *P* = .778	1.06 (0.56, 2.02), *P* = .838	1.07 (0.37, 3.09), *P* = .902	NA
Other vs control*	0.91 (0.39, 2.13), *P* = .822	1.44 (0.69, 3.01), *P* = .331	1.78 (0.55, 5.80), *P* = .937	NA
Symptomatic vs other*	1.23 (0.69, 2.17), *P* = .483	0.74 (0.46, 1.19), *P* = .216	0.60 (0.27, 1.33), *P* = .209	NA

Abbreviations: AP; anteroposterior; LCEA, lateral-centre-edge-angle; NA, not estimated.
* Referent group.
† Odds ratios presented for football players were adjusted for sex.
‡ Pincer morphology in football players (control = 107 hips; symptomatic = 271 hips; other = 65 hips).
§ Acetabular dysplasia in football players (control = 102 hips; symptomatic = 262 hips; other = 59 hips).
II Pincer morphology in male football players (control = 82 hips; symptomatic = 212 hips; other = 51 hips).
Acetabular dysplasia in male football players (control = 75 hips; symptomatic = 205 hips; other = 44 hips).

Appendix 32. Probability from 0 (0%) to 1 (100%) of early hip OA features (presence) for values of alpha angle (AP and Dunn 45°) in 5° increments (Study 5 (Chapter 8)*§.

Alpha angle	Probability of cartilage defect % (95%CI)		Probability of labral tear % (95%CI)	
	AP	Dunn 45º	AP	Dunn 45º
40°	38 (29, 46)	37 (25, 49)	62 (54, 71)	57 (44, 71)
45°	41 (33, 48)	39 (29, 50)	65 (58, 72)	60 (49, 71)
50°	44 (37, 51)	42 (32, 51)	67 (61, 73)	63 (54, 72)
55°	47 (41, 53)	44 (36, 52)	70 (64, 75)	65 (58, 73)
60°	50 (44, 56)	46 (39, 53)	72 (66, 77)	68 (62, 74)
65°	53 (47, 60)	49 (42, 55)	74 (68, 79)	70 (65, 76)
70°	57 (50, 64)	51 (45, 57)	76 (70, 82)	73 (67, 78)
75°	60 (52, 68)	53 (46, 60)	78 (71, 84)	75 (69, 81)
80°	63 (54, 71)	56 (48, 64)	79 (72, 86)	77 (70, 83)
85°	66 (56, 75)	58 (49, 67)	81 (74, 89)	79 (72, 86)
90°	69 (58, 79)	60 (50, 71)	83 (75, 91)	81 (73, 89)
95°	71 (60, 82)	62 (51, 74)	84 (76, 92)	82 (74, 91)
100°	74 (63, 85)	65 (51, 78)	85 (77, 94)	84 (75, 93)
105°	76 (65, 88)	67 (52, 81)	87 (78, 95)	85 (76, 95)
110°	79 (67, 91)	69 (53, 85)	88 (79, 97)	87 (77, 97)

*Adjusted for age, sex, body mass index, KL grade, and symptoms.
§ Hip/groin pain and control hips.
AP, anteroposterior; Pr, probability.

Appendix 33. Association between cam morphology parameters and early OA features (presence) for all hips (hip/groin pain and control) in Study 5 (Chapter 8).

			Odds ratios (OR)			
	No. of hips without feature	No. of hips with feature	Unadjusted OR (95%CI) *P*-value	Interaction term† *P*-value	Adjusted OR (95%CI) *P*-value	Interaction term† *P*-value
OA feature						
Cartilage defect.						
Large cam morphology *(alpha angle >78°)*	55/144	89/144	2.91 (1.7, 5.0) <0.001		2.58 (1.5, 4.6) 0.001	
Cam morphology *(alpha angle >60° and ≤78°)*	54/117	63/117	2.53 (1.5, 4.3) <0.001	0.434	2.12 (1.2, 3.7) 0.008	0.473
No cam morphology (ref) *(alpha angle ≤60°).*	85/121	36/121				
Labral tear						
Large cam morphology *(alpha angle >78°)*	28/144	116/144	2.49 (1.4, 4.5) 0.003		2.53 (1.3, 4.7) 0.004	
Cam morphology *(alpha angle >60° and ≤78°)*	42/117	75/117	1.15 (0.7, 2.0) 0.605	0.934	1.12 (0.6, 2.0) 0.695	0.907
No cam morphology (ref) *(alpha angle ≤60°)*	43/121	78/121				

*Adjusted for age, sex, body mass index, KL grade, and symptoms.
†Cam morphology by presence of symptoms (hip/groin pain and positive FADIR test).

