The Burden of Hip and Groin Pain in Football Players: Relationships With Hip Joint Structure and Running Biomechanics.

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Bachelor of Physiotherapy

Master of Sports and Exercise Physiotherapy

This thesis submitted in total fulfillment of the requirements for the degree of Doctor of Philosophy

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Victoria, Australia

January 2022

Table of Contents

List of Figures

List of Tables

List of Abbreviations

3.0T	3.0 Tesla
95% CI	95% confidence interval
AIC	Akaike information criterion
AP	Anteroposterior pelvis
ASM	Active shape modelling
BMI	Body mass index
CHECK	Cohort hip and cohort knee
COSMIN	Consensus-based standards for the selection of health measurement instruments
CT	Computed tomography
dGEMRIC	Delayed gadolinium enhanced MRI of cartilage
ES	Effect size
FADIR	Flexion-adduction-internal rotation
FAI syndrome	Femoroacetabular impingement syndrome
FORCe	Femoroacetabular impingement and hip osteoarthritis cohort
GRF	Ground reaction force
GROC	Global rating of change
HAGOS	Copenhagen Hip and Groin Outcome Score
HAGOS-ADL	HAGOS Activities of daily living subscale
HAGOS-PA	HAGOS Participation in physical activities subscale
HAGOS-Pain	HAGOS Pain subscale
HAGOS-QOL	HAGOS Quality of life subscale
HAGOS-Sport	HAGOS Sport and recreational activities subscale
HAGOS-Symptoms	HAGOS Symptoms subscale
Hip/groin	Hip and/or groin
HIP-RSI	Hip-Return to Sport After Injury
HOOS	Hip Dysfunction and Osteoarthritis Outcome Score
Hz	Hertz
ICC	Intraclass correlation coefficient
IHiPRN	International Hip-related Pain Research Network
iHOT-33	International Hip Outcome Tool-33
iHOT-Job	iHOT-33 Job-related concerns subscale

iHOT-Social	iHOT-33 Social, emotional, and lifestyle concerns subscale
iHOT-Sport	iHOT-33 Sport and recreational activities subscale
iHOT-Symptoms	iHOT-33 Symptoms and functional limitations subscale
iHOT-Total	iHOT-33 Total score
IMU	Inertial measurement unit
IQR	Interquartile range
KL	Kellgren and Lawrence
LCEA	Lateral-centre-edge-angle
MDC	Minimal detectable change
MIC	Minimally important change
MRI	Magnetic resonance imaging
$N \cdot m \cdot kg^{-1}$	Newton metres per kilogram
$N \cdot m \cdot s \cdot kg^{-1}$	Newton metre seconds per kilogram
NHMRC	National Health and Medical Research Council
OA	Osteoarthritis
PD SPAIR	Proton density spectral attenuated inversion recovery
PhysioFIRST	Physiotherapist-led treatment for femoroacetabular impingement syndrome
PROM	Patient-reported outcome measure
PROMIS	Patient-Reported Outcomes Measurement Information System
QOL	Quality of life
RCT	Randomised controlled trial
ROM	Range of motion
SD	Standard deviation
SEM	Standard error of measurement
SHOMRI	Scoring hip osteoarthritis with MRI
SPM	Statistical parametric mapping
SRM	Standardised response mean
THA	Total hip arthroplasty
UK	United Kingdom
USA	United States of America
VAS	Visual analogue scale
VIF	Variance inflation
WHO	World Health Organisation

List of Appendices

Abstract

Hip and/or groin (hip/groin) pain is common in football players, but its burden (e.g., symptom severity and perceived functional impairments, activity limitations, and participation restrictions) is unknown in those who continue to train and play. One common cause of hip/groin pain in football players is femoroacetabular impingement (FAI) syndrome, which is defined as a motion-related condition and associated with distinct bony (pincer and/or cam) morphology. However, little is known about how physical features (e.g., bony morphology or movement patterns) might relate to self-reported burden. This thesis investigated potential relationships between hip joint structure, biomechanics, and self-reported burden in football players with and without longstanding hip/groin pain, aiming to provide insights into the pathogenesis of FAI syndrome and inform treatments for football players with hip/groin pain. This thesis includes six studies divided across three parts:

Part A (Study 1, **Chapter 3**) evaluated the measurement properties of the International Hip Outcome Tool-33 (iHOT-33), finding that scores were valid, reliable, and responsive in people with hip/groin pain not seeking surgery.

Part B described self-reported burden in symptomatic football players (Study 2, **Chapter 4**) and investigated relationships with hip joint structure (Studies 3 and 4, **Chapters 5** and **6**). Football players with FAI syndrome did not report worse burden than those with other causes of hip/groin pain. Chondrolabral pathology was not associated with self-reported burden and thus, did not mediate the effect of FAI syndrome. In players with FAI syndrome, larger anterosuperior cam morphology was associated with worse self-reported burden.

Part C found that running biomechanics did not differ between football players with and without hip/groin pain (Study 5, **Chapter 8**). In players with FAI syndrome, running biomechanics were mostly unrelated to self-reported burden and cam morphology size (Study 6, **Chapter 9**). Prospective studies are needed to discern the importance of these factors on structural hip disease over time.

In conclusion, the findings of this thesis suggest that whilst hip/groin pain is burdensome in football players still capable of training and match play, it is unclear what role, if any, hip joint structure and running biomechanics play with respect to symptom severity.

Keywords

Hip joint, Groin, Football, Soccer, Patient-reported outcome measures, Rehabilitation, Femoroacetabular impingement syndrome, Cam morphology, Radiography, Biomechanics, Running

Australian and New Zealand Standard Research Classifications (ANZSRC)

Type of activity:

Applied research

Field(s) of research:

420106 – Physiotherapy, 60%

320216 – Orthopaedics, 20%

320225 – Sports Medicine, 10%

320204 – Clinimetrics, 10%

Socioeconomic objective(s):

200202 – Evaluation of health outcomes

Statement of Authorship

I, Mark James Scholes, declare that thesis includes work 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 acknowledgement 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.

This thesis includes published works which involved collaborative input from co-authors. Although the published manuscripts involved joint authorship, I made significant and leading contribution to all work included in this thesis, equivalent to that expected for a traditional thesis. I am the primary author for the four published manuscripts presented in this thesis, with confirmation of authorship documentation provided in **Appendix T**.

All research procedures reported in this thesis were approved by the La Trobe University Human Ethics Committee (HEC17-080, HEC16-045, HEC15-019) and the University of Queensland Human Ethics Committee (2015000916 & 2016001694). This work was supported by an Australian Government Research Training Program Scholarship and La Trobe University Postgraduate Scholarship. Additional funding for participant radiographs and magnetic resonance imaging was obtained from the National Health and Medical Research Council project grant (GTN 1088683), titled 'Femoroacetabular impingement and early osteoarthritis'. Reduced service fees were granted by Imaging @ Olympic Park (Melbourne), Q-Scan (Brisbane), and Lake Imaging (Ballarat) for completion of participant radiographs and magnetic resonance imaging. This thesis has been professionally proofread for spelling, grammar, and punctuation by Jess Fredo (The Expert Editor) in accordance with the Guidelines for Editing Research Theses under the Australian Standards for Editing Practices.

Name: Mark James Scholes
Date: 28th January 2022

Acknowledgements

Supervisors

This PhD thesis would not have been possible without the support of my supervisory team: Professor Kay Crossley, Associate Professor Joanne Kemp, and Dr Benjamin Mentiplay. You inspire me daily and I am incredibly honoured to have had the opportunity to learn from you. Thank you for continually encouraging and supporting me throughout this journey.

Kay, thank you for taking a chance on me four years ago and your patience as I found my feet in the research world. You supported my research ideas, and generously provided opportunities to travel and collaborate with world-leading researchers and clinicians, for which I am forever grateful. Your passion for what we do is truly inspiring, and I continue to learn from you every day. Thank you for challenging me, and doing so in the most supportive and caring way. Kay, it is a privilege to have had your expertise, mentorship, and friendship throughout this time. Thank you for all you have done for me and my family.

Jo, you have been the most outstanding mentor and friend that I could have hoped for. You have an amazing ability to bring the best out in people, for which I, and I am sure all LASEM, are thankful. You have been so generous with your time and knowledge, and I will be forever indebted to you. Thank you for being there for my family when life seemed to only throw us curve balls, your support during this period will not be forgotten.

Ben, thank you for your friendship and guidance over the last four years. Your advice has always been thoughtful and practical, helping me to see the bigger picture in the complicated world of research and academia. Your attention to detail was invaluable, as was your sense of humour. Thank you for your support.

Whilst not part of my supervisory team, I would like to thank Dr Anthony Schache, my committee chair, for his support throughout my candidature. Anthony, your time, expertise, and considered advice for my running biomechanics studies was truly invaluable. Thank you.

Research team

Thank you to the original FORCe team members (Dr Joshua Heerey, Dr Matthew King, and Dr Peter Lawrenson) for your passion, hard work, and dedication to this project, and trusting me to carry on what you started. Thank you to Dr Adam Semciw for sharing a tiny fraction of your extensive stats knowledge, and your patience throughout that process. My grateful thanks go to Dr Andrea Mosler for your friendship, mentorship, and support; I truly valued our Friday morning life-chats and your reassurance during difficult times. Thank you to Dr Rintje Agricola for generously sharing your expertise and time; your contribution to this thesis and my learning has been immense.

I am incredibly fortunate to have worked with an amazing team at La Trobe Sport and Exercise Medicine Research Centre. Thank you to Professor Peter Brukner, Dr Denise Jones, Dr Danilo De Oliveira Silva, Dr Adam Culvenor, and Dr Richard Johnston for your wise words throughout my candidature. To the original HDR team (Brooke, Jade, Maddy, Brady, Brod) and to those who came later (Milly, Sally, Leanne, Mike, and Mick), thank you for your friendship, advice about navigating academia (and life), and the many laughs we shared.

Dr Joshua Heerey and Dr Matthew King deserve special mentions. To you both, I cannot thank you enough for your unwavering support. You have ridden the highs with me and picked me up from my lowest ebb; if nothing else, the friendship I share with each of you has made this adventure worthwhile, 100 times over. Josh, you helped shape this thesis and navigated me through a PhD and fatherhood with wit, good humour, and humility, and I am so very thankful for that. Matt, thank you for everything you taught me about biomechanics, math, stats, and research methods. Most of all, thank you for your unconditional support and friendship, for checking in when you intuitively knew I needed to vent, and for our weekly Scholes-Bing zooms on Saturday afternoons during endless COVID lockdowns. I look forward to sharing many years of friendship and research collaborations with you both.

Thank you to Dr Peter Malliaras and Dr Christian Barton for inspiring me to undertake this PhD. I am so grateful for your steadfast support of my research journey, regardless of it detracting from my time in the clinic. Thank you for your mentorship and for giving me a chance at Complete Sports Care all those years ago; it is hard to imagine where I would be

if I had not met you both. Yes, Christian, completing this PhD has been one of the most challenging but rewarding experiences of my life, so thank you to you and Pete.

Family

To my mum, Lyn, thank you for instilling in me the importance of hard work and dogged persistence. Thank you for making sacrifices to afford me an amazing education, which instilled in me the value of lifelong learning. Thank you for your unwavering support, no matter where life takes me.

To my mother-in-law, Wendyanne, thank you for your unconditional love and support, especially in the last 18 months. Thank you for taking an interest in what I do, your constant reassurance, and most of all the amazing support you have provided Em and I. Thank you so much, we could not have achieved this without you.

To my wife, Emma, I am forever indebted to you for all that you sacrificed over the last 4 years. Thank you for your endless love and encouragement, I could not have finished this without you. This is for you, for all the times when I said no because I had to work, the nights when it seemed I never came to bed, and the times when you felt like you were raising Poppy alone. You have been so strong, and I love you.

With love, for Emma, Poppy, and little Hamish arriving May 2022.

Professional service acknowledgements

Thank you to Dr Ramya Srinivasan (Department of Radiology and Biomedical Imaging, University of California, San Francisco) for contributing to MRI analysis in **Chapter 5**.

Thank you to the staff at Imaging @ Olympic Park (Melbourne), Q-Scan (Brisbane), and Lake Imaging (Ballarat) for completion of participant radiographs and magnetic resonance imaging.

Thank you to Jess Fredo (The Expert Editor) for professionally proofreading this thesis for spelling, grammar, and punctuation in accordance with the Guidelines for Editing Research Theses under the Australian Standards for Editing Practices.

Grants and Funding Awarded During PhD Candidature

Grant/funding description	Awarding Organisation	Amount
Scholes MJ, Kemp JL, Semciw AI, Mentiplay BF, & King MG. (2019) *The immediate effect of running retraining on hip joint pain and biomechanics in people with hip-related pain. A randomised, controlled crossover trial.*	Physiotherapy Research Foundation, Australian Physiotherapy Association	$9,981
Kemp JL, Crossley KM, Shawdon A, Makdissi M, Heerey JJ, **Scholes MJ** (2019) *Imaging and clinical factors associated with hip and groin pain in AFL players.*	VALD Performance	$10,000
Scholes MJ (2018) *Higher degree support grant*	School of Allied Health, Human Services and Sport	$5,000
Scholes MJ (2018) *Research Training Program Scholarship*	Graduate Research School, La Trobe University	$98,322 ($28,092 p.a. for 3.5 years)
Scholes MJ (2018) *Research Training Program Fees Offset Scholarship*	Australian Government	$36,512 (10,432 p.a. for 3.5 years)
		$159,815

Publications, Presentations, and Awards Arising from this Thesis

Peer reviewed publications

1. **Scholes MJ**, King MG, Crossley KM, Jones DM, Semciw AI, Mentiplay BF, Heerey JJ, Lawrenson PR, Coburn SL, Johnston RTR, Bell EC, Girdwood M, Kemp JL. The International Hip Outcome Tool 33 (iHOT-33) is valid, reliable, and responsive in patients with hip and groin pain treated without surgery. *American Journal of Sports Medicine*. 2021;49(10):2677-88.

2. **Scholes MJ**, Crossley KM, King MG, Schache AG, Kemp JL, Semciw AI, Sritharan P, Heerey JJ, Mentiplay BF. Running biomechanics in football players with and without hip and groin pain. A cross-sectional analysis of 116 sub-elite players. *Physical Therapy in Sport*. 2021;52:312-21.

3. **Scholes MJ**, Kemp JL, Mentiplay BF, Heerey JJ, Agricola R, King MG, Semciw AI, Lawrenson PR, Crossley KM. Are cam morphology size and location associated with self-reported burden in football players with FAI syndrome? *Scandinavian Journal of Medicine & Science in Sports*. 2022. In press.

4. **Scholes MJ**, Kemp JL, Mentiplay BF, Heerey JJ, Agricola R, Semciw AI, Souza RB, Link T, Majumdar S, King MG, Lawrenson PR, Crossley, KM. Does femoroacetabular impingement syndrome affect self-reported burden in football players with hip and groin pain? A cross-sectional study of 165 symptomatic sub-elite players. *Sports Health: A Multidisciplinary Approach*. 2022. Accepted.

Conference presentations and posters

1. **Scholes MJ**, Kemp JL, Mentiplay BF, Heerey JJ, Agricola R, King MG, Semciw AI, Lawrenson PR, Crossley, KM. Does cam morphology size and location affect self-reported burden in football players with femoroacetabular impingement syndrome? *Sports Medicine Australia 2021 eConference, October 2021*.

2. **Scholes MJ**, Crossley KM, King MG, Schache AG, Kemp JL, Semciw AI, Sritharan P, Heerey JJ, Mentiplay BF. Lower limb biomechanics during running do not differ between football players with and without hip and groin pain. *Sports Medicine Australia 2021 eConference, October 2021*.

3. **Scholes MJ**, Kemp JL, Mentiplay BF, Heerey JJ, Agricola R, King MG, Souza R, Link T, Majumdar S, Semciw AI, Lawrenson PR, Crossley KM. Does femoroacetabular impingement syndrome affect self-reported burden in football players with hip and groin pain? *World Physiotherapy Congress 2021 Online, April 2021*.

4. **Scholes MJ**, Kemp JL, Mentiplay BF, Heerey JJ, King MG, Semciw AI, Lawrenson PR, Crossley KM. What is the burden of hip-related pain in high impact athletes and do sex-based differences exist? *OARSI World Congress of Osteoarthritis, Vienna, Austria, 2020 – Cancelled due to COVID-19* [Poster presentation].

5. **Scholes MJ**, Kemp JL, Mentiplay BF, Heerey JJ, King MG, Semciw AI, Lawrenson PR, Crossley KM. What is the burden of hip-related pain competitive football players, and do sex-based differences exist?" *Sports Medicine Australia 2019 Conference, Sunshine Coast, Australia, October 2019.*

6. **Scholes MJ**, Kemp JL, Mentiplay BF, Semciw AI, Heerey JJ, King MG, Lawrenson PR, Crossley KM. What is the domain-specific burden of hip-related pain in men and women who play competitive football? *IFSPT 3rd World Congress of Sports Physical Therapy, Vancouver, Canada, October 2019.*

7. **Scholes MJ**, Mentiplay BF, Schache AG, King MG, Heerey JJ, Crossley KM. Investigation of hip biomechanics during running in male football players with and without hip-related pain. *37th International Society of Biomechanics in Sport Conference, Ohio, USA, July 2019.*

8. **Scholes MJ**, Mentiplay BF, Schache AG, King MG, Heerey JJ, Crossley KM. Investigation of hip biomechanics during running in male football players with and without hip-related pain. *International Society of Biomechanics 2019 Conference, Calgary, Canada, August 2019.*

Awards and prizes

Finalist – Best Paper (Clinical Sports Medicine and Sports Injury Prevention)

Scholes MJ, Kemp JL, Mentiplay BF, Semciw AI, Heerey JJ, King MG, Lawrenson PR, Crossley KM. What is the burden of hip-related pain competitive football players, and do sex-based differences exist? *Sports Medicine Australia 2019 Conference, Sunshine Coast, Australia, October 2019*

Additional Publications and Presentations During PhD Candidature

Peer reviewed publications

1. 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 MRI-defined cartilage defects and labral tears: a case-control study of 237 young adult football players with and without hip and groin pain. *BMJ Open Sport & Exercise Medicine*. 2021;7(4):e001199.

2. Kemp JL, Johnston RTR, Coburn SL, Jones DM, Schache AG, Mentiplay BF, King MG, **Scholes MJ**, de Oliveira Silva D, Smith A, McPhail SM, Crossley KM. Physiotherapist-led treatment for femoroacetabular impingement syndrome (the PhysioFIRST study): a protocol for a participant and assessor-blinded randomised controlled trial. *BMJ Open*. 2021; 11(4):e041742.

3. Heerey J, Agricola R, Smith A, Kemp J, Pizzari T, King M, Lawrenson PR, **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. *Journal of Orthopaedic and Sports Physical Therapy*. 2021;51(3):115-25.

4. 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):323-34.

5. King MG, Schache AG, Semciw AI, Middleton KJ, Heerey JJ, Kemp JL, Sritharan P, **Scholes MJ**, Mentiplay BF, Crossley KM. Lower-limb work during high- and low-impact activities in hip-related pain: associations with sex and symptom severity. *Gait & Posture*. 2021;83:1-8.

6. King MG, Semciw AI, Schache AG, Middleton KJ, Heerey JJ, Sritharan P, **Scholes MJ**, Mentiplay BF, Crossley KM. Lower-limb biomechanics in football players with and without hip-related pain. *Medicine and Science in Sports and Exercise*. 2020;52(8):1776-84.

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8. Impellizzeri FM, Jones DM, Griffin D, Harris-Hayes M, Thorborg K, Crossley KM, Reiman MP, **Scholes MJ**, Ageberg E, Agricola R, Bizzini M, Bloom N, Casartelli NC, Diamond LE, Dijkstra HP, Di Stasi S, Drew M, Friedman DJ, Freke M, Gojanovic B, Heerey JJ, Holmich P, Hunt MA, Ishøi L, Kassarjian A, King MG, Lawrenson PR, Leunig M, Lewis CL, Warholm KM, Mayes S, Moksnes H, Mosler AB, Risberg MA, Semciw AI, Serner A, van Klij P, Wörner T, Kemp JL. Patient-reported outcome measures for hip-related pain: a review of the available evidence and a consensus statement from the International Hip-related Pain Research Network, Zurich 2018. *British Journal of Sports Medicine*. 2020;54(14):848-57.

9. Mosler AB, Kemp JL, King MG, Lawrenson PR, Semciw AI, Freke M, Jones DM, Casartelli NC, Wörner T, Ishøi L, Ageberg E, Diamond LE, Hunt MA, Di Stasi S, Reiman MP, Drew M, Friedman DJ, 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, Warholm KM, 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. *British Journal of Sports Medicine*. 2020;54(12):702-10

10. Kemp JL, Risberg MA, Mosler AB, 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 DJ, Ageberg E, Agricola R, Casartelli NC, Diamond LE, Dijkstra HP, 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. *British Journal of Sports Medicine*. 2020;54(9):504-11.

11. Reiman MP, Agricola R, Kemp JL, Heerey JJ, Weir A, van Klij P, Kassarjian A, Mosler AB, Ageberg E, Hölmich P, Warholm KM, Griffin D, Mayes S, Khan KM, Crossley KM, Bizzini M, Bloom N, Casartelli NC, Diamond LE, Di Stasi S, Drew M, Friedman DJ, Freke M, Glyn Jones S, Gojanovic B, Harris-Hayes M, Hunt MA, Impellizzeri FM, Ishøi L, Jones DM, King MG, Lawrenson PR, Leunig M, Lewis CL, Moksnes H, Risberg MA, **Scholes MJ**, Semciw AI, Serner A, Thorborg K, Wörner T, Dijkstra HP. Consensus recommendations on the classification, definition and diagnostic criteria of hip-related pain in young and middle-aged active adults from the International Hip-related Pain Research Network, Zurich 2018. *British Journal of Sports Medicine*. 2020;54(11):631-41.

12. 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 Medicine*. 2019;49(6):951-72.

13. Kemp JL, King MG, Barton C, Schache AG, Thorborg K, Roos EM, **Scholes MJ**, 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. *British Journal of Sports Medicine*. 2019;53(19):1204-5. (Editorial).

14. Kemp JL, Grimaldi A, Heerey JJ, Jones DM, **Scholes MJ**, Lawrenson P, Coburn SL, 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 Practice & Research: Clinical Rheumatology*. 2019;33(1):66-87.

Presentations (invited speaker) during PhD candidature

1. **Scholes MJ.** Biomechanics in hip and groin pain, *University College London/Institute of Sport Exercise and Health (UK), Lecture (online), December 2021*.

2. **Scholes MJ.** Lower-limb biomechanics: considerations for injury rehabilitation, *Australasian College of Sport and Exercise Physicians*, *Lecture (online), August 2020.*

3. **Scholes MJ.** Exercise for intra-articular hip pain, *Australasian College of Sport and Exercise Physicians*, *Lecture (online), July 2020.*

4. **Scholes MJ.** Assessment and management of hip and groin pain, *Osteopathy Australia Hip Masterclass, Melbourne, Australia, August 2019.*

5. **Scholes MJ,** Heerey JJ. Assessment and management of hip and groin pain, *United Physiotherapy Masterclass,* M*elbourne, Australia, July 2019.*

6. **Scholes MJ.** Biomechanical characteristics of athletic hip pain, *La Trobe Sport and Exercise Medicine Research Centre Early OA Symposium, Melbourne, Australia, April 2019.*

7. **Scholes MJ.** Managing hip and groin pain in the adolescent athlete, *Sports and Exercise Medicine Student Association (SEMSA) Annual Conference, Melbourne, Australia, October 2018.*

Research training and contribution to data collection during PhD Candidature

Throughout my PhD candidature, I undertook advanced training in methodologies for studies of clinimetrics, imaging, and biomechanics. I completed the Amsterdam University Medical Centre Clinimetrics course, led by world-leading experts Associate Professor Caroline Terwee and Professor Raymond Ostelo. Additional training in clinimetrics methodology was provided by Associate Professor Joanne Kemp during my candidature. Training in methodology for the analysis of imaging data was provided by Dr Rintje Agricola (Erasmus University Medical Centre) and Dr Joshua Heerey, who are experts in the study of hip joint bony and soft tissue morphology. Training in biomechanical data collection and processing was provided by three experienced post-doctoral research fellows: Dr Benjamin Mentiplay, Dr Anthony Schache, and Dr Matthew King. Dr Anthony Schache, whose musculoskeletal model was used for biomechanics studies in this thesis, provided additional mentorship throughout my PhD candidature.

During my PhD candidature, I made extensive contributions to data collection and management for the Femoroacetabular impingement and hip osteoarthritis cohort (FORCe) study. I was the project manager for the FORCe study for a period of three years, coordinating data collection at four timepoints (baseline and 6, 12, and 24 months). I recruited two-thirds of participants in the FORCe cohort (n>100), employing various recruitment strategies including social and print media advertising, widespread email distribution throughout football leagues in Victoria, and in-person education sessions at football clubs. I screened more than 250 potential participants over the phone or in-person. Of the participants that attended La Trobe University for the baseline and 2-year follow up testing sessions, I was the primary person collecting data for more than one-third (n>60) at baseline and 90% (n=35) at 2-year. During in-person testing sessions, which were of at least three hours duration, I administered numerous clinical and functional performance tests, and collected biomechanical data for a variety of tasks (e.g., walking, running, and jumping). For the running biomechanics data, I processed all marker trajectory and ground reaction force data. In total, I labelled, cleaned, processed, and comprehensively checked more than 928 running trials over 18 months, equating to more than 1000 hours of biomechanics data processing.

INTRODUCTION

Chapter 1. Introduction

1.1. Thesis overview

Hip and/or groin (hip/groin) pain is common in football players (1-5). To date, knowledge of self-reported burden (i.e., symptom severity and perceived functional impairments, activity limitations, and participation restrictions) is limited in football players with hip/groin pain. Hip-related pain conditions, such as femoroacetabular impingement (FAI) syndrome, have specific bony or soft-tissue imaging findings and may be common in athletes with long-standing hip/groin pain (6). The severity of bony morphology and soft tissue findings might affect self-reported burden in symptomatic football players. The way that players move during sporting endeavours might also contribute to the development and severity of symptoms. Therefore, this thesis aims to describe self-reported burden in symptomatic football players and explore the relationship between physical features of hip/groin pain (e.g., hip joint structure and biomechanics) and self-reported pain, symptoms, and physical impairment.

This chapter will provide an overview of hip joint anatomy and discuss the classification of hip-related and groin pain entities, including a specific focus on the epidemiology, clinical presentation, and diagnosis of hip-related pain conditions. The assessment of self-reported hip/groin burden using patient reported outcome measures (PROMs) will then be described, and the relationship between hip joint imaging findings and reported burden will be explored. Finally, knowledge of lower-limb biomechanics in athletes with hip/groin pain will be discussed.

1.2. Functional anatomy of the hip joint

The hip joint is a synovial ball-and-socket joint formed by the head of the femur and the acetabulum. The hip joint allows movement in the three anatomical planes: flexion/extension (sagittal plane), abduction/adduction (frontal plane), and internal/external rotation (transverse plane). The primary role of the hip joint is to transmit gravitational and ground reaction forces (GRFs) to afford movement and bear loads during upright standing, locomotion, and other daily tasks.

The acetabulum is formed by the three pelvic bones (ilium, ischium, pubis) and faces laterally, anteriorly, and inferiorly **(Figure 1.1)**. A horseshoe-shaped portion of the periphery of the acetabulum (i.e., the lunate surface) is covered with hyaline (articular) cartilage and articulates with the femoral head (7). The acetabular labrum is a fibrocartilaginous wedge that is attached to and traverses the acetabular rim, and is joined inferiorly by the transverse acetabular ligament (7, 8). The labrum deepens the acetabulum, delivers proprioceptive feedback, and assists with the distribution of joint contact stresses by maintaining a negative intra-articular pressure (7, 8).

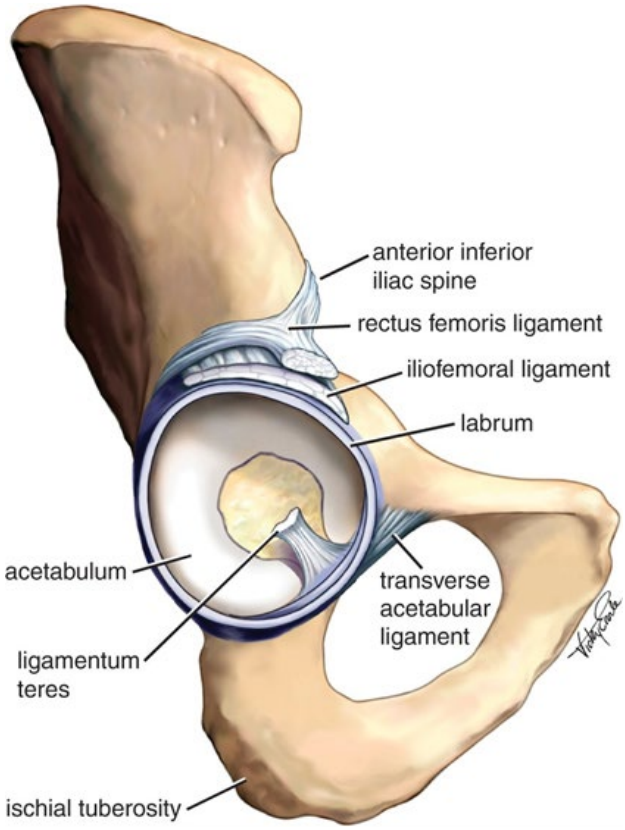


Figure 1.1. The acetabular aspect of the hip joint, including the acetabulum, acetabular labrum, and ligamentum teres.
Source: Brukner & Khan (2017) (9). Reproduced with permission.

The femoral head, which attaches to the femoral neck, has a much larger articular surface than the acetabulum. The orientation of the femoral neck with respect to the femoral shaft determines the projection of the femoral head superiorly, medially, and anteriorly toward the acetabulum. In the frontal plane, the angle between the long axes of the femoral neck and shaft (angle of inclination) determines the superomedial projection. In the transverse plane, the angle between the axes of the femoral neck and femoral condyles (angle of torsion) determines the anterior projection of the femoral head. In upright standing, the anterior superior femoral head is exposed due to the relative incongruence between the femoral head and acetabulum, with the structure of the joint capsule and capsular ligaments reflecting this (7) **(Figure 1.2)**. The dense fibrous joint capsule is thickened anterosuperiorly and reinforced anteriorly by the iliofemoral and pubofemoral ligaments, collectively acting to resist hip joint extension and external rotation in standing (7, 10). The posteriorly-located ischiofemoral ligament reinforces the joint capsule during internal rotation in neutral hip positions and in combined hip flexion-adduction (10). The intra-articular, but extra-synovial, 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 (7, 10, 11). Dynamic support for the passive capsuloligamentous structures is also provided by surrounding hip and groin muscles (7).

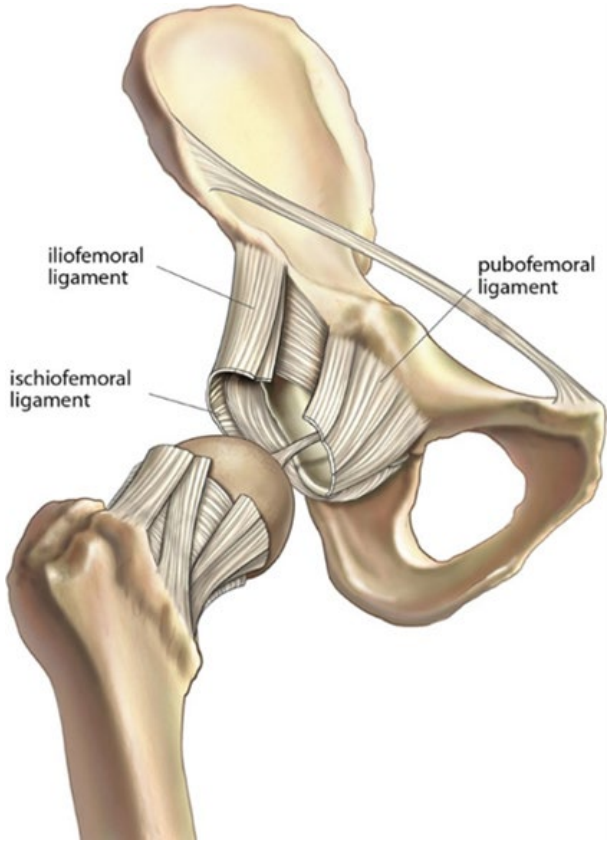


Figure 1.2. Capsular ligaments of the hip.
Source: Brukner & Khan (2017) (9). Reproduced with permission.

1.2.1 Development of cam morphology

The development of the femoral head and neck during skeletal maturation is determined by the relative activity of the three growth zones: the longitudinal growth plate of the neck, the trochanteric growth plate, and the femoral neck isthmus (12). The growth zones determine the length of the femur, the width and length of the femoral neck, the size of the femoral head and greater trochanter, and the neck-shaft angle (12). Skeletal growth in these zones can be stimulated or inhibited by genetic, hormonal, biological (e.g., inflammation or infection), or biomechanical factors (12). Imbalance between the growth rates of the three zones may lead to abnormal or incongruent hip joint morphology (12).

Primary cam morphology is the presence of additional bone on the anterosuperior femoral neck that develops during skeletal maturation (13-16). Cam morphology can be seen in those as young as 12 years (13, 14, 16), with cartilaginous changes preceding cam morphology evident in those even younger (16). Importantly, cam morphology appears to develop almost exclusively whilst the longitudinal growth plate of the neck is open (13, 14, 16). Whilst the aetiology of cam morphology is not entirely understood, epiphyseal cartilage hypertrophy and extension in response to high-volume high-impact physical activity (e.g., football) are proposed mechanisms (13, 14, 16). Cam morphology is prevalent in athletes (17), including football players (18), and over time may contribute to the development of hip/groin pain and hip joint disease.

1.3. Epidemiology of hip/groin pain in football players

Football (soccer) is the most popular sport worldwide, with over 400 million active players (19). In Australia, more than 3.5 million people participate in football or Australian football (20, 21). Football players may be injured during training and match play, with lower-limb injuries most frequently reported (22-25). Hip/groin injuries are particularly common in both football codes (22-24, 26, 27) and can be categorised as time-loss (i.e., a player is unable to participate fully in training or match play) or non-time-loss.

Hip/groin injuries are more common in male than female football players (1, 27), accounting for up to 18% and 9% of all time-loss injuries, respectively (1, 27-30). Injury frequency can also be described by its incidence (i.e., the number of new injuries). The incidence of hip/groin injuries ranges from 0.8 to 2.0 per 1000 hours for male football

players (4, 24, 27-29, 31) and 0.4 per 1000 hours for women (23, 27). For male Australian football players, hip/groin injuries accounted for 11% of all time-loss injuries, with a 10-season average incidence of 3.2 groin and 0.9 hip injuries per club per season (26, 32). Female Australian football players had a lower incidence of hip/groin injuries than men (0.4 combined hip/groin injuries per club per season) (25), consistent with findings from football.

The severity of hip/groin injury can be quantified by time-loss duration. Nearly 60% of hip/groin injuries in male football players resulted in moderate (8 to 28 days) or severe (>28 days) time loss from training or match play (29, 30). Compared to men, fewer female football players (11%) report moderate or severe time-loss injuries (1). For male Australian football players, hip/groin injuries resulted in 16.2 missed games per club per season (26). Female Australian football players recorded less than one missed game per club per season (25); however, the shorter women's season (8-weeks vs 22-weeks) may affect this finding.

Importantly, not all hip/groin injuries result in time loss (1-5). For example, 53% of male sub-elite football players reported hip/groin pain in one season, yet time-loss injury accounted for only 11% of these players (4). Furthermore, more than one third of football players per season have reported impaired training and match performance due to non-time-loss hip/groin pain (1, 3). These findings suggest that hip/groin pain is prevalent in football players, yet its burden is likely underestimated when using time-loss measures.

The Doha agreement (33), a clinical examination-based classification system for groin pain, has been used to characterise hip/groin conditions in male football players **(Figure 1.3)**. Adductor-related groin pain was the most common entity reported, accounting for 62 to 68% of all hip/groin injuries in male football players (28-30). Iliopsoas (8 and 12%), inguinal (4 and 8%), pubic (3 and 9%), and other causes (3 and 18%) of hip/groin pain were less likely (29, 30). Although hip-related time-loss injury was rarely reported in male football players (1 and 4%) (29, 30), it has been found in up to 64% of athletes seeking treatment for longstanding (>6-weeks) hip/groin pain (6), suggesting hip-related pain conditions maybe more prevalent in football players than previously reported.

The Doha agreement has not been used to classify hip/groin injuries in Australian football players or female football players.

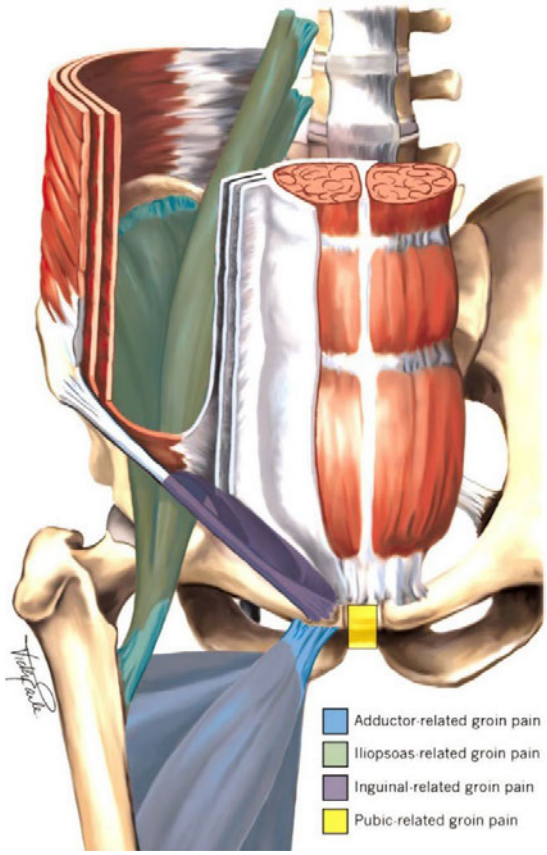


Figure 1.3. Defined groin pain entities according to the Doha agreement.
Figure adapted from Weir et al. (2015) (33).

1.4. Classification of hip/groin pain

Diagnosing hip/groin pain in athletes is challenging (34), complicated by the close proximity of bony, musculotendinous, and articular structures; the limited usefulness of clinical tests; and the potential for concurrent problems (6, 30, 33-39). Complexity is added by the numerous diagnostic terms used to describe similar conditions (40-42). For example, a recent study with 21 groin pain experts reported up to 11 different diagnoses for each clinical case that was presented (42). Different diagnoses for the same hip/groin condition confuse clinicians and patients alike, and limits knowledge of treatment efficacy (40). Furthermore, the language used by clinicians might affect the way that patients perceive their condition and impact their self-efficacy, treatment decision-making, and pain behaviours (43).

Elements of hip/groin pain taxonomy have been addressed through various consensus statements from research groups around the world (33, 38, 44-46). The Doha Agreement Meeting (2014) included 21 international experts who recommended classifying groin pain in athletes according to three major subheadings: 1) defined clinical entities for groin pain

(including adductor-related, iliopsoas-related, inguinal-related, and pubic-related groin pain), 2) hip-related groin pain, or 3) other causes of groin pain (33). Describing hip-related groin pain in more depth was beyond the scope of the Doha Agreement Meeting (33). 'Non-arthritic hip joint pain', a term used to described a collection of intra-articular hip joint conditions (e.g., femoroacetabular impingement, structural instability, and labral tears), was first proposed by experts from the American Physical Therapy Association in 2014 (46). Subsequent meetings by other expert groups further refined these classifications. The Warwick Agreement (2016) on FAI syndrome included 22 clinical and research experts and provided consensus statements regarding terminology, assessment, treatment, and future research needs for FAI syndrome (45). In 2018, 38 international experts involved in research and/or clinical practice in the field of hip-related pain met for the International Hip-related Pain Research Network (IHiPRN) meeting (38). 'Hip-related pain' was recommended as the overarching term to define non-arthritic pain originating from the hip joint. Hip-related pain could be further categorised according to three conditions: 1) FAI syndrome, 2) acetabular dysplasia and/or hip instability, and 3) other hip conditions without distinct osseous morphology (e.g., chondral, labral, and ligamentum teres findings). Classification of hip-related pain entities requires imaging; however, it is possible that hip/groin pain may occur without imaging evidence of pathology (38). **Figure 1.4** summarises the hip-related pain and groin pain taxonomy. The following sections will provide an overview of hip-related pain (38).

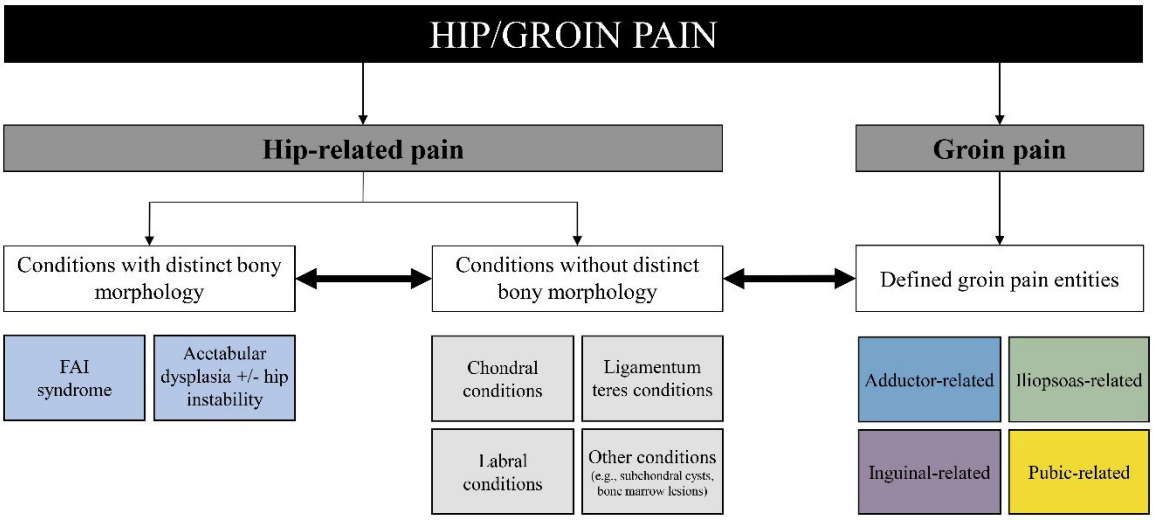


Figure 1.4. Summary of hip/groin pain classifications.
Horizontal black arrows indicate that hip-related conditions and groin pain entities may co-exist. Abbreviation: FAI = femoroacetabular impingement. Figure adapted from Weir et al. (2015) (33) and Reiman et al. (2020) (38). 'Inguinal-related pain' was an updated term from 'inguinal disruption', which was previously proposed by experts from the British Hernia Society (44).

1.5. Hip-related pain

Hip-related pain is the recommended term to describe non-arthritic hip disease in young and middle-aged active adults (38). Hip-related pain excludes serious hip joint conditions (e.g., tumour, infection, stress fracture, or slipped capital femoral epiphysis) and is distinct from non-musculoskeletal or other musculoskeletal conditions (e.g., lumbar spine) that may cause hip pain (38). Using imaging findings, hip-related pain conditions can be classified into three categories: 1) FAI syndrome, 2) acetabular dysplasia and/or hip instability, and 3) other hip conditions without distinct osseous morphology (e.g., chondral, labral, and ligamentum teres findings) (38). These can occur in isolation or co-exist with other hip-related or groin pain entities (6, 33, 38) **(Figure 1.4)**. The clinical classification of groin pain entities and hip-related pain conditions is summarised in **Table 1.1** at the end of **Section 1.5.**

1.5.1 Femoroacetabular impingement (FAI) syndrome

Femoroacetabular impingement syndrome is a clinical condition caused by premature contact between the proximal femoral head-neck junction and the acetabulum that is associated with hip-related pain, chondrolabral damage, and hip osteoarthritis (OA) (45, 47, 48). Although awareness of the pathomechanical process dates back over 50 years (49), clinical and research interest in FAI syndrome increased after Ganz et al. (2003) formally defined the condition (47). In 2013, five essential elements of FAI syndrome were proposed: 1) abnormal morphology of the proximal femur and/or acetabulum, 2) abnormal contact between these two structures, 3) especially vigorous supraphysiological motion resulting in such abnormal contact and collision, 4) repetitive motion resulting in the continuous insult, and 5) the presence of soft tissue damage (48). As early classifications of FAI syndrome (47, 48) underemphasised the importance of symptoms for diagnosis, the 2016 Warwick Agreement on FAI syndrome (45) further defined the condition as a "motion-related clinical disorder of the hip with a triad of symptoms, clinical signs, and imaging findings." Symptoms, now essential to diagnose FAI syndrome, may represent the underlying premature contact between the proximal femur and acetabulum (45).

Symptoms and positive clinical examination and imaging findings are required to diagnose FAI syndrome (45). Anterior hip/groin pain is the primary symptom of FAI syndrome (45, 50), but pain can be reported in the lateral hip, buttock, anterior and posterior thigh, and

lumbar region (50, 51). Pain is usually of insidious onset and can be aggravated by activity or sustained postures such as sitting (50). Mechanical symptoms such as clicking, locking, and catching may also be associated with FAI syndrome (45, 50). Clinical examination may identify limited hip range of motion (ROM) (45); however, evidence of this is conflicting (52, 53). The flexion-adduction-internal rotation (FADIR) **(Figure 1.5)** and flexion-internal rotation tests are commonly used to aid diagnosis of FAI syndrome and cartilage and labral conditions (38, 54); however, their high sensitivity but low specificity means they are most effective as screening tests (i.e., excluding FAI syndrome and/or chondrolabral pathology with a negative test result) and cannot be used to diagnose any hip-related conditions (38, 45, 54, 55). Finally, FAI syndrome is confirmed and classified by the bony morphology that is present, such as: 1) cam morphology, 2) pincer morphology, or 3) mixed (both cam and pincer) morphology **(Figure 1.6)** (15, 38, 56). Cam morphology is characterised by additional bone at the anterosuperior aspect of the proximal femur that results in a non-spherical femoral head (47, 57). Pincer morphology is over-coverage of the femoral head caused by increased depth and/or altered orientation of the acetabulum (47, 56, 58). Cam and pincer morphology may be associated with unique patterns of acetabular chondrolabral damage. Contact between the prominent femoral-head neck junction and the acetabulum (i.e., cam impingement) has been associated with chondrolabral damage in the superolateral region of the acetabulum (59-62), whereas pincer impingement has been associated with circumferential chondrolabral damage to the acetabulum (47, 62). Labral and chondral conditions often co-exist with FAI syndrome (38), and more detail about these conditions is contained in **Section 1.5.3**. Cam and/or pincer morphology can be identified using radiographs, magnetic resonance imaging (MRI), or computed tomography (CT) (38, 45, 56, 58, 63).

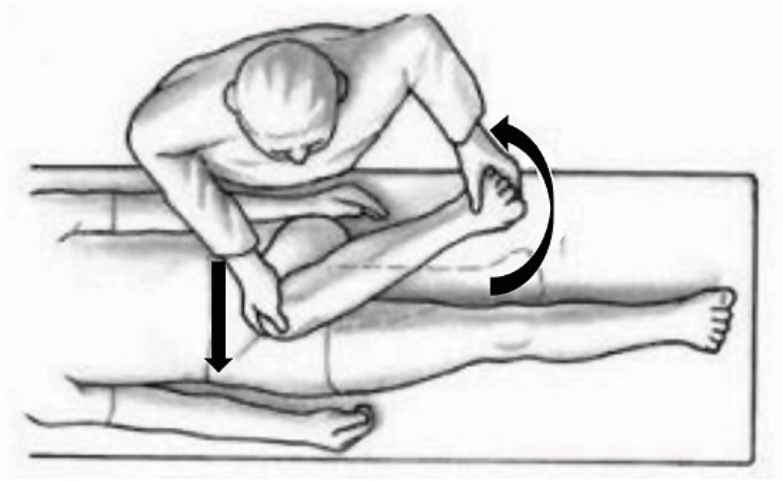


Figure 1.5. The flexion-adduction-internal rotation test.
Figure adapted from Tannast et al. (2007) (58).

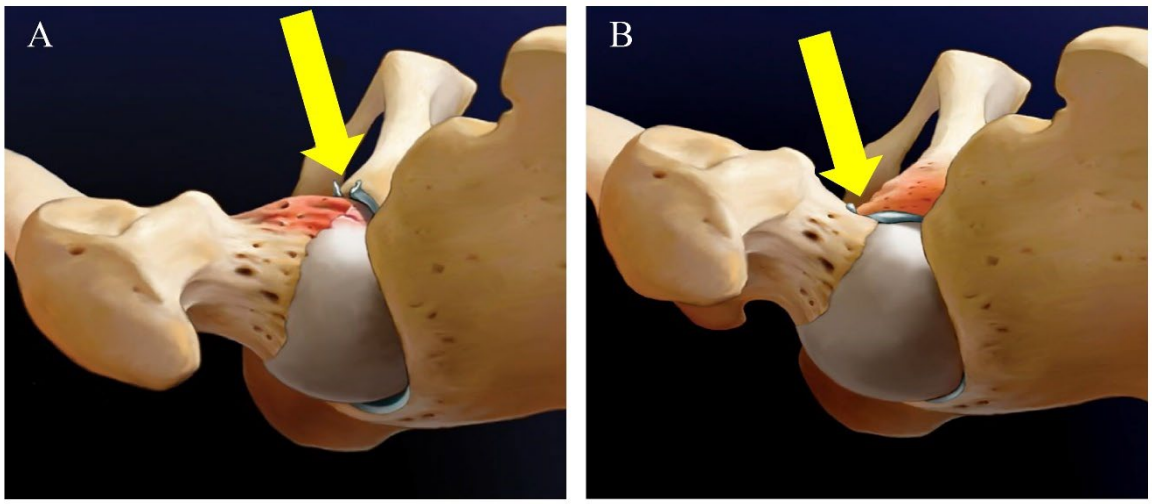


Figure 1.6. Femoroacetabular impingement syndrome with cam (A) or pincer (B) morphology.
Source: Brukner & Khan (2017) (9). Reproduced with permission.

Anteroposterior pelvis (AP) and Dunn 45° radiographs are recommended as the initial imaging methods to diagnose FAI syndrome (56). Radiographic evaluation may be complemented with MRI and CT to assess the bony and soft tissue anatomy of the proximal femur and acetabulum more comprehensively (56). Cam morphology size (i.e., the magnitude of femoral head neck asphericity) is quantified using the alpha angle **(Figure 1.7)** (38, 56, 57). An alpha angle ≥60° is recommended to define cam morphology in men and women (38, 56, 64), although various alpha angle threshold values (50° to 86°) have been used (17, 64, 65). Cam morphology can also be described using the femoral offset (i.e., the width of the femoral head-neck junction relative to the femoral head) and femoral offset ratio; however, the validity of these measures is unclear and they are rarely used in research or clinical practice (56, 63). Acetabular morphology can be described by the magnitude of coverage of the femoral head (e.g., centre-edge-of-Wiberg, lateral-centre-edge-angle (LCEA), and protrusio acetabuli) and orientation (e.g., crossover sign, posterior wall sign) (56, 63, 66). The centre-edge-angle (Wiberg or lateral) is a commonly used measure, with a threshold value of 40° (i.e., ≥40°) used to identify pincer morphology (63). The LCEA is depicted in **Figure 1.7**.

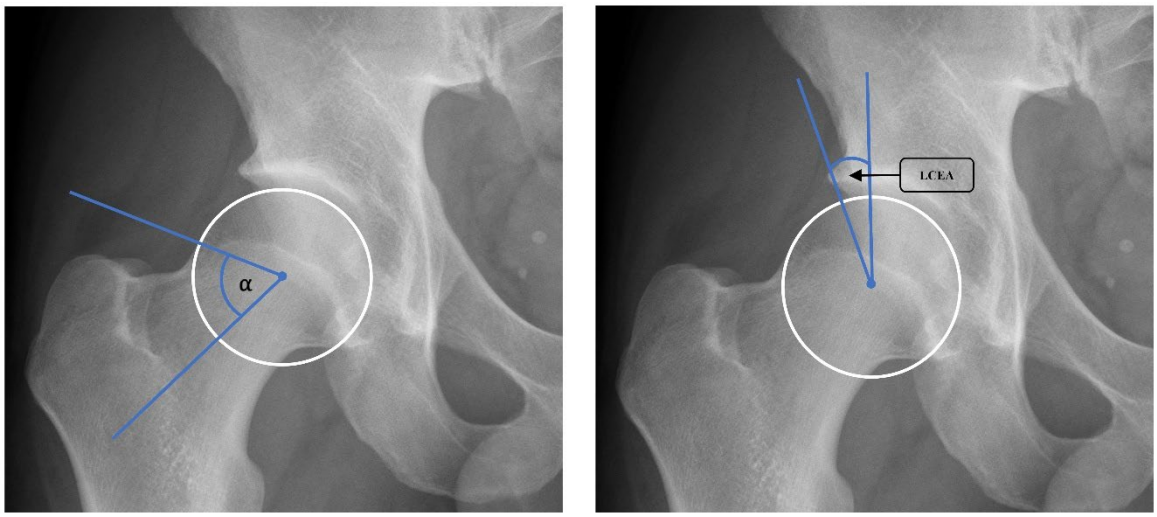


Figure 1.7. The alpha angle (α) and lateral-centre-edge-angle (LCEA) measured using the anteroposterior radiograph.