Appendix 34. Predicted probabilities of cartilage defect and labral tear for large cam morphology, cam morphology and no cam morphology for all hips (hip/groin pain and control) in Study 5 (Chapter 8)*§.

Cam morphology	Probability of cartilage defect % (95%CI)	Probability of labral tear % (95%CI)
No cam morphology *(alpha angle ≤60°)*	35 (25, 46)	64 (54, 73)
Cam morphology *(alpha angle >60° and ≤78°)*	54 (44, 64)	66 (57, 75)
Large cam morphology *(alpha angle >78°)*	59 (59, 68)	82 (75, 88)

* Adjusted for age, sex, body mass index, KL grade, and symptoms.
§ Hip/groin pain and control hips.

Appendix 35. Probability from 0 (0%) to 1 (100%) of early hip OA features (location) for values of alpha angle (AP and Dunn 45°) in 5° increments for all hips (hip/groin pain and control) (Study 5 (Chapter 8)*§.

Alpha angle	Probability of superolateral cartilage defect % (95%CI)		Probability of superior labral tear % (95%CI)	
	AP	Dunn 45º	AP	Dunn 45º
40°	25 (18, 32)	19 (10, 27)	24 (17, 31)	23 (13, 32)
45°	28 (21, 35)	22 (13, 30)	27 (21, 33)	25 (16, 34)
50°	31 (25, 38)	25 (17, 33)	30 (24, 36)	28 (20, 35)
55°	35 (29, 41)	28 (21, 35)	34 (28, 39)	30 (23, 37)
60°	39 (33, 45)	32 (26, 38)	37 (32, 43)	33 (27, 39)
65°	43 (37, 49)	36 (30, 42)	41 (35, 47)	36 (30, 42)
70°	47 (40, 54)	40 (34, 46)	45 (38, 51)	39 (33, 45)
75°	51 (43, 59)	44 (38, 51)	49 (41, 56)	42 (36, 49)
80°	55 (46, 64)	49 (41, 57)	52 (44, 61)	45 (38, 53)
85°	59 (49, 69)	53 (44, 63)	56 (47, 66)	49 (39, 58)
90°	63 (52, 74)	58 (47, 68)	60 (49, 71)	52 (41, 63)
95°	67 (55, 78)	62 (50, 74)	64 (52, 76)	55 (43, 67)
100°	70 (58, 82)	66 (53, 79)	67 (55, 80)	58 (44, 72)
105°	74 (61, 86)	70 (56, 84)	71 (58, 84)	61 (46, 77)
110°	77 (64, 89)	73 (59, 88)	74 (60, 87)	64 (48, 81)

*Adjusted for age, sex, body mass index, and KL grade.
§ Hip/groin pain and control hips.
AP, anteroposterior; Pr, probability.

Appendix 36. Association between cam morphology parameters and cartilage defects (location) for all hips (hip/groin pain and control) in Study 5 (Chapter 8).

			Odds ratios (OR)			
	No. of hips without cartilage defect	No. of hips with cartilage defect	Unadjusted OR (95%CI) *P*-value	Interaction term† *P*-value	Adjusted OR (95%CI) *P*-value	Interaction term† *P*-value
Cartilage defect location						
Superolateral subregion						
Large cam morphology *(alpha angle >78°)*	62/144	82/144	5.45 (3.0, 10.0) <0.001		4.67 (2.5, 8.9) <0.001	
Cam morphology *(alpha angle >60° and ≤78°)*	70/117	47/117	3.34 (1.8, 6.1) <0.001	0.459	2.62 (1.4, 5.0) 0.003	0.545
No cam morphology (ref) *(alpha angle ≤60°)*	100/121	21/121				
Superomedial subregion						
Large cam morphology *(alpha angle >78°)*	132/144	12/144	0.70 (0.3, 1.7) 0.421		0.65 (0.3, 1.7) 0.369	
Cam morphology *(alpha angle >60° and ≤78°)*	105/117	12/117	0.92 (0.4, 2.1) 0.847	0.970	0.78 (0.3, 2.0) 0.597	0.985
No cam morphology (ref) *(alpha angle ≤60°)*	109/121	12/121				
Lateral subregion						
Large cam morphology *(alpha angle >78°)*	96/144	48/144	1.37 (0.8, 2.4) 0.280		1.41 (0.8, 2.6) 0.278	
Cam morphology *(alpha angle >60° and ≤78°)*	75/117	42/117	1.65 (0.9, 2.9) 0.086	0.617	1.63 (0.9, 3.0) 0.116	0.692
No cam morphology (ref) *(alpha angle ≤60°)*	93/121	28/121				

*Adjusted for age, sex, body mass index, KL grade, and symptoms.

§ Hip/groin pain and control hips.

†Cam morphology by presence of symptoms (hip/groin pain and positive FADIR test).

Appendix 37. Predicted probabilities of superolateral cartilage defect and superior labral tear for large cam morphology, cam morphology and no cam morphology for all hips (hip/groin pain and control) in Study 5 (Chapter 8)*§.

Cam morphology	Probability of superolateral cartilage defect % (95%CI)	Probability of superior labral tear % (95%CI)
No cam morphology *(alpha angle ≤60°)*	20 (12, 28)	23 (15, 32)
Cam morphology *(alpha angle >60° and ≤78°)*	40 (30, 49)	37 (28, 47)
Large cam morphology *(alpha angle >78°)*	54 (45, 63)	51 (42, 60)

*Adjusted for age, sex, body mass index, KL grade, and symptoms.
§ Hip/groin pain and control hips.

Appendix 38. Association between cam morphology parameters and labral tears (location) for all hips (hip/groin pain and control) in Study 5 (Chapter 8)*§.

			Odds ratios (OR)			
	No. of hips without labral tear	No. of hips with labral tear	Unadjusted OR (95%CI) *P*-value	Interaction term† *P*-value	Adjusted OR (95%CI) *P*-value	Interaction term† *P*-value
Labral tear location						
Superior subregion						
Large cam morphology *(alpha angle >78°)*	68/144	76/144	3.97 (2.2, 7.0) <0.001		3.41 (1.8, 6.3) <0.001	
Cam morphology *(alpha angle >60° and ≤78°)*	72/117	45/117	2.39 (1.3, 4.3) 0.003	0.597	1.98 (1.1, 3.7) 0.031	0.790
No cam morphology (ref) *(alpha angle ≤60°)*	96/121	25/121				
Anterosuperior subregion						
Large cam morphology *(alpha angle >78°)*	60/144	84/144	1.41 (0.8, 2.4) 0.194		1.60 (0.9, 2.8) 0.102	
Cam morphology *(alpha angle >60° and ≤78°)*	62/117	55/117	0.97 (0.6, 1.6) 0.918	0.390	1.07 (0.6, 1.8) 0.817	0.467
No cam morphology (ref) *(alpha angle ≤60°)*	60/121	61/121				

*Adjusted for age, sex, body mass index, KL grade, and symptoms.
§ Hip/groin pain and control hips.
†Cam morphology by presence of symptoms (hip/groin pain and positive FADIR test).

Appendix 39. Association between alpha angle and cartilage defects (severity) for all hips (hip/groin pain and control) in Study 5 (Chapter 8)*§.

		Cartilage score			
	No. of hips	Unadjusted IRR (95%CI) *P*-value	Interaction term† *P*-value	Adjusted IRR (95%CI)* *P*-value	Interaction term† *P*-value
Radiographic variable.					
Alpha angle (AP view)	398	1.01 (1.01, 1.02) 0.001	0.610	1.01 (1.00, 1.02) 0.017	0.393
Alpha angle (Dunn 45° view)	382	1.01 (1.00, 1.02) 0.074	0.424	1.00 (0.99, 1.01) 0.476	0.859

*Adjusted for age, sex, body mass index, and KL grade and symptoms.
§ Hip/groin pain and control hips.
†Alpha angle by presence of symptoms (hip/groin pain and positive FADIR test).
AP, anteroposterior; IRR, incidence rate ratio.