Few studies have reported the prevalence of FAI syndrome (i.e., symptoms, clinical signs, and imaging findings) in any population. Whilst FAI syndrome was common in athletes who sought treatment for persistent hip/groin pain (up to 45% of men and 21% of women) (6), its prevalence in the general population appears considerably less (67, 68). The prevalence of cam and pincer morphology has been studied in greater detail than that of FAI syndrome (17, 69, 70), but knowledge of cam morphology prevalence is limited by the variable threshold values and imaging methods used (65). Two systematic reviews pooled data from heterogenous studies, reporting that cam morphology was present in up to 66% of athletes, 23% of asymptomatic non-athletes, and 49% of symptomatic non-athletes (69, 70). A third systematic review, which did not pool study findings, reported cam morphology prevalence ranging from 5 to 75% in athletes and people with and without hip/groin pain (17). Sex-based differences in cam morphology prevalence may exist, with cam morphology seemingly more common in men (29 to 58%) than women (5-36%) (17, 68, 71). For pincer morphology, knowledge of its prevalence is similarly limited by heterogenous classifications across studies (65). Two systematic reviews reported that pincer morphology was common in asymptomatic non-athletes (57%) and athletes (51%), but less prevalent in people with hip/groin pain (29%) (69, 70). Pincer morphology appears to be equally prevalent in men and women (65).

1.5.2 Acetabular dysplasia and/or hip instability

Hip dysplasia refers to misalignment of the femoral head and the acetabulum secondary to changes in their size, shape, and orientation (72). Altered bony anatomy at the acetabulum

and subsequent structural instability of the femoral head may be associated with increased joint contact stresses, chondrolabral damage, and hip OA (72-76). Hip instability refers to painful, extra-physiologic hip motion with or without symptoms of joint unsteadiness (73, 77). The aetiology of hip instability may involve altered bony anatomy, systemic connective tissue disorders (e.g., Ehlers-Danlos syndrome), iatrogenic causes (e.g., surgery), or deficits in the capsuloligamentous, intra-articular, or musculotendinous structures (72, 73, 77). Labral and chondral conditions often co-exist with acetabular dysplasia and hip instability (38), and more detail about these conditions is contained in **Section 1.5.3**.

The usefulness of clinical tests to diagnose acetabular dysplasia and/or hip instability are limited (78). Imaging modalities such as radiographs, CT, or MRI can aid diagnosis by determining acetabular orientation and coverage of the femoral head (72, 78). The LCEA quantifies superolateral coverage of the femoral head by the acetabulum **(Figure 1.7)**, where an LCEA <20° indicates acetabular dysplasia (72). In contrast, no established imaging criteria exist for hip instability (38, 73). The prevalence of radiographic signs of acetabular dysplasia (defined by LCEA <20°) ranges from 3.1 to 3.9% in European adults from the general population (79-81). Acetabular dysplasia appears equally as prevalent in men and women (79-82), and those with and without symptoms (79, 82, 83). In athletes, the prevalence of radiographic findings of acetabular dysplasia varies across different sports (ranging from 1.7 to 37%) (18, 84-86), with reported prevalence in football players ranging from 1.9 to 16.7% depending on ethnicity (18).

Acetabular dysplasia and hip instability are uncommon in football players (18), hence this thesis will focus on FAI syndrome with cam morphology.

1.5.3 Hip conditions without distinct osseus morphology

Hip-related pain may be associated with isolated or combined intra-articular pathologies, such as bone marrow oedema, effusion-synovitis, subchondral cysts, paralabral cysts, intra-articular bodies, and chondral, labral, and ligamentum teres conditions (38, 87). Magnetic resonance imaging can be used to identify these pathologies; however, they are difficult to distinguish from incidental findings in asymptomatic people (38, 88, 89). Most of these pathologies, except chondral, labral, and ligamentum teres conditions, have uncertain clinical presentations, diagnostic criteria, and prevalence and hence were not defined as

hip-related pain conditions by experts from the IHiPRN (38). Ligamentum teres tears are difficult to diagnose using unenhanced MRI (90) and thus are not a focus of this thesis. As such, the clinical presentation, diagnosis, and epidemiology of chondral and labral conditions are described in the sections below.

(i) Chondral conditions

Chondral conditions (e.g., cartilage defects) can occur in the articular cartilage of the femoral head and acetabulum (38, 60, 91). Healthy articular cartilage is avascular, aneural, and devoid of lymphatic vessels, with limited capacity to repair its structure or generate symptoms (92-95). Progressive chondral damage, however, can generate nociception through secondary mechanisms, such as exposing richly innervated subchondral bone or releasing inflammatory mediators that stimulate synovitis (93-95). Mechanical forces in the hip joint may affect cartilage health, with the anatomical location and severity of damage to the articular surfaces associated with specific femoral or acetabular bony morphologies (59-62). For example, anterosuperior acetabular cartilage damage is often evident in hips with cam morphology (59-62), whereas circumferential cartilage damage may be found in those with pincer morphology (62). Articular cartilage health may also be affected by systemic factors (94), with demographic features such as increasing age (60, 96, 97), male sex (60, 96, 97), increasing body mass index (BMI) (96), and level of physical activity (60) associated with cartilage defects.

It is not known if people with chondral conditions exhibit specific clinical signs and/or symptoms (38). Given that chondral conditions frequently co-exist with other hip-related pain conditions, it is likely that their clinical profiles would overlap (38). Chondral conditions are highly prevalent in adults undergoing hip surgery (60, 98, 99) and whilst hip arthroscopy is often used to assess chondral conditions, imaging modalities offer alternative methods to identify chondral defects in those not seeking surgery.

Magnetic resonance imaging is the preferred modality to assess chondral morphology and composition (100, 101), but its use is complicated by the deep location of the hip joint, and the thin, curved, and closely apposed femoral and acetabular chondral surfaces **(Figure 1.8)** (100). High-resolution MRI can accurately determine the presence of chondral conditions (102-104) and circumvents the risks associated with using contrast-based imaging techniques such as magnetic resonance arthrogram (100, 102, 104). High-resolution MRI provides sufficient tissue contrast to measure change to chondral morphology (i.e., the

severity of chondral defects) using semi-quantitative measures (87, 100, 105). Specific MRI techniques such as delayed gadolinium enhanced MRI of cartilage (dGEMRIC) and T2 and T1rho mapping can evaluate the biochemical composition of articular cartilage, with studies continuing to investigate their research and clinical utility for the hip joint (100, 106-108).

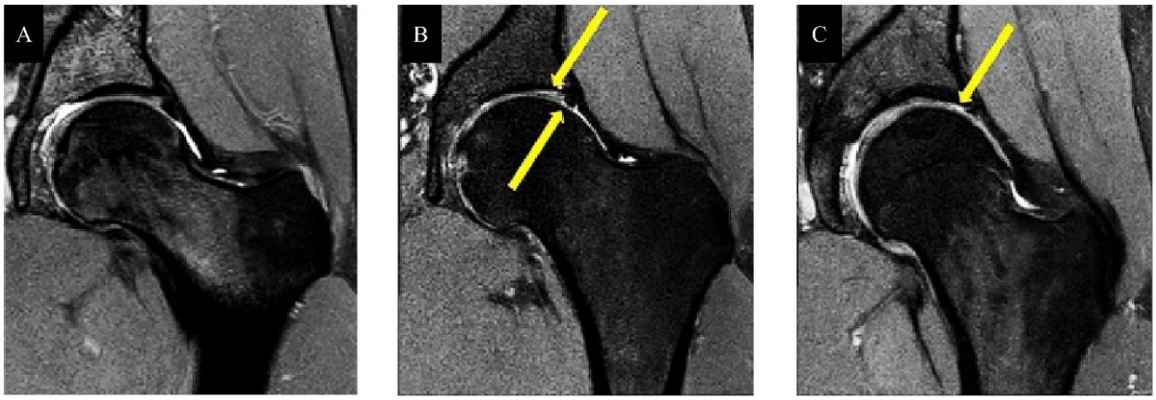


Figure 1.8. Articular cartilage conditions seen using magnetic resonance imaging.
A) no cartilage defect, B) partial thickness femoral and acetabular cartilage defects, and C) full thickness acetabular cartilage defect. Figure adapted from Heerey (2021) (109).

Knowledge of the prevalence of imaging-defined chondral conditions in people with hip/groin pain is limited. In a recent systematic review of 19 studies by Heerey et al. (2018) (89), cartilage defects were more prevalent in people with hip/groin pain (64%) than without (12%). Another review reported similar findings in athletes with and without pain, albeit fewer cartilage defects were observed overall (88). Whilst chondral defects may be associated with pain status, the poor methodological quality of the included studies limited the findings from both reviews (88, 89). The prevalence of chondral conditions may differ between men and women, with studies of surgical populations reporting that severe chondral pathology was more common in men than women (60, 97).

(ii) Labral conditions

Labral conditions (e.g., labral tears), which commonly occur in the superior and anterosuperior quadrant of the acetabulum, may be a source of nociception (110, 111). Labral conditions can be classified by their location, morphology (e.g., radial flap, radial fibrillated, or longitudinal peripheral), and aetiology (111). The aetiology of labral conditions may be multifactorial, involving joint trauma, congenital hip conditions (e.g., developmental dysplasia of the hip), degeneration, capsular laxity (focal or systemic), or cam or pincer morphology (110, 111). Groin and/or anterior hip pain is the most common

symptom in people with acetabular labral tears and may occur with or without mechanical symptoms such as clicking, locking, or catching (38, 110, 111).

Accurately diagnosing labral conditions is challenging and patients' subjective, physical, and imaging findings should be considered (38, 110). Clinical tests for labral conditions are the same as for FAI syndrome and are similarly sensitive but not specific, indicating greater value as screening tests (i.e., excluding labral tears with a negative test result) than to confirm labral tear presence (35, 38, 110). The FADIR (**Figure 1.5**) and flexion-internal rotation tests may be the most useful tests to exclude labral conditions (35, 38), but no tests can distinguish labral tears from FAI syndrome nor chondral conditions. Magnetic resonance imaging, with its excellent soft tissue contrast, is recommended to assist the diagnosis of labral conditions (38, 110). Magnetic resonance arthrogram (i.e., contrast-enhanced MRI) may afford better diagnostic accuracy than conventional MRI for labral conditions (38, 104, 112); however, high-resolution unenhanced MRI has recently demonstrated equivalent accuracy **(Figure 1.9)** (102, 113, 114).

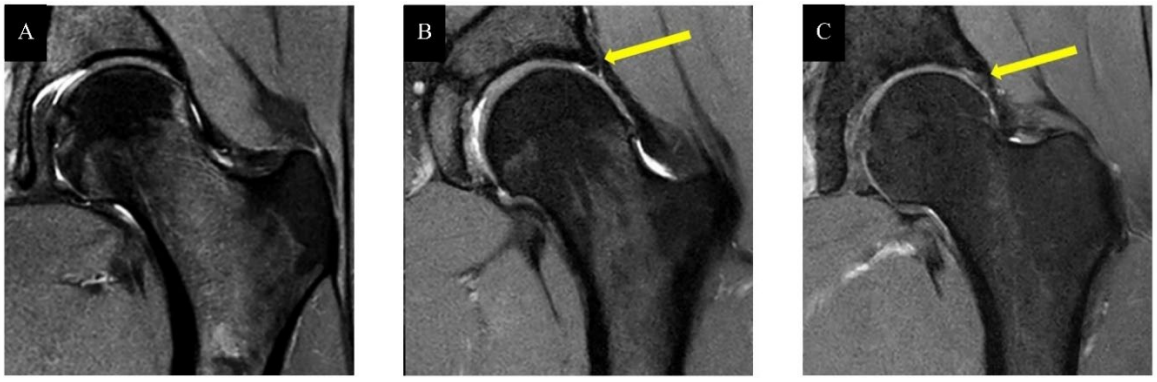


Figure 1.9. Labral conditions seen using unenhanced magnetic resonance imaging.
A) no labral tear, B) labral tear with chondrolabral separation, and C) labral tear with maceration. Figure adapted from Heerey (2021) (109).

Labral tears identified using MRI are common in people with and without hip/groin pain (88, 89). The recent systematic review and meta-analysis by Heerey et al. (2018) (89) reported that 62% of adults with hip/groin pain had MRI-defined labral conditions; however, 54% of asymptomatic people had similar labral findings. Interestingly, a review of athletes found that labral tears were more common in asymptomatic than symptomatic hips (33% vs 20%, respectively) (88). Although labral tears can be associated with hip/groin pain, their high prevalence in asymptomatic athletes clouds understanding of this relationship. More knowledge of the effect of labral tears on symptom severity is needed in those with hip/groin pain.

Table 1.1. Clinical classification of groin pain entities and hip-related pain conditions.

Nomenclature	Classification (symptoms and signs)	Utility of clinical tests	Potential imaging
Clinical groin pain entities			
Adductor-related groin pain	*Classification:* Pain in the adductor region AND adductor tenderness AND pain with resisted adduction testing *Other symptoms/signs:* Pain with adductor stretching	*Good intra- and inter-observer reliability (115) *Excellent accuracy (positive and negative predictive values >90%) for acute adductor injury (116)	Ultrasound MRI
Iliopsoas-related groin pain	*Classification:* Pain in the iliopsoas region AND illiopsoas tenderness (either suprainguinal or infrainguinal) AND pain reproduced with resisted hip flexion and/or hip flexor stretching *Other symptoms/signs:* Nil	*Poor evidence for identifying iliopsoas injury (positive predictive values = 34-50%) (116) *>90% negative predictive values for ruling out acute iliopsoas injury (116)	Ultrasound MRI
Inguinal-related groin pain	*Classification:* Pain in the inguinal canal region AND inguinal canal tenderness AND pain with Valsalva manoeuvre, coughing, sneezing and/or resisted abdominal muscle testing *Other symptoms/signs:* No palpable inguinal hernia found, including with invagination of the scrotum to palpate inguinal canal	*Unknown	Ultrasound
Pubic-related groin pain	*Classification:* Pain in the pubic region AND local tenderness of the pubic symphysis and the immediately adjacent bone *Other symptoms/signs:* No specific resistance test, but more likely if pain is reproduced with resisted abdominal and hip adductor testing	*Unknown	Ultrasound MRI
Hip-related pain conditions			
FAI syndrome	*Classification:* Hip/groin pain, positive clinical signs (such as positive pain provocation test result(s) and/or loss of hip ROM), and imaging evidence of cam and/or pincer morphology (45). *Other symptoms/signs:* Mechanical clicking, locking, or catching	*High sensitivity and low specificity of the FADIR and FIR tests indicates usefulness for ruling out FAI syndrome (including cartilage defects and labral tears) (54) FADIR: sensitivity = 94-99%; specificity = 5-9% FIR: sensitivity = 96%; specificity = 25%	Radiograph MRI MRA CT
Hip dysplasia and/or instability	*Classification (Hip dysplasia):* Hip/groin pain with imaging evidence of altered size, shape, and/or orientation of the acetabulum or femoral head *Classification (Instability):* Hip/groin pain with extra-physiologic hip motion (no imaging criteria exist) *Other symptoms/signs:* Symptoms of joint unsteadiness	*Unknown (Knowledge of diagnostic accuracy of clinical tests is limited due to the low methodological quality of diagnostic accuracy studies (78))	Radiograph MRI CT
Chondral conditions	*Classification:* Hip/groin pain AND imaging evidence of articular cartilage defect(s) *Other symptoms/signs*: Presentation may overlap with other hip-related pain conditions	As per "FAI Syndrome"	MRI CT
Labral conditions	*Classification:* Hip/groin pain AND imaging evidence of labral tear(s) *Other symptoms/signs*: Mechanical clocking, locking, or catching. Presentation may overlap with other hip-related pain conditions	As per "FAI syndrome"	MRI MRA CT

Abbreviations: CT = computed tomography; FADIR = flexion-adduction-internal rotation; FAI = femoroacetabular impingement; FIR = flexion-internal rotation; MRA = magnetic resonance arthrogram; MRI = magnetic resonance imaging. Table adapted from Weir et al. (2016) (33), Thorborg et al. (2018) (34) and Reiman et al. (2020) (38).

1.6. Hip-related pain and hip osteoarthritis

Osteoarthritis is a disease of the whole synovial joint that can ultimately cause joint failure (93-95). Hip OA is associated with pain, disability, and markedly reduced quality of life (QOL) (93), leading to significant socioeconomic burden (117). Hip OA is characterised by changes to the articular cartilage morphology and/or composition, as well as the surrounding soft tissues, such as the synovium, ligaments, subchondral bone, and periarticular muscles (93-95). In those with advanced hip OA, treatment options are often limited to joint replacement (93-95). Given the high personal and societal costs of hip OA, early identification of at-risk individuals may afford interventions that might prevent or delay the need for total hip arthroplasty (THA).

An individual's risk of developing hip OA might be affected by "whole person" and/or joint-level risk factors. "Whole person" risk factors for hip OA might include, for example, an individual's genetics, ethnicity, increasing age, or BMI (118, 119). Hip-related pain conditions (e.g., FAI syndrome) may be associated with hip OA and could represent an early stage on the continuum from early to more severe hip joint disease **(Figure 1.10)**. The distinct bony morphologies (e.g., cam and pincer morphology) and/or chondrolabral conditions associated with hip-related pain conditions may be joint-level risk factors for the development of hip OA. Known joint-level risk factors for hip OA are discussed in the sections below.

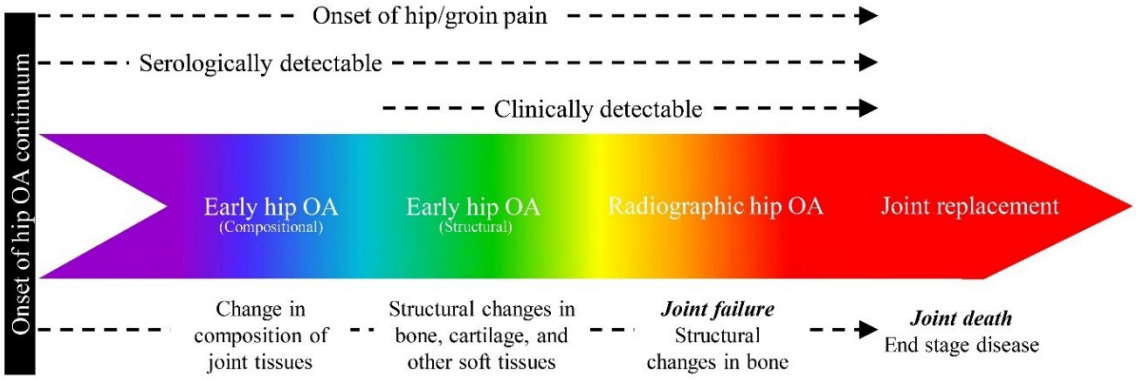


Figure 1.10. Hip osteoarthritis (OA) continuum.
Figure adapted from Hunter et al. (2013) (95).

1.6.1 Cam morphology

The relationship between cam morphology and chondrolabral changes may start as early as adolescence. For example, young athletes (n=13, mean age = 15 years) with cam

morphology had 2.5-fold increased risk of developing new or progressive MRI-defined joint changes (including labral tears, cartilage defects, os acetabuli, osteophytes, cysts, and herniation pits) over a 5-year period, when compared to those without cam morphology (120). In middle-aged and older adults (aged >45 years), findings from three large prospective studies indicate that cam morphology is a strong risk factor for hip OA (75, 76, 121). The Cohort Hip and Cohort Knee (CHECK) study investigated 1002 adults with clinical signs of early hip or knee OA (121). Participants aged 45 to 65 years underwent radiographs at baseline and at a 5-year follow up. In individuals without definite hip OA, cam morphology (alpha angle >60°) was associated with an almost 4-fold increased odds of developing end-stage hip OA (i.e., Kellgren and Lawrence (KL) grade 3 or 4 or undergoing THA). Large cam morphology (alpha angle >83) was associated with an almost 10-fold increased odds. For individuals with large cam morphology and reduced internal rotation ROM (≤20°) at baseline, their odds of developing end-stage hip OA increased 25-fold. Further analysis indicated that one in two individuals with large cam morphology and reduced hip ROM developed end-stage hip OA at 5-year follow up (121). The Rotterdam study investigated 4438 adults aged 55 years or older (75). Cam morphology (alpha angle >60°) was associated with a 2-fold increased odds of developing definitive hip OA (KL ≥2) or undergoing THA (75). The Chingford cohort investigated 1003 women aged 44 to 67 years (76). Larger cam morphology was associated with an increased odds of developing hip OA at 19-year follow up. Specifically, a one degree increase in alpha angle above 65° was associated with a 4% increase in the odds of undergoing THA (76).

1.6.2 Pincer morphology

Unlike cam morphology, the relationship between pincer morphology and hip OA is less apparent. Pincer morphology was not associated with the development of end-stage hip OA in the CHECK or Chingford cohort studies (76, 121). In the Rotterdam study, pincer morphology was associated with a 1.5-fold increased odds of developing radiographic hip OA (defined by KL≥ 2) at ≥9-years follow up, but it was unrelated to THA (75).

1.6.3 Self-reported joint injury

A review by Richmond et al. (2013) (119) found that self-reported history of hip joint injury was a risk factor for clinical or radiographic (KL >2) hip OA (odds ratio 5.0 [95% confidence interval (95%CI) 1.4, 18.2]). However, as hip injuries were not classified by

type or anatomical location, and study findings were likely affected by recall bias, it is difficult to interpret the relevance of joint injury to OA risk. Labral tears may present as an acute hip joint injury (38), but prospective studies are needed to understand their role in hip OA development.

1.6.4 Periarticular muscles and hip joint biomechanics

Exposure to heavy manual labour occupations (118) and/or high-impact physical activity such as football might accelerate the development of hip OA (122-124). For example, retired elite-level football players have a 2-fold and 3-fold increased odds of having radiographic hip OA or undergoing THA, respectively, when compared to matched non-athletic individuals (122, 125). The way that a person moves during work or sporting endeavours might affect the forces and loads experienced by joints. People with hip/groin pain have less muscular strength (52) and altered biomechanical patterns (126) when compared to controls, potentially affecting their hip joint loading and structure over time (127, 128). **Section 1.12.2** discusses known biomechanical impairments in people with hip/groin pain; however, prospective studies are needed to understand the relationships between movement patterns and the development of hip OA.

1.7. The femoroacetabular impingement and hip osteoarthritis cohort (FORCe) study

This thesis will use data collected for the femoroacetabular impingement and hip osteoarthritis cohort (FORCe) study, a prospective cohort study investigating the natural history of, and factors associated with, structural hip disease progression in football (football or Australian football) players with hip/groin pain (**Figure 1.11**). Football players have an increased lifetime risk of hip OA (122, 125), but the reason for this is unclear. Cam morphology appears to be a risk factor for hip joint disease progression, but previous reports have investigated older adults (>45 years) and outcomes such as end-stage radiographic hip OA and/or THA (75, 76, 121). Interventions that might change the natural history of hip disease are needed early in the disease process; however, factors that lead to early signs of hip joint degeneration are unknown. Radiographs are insensitive to early stages of hip disease (129), but MRI can be used to grade alterations to intra-articular soft tissue structures, such as those seen in chondral and labral conditions (87). Therefore, the FORCe study aims to 1) evaluate changes in hip joint structure using MRI over a 2-year

period, and 2) determine if baseline measures of potentially modifiable baseline factors (e.g., cam morphology, hip joint contact force, muscle strength, or joint ROM) predict worsening of joint structure over 2 years.

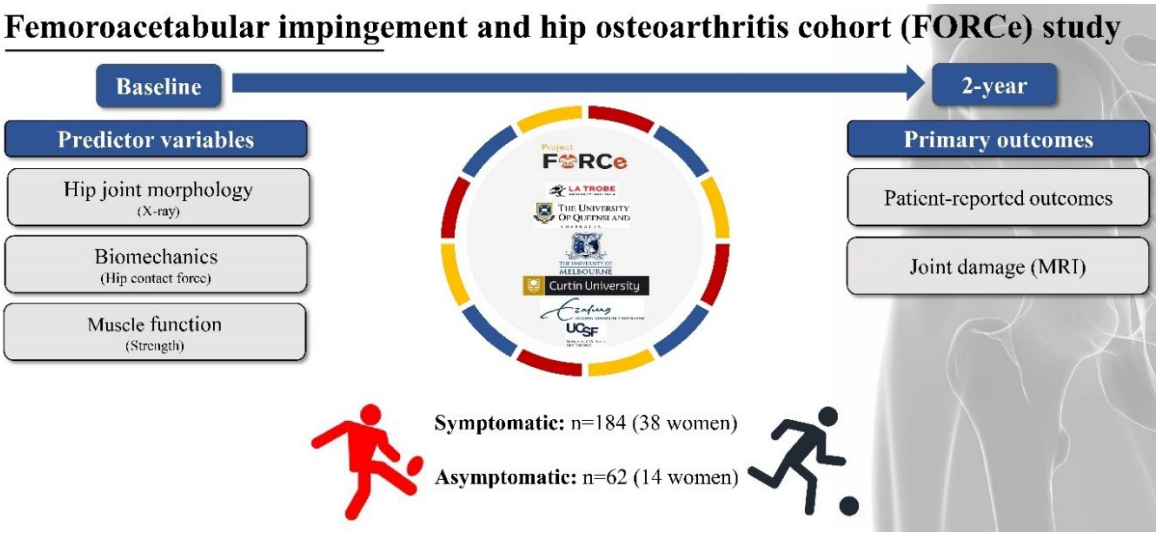


Figure 1.11. The femoroacetabular impingement and hip osteoarthritis cohort (FORCe) study.
Abbreviation: MRI = magnetic resonance imaging. Figure adapted from Crossley et al. (2018) (130).

Cross-sectional analyses using baseline data from the FORCe cohort (symptomatic n=184; asymptomatic n=55) have provided new insights into the prevalence of imaging features of hip-related pain conditions in football players. Hip joint bony morphology was similar between players with and without hip/groin pain, with no between-group differences for the prevalence of cam morphology (71% vs 63%), pincer morphology (7% vs 7%), or acetabular dysplasia (4% vs 3%) (131). Cam morphology was associated with the presence and severity of chondral and labral conditions in hips with and without pain (59). Cartilage defects and labral tears were equally prevalent in symptomatic and control hips (50% vs 47% and 72% vs 66%, respectively), with no difference observed between men and women. Interestingly, full thickness cartilage defects were more prevalent in symptomatic than control hips (17% vs 2%), suggesting that more severe chondral conditions may be relevant for pain and symptoms in these players. Overall, few differences in hip joint bony or soft tissue morphology existed between football players with and without symptoms, consistent with the discordant relationship between imaging findings and pain that has been reported in other body regions (132, 133). In the absence of prospective data, understanding the relationship between specific hip-related pain conditions and the severity of pain, symptoms, and self-reported functional limitations (i.e., burden) may help to discern the relevance of these findings in symptomatic individuals.

1.8. Measurement of self-reported burden

The World Health Organisation (WHO) defines health as a "state of complete physical, mental, and social well-being, not merely the absence of disease or infirmity." Health status is not a dichotomy; instead, a spectrum of health exists, encompassing all aspects of physical, psychological, and social functioning. How individuals perceive their health across these three aspects is known as their health-related QOL (134). Patient-centred care is the cornerstone of contemporary health care delivery, where the severity of health conditions and the success of their treatments may be measured by an individual's change in health-related QOL (135, 136).

Musculoskeletal conditions such as hip-related pain cause disability and impact an individual's health-related QOL. Disability can be defined by the WHO's International Classification of Functioning, Disability and Health biopsychosocial model, whereby people experience dysfunction at one or more of the following three levels: 1) body structure or function, 2) activities, or 3) participation in normal life situations (137). For example, a football player with FAI syndrome may have reduced hip flexion ROM (body function impairment) that restricts their ability to run (activity limitation) and complete normal training and match play (participation restriction). Health-related QOL may be impacted by the severity of the condition, where patients with the same diagnosis may report different symptoms and perceived QOL (138). Conversely, for a given physiological/pathological tissue state, perceived health-related QOL may theoretically vary between individuals according to differences in their personal characteristics (e.g., attitudes or beliefs), environment (e.g., physical, psychological, or social supports), or other non-medical factors (e.g., financial situation) (134, 136). Wilson and Cleary (1995) (134) proposed a conceptual model for the relationships between physical characteristics of disease and self-reported health concepts **(Figure 1.12)**. Within this model, valid and accurate measurement tools are needed to assess disease burden at various levels of health, from the pathophysiological (i.e., molecular or cellular) level through to the impact of disease on an individual at a societal level (134, 136). Disease characteristics can often be directly observed at the pathophysiological level, which often afford tissue-based diagnoses (e.g., FAI syndrome or chondral conditions as observed using MRI) (134, 136). In contrast, assessment of non-observable characteristics (e.g., symptoms, perceived function, and QOL) relies on an individual's appraisal of their health (134, 136). Non-observable

characteristics of disease are called constructs and are measured using PROM scores (136). For this thesis, self-reported burden refers to an individual's perceived symptom severity and disability (i.e., functional impairments, activity limitations, and participation restrictions consistent with the WHO's classification of functioning), as measured using hip-related PROM instruments.

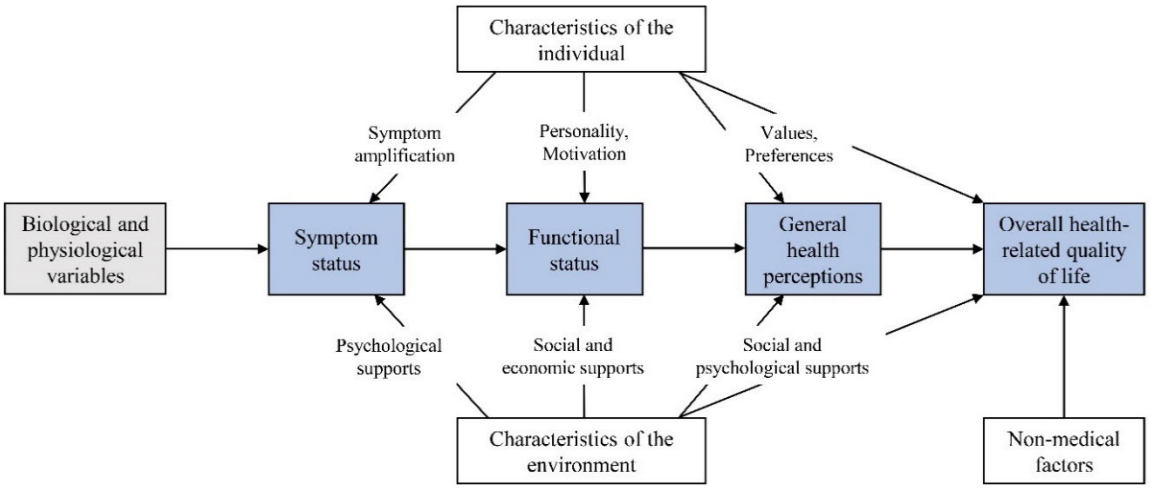


Figure 1.12. Conceptual model for assessing health-related quality of life.
Figure adapted from Wilson and Cleary (1995) (134).

Patient-reported outcome measures are multi-item (i.e., multi-question) instruments that originated in the field of psychology, where measurement of non-observable constructs is common (136). Patient reported outcome measures indirectly measure non-observable constructs; namely, by measuring observable characteristics that are related to the construct (136). Knowing the underlying relationship between the items and the construct is essential for interpreting and evaluating a PROM. Relationships can be described using reflective and formative models (136, 139) and are depicted in **Figure 1.13A** and **Figure 1.13B**, respectively. Briefly, for reflective models the construct manifests itself in the items (i.e., the items are effect indicators), whereas for formative models the construct is the result of the items (i.e., the items are causal variables) (139). Most musculoskeletal condition-specific PROMs follow a reflective model, whereby measuring condition characteristics (i.e., items) we can indirectly assess the severity of the underlying construct (136). Reflective models are underpinned by two measurement theories, the Classical Test Theory and the Item Response Theory, that explain the statistical relationship between the items and the construct (136). The usefulness of a PROM can be determined by assessing its measurement properties.

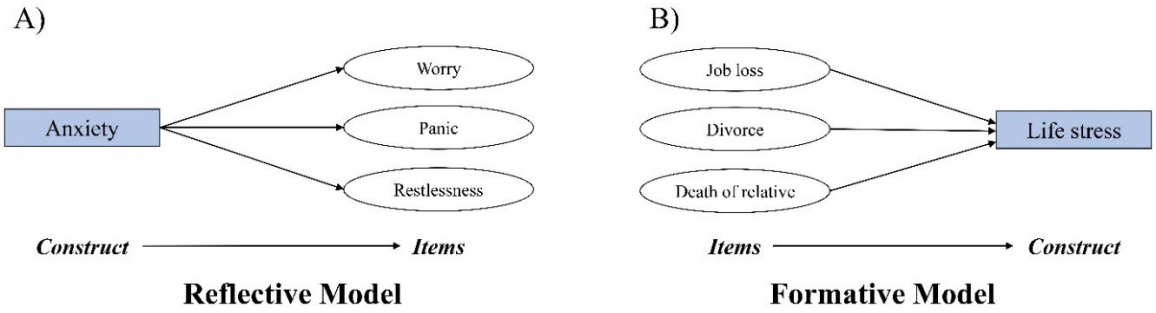


Figure 1.13. Graphical representation of a reflective model (A) and formative model (B). Adapted from Edwards & Bagozzi (2000) (139) and de Vet et al. (2011) (136).

1.8.1 Measurement properties of patient-reported outcome measures

Patient-reported outcome measures are not inherently valid, and may function differently in different situations (136). For example, the utility of a PROM may vary depending on the characteristics of the population or context in which it is tested. Patient-reported outcome measures are often used to evaluate individuals' health status over time (e.g., to determine natural history or treatment effects) (140), yet unfortunately, studies frequently use PROMs with poor or unknown quality (138, 141, 142). When selecting a PROM, clinicians and researchers must ensure that the construct(s) measured by the PROM aligns with their outcome of interest and that adequate measurement properties are known for the target population (136).

Knowledge of the measurement properties of PROMs has been limited by the variable terminology used in the literature (140). In 2010, 51 experts from the fields of psychology, epidemiology, statistics, and clinical medicine met as part of the Consensus-based Standards for the selection of Health Measurement Instruments (COSMIN) initiative, aiming to improve the quality of studies on measurement properties and help clinicians and researchers choose the most appropriate PROM from the available literature (140). To achieve these goals, experts from the COSMIN initiative: 1) defined relevant measurement properties, 2) provided terminology and definitions for these measurement properties, and 3) established the design requirements and preferred statistical methods for studies of measurement properties (140). Measurement properties are assessed across three domains: validity, reliability, and responsiveness. The agreed taxonomy for the relationships between measurement properties is provided in **Figure 1.14** and the definitions are provided **Table 1.2**.

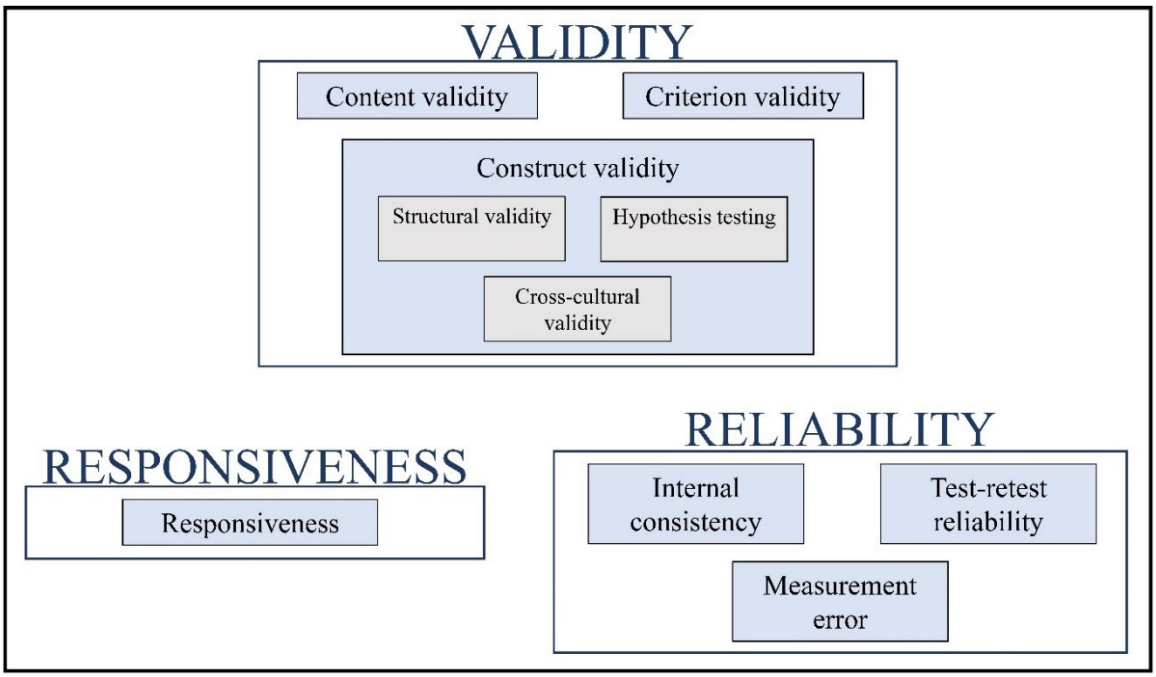


Figure 1.14. COSMIN taxonomy of measurement properties for patient-reported outcome measures.
Abbreviation: COSMIN = Consensus-based standards for the selection of health measurement instruments (COSMIN). Figure adapted from Mokkink et al. (2010) (140).

Table 1.2. Definitions for the measurement properties of patient-reported outcome measures (PROMs).

Term			
Domain	**Measurement property**	**Aspect of the measurement property**	**Definition**
Validity			The degree to which a PROM instrument measures the construct(s) it intends to measure
	Content validity		The degree to which the items of a PROM adequately reflect the construct(s) to be measured. All items should be relevant to the construct (within a specific population and context of use), comprehensive with respect to patient concerns, and be understood as it is intended
	Construct validity		Construct validity is the degree to which scores on a measurement instrument are consistent with hypothesised relationships between: 1) items of the PROM, 2) the construct of interest and constructs from another PROM, or 3) scores for the construct of interest for different groups
		Structural validity	The degree to which PROM scores adequately reflect the dimensionality of the construct to be measured (e.g., items of a unidimensional scale should load on to a single factor)
		Hypothesis testing	As per "Construct validity" above
		Cross-cultural validity	The degree to which the performance of the items on a translated or culturally adapted PROM adequately reflects the performance of the items of the original version of the PROM
	Criterion validity		The degree to which scores of a PROM adequately reflect a "gold standard". This measurement property is not relevant for PROMs as no gold standard comparators exist for the construct(s) of interest
Reliability			The degree to which measurement is free from measurement error. Specifically, reliability is the extent that scores for people whose condition is unchanged are the same for repeated measures
	Reliability		The proportion of total variance in the measurements which is due to "true" differences among patients and not measurement error. Hence, parameters of reliability (e.g., intraclass correlation coefficient) allow us to distinguish between people or groups
	Measurement error		The systematic and random error of a score that is not attributable to true changes in the construct being measured. The magnitude of measurement error can be quantified cross-sectionally (e.g., standard error of measurement) or over time (e.g., minimal detectable change)
	Internal consistency		The degree of interrelatedness of items of a PROM or its subscale
Responsiveness			The ability of the PROM to detect change over time in the construct(s) being measured. Floor and ceiling effects measure the ability of an instrument to demonstrate deterioration (floor effect) or improvement (ceiling effect).

Table adapted from Mokkink et al. (2010) (140), de Vet et al. (2011) (136), and Terwee et al. (2018) (143). .

1.9. Patient-reported outcome measures for hip/groin pain conditions

Many PROMs exist for people with hip/groin pain conditions; however, not all PROMs are relevant for all patients in all contexts (144, 145). A wide spectrum of burden exists in people with hip-related pain, where, for example, some people may seek surgery to relieve pain and improve daily function (146), whereas others can participate in competitive sport (5, 131). A systematic review by Thorborg et al. (2015) (145) identified nine PROMs that assess young- to middle-aged adults with hip/groin disability. Three PROMs were deemed to have adequate measurement properties for this population: the International Hip Outcome Tool-33 (iHOT-33) (147), the Copenhagen Hip and Groin Outcome Score (HAGOS) (148) and the Hip Outcome Score (149). Recently, experts from the IHiPRN Consensus Meeting did not recommend using the Hip Outcome Score, as it was developed without the involvement of patients (149) and hence its content validity was deemed to be inadequate (144, 150). The iHOT-33 and HAGOS were therefore the only PROMs recommended to assess young- to middle-aged adults with hip/groin pain (144). Their measurement properties are described in the following sections.

1.9.1 The International Hip Outcome Tool-33 (iHOT-33)

The iHOT-33 was designed to evaluate hip-related QOL in active adults with various hip-related conditions (147). It consists of 33 items scored on a visual analogue scale (VAS) from 0 (worst possible score) to 100 (best possible score). Items are grouped into four domains (i.e., subscales) that evaluate different constructs of hip/groin burden, including: symptoms and functional limitations (iHOT-Symptoms), sport and recreational activities (iHOT-Sport), job-related concerns (iHOT-Job), and social, emotional, and lifestyle concerns (iHOT-Social). Whilst four distinct constructs exist, the iHOT-33 is reported as a single total score (from 0 to 100), representing an individual's overall hip-related QOL (147). The iHOT-33 total (iHOT-Total) score is calculated by summing all item scores and dividing by the total number of items answered (147).

(i) Content validity

Two systematic reviews deemed that the iHOT-33 had sufficient content validity for use in active adults with hip/groin pain (144, 145); however, this finding is supported by low

quality evidence from the development study only (144, 147). Evaluating content validity is difficult, requiring an overall subjective judgement by reviewers regarding numerous criteria proposed by the COSMIN guidelines (143, 150). For example, Impellizzeri et al. (2020) (144) reported inconsistent ratings for the relevance, comprehensiveness, and comprehensibility of the iHOT-33, but deemed its content validity to be sufficient based on the assumption that, even if not reported, "some validity issues were probably addressed" during the development process. Furthermore, evidence of content validity for the iHOT-33 is specific to the pre-surgical population in which it was developed (147). Items were generated for the iHOT-33 by patients with various hip-related conditions who sought, and mostly underwent, surgery (147). People undergoing surgery may have worse hip disease and functional impairment than those not seeking surgery, meaning items generated for the iHOT-33 may not be relevant to people with hip/groin pain who, for example, continue to participate in football competition. Currently, the content validity of the iHOT-33 is unknown in people with hip/groin pain who do not seek surgery.

(ii) Construct validity

There is high quality evidence supporting sufficient construct validity for the iHOT-33 (144, 145). Almost all hypothesised relationships between the iHOT-Total score and comparator PROMs (four hip-specific and one generic health instrument) were confirmed in the six studies that investigated construct validity **(Table 1.3)** (144, 147, 151-154). These findings suggest that the iHOT-Total score appears to measure a similar construct to other hip-specific PROMs.

A component of construct validity is structural validity; that is, the extent to which scores of a PROM are an adequate reflection of the dimensionality of the construct to be measured (136, 140). Factor analysis during iHOT-33 development (147) and translation to Dutch (152) confirmed that items are grouped into four distinct constructs; namely, the four subscales of the iHOT-33. Importantly, neither report (147, 152) established how the four constructs were linked to the iHOT-Total score. The dimensionality of the iHOT-33 is therefore not reflected by the single iHOT-Total score (144). Validating the subscale scores may somewhat overcome this problem, allowing each score to be reported and interpreted independently; however, this is yet to be undertaken in any hip/groin pain population.

(iii) Reliability

There is high quality evidence supporting sufficient test-retest reliability for the iHOT-Total score (144, 145). Time-intervals between testing sessions have ranged from one to 90 days; however, most studies examined test-retest reliability over a 2-week period **(Table 1.3)**. de Vet and colleagues (2011) (136) argued that the reliability of a PROM should be tested in the context in which it is used. In clinical practice, the iHOT-33 is primarily used to evaluate treatment efficacy, with most treatment programmes (surgical or non-surgical) likely to continue for much longer than 2 weeks (155).

(iv) Responsiveness

The iHOT-Total score is responsive to change in surgical populations (144, 145), with a reported responsiveness ratio of 6.7 in the development study (147). The magnitude of treatment effects from surgery may not be comparable to other treatments. Currently, the responsiveness of the iHOT-33 in non-surgical populations is unknown.

Table 1.3. Studies reporting the measurement properties of the International Hip Outcome Tool-33.

Study	Population	Disease characteristics	Content validity	Construct validity	Reliability (Test-retest time)	Measurement error	Responsiveness
Mohtadi (2012) (147)	n=27 to 150 Female = 56% Mean age (range) = 40 (18-60) Setting: pre- and post-surgical	Hip-related conditions Duration: 2.5 to 6.3 years	Sufficient	Sufficient Comparator(s): NAHS	Sufficient ICC= 0.78 (95%CI NR) Test-retest time: 14-90 days	NA	Indeterminate
Kemp (2013) (151)	n=50 Female = 51% Mean age (range) = 37 (18-57) Setting: post-surgical	Hip-related conditions Duration: 19 (12-24) months post-surgery	NA	Sufficient Comparator(s): SF-36	Sufficient ICC=0.93 (95%CI 0.87,0.96) Test-retest time: 3-14 days	Insufficient SEM = 6.0	Sufficient
Hinman (2014) (156)	n=30 Female = 50% Mean age (range) = 24 (18-30) Setting: pre-surgical or non-surgical treatment	Hip-related conditions Duration: 14 (2-84) months	NA	NA	Sufficient ICC=0.93 (95%CI 0.85,0.97) Test-retest time: 7-14 days	Insufficient SEM = 5.6	NA
Ruiz-Iban* (2015) (157)	n=97 Female = 38% Mean age (range) = 44 (22-60) Setting: pre- and post-surgical	Hip-related conditions Duration: >6 months	NA	Indeterminate (inadequate methodological quality)	Sufficient ICC=0.97 (95%CI 0.96,0.99) Test-retest time: <15 days	Insufficient SEM = 4.7	Indeterminate (inappropriate methodological quality)
Baumann* (2016) (154)	n=83 Female = 29% Mean age (range) = 34 (14-63) Setting: Unclear	Hip-related conditions Duration: NR	NA	Sufficient Comparator(s): HOS, EQ-5D	Indeterminate (doubtful methodological quality) ICC=0.88 (95%CI 0.80,0.93) Test-retest time: >14 days	Indeterminate (doubtful methodological quality)	Indeterminate (doubtful methodological quality)
Tijssen* (2016) (152)	n=214 Female = 50% Mean age (range) = 33 (18-50) Setting: pre- and post-surgical	Hip-related conditions Duration: NR	NA	Sufficient Comparator(s): HOOS, EQ-5D, NPRS	Sufficient ICC=0.92 (95%CI 0.88,0.94) Test-retest time: 1-23 days	Insufficient SEM = 6.0	NA
Li* (2017) (153)	n=138 Female = 39% Mean age (range) = 43 (18-60) Setting: pre- and post-surgical	Hip-related conditions Duration: NR	NA	Sufficient Comparator(s): WOMAC, EQ-5D	Sufficient ICC=0.87 (95%CI 0.82,0.93) Test-retest time: 14 days	Indeterminate SEM = NR	Sufficient
Dion* (2021) (158)	n=101 Female = 42% Mean age (range) = 32 (16-50) Setting: pre-surgical	Hip-related conditions Duration: NR	NA	Indeterminate Comparator(s): HOOS, NAHS	Sufficient ICC=0.87 (95%CI 0.78,0.92) Test-retest time: 14 days	Insufficient SEM = 6.4	NA

* indicates cross-cultural validation study. Measurement properties are rated as sufficient, insufficient, or indeterminate against criteria from the COSMIN guidelines (141). Abbreviations: NR = not reported; NA = not assessed; HOOS = Hip disability and Osteoarthritis Outcome Score (159); HOS = Hip Outcome Score (149); ICC = intraclass correlation coefficient; NAHS = Non-arthritic hip score (160); NPRS = numerical pain rating scale; SEM = standard error of measurement; SF-36 = Medical Outcomes Study 36-Item Short Form (161); WOMAC = Western Ontario and MacMaster Universities Osteoarthritis Index (162). EQ-5D (163). Table adapted from Impellizzeri et al. (2020) (144).

1.9.2 The Copenhagen Hip and Groin Outcome Score (HAGOS)

The HAGOS was designed to evaluate hip and/or groin conditions in active adults (148). The HAGOS consists of 37 items scored on a 5-point Likert scale (scored 0 to 4). Items are distributed among six subscales that evaluate different constructs of hip/groin related burden, including: symptoms (HAGOS-Symptoms), pain (HAGOS-Pain), physical function during activities of daily living (HAGOS-ADL), function during sports and recreational activities (HAGOS-Sport), participation in physical activities (HAGOS-PA), and quality of life (HAGOS-QOL). Scores for the six subscales are calculated and reported separately (i.e., no total score is calculated), ranging from 0 (worst possible score) to 100 (best possible score). Measurement properties of the HAGOS are summarised in **Table 1.4** and discussed below.

(i) Content validity

The HAGOS has adequate content validity for use in active adults with hip/groin pain (144, 148). Semi-structured, one-on-one interviews involving those with hip/groin pain helped to generate items and examine the relevance, comprehensiveness, and comprehensibility of the HAGOS (148).

(ii) Construct validity

Scores for the HAGOS have sufficient construct validity for use in active adults (144, 145). All scores, except for HAGOS-PA, have correlated strongly (Spearman's correlation coefficient >0.5) with Short Form-36 subscales (148). The six subscales have good internal consistency, indicating that the items of each subscale measure a similar construct (144, 145, 148).

(iii) Reliability

The HAGOS is reliable in active adults with hip/groin pain (144), with intraclass correlation coefficients (ICCs) ranging from 0.82 to 0.91 [95%CI 0.68, 0.95] (148). Test-retest reliability has been examined over 3 to 21 days, with standard error of measurement (SEM) values ranging from 2.8 to 12.2 (**Table 1.4**).

(iv) Responsiveness

The HAGOS subscale scores are responsive following hip arthroscopy (151, 164). It is unclear if the responsiveness of the HAGOS varies in people undertaking surgical or non-surgical treatment (144, 148).

Table 1.4. Studies reporting the measurement properties of the Copenhagen Hip and Groin Outcome Score.

Study	Population	Disease characteristics	Content validity	Construct validity	Reliability (Test-retest time)	Measurement error	Responsiveness
Thorborg (2011) (148)	n=101 Female = 50% Mean age (range) = 36 (18-63) Setting: Treatment not specified	Hip and/or groin conditions Duration: >6weeks (75% >12months)	Sufficient	Sufficient Comparator(s): SF-36	Sufficient ICCs=0.82-0.91 (95% Cis 0.69,0.95) Test-retest time: 7-21 days	Insufficient SEM = 6.4 to 12.2	Sufficient
Kemp (2013) (151)	n=50 Female = 51% Mean age (range) = 37 (18-57) Setting: post-surgical	Hip-related conditions Duration: 19 (12-24) months post-surgery	NA	Sufficient Comparator(s): SF-36	Sufficient ICCs=0.92-0.97 (95% Cis 0.85,0.98) Test-retest time: 3-14 days	Insufficient SEM = 3.0 to 7.0	Sufficient
Hinman (2014) (156)	n=30 Female = 50% Mean age (range) = 24 (18-30) Setting: pre-surgical or non-surgical treatment	Hip-related conditions Duration: 14 (2-84) months	NA	NA	Sufficient ICCs=0.79-0.94 (95% Cis 0.64,0.98) Test-retest time: 7-14 days	Insufficient SEM = 5.5 to 8.0	NA
Thomee* (2014) (164)	n=502 Female = 33% Mean age (range) = 37 (15-75) Setting: pre- and post-surgery	Femoroacetabular impingement syndrome Duration: NR	NA	Sufficient Comparator(s): EQ-5D, iHOT-12	Sufficient ICCs=0.81-0.87 (95% Cis 0.62,0.96) Test-retest time: 9-20 days	Insufficient SEM = 2.8 to 5.8	Sufficient

* indicates cross-cultural validation study. Measurement properties are rated as sufficient, insufficient, or indeterminate against criteria from the COSMIN guidelines (141). Abbreviations: NR = not reported; NA = not assessed; iHOT-12 = International Hip Outcome Tool-12 (165); ICC = intraclass correlation coefficient; SEM = standard error of measurement; SF-36 = Medical Outcomes Study 36-Item Short Form. EQ-5D (163). Table adapted from Impellizzeri et al. (2020) (144).

1.10. Self-reported burden in people with hip/groin pain

Patient-reported outcome measures such as the iHOT-33 and HAGOS allow clinicians and researchers to quantify the severity of hip/groin burden across different constructs; however, knowledge of how symptoms and physical and social impairments vary in people with hip/groin pain is limited. For people with non-arthritic hip/groin pain, reported burden is uncertain.

Few studies have described self-reported burden in people with hip/groin pain. Palsson et al. (2019) (51) investigated 70 adults (mean age = 36 years, 47% female) seeking tertiary care for longstanding hip/groin pain. Participants with hip-related pain (n=33; classified using imaging, physical tests, and a positive response to intra-articular injection) did not report worse HAGOS scores than those with other causes of hip/groin pain (n=37) (51). The lowest (worst) scores were recorded on the HAGOS-QOL subscale, whereas scores on the HAGOS-ADL were the least impaired (51). Findings from this small sample may not be generalisable to people across the hip/groin pain spectrum; therefore, further insights might be gained from the PROM scores of people seeking various treatments for hip/groin pain.

1.10.1 People seeking treatment for hip/groin pain

Most studies reporting hip/groin burden are in people undergoing hip surgery, with fewer studies investigating non-surgical treatments (155, 166, 167). However, as surgical studies have rarely used recommended PROMs (i.e., the iHOT-33 or HAGOS) (167), valid estimates of self-reported burden across the disease spectrum are sparse.