Appendix 40. Association between alpha angle and labral tears (severity) for all hips (hip/groin pain and control) in Study 5 (Chapter 8)*§.

		Labral score			
	No. of hips	Unadjusted IRR (95%CI) *P*-value	Interaction term† *P*-value	Adjusted IRR (95%CI)* *P*-value	Interaction term† *P*-value
Radiographic variable.					
Alpha angle (AP view)	398	1.01 (1.01, 1.02) <0.001	0.404	1.01 (1.00, 1.01) <0.001	0.590
Alpha angle (Dunn 45° view)	382	1.01 (1.00, 1.01) 0.013	0.571	1.01 (1.00, 1.01) 0.021	0.889

*Adjusted for age, sex, body mass index, and KL grade and symptoms.
§ Hip/groin pain and control hips.
†Alpha angle by presence of symptoms (hip/groin pain and positive FADIR test).
AP, anteroposterior; IRR, incidence rate ratio.

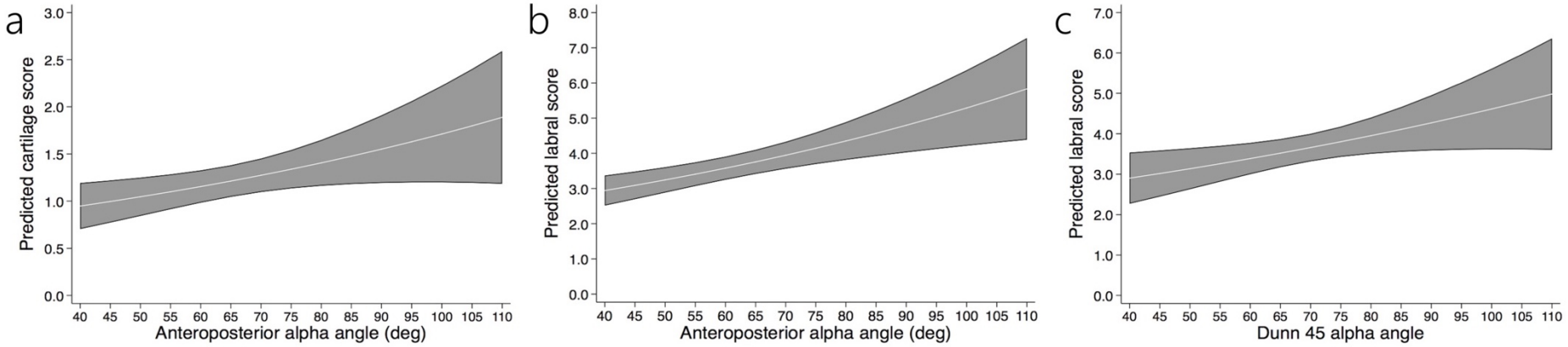
Appendix 41. Predicted OA feature score for values of alpha angle (AP and Dunn 45°) in 5° increments for all hips (hip/groin pain and control) in Study 5 (Chapter 8)*§.

Alpha angle (AP)	Predicted cartilage score (95%CI)	Predicted labral score (95%CI)	
	AP	AP	Dunn 45°
40°	0.95 (0.70, 1.19)	2.94 (2.52, 3.37)	2.90 (2.27, 3.53)
45°	1.00 (0.77, 1.22)	3.09 (2.70, 3.48)	3.02 (2.45, 3.58)
50°	1.05 (0.84, 1.25)	3.24 (2.89, 3.60)	3.13 (2.63, 3.64)
55°	1.10 (0.92, 1.28)	3.41 (3.07, 3.74)	3.26 (2.82, 3.70)
60°	1.15 (0.98, 1.33)	3.58 (3.25, 3.90)	3.39 (3.00, 3.77)
65°	1.21 (1.05, 1.38)	3.76 (3.42, 4.10)	3.52 (3.17, 3.87)
70°	1.27 (1.10, 1.45)	3.94 (3.57, 4.32)	3.66 (3.32, 4.00)
75°	1.34 (1.14, 1.54)	4.14 (3.70, 4.59)	3.80 (3.43, 4.17)
80°	1.41 (1.16, 1.65)	4.35 (3.82, 4.88)	3.95 (3.51, 4.40)
85°	1.48 (1.18, 1.77)	4.57 (3.93, 5.21)	4.11 (3.56, 4.66)
90°	1.55 (1.19, 1.91)	4.80 (4.03, 5.56)	4.27 (3.59, 4.95)
95°	1.63 (1.20, 2.06)	5.04 (4.12, 5.95)	4.44 (3.61, 5.27)
100°	1.71 (1.20, 2.22)	5.29 (4.22, 6.36)	4.61 (3.62, 5.61)
105°	1.80 (1.19, 2.40)	5.55 (4.30, 6.80)	4.79 (3.61, 5.97)
110°	1.89 (1.18, 2.59)	5.83 (4.39, 7.28)	4.98 (3.60, 6.36)