Severe hip/groin pain might incite some people to seek hip surgery. Poor hip-related QOL, as measured with the iHOT-Total score, has been reported by people undertaking hip surgery in three recent large scale randomised controlled trials (RCTs): 1) Griffin et al. (2018) (168) (n=171, mean age = 35 years, 42% women); 2) Palmer et al. (2019) (169) (n=222, mean age = 36 years, 66% women); and 3) Hunter et al. (2021) (170) (n=99, mean age = 33 year, 42% women) **(Figure 1.15)**. Aside from the iHOT-Total score, more insights might be gained from the six HAGOS subscale scores. Pre-operative HAGOS scores for patients from the Danish Hip Arthroscopy Registry (171) (n=2930, mean age = 38 years, 58% women) and a subset of athletes aged 18 to 30 years (n=189, mean age = 24 years,

49% women) (172) are summarised in **Figure 1.16**. Interestingly, participation in physical activity (i.e., HAGOS-PA score) appears similarly impacted in athletes and non-athletes undertaking surgery, despite athletes reporting less pain, symptoms, and physical impairment. This might suggest that a desire to improve sports performance, rather than pain reduction, could incite some athletes to seek surgery (146). Returning to sport was also recently reported as an important reason for people to seek physiotherapist-led treatment (173).

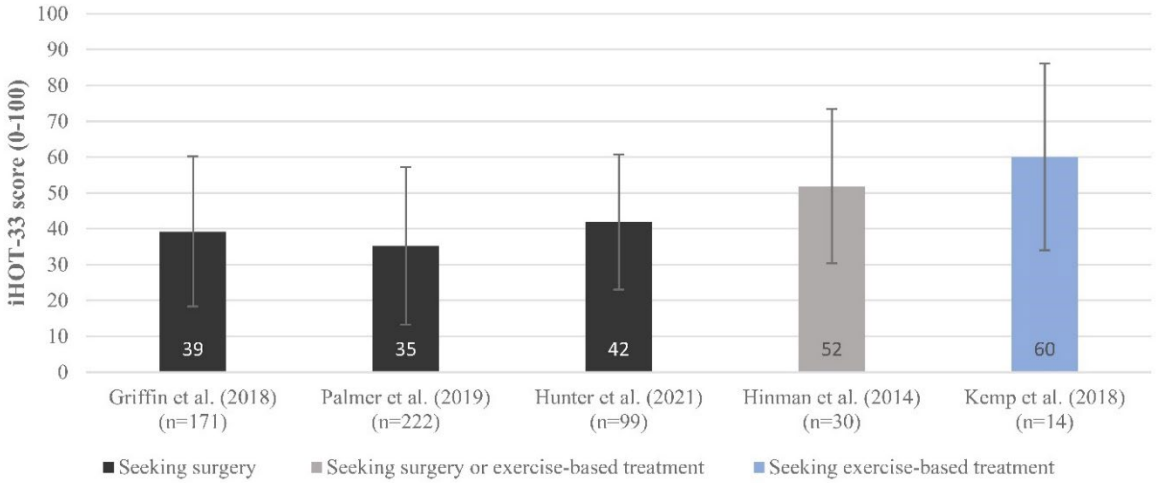


Figure 1.15. International Hip Outcome Tool-33 (iHOT-33) scores in people seeking treatment for hip and/or groin pain.
Group mean iHOT-33 total score reported (error bar indicates one standard deviation above and below the mean) for Griffin et al. (2018) (168), Palmer et al. (2019) (169), Hunter et al. (2021) (170), Hinman et al. (2014) (156), and Kemp et al. (2018) (174).

Hip/groin pain appears less burdensome in people seeking non-surgical treatment, when compared to those undertaking surgery. Few studies have reported the iHOT-Total score in people seeking exercise-based treatment (156, 174). **Figure 1.15** presents mean iHOT-Total scores for people seeking an exercise intervention in a small pilot study (n=14, mean age = 37, 71% women) (174) and individuals seeking tertiary (surgical or non-surgical) care (n= 30, mean age = 24, 50% women) (156), suggesting a trend toward less self-reported pain, symptoms, and functional impairment in those seeking non-surgical than surgical treatment. A similar spectrum of hip/groin burden is evident when examining HAGOS scores in **Figure 1.16**, where hip/groin pain appears to be less burdensome in male athletes seeking exercise-based treatment (n=205, mean age = 25 years) (175) than in people (athletes and non-athletes) seeking surgery (171, 172) .

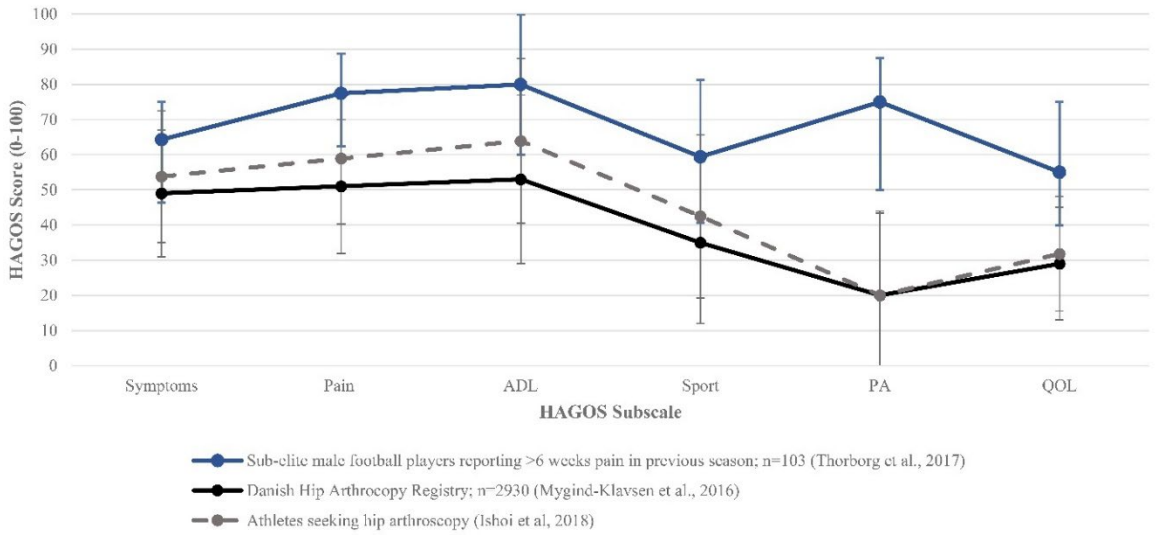


Figure 1.16. Copenhagen Hip and Groin Outcome Scores (HAGOS) for people seeking treatment for hip and /or groin pain.
Group mean HAGOS scores reported (error bars indicate one standard deviation above and below the mean) for King et al. (2018) (175), Ishoi et al. (2018) (172), and Mygind-Klavsen et al. (2020) (171). Abbreviations: ADL = activities of daily living; PA = participation in physical activities; QOL = quality of life.

1.10.2 Football and Australian football players

Many players continue to participate in football training and match play despite persistent hip/groin pain (4). Non-time-loss injury burden has been described by its duration; however, this provides little understanding of the severity of pain, nor the extent of physical or performance impairment. Valid PROMs, which explore varying hip-related QOL constructs, might provide insights into the reported burden of football players with hip/groin pain.

The HAGOS has quantified burden in male (4, 5) and female (1) football players. In Spain, male sub-elite football players with hip/groin pain (n=216) reported worse HAGOS-Sport scores than those without (n=191) (4). Interestingly, scores did not differ between symptomatic players with time-loss and non-time-loss injuries, emphasising that players with non-time-loss injuries reported a high degree of difficulty during sporting tasks over the course of the season (4). Two studies reported HAGOS scores for sub-elite male (Danish, n=695) and female (Dutch, n=434) football players at the beginning of a season (1, 5) **(Figure 1.17)**. Players with prolonged hip/groin pain in the previous season reported worse HAGOS scores than those with shorter duration or no symptoms (1, 5). Most (≥70%) symptomatic players reported pain lasting less than 6 weeks, indicating that although hip/groin pain is prevalent (1, 4, 5), it is often transient in football players (1, 5).

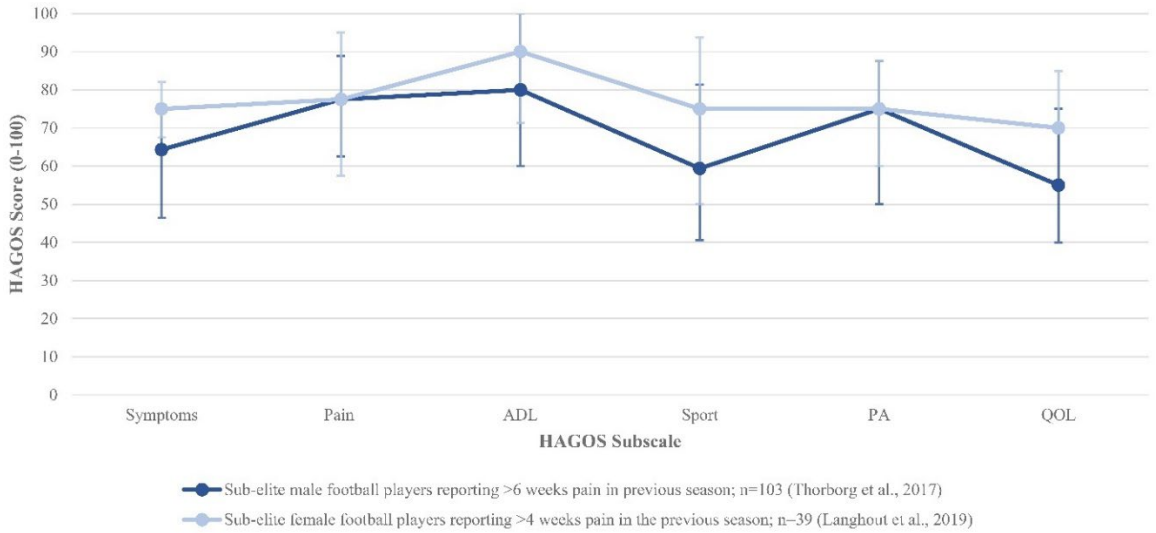


Figure 1.17. Copenhagen Hip and Groin Outcome Scores (HAGOS) for male and female football players with current or previous hip/groin pain.
Data presented as median and interquartile range for Thorborg et al. (2017) (5) and Langhout et al. (2019) (1). Abbreviations: ADL = physical function during activities of daily living; PA = participation in physical activities; QOL = hip-related quality of life.

Analysing HAGOS scores according to pain status in the previous season may not accurately describe burden in football players with current hip/groin pain. Due to the retrospective design of these epidemiological studies (1, 5), the reported HAGOS scores likely represent an unknown mix of symptomatic players and asymptomatic players with a history of hip/groin pain. Furthermore, the failure to classify the nature of hip/groin injuries (e.g., acute versus gradual-onset) and undertake clinical assessments in these studies (1, 4, 5) limits our interpretation of the findings. Prospective cohort studies with well-defined eligibility criteria are needed to improve our understanding of self-reported burden in football players with longstanding hip/groin pain.

1.11. Relationship between hip joint structure and reported burden

Improved knowledge of the relationship between hip joint structure (i.e., bony or soft tissue morphology) and self-reported burden may provide insights into the pathogenesis of hip-related pain conditions. People undergoing surgery appear to report worse symptoms and functional impairment than those seeking exercise-based treatment, and the relationship between hip joint structure and self-reported burden in surgical and non-surgical settings are discussed in the following sections.

1.11.1 Cam morphology

Although larger cam morphology is associated with worse chondral and labral pathology in those undergoing surgery (60), its relationship with self-reported burden is less certain. Cam morphology is often resected during hip arthroscopy, but the amount of resection appears unrelated to post-operative PROM scores (176). Pre-operative self-reported burden was unrelated to cam morphology size in two small, low-quality studies (177, 178), where alpha angles were assessed using CT (177) and radiographs (AP and frog-leg lateral) (178).

Cam morphology is common in people with hip/groin pain who do not seek surgery (17, 70, 131), yet it is unclear what relationship, if any, it has with pain and symptom severity. For example, in people with self-reported hip OA, PROM scores were similar in those with and without cam morphology (179). Importantly, cam morphology may only be relevant for an individual's clinical presentation when it is accompanied by appropriate physical signs of femoroacetabular impingement (38, 45). No studies have examined whether people with FAI syndrome (i.e., hip/groin pain, cam morphology, and positive physical signs) report worse burden than people with other causes of hip/groin pain. Furthermore, cam morphology size is a continuous measure, and it is possible that people with larger cam morphology might report worse burden. **Table 1.5** summarises studies investigating relationships between cam morphology size and PROM scores in various athletic populations. Larger cam morphology was associated with worse PROM scores in golf (180) and capoeira (181) players, despite most not reporting hip/groin pain. In contrast, cam morphology size was not related to PROM scores (HAGOS-Pain, HAGOS-Symptoms, and iHOT-33) in symptomatic participants in the FORCe cohort (131). No studies have investigated the relationship between cam morphology size and reported burden in people with FAI syndrome who do not seek surgery.

Table 1.5. Studies investigating relationships between PROM scores and bony hip morphology as continuous variables in athletes.

Study	Population	Imaging method	PROM scores	Findings
Mariconda (2014) (181)	***Capoeira players*** n=24 (48 hips) Female = 41% Age = 32 ± 5 years Self-reported pain = 4 athletes (7 hips)	Radiographs (AP and frog-leg lateral)	NAHS 96 ± 9 WOMAC 97 ± 8	10° increase in alpha angle (AP radiograph) associated with 4-point worsening of NAHS and WOMAC scores (***P*<0.05**). Relationship between LCEA and PROM scores not reported.
Dickenson (2016) (182)	***Professional male golfers*** n=55 (110 hips) Age = 29 ± 6 years Self-reported pain = 21 players (23 hips) reported ≥1day of pain in the previous month	1.5T MRI Alpha angle calculated as the mean of 12, 1, 2, and 3 o'clock measurements.	iHOT-12 Lead hip: 94 [IQR 86-98] Trail hip: 95 [IQR 90-99]	10° increase in mean alpha angle associated with 5-point worsening of iHOT-12 scores (***P*<0.001**).
Heerey (2021)* (183)	***Sub-elite football players with hip/groin pain*** n=184 Female = 21% Age = 26 [IQR 23, 30]	Radiographs (AP and Dunn 45°)	iHOT-33 64 [IQR 50, 74] HAGOS-Symptoms 61 [IQR 50-74] HAGOS-Pain 75 [IQR 65-83]	Alpha angle (AP or Dunn 45° view) not associated with iHOT-33, HAGOS-Pain, or HAGOS-Symptoms scores in men (Pearson's r -0.15-0.03, P>0.05) and women (r -0.31-0.05, P>0.05). Larger LCEA values were associated with worse HAGOS-pain scores in women only (r -0.37, ***P*=0.027**).

Data presented as mean ± standard deviation or median and interquartile range [IQR]. *indicates findings from the femoroacetabular impingement and hip osteoarthritis cohort (FORCe) study (130). Abbreviations: AP = anteroposterior pelvis; HAGOS = Copenhagen Hip and Groin Outcome Score (148); iHOT = International Hip Outcome Tool (147, 165); IQR = interquartile range; LCEA = lateral-centre-edge-angle; NAHS = Non-arthritic hip score (160); PROM = patient-reported outcome measure; WOMAC = Western Ontario and MacMaster Universities Osteoarthritis Index (162); 1.5T = 1.5 Tesla.

1.11.2 Pincer morphology

Lateral-centre-edge-angle values, which quantify the size of pincer morphology, were not associated with PROM scores in people undergoing hip arthroscopy (177, 178). In FORCe study participants, the LCEA was not associated with self-reported burden in men; however, for women (n=38), larger LCEA values were associated with worse HAGOS-Pain scores, but no other PROM scores (131).

1.11.3 Chondral and labral conditions

Cartilage defects and labral tears, which are common in people undergoing hip arthroscopy (171), are inconsistently associated with patients' pre-operative self-reported burden (178, 184, 185). For example, military personnel (n=67, 33% female) with severe femoral head chondral pathology and large labral tears reported worse pre-operative iHOT-Symptoms and iHOT-Job scores, respectively, when compared to individuals without these conditions (184). In contrast, scores for the Hip Dysfunction and Osteoarthritis Outcome Score (HOOS) were not associated with intra-operative findings in larger, non-military cohorts with proportionally more women (178, 185).

In people not undergoing surgery, high-resolution MRI and semi-quantitative scoring systems provide a valid method of assessing intra-articular soft tissue pathology (87, 105). Relationships between PROM scores and the severity of MRI-defined cartilage defects and labral tears are summarised in **Table 1.6** (87, 105, 183, 186, 187). Overall, few studies exclusively investigated symptomatic people (183, 187). The severity of cartilage defects and labral tears were unrelated to reported burden (HAGOS-Symptoms, HAGOS-Pain, and iHOT-Total) in symptomatic football players from the FORCe study (183). In people awaiting surgery for FAI syndrome, MRI-defined labral tear severity, but not cartilage defect severity, was related to pre-operative HOOS (Pain, ADL, and Sports) subscale scores (187). Improved understanding of the relationships between self-reported burden and intra-articular soft tissue conditions is needed in people with specific hip-related pain conditions (e.g., FAI syndrome) who do not seek surgery.

Table 1.6. Relationship between patient-reported outcome measure scores and the severity of cartilage and labral findings.

Study	Population	MRI and scoring	PROM	Findings
Roemer (2011) (105)	***Chronic hip pain in adults aged >50 years seeking tertiary care*** n=52 Female = 54% Age = 64 (± 10) years	1.5T MRI Semi-quantitative (HOAMS) Maximum score for labrum and cartilage in any subregion	HOOS-Pain HOOS-Function Maximum item score dichotomised into mild (response 1 or 2) or moderate-to-extreme (responses 3-5)	***Cartilage:*** Cartilage defect severity not associated with increased odds of reporting moderate-to severe pain or functional impairment ***Labrum:*** Labral tear severity not associated with increased odds of reporting moderate-to severe pain or functional impairment
Kumar (2013) (186)	***Radiographic hip OA (KL grade 2-3):*** n=30 Female = 43% Age = 54 (± 11) years ***No radiographic hip OA (KL grade 0-1):*** n=55 Female = 51% Age = 43 (± 14) years	3T MRI Semi-quantitative: Total scores calculated for labrum and cartilage (sum of subregion scores)	HOOS-Symptoms HOOS-Pain HOOS-ADL	***Cartilage:*** Worse total cartilage score associated with worse HOOS-Symptoms (p -0.34) P=0.003), HOOS-ADL (p -0.32, P=0.004), and HOOS-Pain (p -0.25, P=0.026) scores. ***Labrum:*** Total labral score not associated with any HOOS scores (p -0.10 to -0.18, P>0.05)
Lee (2015) (87)	***Adults from the community*** n=98 Female = 53% Age = 44 (± 13) years Report hip pain = 51%	3T MRI Semi-quantitative (SHOMRI) Total scores calculated for labrum and cartilage (sum of subregion scores)	HOOS-Symptoms HOOS-Pain HOOS-ADL	***Cartilage:*** Worse total cartilage score associated with worse HOOS Symptoms (p -0.24, P=0.03) and HOOS ADL (p -0.27, P=0.01) scores, but not HOOS-Pain (p -0.17, P=0.12). ***Labrum:*** Worse labral score associated with worse HOOS Symptoms score (p -0.24, P=0.03), but no other scores (p -0.13 to -0.08, P>0.05)
Grace (2018) (187)	***Patients undergoing surgery for FAI syndrome*** n=43 Female = 42% Age = 36 (± 10) years	3T MRI Semi-quantitative (SHOMRI) Total scores calculated for labrum and cartilage (sum of subregion scores)	HOOS (all subscales)	***Cartilage:*** Total cartilage score not associated with any HOOS scores (p -0.23 to -0.10, P>0.05) ***Labrum:*** Worse total labral score associated with HOOS-Pain (p -0.50, P<0.001), HOOS-ADL (p -0.47, P<0.001) and HOOS-Sports (p -0.38, P=0.01) scores
Heerey (2021)* (183)	***Sub-elite football players with hip/groin pain*** n=182 Female = 20% Age = 26 [IQR 23, 30] years	3T MRI Semi-quantitative (SHOMRI) Total scores calculated for labrum and cartilage (sum of subregion scores)	iHOT-33 HAGOS-Pain HAGOS-Symptoms	***Cartilage:*** Total cartilage score not associated with iHOT-33, HAGOS-Pain or HAGOS-Symptoms scores (p -0.09 to 0.09, P>0.05) ***Labrum:*** Total labral score not associated with iHOT-33, HAGOS-Pain or HAGOS-Symptoms scores (p -0.05 to 0.04, P>0.05)

*indicates findings from the femoroacetabular impingement and hip osteoarthritis cohort (FORCe) study (130). Abbreviations: ADL = activities of daily living; FAI = femoroacetabular impingement; HAGOS = Copenhagen Hip and Groin Outcome Score; HOAMS = Hip osteoarthritis MRI scoring system; HOOS = Hip Dysfunction and Osteoarthritis Outcome Score; iHOT-33 = International Hip Outcome Tool-33; KL = Kellgren and Lawrence (188); MRI = magnetic resonance imaging; OA = osteoarthritis; PROM = patient-reported outcome measure; SHOMRI = Scoring Hip Osteoarthritis with MRI tool; p = Spearman's correlation coefficient.

1.12. Movement impairments in people with hip/groin pain

The way that a person moves can alter the direction and magnitude of joint loads, potentially altering joint structure over time (127, 128). Joint structures can adapt to the forces and loads to which they are exposed (127); however, joint loads may also initiate and/or lead to worsening structural changes (189) such as cartilage defects, labral tears, and eventually hip OA. Femoroacetabular impingement syndrome is a "motion-related" condition (45), and thus an individual's movement patterns might contribute to the development and persistence of hip/groin pain. Identifying biomechanical impairments in people at risk of hip osteoarthritis (e.g., football players with hip/groin pain) might improve knowledge of the pathogenesis of structural hip disease and provide insights for treatments.

1.12.1 Biomechanical variables assessed in hip/groin pain

The following sections provide definitions and interpretations of commonly assessed biomechanical variables in people with hip/groin pain. Joint angles and moments are often assessed in studies of lower-limb biomechanics and are examined in this thesis.

(i) Joint angles

In biomechanics, kinematic data describes the movement of body segments and can include variables such as linear or angular displacements, velocities, and accelerations (190). Joint angles represent the relative angle created by two adjacent body segments (e.g., the hip flexion angle is the internal angle created by the pelvis and femur segments in the sagittal plane). Joint angles are typically described relative to an anatomical coordinate system that is unique to each joint. In contrast, an individual body segment (e.g., pelvis) can be described as an absolute angle with respect to an external spatial reference system (e.g., pelvic tilt angle is the absolute angle between the pelvis and the laboratory in the sagittal plane). Kinematic data can be reported in many ways, including as a continuous variable across time or as a variety of discrete variables **(Figure 1.18)**. Discrete variables produce a single value and can include variables such as: 1) the total ROM experienced by the joint during a given task (i.e., excursion), 2) peak angle (either positive or negative), 3) average angle throughout the task, or 4) angle at a particular point in time (e.g., at contralateral toe-off during walking).

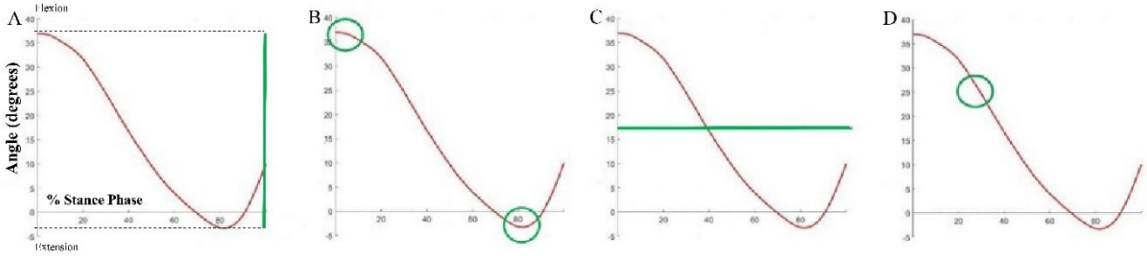


Figure 1.18. Common discrete kinematic variables reported in people with hip/groin pain. Examples are provided for the sagittal plane hip angle during the stance phase of walking, including the A) total hip sagittal plane range of motion (i.e., excursion); B) peak hip flexion (maximum value) and hip extension angle (minimum value); 3) average hip sagittal plane angle throughout the task; or 4) hip flexion angle at a particular point in time (e.g., at contralateral toe-off). Figure adapted from King (2020) (191).

(ii) Joint moments

Kinetics is the term given to the internal and external forces that act on the body to cause movement (190). External forces originate from outside the human body (e.g., gravity or the GRF), whereas internal forces occur due to muscle activity, joint frictions, ligaments, and tendons (190). Internal and external forces that rotate a body segment are termed "moments". A joint moment is calculated as the product of a force (measured in Newtons) and the perpendicular distance (measured in metres) to the centre of rotation (i.e., the joint axis).

Joint moments (i.e., joint torques) are commonly reported in biomechanics literature and represent the rotational forces acting about a joint. Joint moments can be calculated and reported as external or internal moments. External moments represent the rotational effect of the GRF on the joint, whereas internal moments represent the net forces within the body (i.e., muscle, ligament, tendon, and joint friction forces) that oppose the external forces (190). Like kinematics, joint moments can be reported as continuous variables or as a variety of discrete variables such as: 1) the peak moment (either positive or negative), 2) average moment across a period of time, or 3) moment at a particular point in time (e.g., at contralateral toe-off during walking) **(Figure 1.19)**. The impulse of the joint moment (area under the moment-time curve) is also frequently reported. Joint moment impulses provide insights into of the accumulative global load experienced by passive (e.g., ligament) and active (e.g., muscle) structures for a given task, accounting for the varying magnitude of the joint moment and the duration over which it acts (192); hence, greater joint moment impulses may result from larger or more prolonged moments.

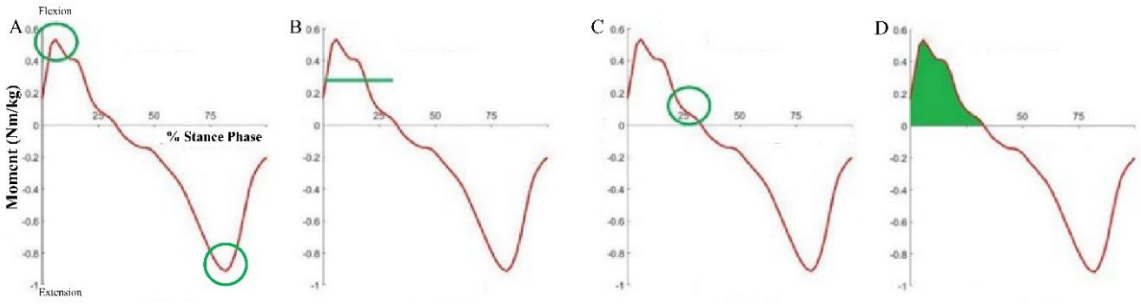


Figure 1.19. Common joint moment variables reported in people with hip/groin pain.
Examples are provided for the 'external' hip sagittal plane hip moment during the stance phase of walking, including the A) peak hip flexion (maximum value) and extension (minimum value) moments; B) average hip flexion moment during double support; C) hip sagittal plane moment at a particular point in time (e.g., at contralateral toe-off during walking); and D) impulse of the hip flexion moment. Figure adapted from King (2020) (191).

1.12.2 Biomechanical impairments in people with hip/groin pain

Altered lower-limb biomechanics are evident in people with hip/groin pain during some tasks when compared to pain-free individuals (53, 126, 193). Studies investigating people with hip-related pain conditions have generally examined low-impact tasks such as walking, squatting, or stair ascent in pre-surgical populations, limiting their generalisability to non-surgical or athletic populations (126, 194). Recent reports have examined walking biomechanics in people with hip/groin pain who were not seeking surgery (195, 196), providing insights into the relationship between lower-limb biomechanics and hip joint health across the continuum of hip joint disease.

(i) Walking biomechanics across the spectrum of hip/groin pain

People with hip OA walk with biomechanical patterns that tend to reduce hip joint loads (193), including smaller external hip flexion and adduction peak moments (193) and a smaller peak hip extension angle (197-199). The magnitudes of these biomechanical impairments appear to be related to the severity of hip OA, with more pronounced hip joint offloading during walking evident in those with worse disease (193). In people with non-arthritic hip/groin pain, biomechanical impairments during walking are less evident (126). For example, a recent systematic review reported that people with FAI syndrome walk with a slightly smaller peak hip extension angle but no differences in sagittal or frontal plane hip moments when compared to controls (126). Similarly, few differences existed between symptomatic and asymptomatic participants in the FORCe cohort during walking, with hip-

specific impairments limited to a smaller transverse plane moment impulse in symptomatic men only (196). Taking these findings together, obvious biomechanical impairments during walking appear limited to people with worse hip/groin pain or more advanced hip joint disease. As athletes with hip/groin pain are unlikely to display altered biomechanics during walking, knowledge of movement pattern impairments during relevant sporting tasks might better inform exercise-based treatments.

(ii) Athletes with hip/groin pain

Few studies have compared lower-limb biomechanics in athletes with and without hip/groin pain (196, 200-203); however, a variety of tasks have been investigated, including walking (196), single leg drop jumping (196), lateral hopping (200), single leg drop landing (201), and kicking (203). Overall, subtle task-specific biomechanical impairments were evident in symptomatic athletes and are summarised in **Table 1.7**. Whilst this is not a comprehensive systematic review of the literature, the dearth of studies investigating athletes with hip/groin pain is apparent. Female athletes were investigated in one study only (196), and two out of five studies investigated athletes with a history of hip/groin pain who were asymptomatic at the time of testing (202, 203). Running is fundamental to most field sports yet running biomechanics have not been investigated in any hip/groin pain population.

Table 1.7. Studies investigating biomechanical patterns in athletes with and without hip/groin pain.

Study	Population	Comparability	Task	Difference in kinematics and moments compared to controls
Gore (2020) (200)	***Male athletes with hip/groin pain seeking treatment*** n=65 Age =25 (± 5) years Symptom duration: >4 weeks ***Male asymptomatic athletes*** n=50 Age =24 (± 3) years	Sport Participation level Age Leg dominance	Lateral hop	**Symptomatic athletes (pre-intervention) performed the lateral hop with:** *Hip* Smaller hip abduction moment (*d*=0.43, ***P*=0.02**) Smaller hip flexion moment (*d*=0.45, ***P*=0.02**) *Knee* Greater knee flexion moment (*d*=0.48, ***P*=0.01**) *Ankle* Greater ankle dorsiflexion angle (*d*=0.46, ***P*=0.02**) Smaller ankle dorsiflexion moment (*d*=0.71, ***P*<0.01**)
King (2020)* (196)	***Football players with hip/groin pain*** n=88 (26% female) Age = 26 [IQR 7] Symptom duration: 24 [IQR 34] months ***Asymptomatic football players*** n=30 (43% female) Age = 27 [IQR 8]	Sport Participation level Age Leg dominance	Single leg drop jump Walking	**Symptomatic football players performed the *single leg drop jump* with:** Greater pelvic hike (i.e., trial side of pelvis lower) (*d*=0.44, ***P*<0.05**) **Symptomatic football players *walked* with:** Smaller frontal plane pelvis drop (i.e., less lateral tilt toward contralateral side) (*d*=0.48, ***P*=0.03**) ***Sex-specific findings*** Symptomatic male football players **walked** with a lower hip transverse plane moment impulse (*d*=0.59, ***P*=0.03**) when compared to asymptomatic men Symptomatic female football players **walked** with greater knee sagittal plane excursion (*d*=1.0, ***P*=0.01**) when compared to asymptomatic women
Janse van Rensberg (2017) (201)	***Male athletes with hip/groin pain*** n=10 Age = 29 years (range 22-48) Symptom duration: >3months (range 6 to 72) ***Asymptomatic male athletes*** n=10 Age = 28 years (range 19-54)	Sport Participation level Age	Single leg drop landing	**Symptomatic athletes performed the drop landing with:** *Pelvis (angle)* Greater frontal plane pelvic drop at initial contact (*d*=0.35, ***P*=0.01**) Greater pelvic rotation toward the trial leg at the lowest vertical position (*d*=0.30, ***P*=0.02**) *Hip* Greater hip abduction angle at initial contact (*d*=0.49, ***P*=0.001**) Greater hip external rotation angle at initial contact (*d*=0 29, ***P*=0.03**)
Edwards (2017) (202)	***Male football players with history of groin pain*** n=7 Age = 23 (± 4) years ***Male football players without history of groin pain*** n=7 Age = 21 (± 1) years	Sport Participation level Age	Cut manoeuvre	No between-groups differences in lower-limb joint angles or moments were observed during the cut manoeuvre (*P*>0.05)
Severin (2017) (203)	***Male football players with history of groin pain*** n=11 Age = 23 years (range 17 to 28) ***Male football players without history of groin pain*** n=11 Age = 24 years (range 19 to 26)	Sport Participation level Age	Kicking	**Football players with a history of hip/groin pain kicked with:** *Pelvis* Smaller sagittal (*d*=0.60, *P*=0.002) and transverse (*d*=0.46, ***P*=0.006**) plane excursion Smaller peak posterior tilt (*d*=0.87, *P*<0.001) and rotation (*d*=0.40, ***P*=0.011**) velocities *Hip* Smaller sagittal plane excursion (*d*=0.74, ***P*<0.001**) Smaller peak flexion velocity (*d*=0.53, ***P*=0.015**)

*indicates findings from the femoroacetabular impingement and hip osteoarthritis cohort (FORCe) study (130). Data presented as mean ± standard deviation or median and interquartile range [IQR], unless otherwise stated. Abbreviation: *d* = Cohen's *d* effect size (204), where the effect is interpreted as small (≥0.20 to ≤0.50), moderate (>0.50 to <0.80), or large (≥0.80).

(iii) Biomechanical impairments at the knee and ankle in people with hip/groin pain

Movement patterns throughout the lower-limb kinetic chain can affect the magnitude and direction of hip joint forces (205). For example, non-hip spanning muscles such as the vasti, gastrocnemius, and soleus contribute to superior hip joint contact forces during walking (206). Furthermore, deliberately increasing plantar flexor activity during walking can reduce sagittal plane hip forces without changing hip joint angles (207). Movement strategies at distal joints might therefore meaningfully impact hip joint loads, and thus symptoms, in people with hip/groin pain.

Biomechanical differences between athletes with and without hip/groin pain were recently found to be more pronounced at the knee and ankle than at the hip (196, 200) **(Table 1.7)**. Whilst altered movement patterns in symptomatic individuals could represent causal or compensatory mechanisms, the existence of such differences indicates that their investigation is warranted.

1.13. Summary and knowledge gaps

Hip/groin pain is common in football players (1-5). Hip-related pain conditions such as FAI syndrome may be prevalent in athletes with longstanding hip/groin pain (6) and might represent those at an early stage on the continuum toward more severe hip joint disease. Whilst the burden of hip OA is well established, knowledge of symptoms and self-reported functional impairments in people with hip-related pain conditions is limited to those seeking surgery (99, 171). To date, self-reported burden in football players with current hip/groin pain is unknown, as is the relationship between specific hip-related pain conditions (e.g., FAI syndrome) and reported burden in any non-surgical population. Few PROMs can accurately assess self-reported burden in active athletes with hip/groin pain (145). Whilst experts recommend using the iHOT-33 (144), its measurement properties are unknown in people with hip/groin pain who do not seek surgery. Once these measurement properties are known, the iHOT-33 can be used to improve our understanding of hip/groin burden in symptomatic football players, providing insights which might then guide assessment and interventions in those with less advanced hip joint disease.

Many physical factors might be associated with the severity of symptoms and physical impairment reported by football players with hip/groin pain. Cam morphology is common

in football players, but it is unknown if larger cam morphology size (i.e., greater alpha angle) is associated with worse reported burden in people with FAI syndrome who do not seek surgery. An athlete's movement patterns during sport may also contribute to the genesis and severity of hip/groin pain, but few studies have compared biomechanical patterns between symptomatic and asymptomatic individuals during sporting tasks (196, 200, 201). Furthermore, the relationship between cam morphology size and hip joint kinematics is unknown in people with FAI syndrome who do not seek surgery. Understanding the relationship between hip joint structure, biomechanics, and self-reported burden might provide insights for the pathogenesis of hip-related pain conditions, inform treatments, and subsequently improve outcomes for football players with hip/groin pain.

1.13.1 Aims of this thesis

This thesis aims to describe self-reported burden in football players with hip/groin pain and investigate relationships between physical findings (including hip joint structure and biomechanics) and the severity of self-reported burden. This thesis is divided into 3 parts:

PART A:

Study 1: Determine the measurement properties of the iHOT-33 in active adults with hip/groin pain who do not seek surgery.

PART B:

Study 2: Examine the self-reported burden of hip/groin pain in football players and investigate if differences exist between male and female players.

Study 3: Determine whether football players with FAI syndrome report worse burden than players with other causes of hip/groin pain and explore whether symptom severity in those with FAI syndrome is explained by chondrolabral pathology.

Study 4: Investigate whether cam morphology size and location are associated with self-reported burden in football players with FAI syndrome.

PART C:

Study 5: Determine whether running biomechanics differ between football players with and without hip/groin pain.

Study 6: Investigate whether self-reported burden or cam morphology size are associated with running biomechanics in football players with FAI syndrome.

Chapter 2. Study participants, hip joint imaging, and patient-reported outcome measures

2.1. Preface

The studies presented in this thesis were undertaken as part of the FORCe study (130) and the physiotherapist-led treatment for femoroacetabular impingement syndrome (PhysioFIRST) randomised controlled trial (RCT) (208). This chapter provides an overview of the methods used to recruit participants, determine eligibility, and undertake clinical assessment for the six studies included in this thesis. Throughout my PhD candidature, I was the project manager for the FORCe study for a period of three years, coordinating data collection at four timepoints (baseline and 6, 12, and 24 months). I recruited two-thirds of participants in the FORCe cohort (n>100) and was the primary person collecting in-person data for more than one-third (n>60). During baseline and 2-year follow up testing sessions, which were approximately three hours in duration, I administered numerous clinical and functional performance tests, and collected biomechanical data for a variety of tasks (e.g., walking, running, and jumping). Methods used for collecting and processing biomechanical data for this thesis are described in **Chapter 7.** .

2.2. FORCe Study

The FORCe study is a prospective cohort study investigating 18- to 50-year-old sub-elite (non-professional) football (football or Australian football) players in Melbourne and Brisbane, Australia. Prior studies describing the burden of hip/groin pain and the associated physical impairments had focussed on individuals undergoing hip surgery who were likely to have ceased all sporting activities. Impairments in these individuals were likely confounded by reduced sporting and physical activity participation, and any features associated with self-reported burden may be less amenable to interventions. The FORCe study was designed to explore factors related to the presence and worsening of hip joint symptoms (PROM scores) and MRI features of OA, in those who were still participating in football. It was hypothesised the features associated with self-reported burden and imaging findings might be modifiable, affording interventions that might slow or prevent the progression to more debilitating hip disease.

Data for the FORCe study were collected at baseline and at three follow-up timepoints (6, 12 and 24 months after baseline assessment). Data collection and analysis for the 24-month timepoint were delayed due to COVID-19 restrictions, hence baseline and 6-month data from the FORCe study were used for this thesis. A convenience sample of 62 young adult football players without hip/groin pain was recruited to act as the control group for the FORCe study participants.

2.2.1 Funding

The FORCe study was funded by a National Health and Medical Research Council (NHMRC) project grant titled “Femoroacetabular impingement and early osteoarthritis” (GNT 1088683). An Australian Government Research Training Program Scholarship was awarded to Mr Mark Scholes to complete this thesis. All studies in this thesis used data collected for the FORCe study.

2.2.2 Ethics

The studies included in this thesis received ethics approval from the La Trobe University Human Ethics Committee (HEC 015-109 (**Appendix A**) and HEC 16-045 (**Appendix B**)) and the University of Queensland Human Ethics Committee (2015000916 (**Appendix C**) and 2016001694 (**Appendix D**). All participants read a plain language statement

(**Appendix E** to **Appendix H**) and provided written informed consent (**Appendix I** to **Appendix L**) prior to participating in the study.

2.2.3 Participant recruitment

Football players residing in Melbourne or Brisbane, Australia, were recruited through: 1) print, electronic, and social media advertisements to football clubs and leagues; 2) direct advertisements to and within sports medicine and physiotherapy clinics; or 3) information sessions conducted at football clubs. All participants were recruited between August 2015 and March 2020. Recruitment of symptomatic and asymptomatic football players into the larger FORCe study is summarised in **Figure 2.1** and **Figure 2.2**, respectively. As additional eligibility criteria were applied for all studies in this thesis (excluding **Chapter 4**), participant flow within this thesis is further described in **Figure 2.8**.

2.2.4 Participant eligibility

(i) Football players with hip/groin pain (symptomatic players)

Symptomatic male and female football players were eligible to participate in the longitudinal FORCe study if they fulfilled the criteria outlined in **Table 2.1**. Additional eligibility criteria were applied for all studies in this thesis except for Study 2 (**Chapter 4**).

Table 2.1. Eligibility criteria for symptomatic football players.

Inclusion criteria
▪ Age: 18 to 50 years ▪ Playing football (soccer or Australian football) in sub-elite competition ▪ Undertaking at least two football sessions (training or matches) per week ▪ Reported hip (anterior/lateral/posterior)/groin pain that fulfilled criteria 1-3: 1. Gradual onset 2. Greater than six months in duration 3. Average hip/groin pain ≥3 and ≤8 on an 11-point numerical pain rating scale during football or football specific movements (including squatting, kicking or cutting/change of direction), with or without symptoms including clicking, giving way, locking, or catching ▪ Positive FADIR pain provocation test result in at least one hip
Exclusion criteria
▪ Self-reported history of significant hip or groin condition, specifically: > Congenital dislocation of the hip > Bursitis > Fracture > Osteochondritis dissecans > Legg-Calvé-Perthes disease > Septic or rheumatoid arthritis > Slipped capital femoral epiphysis > Subluxation or dislocation ▪ Previous hip and/or pelvis surgery ▪ KL grade 2 or greater on AP radiograph ▪ Any lumbar spine or lower-limb injury/complaint in the previous three months (e.g., ankle ligament sprain) that led to being unable to weight-bear fully or undertake testing procedures ▪ Contraindications to radiographs (e.g., pregnancy) or MRI (e.g., claustrophobia) ▪ Received intra-articular hip injection (of any type) in the previous three months ▪ Unable to understand written or spoken English.

Abbreviations: AP = anteroposterior pelvis; FADIR = flexion-adduction-internal rotation; KL = Kellgren and Lawrence (188); MRI = magnetic resonance imaging. Table adapted from Crossley et al. (2018) (130).

(ii) Football players without hip/groin pain (asymptomatic players)

Asymptomatic male and female football players were eligible to participate in the control arm of the FORCe study if they fulfilled the criteria outlined in **Table 2.2**.

Table 2.2. Eligibility criteria for asymptomatic football players.

Inclusion criteria
▪ Age: 18 to 50 years
▪ Playing football (soccer or Australian football) in sub-elite competition
▪ Undertaking at least two football sessions (training or matches) per week
▪ Negative FADIR pain provocation test result in both hips
Exclusion criteria
▪ Self-reported history of significant hip or groin condition, specifically:
> Congenital dislocation of the hip
> Bursitis
> Fracture
> Osteochondritis dissecans
> Legg-Calvé-Perthes disease
> Septic or rheumatoid arthritis
> Slipped capital femoral epiphysis
> Subluxation or dislocation
▪ Pelvic or lower-limb surgery (e.g., anterior cruciate ligament reconstruction)
▪ KL grade 2 or greater on AP radiograph
▪ Any lumbar spine or lower-limb injury/complaint in the previous three months (e.g., ankle ligament sprain) that led to being unable to weight-bear fully or undertake testing procedures
▪ Contraindications to radiographs (e.g., pregnancy) or MRI (e.g., claustrophobia)
▪ Unable to understand written or spoken English.

Abbreviations: AP = anteroposterior pelvis; FADIR = flexion-adduction-internal rotation; KL = Kellgren and Lawrence (188); MRI = magnetic resonance imaging. Table adapted from Heerey et al. (2021) (131).

2.2.5 Assessment of participant eligibility

(i) Non-radiologic evaluation

Football players (symptomatic and asymptomatic) who expressed interest in participating in the FORCe study were screened verbally (in person or over the phone) to establish eligibility. Men and women who fulfilled the study eligibility criteria then underwent physical screening with one of four trained researchers (Melbourne: Mr Mark Scholes, Dr Joshua Heerey, Dr Matthew King; Brisbane: Dr Peter Lawrenson) to determine study eligibility.

(ii) Radiologic evaluation

All football players who fulfilled the non-radiologic eligibility criteria underwent supine AP and Dunn 45° radiographs according to a standardised protocol (**Section 2.2.9**). Features of radiographic hip osteoarthritis were evaluated on the AP radiograph by one blinded orthopaedic surgeon registrar (Dr Rintje Agricola) with more than 10 years' experience reading pelvic radiographs. Kellgren and Lawrence classification (grade 0 to 4) (188) was determined for all hips. Participants with radiographic hip osteoarthritis, determined by a KL grade of 2 or greater, were excluded from the FORCe study. Intra-observer reliability was determined by Dr Rintje Agricola assessing 20 radiographs twice, six months apart. Weighted kappa for KL classification was 0.87 [95% CI 0.71, 1.00] (131).

2.2.6 Participant demographic and anthropometric information

Football players with and without hip/groin pain completed baseline testing for the FORCe study at La Trobe University (Melbourne) or University of Queensland (Brisbane). Participant demographic characteristics (including age, sex, football code, playing level, training and competition frequency, symptom duration, and injury history) and anthropometric information (height and weight) were recorded prior to physical (hip muscle strength, hip joint ROM, and functional performance) and biomechanical testing (described further in **Chapter 7**).

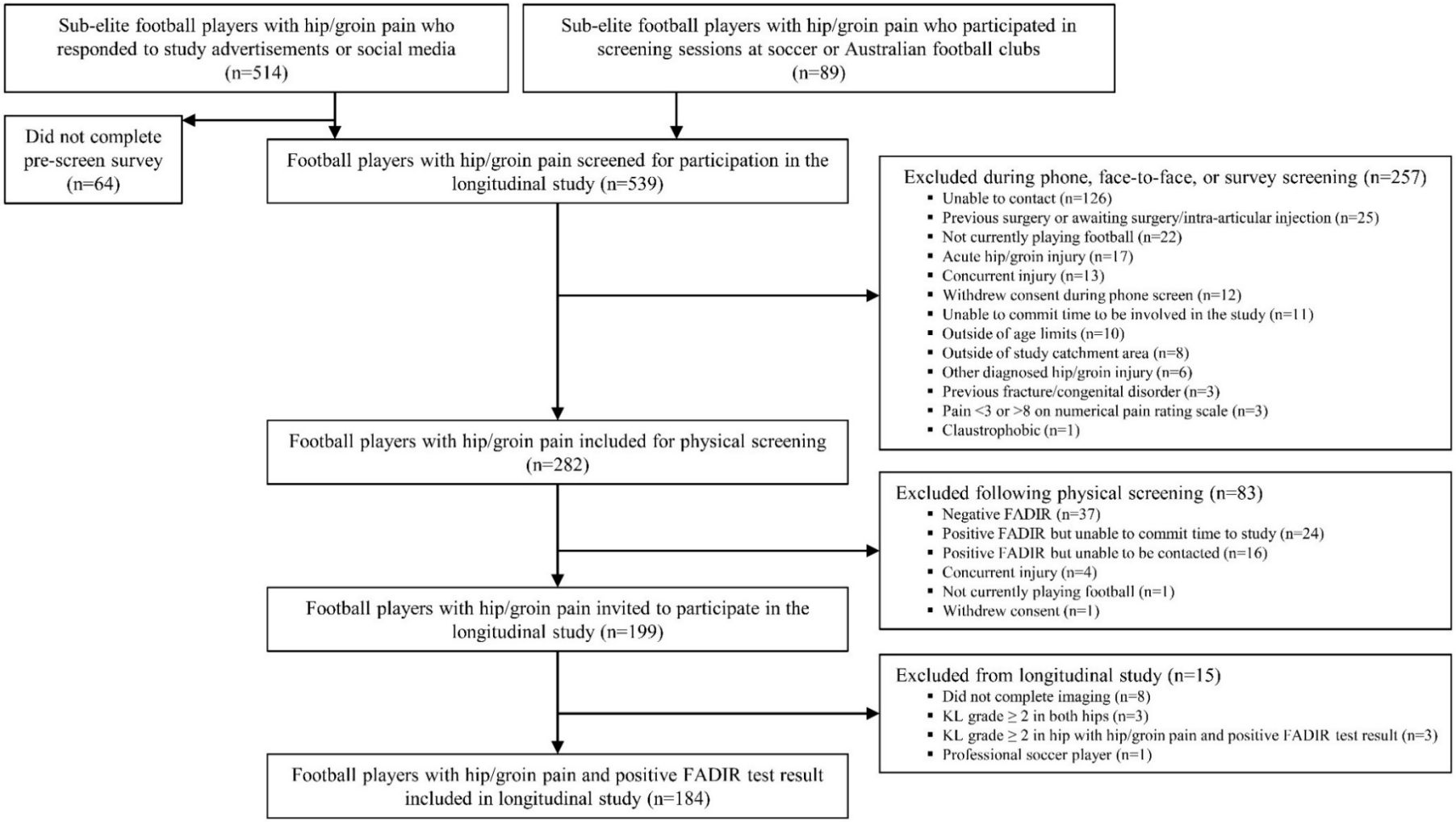


Figure 2.1. Recruitment of symptomatic football players into the femoroacetabular impingement and hip osteoarthritis cohort (FORCe) study.
Abbreviations: FADIR = flexion-adduction-internal rotation; KL = Kellgren and Lawrence (188). Figure adapted from Heerey et al. (2021) (131).

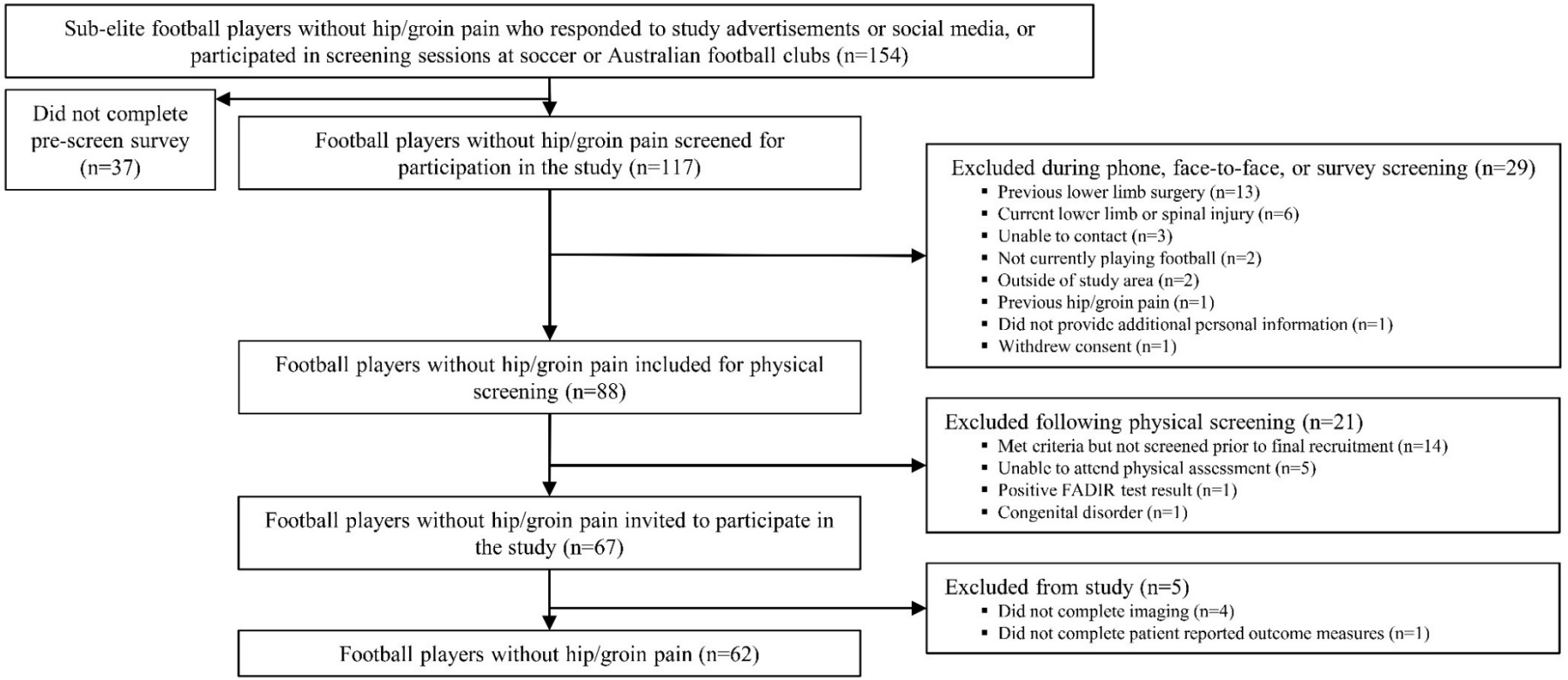


Figure 2.2. Recruitment of asymptomatic football players into the control arm of the femoroacetabular impingement and hip osteoarthritis cohort (FORCe) study.
Abbreviations: FADIR = flexion-adduction-internal rotation; KL = Kellgren and Lawrence (188). Figure adapted from Heerey et al. (2021) (131).