*Adjusted for age, sex, body mass index, KL grade, and symptoms.
§ Hip/groin pain and control hips.
AP, anteroposterior.

Appendix 42. Predicted OA feature score for values of alpha angle (AP and Dunn 45°) in 5° increments for all hips (hip/groin pain and control) in Study 5 (Chapter 8)*§

a) cartilage score (anteroposterior alpha angle); b) labral score(anteroposterior alpha angle); c) labral score (anteroposterior alpha angle).



Appendix 43. Association between cam morphology parameters and cartilage defects (severity) for all hips (hip/groin pain and control) in Study 5 (Chapter 8)*§.

			Incidence rate ratios (IRR)			
	No. of hips	Cartilage score Mean (95%CI)	Unadjusted IRR (95%CI) *P*-value	Interaction term† *P*-value	Adjusted IRR* (95%CI) *P*-value	Interaction term† *P*-value
Radiographic variable						
Large cam morphology *(alpha angle >78°)*	144	1.4 (1.1, 1.6)	1.72 (1.2, 2.6) 0.007		1.53 (1.0, 2.3) 0.047	
Cam morphology *(alpha angle >60° and ≤78°)*	117	1.4 (1.1, 1.6)	1.75 (1.1, 2.6) 0.009	0.256	1.53 (1.0, 2.3) 0.043	0.366
No cam morphology (ref) *(alpha angle ≤60°)*	121	0.9 (0.6, 1.2)				

*Adjusted for age, sex, body mass index, KL grade, and symptoms.
§ Hip/groin pain and control hips.
†Cam morphology by presence of symptoms (hip/groin pain and positive FADIR test.)

Appendix 44. Association between cam morphology parameters and labral tears (severity) for all hips (hip/groin pain and control) in Study 5 (Chapter 8)*§.

			Incidence rate ratios (IRR).			
	No. of hips	Labral score Mean (95%CI)	Unadjusted IRR (95%CI) *P*-value	Interaction term† *P*-value	Adjusted IRR* (95%CI) *P*-value	Interaction term† *P*-value
Radiographic variable						
Large cam morphology *(alpha angle >78°)*	144	4.4 (3.9, 5.0)	1.46 (1.2, 1.8) 0.001		1.45 (1.2, 1.8) 0.001	
Cam morphology *(alpha angle >60° and ≤78°)*	117	3.6 (3.0, 4.1)	1.22 (1.0, 1.5) 0.099	0.127	1.16 (0.9, 1.5) 0.195	0.381
No cam morphology (ref) *(alpha angle ≤60°)*	121	3.1 (2.5, 3.6)				

*Adjusted for age, sex, body mass index, KL grade, and symptoms.
§ Hip/groin pain and control hips.
†Cam morphology by presence of symptoms (hip/groin pain and positive FADIR test).

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STUDY 1 (CHAPTER 4)

Heerey JJ, Kemp JL, Mosler AB, Jones DM, Pizzari T, Souza RB, Crossley KM. What is the prevalence of imaging-defined intra-articular hip pathologies in people with and without pain? A systematic review and meta-analysis. Br J Sports Med. 2018;52(9):581-93.