2.2.7 Patient-reported outcome measures

Three PROMs were used for studies in this thesis: the iHOT-33 (**Appendix M**), the HAGOS (**Appendix N**), and the Global Rating of Change (GROC) score. At baseline assessment, football players with and without hip/groin pain completed the iHOT-33 and HAGOS. At 6-month follow-up, symptomatic participants completed the iHOT-33 and GROC. Questionnaires were completed in hard-copy format or via CheckWare (CheckWare AS, Trondheim, Norway), an online data capture and storage platform. The iHOT-33 and HAGOS are used in all studies in this thesis.

(i) The International Hip Outcome Tool-33

The iHOT-33 and the measurement properties of the iHOT-Total score are described in **Section 1.9.1**. For the four iHOT-33 subscales (i.e., iHOT-Symptoms, iHOT-Sport, iHOT-Job, and iHOT-Social), scores were calculated by summing the item scores for each subscale and dividing by the corresponding number of items answered. Subscale scores were reliable in a small sample of patients (n=30) seeking tertiary care (surgery or physiotherapist-led treatment) for hip/groin pain (ICC values ranged from 0.86 to 0.92 [95% CIs 0.70, 0.97]), with SEM values ranging from 5.6 to 9.0 [95%CIs 4.6, 14.0] (156). Prior to this thesis, the measurement properties of the iHOT-Total were unknown in people not seeking surgery. Furthermore, except for reliability, the measurement properties of the subscale scores were untested in any population.

(ii) The Copenhagen Hip and Groin Outcome Score

The HAGOS and its measurement properties are described in **Section 1.9.2**. Briefly, the HAGOS consists of six subscales scores (HAGOS-Symptoms, HAGOS-Pain, HAGOS-ADL, HAGOS-Sport, HAGOS-PA, and HAGOS-QOL) ranging from 0 (worst possible score) to 100 (best possible sore). Scores for the HAGOS are valid, reliable, and responsive in active adults with hip/groin pain (144, 148).

(iii) The Global Rating of Change score

The GROC score measures participants' perceived change in their condition and consists of seven possible responses ranging from -3 (very much worse) to 3 (very much better). Participants were asked to, "Please circle the response which best describes how the condition of your hip has changed in the past 6 months: 1) very much worse; 2) much

worse; 3) somewhat worse; 4) no change (GROC score = 0); 5) somewhat better; 6) much better; or 7) very much better". The GROC has adequate validity, reliability, and responsiveness to measure patient-reported change in active adults with hip/groin pain (209). In this thesis, the GROC was used as a comparator for testing the measurement properties of the iHOT-33 (**Chapter 3**).

2.2.8 Hip joint imaging acquisition

Symptomatic and asymptomatic football players 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 were collected on the same day where possible for all participants.

2.2.9 Radiographs

(i) Radiograph set-up - 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 1m in Melbourne and 1.1m in Brisbane. The central ray was centred on the symphysis pubis and located between the anterior superior iliac spine and pubic symphysis.

(ii) Radiograph set-up - Dunn 45°

Each participant was positioned on the x-ray table with one hip flexed to 45°, abducted 20° and positioned in neutral axial rotation. Right and left hips were collected separately. The x-ray tube was aligned to the detector at a focal field distance of 1m in Melbourne and 1.1m in Brisbane. The central ray was centred over the hip joint.

(iii) Radiograph assessment

Bony hip morphology was analysed using quantitative measures (74, 121) by one physiotherapist (Dr Joshua Heerey) who had 10 years of clinical experience and who was trained in the methodology. Radiographs were transferred to a workstation and a point set was manually 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 the AP and Dunn 45° radiographs, respectively **(Figure 2.3)**. Alpha angles and the LCEA were calculated from these point sets using MATLAB v7.1.0 (MathWorks Inc, Massachusetts, United States of America (USA)).

Alpha angle

The points placed on the femoral head and neck determined the circle of best fit around the femoral head and centre of femoral neck, respectively. The alpha angle was calculated as the internal angle created 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 2.3)**.

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 weightbearing portion of the acetabular sulcus **(Figure 2.3)**. To correct for pelvic malposition, the vertical line was drawn perpendicular to a horizontal line that connected the two superolateral points of both obturator foramen.

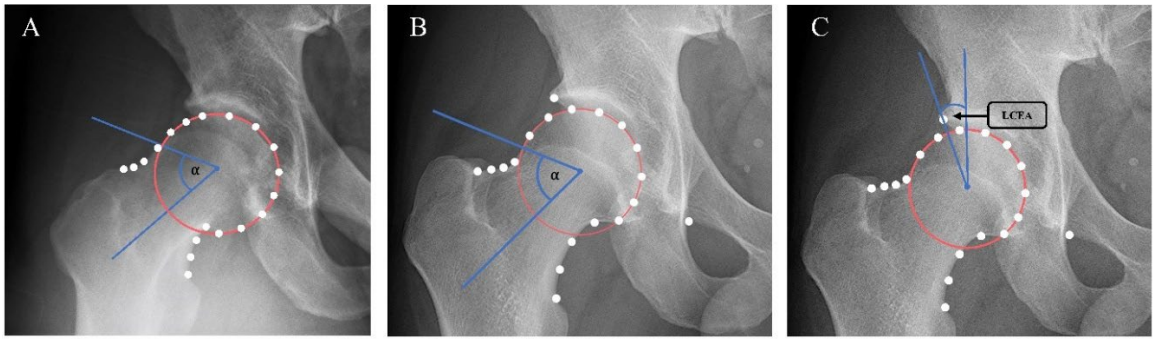


Figure 2.3. Marker set placement for Dunn 45° (A) and anteroposterior pelvis (B & C) radiographs.
A) Alpha angle (α) on the Dunn 45° radiograph; B) Alpha angle on the anteroposterior pelvis radiograph; C) Lateral-centre-edge-angle (LCEA) on the anteroposterior radiograph. Figure adapted from Heerey et al. (2021) (131).

(iv) Radiographic classification of bony morphology

Cam morphology

A gender non-specific alpha angle threshold value of 60° (i.e., alpha angle ≥60°) determined the presence of cam morphology on the AP and Dunn 45° radiographs (63, 64, 210). Cam morphology was analysed as a dichotomous (present/absent) variable in

Chapter 5 and its presence was an additional study inclusion criterion in **Chapter 6** and **Chapter 9**.

Acetabular morphology

The LCEA on the AP radiograph described the superolateral coverage of the femoral head by the acetabulum (74). An LCEA of ≥40° and <20° determined the presence of pincer morphology and acetabular dysplasia, respectively (18, 63, 74). Symptomatic football players with acetabular dysplasia were excluded from studies in **Chapter 5**, **Chapter 6**, and **Chapter 9**.

(v) Reliability of radiographic assessment

Intra-observer reliability for bony hip morphology was determined by Dr 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. Moderate-to-good intra- and inter-observer reliability were demonstrated for bony hip morphology measures (131), with ICC values presented in **Table 2.3**.

Table 2.3. Results of intra-observer and inter-observer reliability assessments.

Radiographic view	Intra-observer reliability	Inter-observer reliability
Anteroposterior pelvis		
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)

Abbreviation: LCEA = lateral-centre-edge-angle. Values are intraclass correlation coefficients (95% confidence interval). Table adapted from Heerey et al. (2021) (131).

2.2.10 Magnetic resonance imaging

(i) Magnetic resonance imaging set-up

Each participant underwent an unenhanced 3.0 Tesla (3T) MRI (Phillips Ingenia, The Netherlands). Participants were positioned in supine, with positioning aids used to maintain each hip in internal rotation and neutral abduction/adduction, and a 32-channel torso coil was placed over the hips and pelvis. Participants' right and left hips were imaged independently. The standardised MRI protocol (**Table 2.4**) included three sequences: coronal proton density spectral attenuated inversion recovery (PD SPAIR), sagittal PD SPAIR, and oblique axial PD SPAIR.

Table 2.4. 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

Abbreviations: mm = millimetres; ms = milliseconds; min:sec = minutes:seconds; MRI = magnetic resonance imaging; PD = proton density; SPAIR = spectral attenuated inversion recovery. Table adapted from Heerey et al. (2021) (183).

(ii) Magnetic resonance imaging assessment - Scoring Hip Osteoarthritis with Magnetic Resonance Imaging (SHOMRI)

All MRI scans were evaluated by a single musculoskeletal radiologist (Dr Ramya Srinivasan) with eight years of experience and who was blinded to radiographic and clinical findings. All images were analysed using a standard clinical picture archiving and communication system (Agfa, New Jersey, USA). The Scoring Hip Osteoarthritis with MRI (SHOMRI) (87) was used to evaluate cartilage defects and labral tears for Study 3 (**Chapter 5**) of this thesis. The SHOMRI method divides the hip joint into 6 femoral subregions and 4 acetabular subregions (**Figure 2.4**).

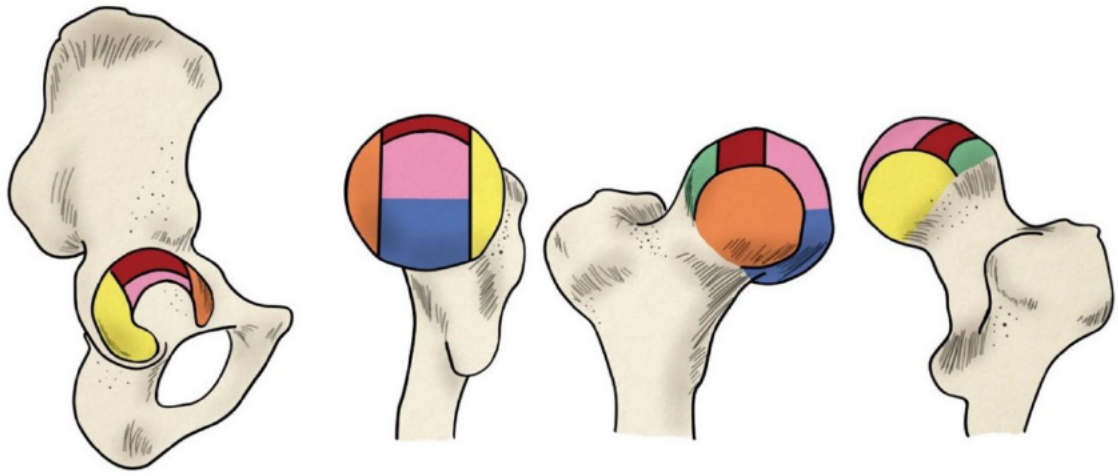


Figure 2.4. Acetabular and femoral subregions for the Scoring of Hip Osteoarthritis with MRI (SHOMRI) assessment.
Moving left to right across the figure: a) lateral view of acetabular subregions (far left of figure); b) medial view of femoral subregions; c) anterior view of femoral subregions; d) posterior view of femoral subregions (far right of figure). Figure adapted from Lee et al. (2015) (87) and Heerey (2021) (109).

Cartilage defects

Cartilage defects were defined as "increased signal intensity extending from the surface of the articular cartilage" and were assessed in all subregions **(Figure 2.4)** (87). For each subregion, cartilage defects were graded on a 3-point scale: 0=no defect, 1=partial defect, or 2=full thickness defect (**Figure 2.5**). Large defects that covered more than one subregion and had a maximal diameter of greater than 10mm were scored in both subregions, with defects less than 10mm scored in the subregion where more than 50% of the defect was present (87).

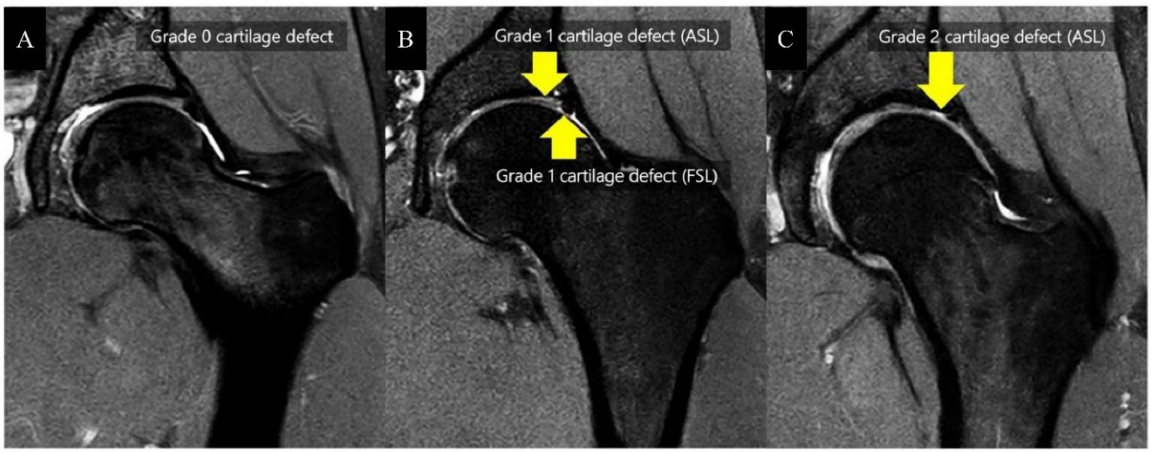


Figure 2.5. Scoring Hip Osteoarthritis with MRI (SHOMRI) assessment of cartilage defects.
a) Grade 0 cartilage defects (no cartilage defects present in any acetabular or femoral subregion); b) Grade 1 (partial thickness) cartilage defect present in the acetabular superolateral (ASL) and femoral superolateral (FSL) subregions; c) Grade 3 cartilage lesion in the ASL subregion. Figure adapted from Heerey (2021) (109).

Labral tears

Labral tears were assessed in the four acetabular subregions and were graded on a 5-point scale: 0=normal or normal variant (e.g., aplasia or hypoplasia), 1=abnormal signal within the labrum and/or fraying present, 2=simple tear, 3=tear with labrocartilage separation, 4=complex tear, or 5=maceration (**Figure 2.6**) (87).

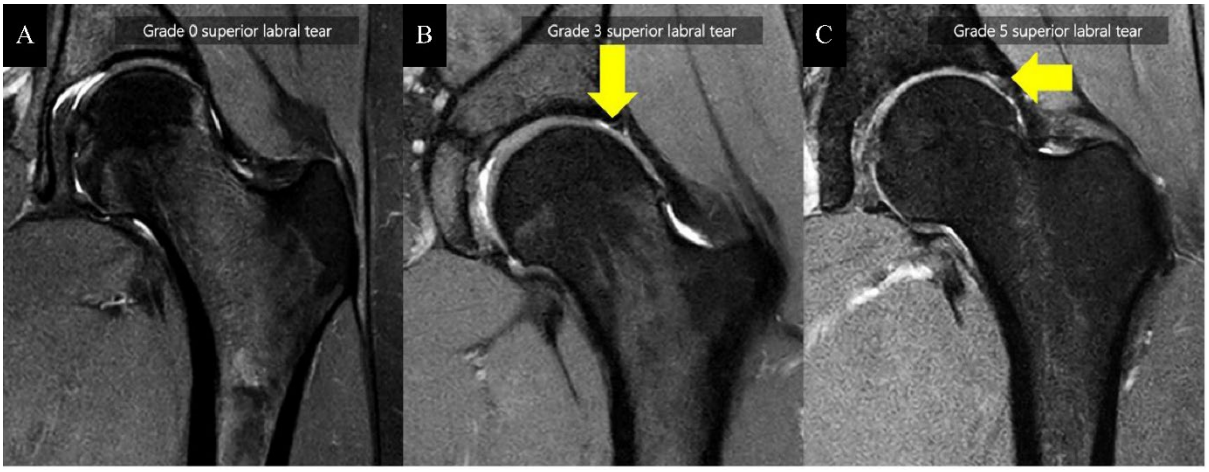


Figure 2.6. Scoring Hip Osteoarthritis with MRI (SHOMRI) assessment of labral abnormalities.
a) Grade 0 superior labral tear grade (no tear present or normal variant); b) Grade 3 superior labral tear (labrocartilage separation); c) Grade 5 labral tear (maceration). Figure adapted from Heerey (2021) (109).

(iii) Classification of cartilage defects and labral tears

Dichotomous scoring of cartilage defects and labral tears was used for **Chapter 5** of this thesis. A cartilage defect was determined to be present if any cartilage defect (grade 1 or grade 2) was present in any femoral or acetabular subregion. A labral tear was determined to be present when a grade 2 (simple) tear or worse was observed in one or more subregions.

(iv) Reliability of magnetic resonance imaging assessment

Intra-observer reliability for the SHOMRI assessment was determined by a single radiologist (Dr Ramya Srinivasan) scoring 20 hips twice, two weeks apart. Potential recall bias was minimised by randomly ordering the de-identified images at each timepoint. Intra-observer agreement for cartilage defect and labral tear grading (dichotomous scoring) had prevalence adjusted bias adjusted kappa values of 0.76 (kappa 0.66) and 0.80 (kappa 0.77), respectively (183).

2.2.11 Classification of symptomatic football players with hip-related pain

As all symptomatic participants in the FORCe study reported hip/groin pain and had a positive FADIR, those players with cam (alpha angle ≥60°) or pincer (LCEA ≥40°) morphology were determined to have FAI syndrome (38, 63, 64). Football players with both cam and pincer morphology were determined to have FAI syndrome with mixed morphology (15).

2.3. PhysioFIRST study

The PhysioFIRST study is a double-blind RCT investigating the effect of two physiotherapist-led interventions on hip-related QOL in people with FAI syndrome (208). Participants in the PhysioFIRST study underwent baseline testing before being randomised to one of two 6-month physiotherapist-led treatment programmes. Data were collected at baseline and at three follow-up timepoints (3, 6 and 12 months after baseline assessment). Baseline and 6-month data from the PhysioFIRST study were used for **Chapter 3** of this thesis.

2.3.1 Funding

The PhysioFIRST study was funded by the La Trobe Sport and Exercise Medicine Research Centre at La Trobe University and an Arthritis Grant in Aid. Lead investigator Associate Professor Joanne Kemp was supported was supported by a NHMRC Early Career Fellowship (1119971).

2.3.2 Ethics

The PhysioFIRST study was registered with the Australian New Zealand Clinical Trials Registry (reference number 12617001350314) and ethics approval was obtained from the La Trobe University Human Ethics Committee (HEC 17-080, **Appendix O**). All participants read a plain language statement (**Appendix P**) and provided written informed consent (**Appendix Q**) prior to participating in the study.

2.3.3 Participant recruitment

Men and women with hip/groin pain were recruited from the general community through 1) print, electronic, and social media advertisements; or 2) direct advertisements to and within general practice, sports medicine, and physiotherapy clinics. All participants were recruited between March 2018 and March 2020. Recruitment of men and women with hip-related pain for the PhysioFIRST study is summarised in **Figure 2.7**. As additional eligibility criteria were applied for all studies in this thesis (excluding **Chapter 4**), participant flow within this thesis is further described in **Figure 2.8**.

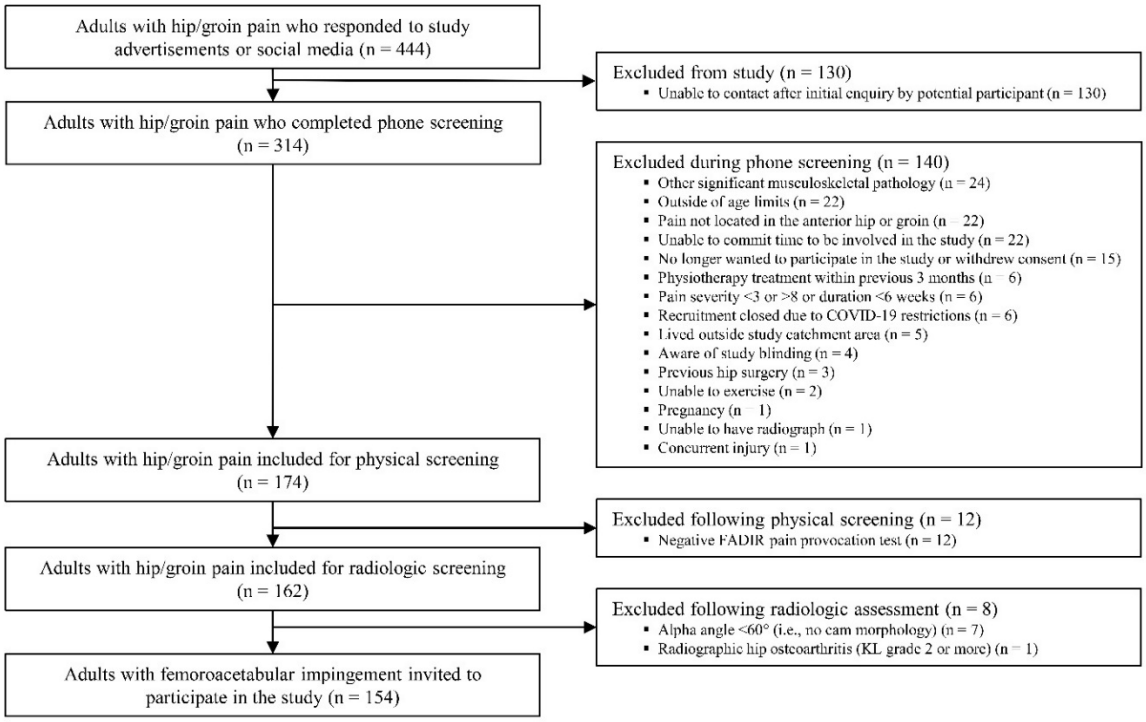


Figure 2.7. Recruitment of participants into the physiotherapist-led treatment for femoroacetabular impingement syndrome (PhysioFIRST) study.
Abbreviations: FADIR = flexion-adduction-internal rotation; KL = Kellgren and Lawrence (188).

2.3.4 Participant eligibility

Adults aged 18 to 50 years with a history of hip/groin pain and who resided in urban (greater Melbourne) or regional Victoria (Ballarat), Australia, were eligible to participate in the PhysioFIRST study if they fulfilled the criteria outlined in **Table 2.5**. Data for PhysioFIRST participants who completed baseline assessment and 6-month PROMs were examined in **Chapter 3** of this thesis.

Table 2.5. Eligibility criteria for PhysioFIRST study participants.

Inclusion criteria
▪ Age: 18 to 50 years ▪ Reported hip-related (anterior hip or groin) pain that fulfilled criteria 1 and 2: 1. Average pain ≥3/10 on numerical pain rating scale for ≥6 weeks 2. Aggravated by prolonged sitting or hip movements into positions of impingement ▪ Positive FADIR pain provocation test result in at least one hip ▪ Radiographic evidence of cam morphology (alpha angle ≥60°) on standing AP or Dunn 45° radiograph in at least one hip with positive FADIR test result.
Exclusion criteria
▪ Physiotherapist-led treatment or intra-articular hip joint injection (any type) in the previous 3 months ▪ Previous hip, pelvis, or spinal surgery ▪ Planned lower-limb surgery in the following year (e.g., hip arthroscopy) ▪ KL grade 2 or greater on AP radiograph ▪ Neurological, systemic arthritis, or other musculoskeletal conditions where FAI syndrome was not considered to be the primary cause of hip pain ▪ Unable to undertake testing procedures ▪ Unable to commit to a 6-month physiotherapist-led treatment programme or the associated outcome assessments ▪ Contraindications to radiographs ▪ Pregnancy at commencement or during trial period ▪ Unable to understand written or spoken English.

Abbreviations: AP = anteroposterior pelvis; FADIR = flexion-adduction-internal rotation; KL = Kellgren and Lawrence (188). Table adapted from Kemp et al. (2021) (208).

2.3.5 Assessment of participant eligibility

(i) Non-radiologic evaluation

Adults with hip/groin pain who expressed interest in participating in the PhysioFIRST study were screened verbally (in person or over the phone) before undergoing physical assessment with a single trained researcher (Mrs Sally Coburn).

2.3.6 Radiologic evaluation

(i) Radiograph acquisition and set up

Men and women with hip/groin pain that fulfilled the non-radiologic eligibility criteria attended a single private radiology clinic in urban (Imaging @ Olympic Park, Melbourne) or regional Victoria (Lake Imaging, Ballarat). Potential participants underwent supine AP and Dunn 45° radiographs according to the same standardised protocol that was used for FORCe participants (see **Section 2.2.9** for more details).

(ii) Radiograph assessment and classification

A single investigator (Associate Professor Joanne Kemp) with >20 years clinical experience reading hip and pelvis radiographs evaluated features of radiographic hip

osteoarthritis and bony hip morphology. Men and women with a KL ≥2 on the AP radiograph were determined to have radiographic hip osteoarthritis (188) and were excluded from the PhysioFIRST study.

Alpha angle was assessed semi-quantitatively using Inteleviewer software (Intelerad, Montreal, Canada) and previously reported methods (211). Briefly, three marks were drawn manually on each radiograph: 1) a best fit circle for the femoral head, 2) a line extending from the centre of the femoral neck at its narrowest point to the centre of the best-fit circle, and 3) a line extending from the centre of the best fit circle to the point where the femoral head extended beyond the margin of the circle (211). The internal angle created by the two lines determined the alpha angle. Good and excellent intra-observer reliability using this method was reported for alpha angle measurements for AP and Dunn 45° radiographs, respectively (AP ICC = 0.88 [95%CI 0.75, 0.95]; Dunn 45° ICC = 0.98 [95%CI 0.95, 0.99]) (211). An alpha angle ≥60° on the AP or Dunn 45° radiograph determined the presence of cam morphology (63, 64, 210). Men and women with hip/groin pain that fulfilled non-radiologic criteria and who had cam morphology were included in the PhysioFIRST study.

2.3.7 Participant demographic and anthropometric information

PhysioFIRST study participants completed baseline testing at La Trobe University (Melbourne). Demographic characteristics (including age, sex, symptom duration, and injury history) and anthropometric information (height, weight) were collected prior to physical (hip muscle strength, hip joint ROM, and functional performance) testing.

2.3.8 Patient-reported outcome measures

Patient-reported outcome measures were completed during the baseline assessment and 6-month follow-up using Promptus (Promptus (DS PRIMA), Melbourne, Australia), an electronic data collection and storage system. Participants in the PhysioFIRST study completed the iHOT-33, HAGOS, and GROC questionnaires in the same sequence as participants in the FORCe study (i.e., iHOT-33 and HAGOS at baseline assessment; iHOT-33 and GROC at 6-month follow-up).

2.3.9 Physiotherapist-led treatments

Participants in the PhysioFIRST study underwent one of two 6-month physiotherapist-led treatment programmes (targeted strengthening or standardised stretching) (208). Both programmes included supervised and unsupervised exercise, education, manual therapy, and equal exposure to treatment.

2.4. Participant flow through this thesis

The movement of participants through this thesis is summarised in **Figure 2.8**.