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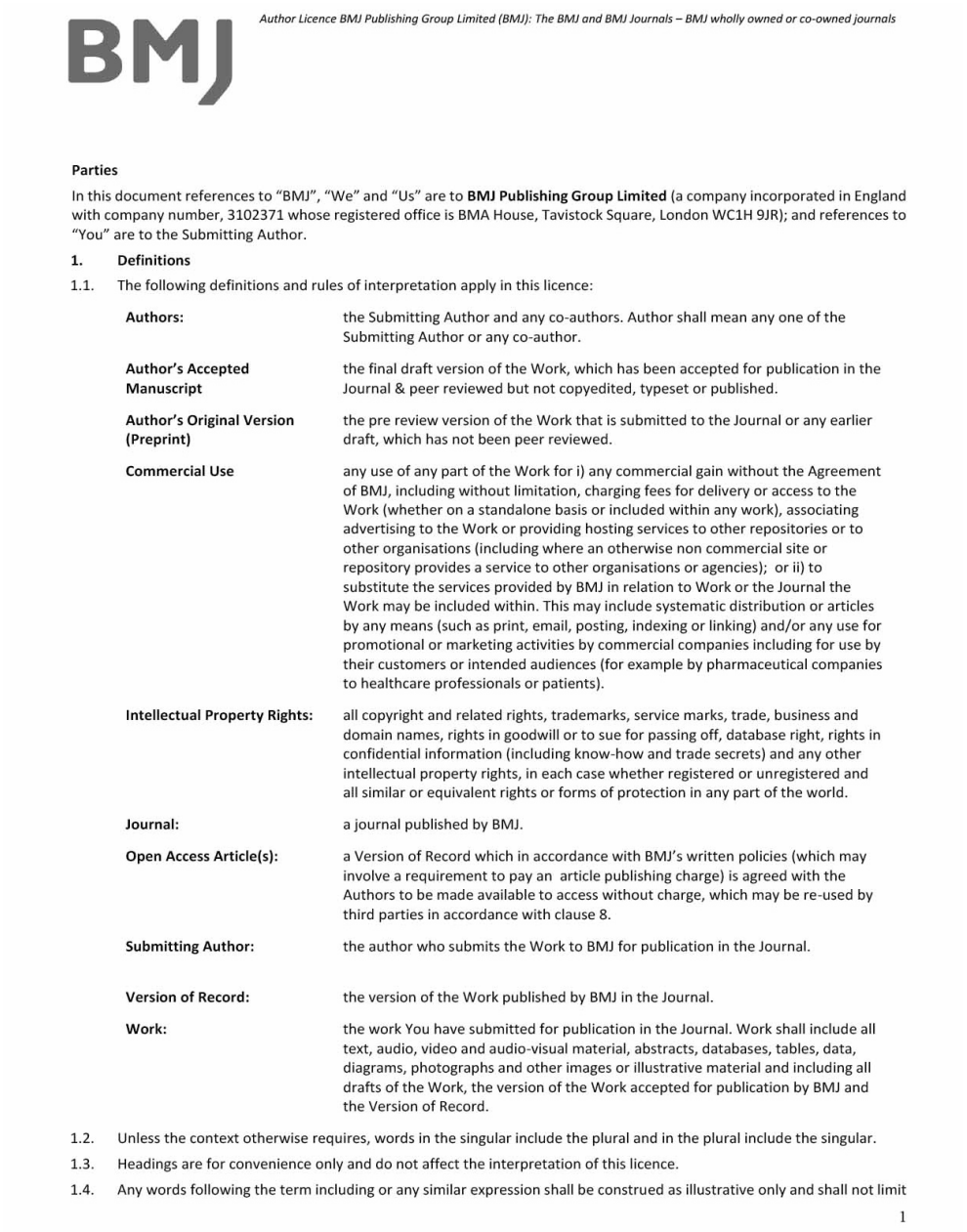

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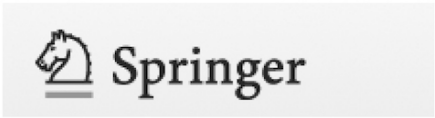
STUDY 2 (CHAPTER 5)

Heerey JJ, Kemp JL, Mosler AB, Jones DM, Pizzari T, Scholes MJ, Agricola R, Crossley KM. What is the prevalence of hip intra-articular pathologies and osteoarthritis in active athletes with hip and groin pain compared with those without? A systematic review and meta-analysis. Sports Med. 2019;49:951-972.



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STUDY 3 (CHAPTER 6)

Heerey JJ, Srinivasan R, Agricola R, Smith A, Kemp JL, Pizzari T, King MG, Lawrenson PL, Scholes MJ, Souza RB, Link T, Majumdar S, Crossley KM. Prevalence of early hip OA features in high-impact athletes. The femoroacetabular impingement and hip osteoarthritis cohort (FORCe) study. Osteoarthritis and Cartilage. In press 2021.

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STUDY 4 (CHAPTER 7)

Heerey JJ, Agricola R, Smith A, Kemp JL, Pizzari T, King MG, Lawrenson PL, Scholes MJ, Crossley KM. The size and prevalence of bony hip morphology does not differ between football players with and without hip and/or groin pain: Findings from the FORCe cohort. J Orthop Sports Phys Ther. In press 2021.

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Appendix 46. Confirmation of authorship.

Study 1 (Chapter 4)

Statement from the authors confirming the authorship contribution of the PhD candidate

As the co-authors of the publication

Heerey JJ, Kemp JL, Mosler AB, Jones DM, Pizzari T, Souza RB, Crossley KM. What is the prevalence of imaging-defined intra-articular hip pathologies in people with and without pain? A systematic review and meta-analysis. British Journal of Sports Medicine. 2018;52(9):581-93.

We certify that Joshua James Heerey has made the following contributions:

- Developed concept and design of systematic review
- Developed and conducted search strategy and study selection
- Completed risk of bias assessment and data extraction, analysis and interpretation
- Writing of manuscript and response to reviewers' comments

Dr Joanne Kemp	Date: 15/12/2020
Dr Andrea Mosler	Date: 15/12/2020
Ms Denise Jones	Date: 15/12/2020
Dr Tania Pizzari	Date: 15/12/2020
Prof. Richard Souza	Date: 15/12/2020
Prof. Kay Crossley	Date: 15/12/2020

Study 2 (Chapter 5)

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As the co-authors of the publication

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Dr Andrea Mosler	Date: 15/12/2020
Ms Denise Jones	Date: 15/12/2020
Dr Tania Pizzari	Date: 15/12/2020
Mr Mark Scholes	Date: 15/12/2020
Dr Rintje Agricola	Date: 15/12/2020
Prof. Kay Crossley	Date: 15/12/2020

Study 3 (Chapter 6)

Statement from the authors confirming the authorship contribution of the PhD candidate

As the co-authors of the publication

Heerey JJ, Srinivasan R, Agricola R, Smith A, Kemp JL, Pizzari T, King MG, Lawrenson PL, Scholes MJ, Souza RB, Link T, Majumdar S, Crossley KM. Prevalence of early hip OA features on MRI in high-impact athletes. The femoroacetabular impingement and hip osteoarthritis cohort (FORCe) study. Osteoarthritis and Cartilage. In press 2021.

We certify that Joshua James Heerey has made the following contributions:

- Study administration
- Developed concept and design of the study
- Development of imaging protocol used in the study
- Participant recruitment
- Data collection, processing and curation
- Statistical analysis and data visualisation
- Writing of manuscript and response to reviewers' comments

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Prof. Kay Crossley	Date: 15/12/2020

Study 4 (Chapter 7)

Statement from the authors confirming the authorship contribution of the PhD candidate

As the co-authors of the publication

Heerey JJ, Agricola R, Smith A, Kemp JL, Pizzari T, King MG, Lawrenson PL, Scholes MJ, Crossley KM. The size and prevalence of bony hip morphology does not differ between football players with and without hip and/or groin pain: Findings from the FORCe cohort. J Orthopaedic and Sports Physical Therapy. In press 2021.

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Prof. Kay Crossley	Date: 15/12/2020

Study 5 (Chapter 8)

Statement from the authors confirming the authorship contribution of the PhD candidate

As the co-authors of the publication

Heerey JJ, Kemp JL, Agricola R, Srinivasan R Smith A, Pizzari T, King MG, Lawrenson PL, Scholes MJ, Souza RB, Link T, Majumdar S, Crossley KM. Cam morphology is associated with early hip OA features in football players with and without hip and groin pain. Under review at British Journal of Sports Medicine 2021.

We certify that Joshua James Heerey has made the following contributions:

- Study administration
- Developed concept and design of the study
- Development of imaging protocol used in the study
- Participant recruitment
- Data collection, processing and curation
- Statistical analysis and data visualisation
- Writing of manuscript and response to reviewers' comments

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