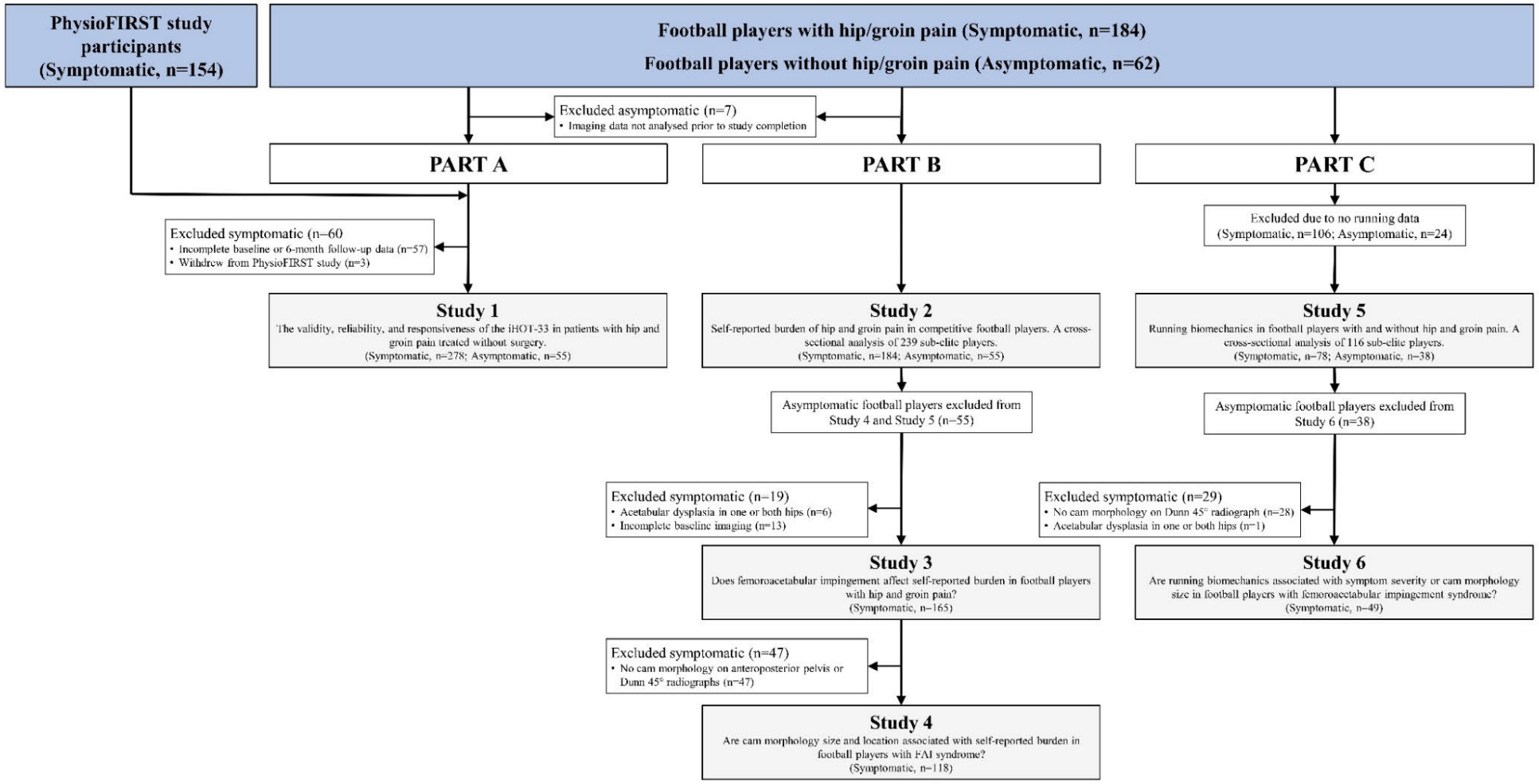


Figure 2.8. Participant flow through this thesis.
Abbreviations: FAI = femoroacetabular impingement; PhysioFIRST = physiotherapist-led treatment for femoroacetabular impingement.

PART A: MEASUREMENT PROPERTIES OF THE iHOT-33

Chapter 3. The iHOT-33 is valid, reliable, and responsive in active adults with hip and groin pain treated without surgery

3.1. Preface

As identified in **Chapter 1**, the measurement properties of the iHOT-33 are unknown in most people with hip/groin pain (i.e., non-surgical populations). Importantly, the utility of PROMs such as the iHOT-33 may vary in different populations. To improve its usefulness in clinical and research settings, this chapter aimed to determine the measurement properties of the iHOT-33 in people not seeking surgery for hip/groin.

Chapter 3 contains an edited version of the following publication:

Scholes MJ, King MG, Crossley KM, Jones DM, Semciw AI, Mentiplay BF, Heerey JJ, Lawrenson PR, Coburn SL, Johnston RTR, Bell EC, Girdwood M, Kemp JL. The International Hip Outcome Tool 33 (iHOT-33) is valid, reliable, and responsive in patients with hip and groin pain treated without surgery. *American Journal of Sports Medicine*. 2021;49(10):2677-88. doi: 10.1177/03635465211027180.

The following minor amendments were made to improve clarity and facilitate consistency throughout this thesis: 1) "No treatment group" renamed to "Symptomatic football players"; 2) "Physiotherapist-led treatment group" renamed to "PhysioFIRST participants"; and 3) "Pain-free control group" renamed to "Asymptomatic football players". **Figure 3.1**, **Table 3.4**, and in-text references to the three groups have been updated, where appropriate. No amendments or additions have been made to the results.

3.2. Abstract

Background: The iHOT-33 was designed and evaluated in patients seeking surgery for hip/groin pain and may not be appropriate for those seeking non-surgical treatment.

Hypothesis/Purpose: Evaluate the psychometric properties of the iHOT-Total score and all subscale scores in adults with hip/groin pain not seeking surgery.

Study Design: Case-control study.

Methods: Participants with hip/groin pain not seeking surgery were recruited from two ongoing studies in Australia. Semi-structured 1:1 interviews assessed content validity. Construct validity was assessed by testing hypothesized correlations between iHOT-33 and HAGOS subscale scores. Test-retest reliability was assessed in participants not undertaking treatment and who reported "no change" on their GROC score at 6-month follow-up. Scores were reliable at a group and individual level if ICC values were ≥0.80 and ≥0.90, respectively. Scores were responsive if Spearman rank correlations (*rho*) between each iHOT-33 change score and the GROC score were ≥0.40.

Results: In total, 278 hip/groin pain (93 women, mean age 31 years) and 55 asymptomatic (14 women, mean age 29 years) participants were recruited. The iHOT-33 demonstrated acceptable content validity. Almost all hypothesized strong positive correlations between iHOT-33 and HAGOS subscale scores were confirmed (*r* range 0.58 to 0.76, *P*<0.001), indicating acceptable construct validity. All scores were reliable at group level except for the iHOT-33 job (iHOT-Job) subscale (ICCs ranged from 0.78 to 0.88 [95%CI 0.60, 0.93]). None of the subscales met the criteria for adequate reliability for use at an individual level (all ICCs < 0.90). Minimal detectable change values (group-level) ranged from 2.3 to 3.6 points [95%CI 1.7, 4.7]. All iHOT-33 scores were responsive (*rho* range 0.40 to 0.58, *P*<0.001) except for the iHOT-Job subscale in participants not undertaking treatment (*rho*=0.27, *P*<0.001).

Conclusion: All iHOT-33 scores were valid for use in patients with hip/groin pain not seeking surgery. Acceptable group-level test-retest reliability was found for all scores except the iHOT-Job. All scores excluding the iHOT-Job were responsive, regardless of undertaking physiotherapist-led treatment or no treatment.

Clinical relevance: All iHOT-33 scores have acceptable psychometric properties for use in young and middle-aged adults with hip/groin pain not seeking surgery.

Key terms: Patient-reported outcome measures; femoroacetabular impingement syndrome; psychometric properties; groin pain; rehabilitation.

3.3. Introduction

Hip/groin pain can affect young- and middle-aged adults (38), reducing physical function and QOL (5, 38, 174, 212). Many intra- and extra-articular conditions are associated with hip/groin pain in active adults (33, 38), and surgical and non-surgical treatment options exist (213). Patients with hip/groin pain report varying levels of pain severity, symptoms, functional impairment, and QOL (144); where some patients may seek surgery to alleviate pain and improve daily function (146), whilst others can participate in competitive sport (5).

Patient reported outcome measures, such as the iHOT-33 (147), are self-reported measures that quantify perceived impacts to health, function, and QOL in hip/groin pain patients (144). Self-reported PROMs might better represent disease burden than clinical or radiological measures in hip/groin pain patients, by considering contextual factors (e.g. activity limitations and participation restrictions) relevant to the respondent (137). However, the utility of PROMs varies depending on the characteristics of the population being studied (136), and it is important to establish the psychometric properties of PROMs in patients with varying severity of hip/groin pain burden in different treatment settings (136, 144).

The iHOT-33 was designed to evaluate four different dimensions of hip/groin pain, culminating in a total hip-related QOL score (147, 165). It was designed for heterogeneous hip/groin pain populations (147, 165) and was recently recommended for use in active adults with hip/groin pain (144, 145). However, the validity (147, 151), reliability (147, 151, 156), and responsiveness (147, 151) of the iHOT-Total score have only been investigated in patients seeking or undertaking hip surgery. These patients may report worse hip/groin pain burden than patients seeking non-surgical treatment, limiting generalizability of the findings to non-surgical populations. Further, construct validity of the iHOT-33 subscale scores has not been investigated in any patient population, and the reliability and responsiveness of these scores are unknown in patients not seeking surgery. Therefore, the aim of this study was to evaluate the psychometric properties of the iHOT-Total and all subscale scores in adults with hip/groin pain who were not seeking surgery. We hypothesize that all iHOT-33 scores will demonstrate appropriate validity, reliability, responsiveness, and interpretability for use in adults with hip/groin pain who do not seek surgery.

3.4. Methods

3.4.1 Study design

Using a retrospective design, this study was undertaken in a community setting and approved by the La Trobe University Human Ethics Committee (HEC17-080, HEC16-045, HEC15-019) and the University of Queensland Human Ethics Committee (2015000916, 2016001694).

3.4.2 Participants

This study involved a subset of participants recruited from three larger ongoing studies in Australia. Participants with hip/groin pain were recruited from two studies; 1) the PhysioFIRST RCT (**Section 2.3**; ACTRN12617001350314) investigating patients undertaking one of two 6-month physiotherapist-led treatments (PhysioFIRST participants) (208), and 2) the FORCe study of sub-elite football players in which treatment was not prescribed (Symptomatic football players) (**Section 2.2**) (130). Healthy control participants were recruited from an observational cohort study of football players without hip/groin pain (Asymptomatic football players) (**Section 2.2**). All participants provided written informed consent prior to data collection.

(i) Participants with hip/groin pain

Symptomatic football players

Between August 2015 and August 2018, 184 (38 women) football players (football and Australian Football) with hip/groin pain were recruited from the greater Melbourne and Brisbane metropolitan regions in Australia. Recruited football players were aged 18 to 50 years and engaged in a structured, sub-elite (non-professional) competition consisting of at least two sessions per week, including training and matches. Eligibility criteria for hip/groin pain participants not undertaking treatment are published (130) and are detailed in **Table 2.1**. Briefly, football players with hip/groin pain were included if they: 1) reported >6-month history of gradual-onset, activity-related hip/groin pain (average pain ≥3/10 but ≤8/10 on numerical pain rating scale during football competition), and 2) had a positive FADIR pain provocation test. Football players with hip/groin pain were excluded if they had: 1) a self-reported history of significant hip or groin condition (e.g. fracture or Legg-Calvé-Perthes disease); 2) neurological or systemic arthritis conditions; 3) previous pelvis

or hip surgery; 4) moderate-to-severe hip osteoarthritis (represented by KL grade ≥2 on anteroposterior radiograph (188)); 5) received an intra-articular hip injection of any type in the three months preceding testing; 6) contraindications to x-ray (e.g. pregnancy); or 7) an inability to understand English language.

PhysioFIRST participants

Between March 2018 and March 2020, 154 participants were recruited from the general community in greater metropolitan Melbourne and regional Victoria, Australia. Patients with hip/groin pain who sought physiotherapist-led treatment were included in the larger RCT if they: 1) were aged 18 to 50 years; 2) reported anterior hip/groin pain that was aggravated by prolonged sitting or hip movements into positions of impingement (45); 3) reported hip/groin pain ≥3/10 on numerical pain scale for ≥6 weeks; 4) had cam morphology (defined as radiographic alpha angle ≥60° on AP or Dunn 45° radiograph (121)); and 5) a positive FADIR test. Individuals were excluded if they: 1) had undertaken physiotherapy treatment for hip/groin pain in the three months preceding testing, 2) had previous hip or back surgery, 3) planned lower limb surgery in the following year, 4) had moderate-to-severe hip osteoarthritis (represented by KL grade ≥2 on AP radiograph (188)), 5) received an intra-articular hip-joint injection of any type in the three months preceding testing, 6) had neurological or other musculoskeletal or systemic arthritis conditions, 7) were unable to perform physical testing procedures, 8) were unable to commit to a 6-month physiotherapy-led intervention or associated outcome assessments, 9) had contraindications to x-ray (e.g. pregnancy), or 10) were unable to understand English language (**Table 2.5**).

(ii) Asymptomatic participants

Asymptomatic football players

Between September 2016 and October 2018, 55 (14 women) football players (football and Australian Football) aged 18 to 50 years were recruited. Eligibility criteria for asymptomatic football players is summarised in **Table 2.2**. Briefly, asymptomatic players were included if they: 1) had no self-reported history of hip or groin pain; 2) had a negative FADIR test; and 3) reported no history of lower limb surgery. The same exclusion criteria described above for symptomatic football players were applied to asymptomatic players.

3.4.3 Additional study inclusion criteria

To be included in this study of psychometric properties, participants with hip/groin pain from the two larger studies (PhysioFIRST and FORCe studies) needed to have completed all relevant PROMS at baseline testing and at six months after baseline testing (6-month follow-up). Asymptomatic football players were only involved in cross-sectional analyses and thus, were included in this study if all relevant baseline assessments were completed.

3.4.4 Sample size

As we aimed to assess the psychometric properties of the iHOT-33 scores and not demonstrate treatment effectiveness, a formal power analysis was not completed. Instead, the COSMIN guidelines were used to inform our sample sizes (214). Recommended sample sizes for evaluating various psychometric properties, our study's respective sample sizes, and the subsequent COSMIN rating are provided in the supplementary information (**Section 3.8.1**).

3.4.5 Testing procedures

Participants attended a baseline testing session where they completed questionnaires and provided demographic details (e.g., age, sex), and where anthropometric properties were measured (height and body mass). Following baseline assessment, PhysioFIRST participants undertook a 6-month physiotherapist-led treatment programme consisting of supervised and unsupervised exercise, manual therapy, and education. Symptomatic football players (FORCe study) were not required to undertake prescribed treatment during the same 6-month period. All participants with hip/groin pain completed follow-up data collection six months after baseline assessment, irrespective of whether treatment was undertaken.

Three PROMS were used in this study: the iHOT-33, the HAGOS, and the GROC score. Participants with hip/groin pain completed the following sequence of PROMs: 1) iHOT-33 and HAGOS at baseline testing; and 2) iHOT-33 and GROC at the 6-month follow-up. Asymptomatic football players completed the iHOT-33 at the baseline testing session only.

The iHOT-33 questionnaire consists of 33 individual items (questions) scored on a visual analogue scale from zero (worst possible score) to 100 (best possible score). The iHOT-33

is recommended for use in active adults with hip/groin pain (144, 147). The iHOT-Total score demonstrates adequate psychometric properties in populations seeking or undertaking surgery, including: a low standard error of measurement (6 points) (151); good responsiveness (147); low minimal detectable change (MDC) values at a group level (2 points) (151); and good interpretability (minimal clinically important difference values ranging from 6 to 10 points) (147, 151). Within the iHOT-33, four distinct constructs are assessed in the subscales, including: symptoms (iHOT-Symptoms), sport-related concerns (iHOT-Sport), job-related concerns (iHOT-Job), and social and emotional concerns (iHOT-Social) (147). Test-retest reliability of the iHOT-33 subscales has been evaluated in a small sample of hip/groin pain patients seeking tertiary care (surgery or physiotherapist-led treatment); with ICC values ranging from 0.86 to 0.93 [95%CI 0.70, 0.97] (156). Validity, responsiveness, and interpretability of the iHOT-33 subscales have not been examined previously.

The HAGOS is a self-reported questionnaire that evaluates six dimensions of hip/groin burden, including: pain (HAGOS-Pain), symptoms (HAGOS-Symptoms), physical function during activities of daily living (HAGOS-ADL), physical function during sport and recreation (HAGOS-Sport), participation in physical activities (HAGOS-PA), and hip-related QOL (HAGOS-QOL). The HAGOS demonstrates good content validity, construct validity, and reliability in active adults with hip/groin pain (148).

The GROC score measures participants' perceived change in their condition and consists of seven possible responses ranging from -3 (very much worse) to 3 (very much better). Participants were asked to, "Please circle the response which best describes how the condition of your hip has changed in the past 6 months: 1) very much worse; 2) much worse; 3) somewhat worse; 4) no change (GROC score = 0); 5) somewhat better; 6) much better; or 7) very much better". The GROC was used to assess responsiveness during the development of the HAGOS (148).

For participants with hip/groin pain, baseline iHOT-33 and HAGOS were administered consecutively in hard-copy paper format or via online data collection platforms (Promptus (DS PRIMA, Melbourne, Australia) or CheckWare (CheckWare AS, Trondheim, Norway)). Asymptomatic participants completed the iHOT-33 in hard-copy paper format at the baseline testing session. All 6-month follow-up PROMs were collected via online data collection platforms and participants were blinded to their baseline responses. The 6-

month follow-up period was considered an appropriate timeframe to observe treatment effects in longstanding hip/groin pain patients (155, 213), while also short enough for participants to accurately recall the change in their condition. Reliability assessments of PROM scores should reflect the clinical situation in which they are used (136), and so the same 6-month time period was chosen.

3.4.6 Psychometric properties and statistical analyses

Demographic data were assessed with boxplots and Shapiro-Wilk analyses and summarised with means and standard deviations (SDs) or medians and interquartile ranges (IQRs), as appropriate. Independent t-tests and Mann-Whitney U tests were used for between-group comparisons of demographic data, as appropriate. To rigorously assess the psychometric properties of the iHOT-33 scores, we followed the COSMIN checklist (214, 215). Our adherence to the COSMIN guidelines is detailed in the supplementary information (**Section 3.8.2**). All statistical analyses were performed using SPSS Version 26 software (SPSS Inc., Chicago IL USA), and α=0.05.

3.4.7 Content validity

Content validity is the extent to which the content of the iHOT-33 subscales adequately reflects the constructs they intend to measure (136, 140). Factor analysis during the development of the iHOT-33 identified four distinct constructs, which then defined the subscales (147). Content validity of the subscale scores were determined in our study by assessing the relevance, comprehensiveness, and comprehensibility (136) of the iHOT-33 in a convenience sample of participants undertaking physiotherapist-led treatment. Twenty PhysioFIRST participants were invited and 14 consented to participate in a 1:1 semi-structured interview, exceeding the minimum number of participants ($n \geq 7$) recommended by the COSMIN guidelines (214). One-on-one telephone/online interviews were conducted by a single investigator/physiotherapist (EB) who had previously undertaken training in qualitative interviewing. Prior to the interview, participants were provided with a copy of the iHOT-33 questionnaire to read and consider. Interviews were structured around the themes of relevance, comprehensiveness, and comprehensibility using the key questions outlined below. All participants were offered the opportunity to contribute additional information at the end of each interview. Interviews were recorded and transcribed

verbatim. Coding of interview data was undertaken by two independent reviewers (EB, JK) using NVivo software under the following structure:

(i) Relevance

Relevance examines whether all items in a questionnaire or subscale are important for the population and the construct it is measuring (136). For each iHOT-33 item, participants were asked whether the item and its response option were relevant to their hip/groin pain experience.

(ii) Comprehensiveness

Comprehensiveness examines whether respondents believe that relevant constructs are missing from the questionnaire (136). For each iHOT-33 subscale, participants were asked, "Were there any important things that you think were not included in the questionnaire that should have been included?"

(iii) Comprehensibility

Participants were asked, "Were there any instructions, questions, or possible answers that you did not understand?".

Qualitative data were analysed descriptively. Interpretation of content validity results required an overall judgement of relevance, comprehensiveness, and comprehensibility (136, 214, 215).

3.4.8 Construct validity

Construct validity is the ability of the instrument to accurately evaluate the construct it is intended to evaluate (215-217).

(i) Structural validity

Structural validity of the iHOT-33 was not assessed. Factor analysis completed during the development of the iHOT-33 confirmed unidimensional subscales (147). The purpose of our study was to test the iHOT-Total score and subscale scores in their original structure (147), rather than remove or replace items.

(ii) Hypothesis testing

Hypothesis testing assesses the relationship between scores from two PROM instruments that measure the same underlying construct (136). Four separate constructs are measured by the iHOT-33, as represented by the names of the four subscales (147). Construct validity was assessed by evaluating hypothesized relationships between iHOT-33 scores and HAGOS subscale scores using Pearson's product moment correlation coefficients (*r*). We hypothesised that statistically significant, strong positive correlations would exist between: 1) iHOT-Total scores and HAGOS-Symptoms, HAGOS-Pain, and HAGOS-QOL scores; 2) iHOT-Symptoms scores and HAGOS-Symptoms and HAGOS-Pain scores; 3) iHOT-Sport scores and HAGOS-Sport and HAGOS-PA scores; 4) iHOT-Job scores and HAGOS-ADL scores; and 5) iHOT-Social scores and HAGOS-QOL scores. The strength of correlations were defined as very weak (r<0.19); weak (r=0.20-0.39); moderate (r=0.40-0.59); strong (r=0.60-0.79); or very strong (r=0.80-1.0) (204, 218).

(iii) Discriminative validity

Discriminative validity refers to the ability of the iHOT-33 total and subscale scores to detect a difference between symptomatic and asymptomatic individuals. It was hypothesised that participants with hip/groin pain would report lower scores than asymptomatic participants for all iHOT-33 scores. Baseline scores were compared between those with and without hip/groin pain using Mann-Whitney U tests.

(iv) Cross cultural validity

Cross cultural validity was not assessed in this study as the iHOT-33 was administered in its original language (English).

3.4.9 Criterion validity

Criterion validity was not assessed as there is no gold standard patient-reported hip-related QOL measurement tool to act as the comparator.

3.4.10 Reliability

(i) Internal consistency

We did not measure internal consistency of the iHOT-33 subscales, as this requires an underlying assumption of unidimensionality (136). As we did not conduct a structural

validity assessment to determine unidimensionality, we could not subsequently assess internal consistency.

(ii) Test-retest reliability

Test-retest reliability of all iHOT-33 scores was evaluated between baseline and 6-month follow-up in participants who had not undertaken physiotherapist-led treatment (i.e., symptomatic football players) and whose condition had not changed (GROC=0). Test-retest reliability was calculated using ICCs (two-way mixed-effects model, absolute agreement, average measures) and 95%CIs. Reliability was determined to be adequate for use at a group level if ICC ≥0.80, and for use at an individual level if ≥0.90 (216, 217).

(iii) Measurement error

The SEM was calculated for all iHOT-33 scores using the formula "SEM = SD x √(1-ICC)", where the SD was the mean SD of all scores for the iHOT-Total or subscale of interest (219). Minimal detectable change values were calculated as "1.96 x √(2) x SEM" for use at the individual level and "1.96 x √(2)xSEM/√(n)" for use in groups (220, 221).

3.4.11 Responsiveness

Responsiveness was determined using an anchor-based approach (222). As all hip/groin participants did not undertake physiotherapist-led treatment, responsiveness was assessed separately for the two groups (treatment and no treatment). Change scores between baseline and 6-month follow-up were determined for the iHOT-Total and each subscale. Spearman rank correlations (*rho*) were used to quantify the relationship between each iHOT-33 change score and the GROC score. We hypothesized that a correlation of *rho*≥0.40 (*P*<0.05) would exist between the change measured in each iHOT-33 score and the GROC score. In addition, we calculated the effect size (ES) and standardised response mean (SRM) of each iHOT-33 score (148). We hypothesized that participants who responded that they were "somewhat better", "much better" or "very much better" would demonstrate larger ES and SRM compared to those who were "no change" or "somewhat worse/much worse/very much worse".

(i) Floor and ceiling effects

Floor and ceiling effects measure the ability of an instrument to demonstrate deterioration (floor effect) or improvement (ceiling effect) (222). Although these measures are not referred to in the COSMIN guidelines, floor and/or ceiling effects can reduce the responsiveness of PROMS (136). Using the baseline data for all participants with hip/groin pain, floor effects were determined to be present if more than 15% of participants recorded the lowest possible score. Ceiling effects were present if more than 15% recorded the highest possible score (148, 216).

3.4.12 Interpretability

Minimally important change (MIC) values for the iHOT-Total and all subscale scores were calculated using the distribution method (223), where "MIC=0.5xSD" of baseline scores for all participants with hip/groin pain.

3.5. Results

3.5.1 Participants

Between August 2015 and March 2020, 338 participants with hip/groin pain were recruited to the larger FORCe study (n=184) and PhysioFIRST RCT (n=154). Fifty-five asymptomatic football players were recruited. A total of 278 participants with hip/groin pain and 55 asymptomatic participants met the selection criteria for this study and were included. A summary of participant flow is provided in **Figure 3.1** and participant demographic characteristics are described in **Table 3.1**.

Table 3.1. Demographic characteristics of hip/groin pain and asymptomatic participants.

	Hip/groin pain participants				Total cohort Vs Asymptomatic football players (*P*-value)
	Symptomatic football players (n=164)	PhysioFIRST participants (n=114)	Total cohort (n=278)	Asymptomatic football players (n=55)	
Sex (female %)	30 (18%)	63 (55%)	93 (33%)	14 (25%)	-
Age (years)	28 ± 6	36 ± 8	31 ± 8	29 ± 6	**0.02***
Height (m)	1.79 ± 0.08	1.73 ± 0.10	1.76 ± 0.10	1.78 ± 0.10	0.13
Mass (kg)	78.9 ± 12.8	76.6 ± 16.4	78.0 ± 14.4	77.6 ± 13.6	0.87
BMI ($kg \cdot m^{-2}$)	24.7 ± 3.2	25.7 ± 5.2	25.1 ± 4.2	24.3 ± 3.1	0.20
Symptom duration (months)	24 [IQR 34]	24 [IQR 51]	24 [IQR 48]	N/A	-
HAGOS-Symptoms	60 ± 14	53 ± 15	57 ± 15	100 ± 1	-
HAGOS-Pain	74 ± 13	62 ± 16	69 ± 16	100 ± 1	-
HAGOS-ADL	81 ± 16	69 ± 17	76 ± 18	100 ± 1	-
HAGOS-Sport	64 ± 18	60 ± 20	62 ± 19	98 ± 6	-
HAGOS-PA	62 ± 26	42 ± 28	54 ± 28	97 ± 8	-
HAGOS-QOL	60 ± 16	43 ± 16	53 ± 18	99 ± 4	-

Data reported as means ± standard deviation (or count and proportion for sex) unless specified. *indicates significant between groups difference ($P<0.05$). Abbreviations: ADL – activities of daily living; BMI = body mass index; HAGOS = Copenhagen Hip and Groin Outcomes Score; IQR = interquartile range; N/A = not appropriate; PA = participation in physical activity; PhysioFIRST = physiotherapist-led treatment for femoroacetabular impingement syndrome; QOL = quality of life; - = not calculated.

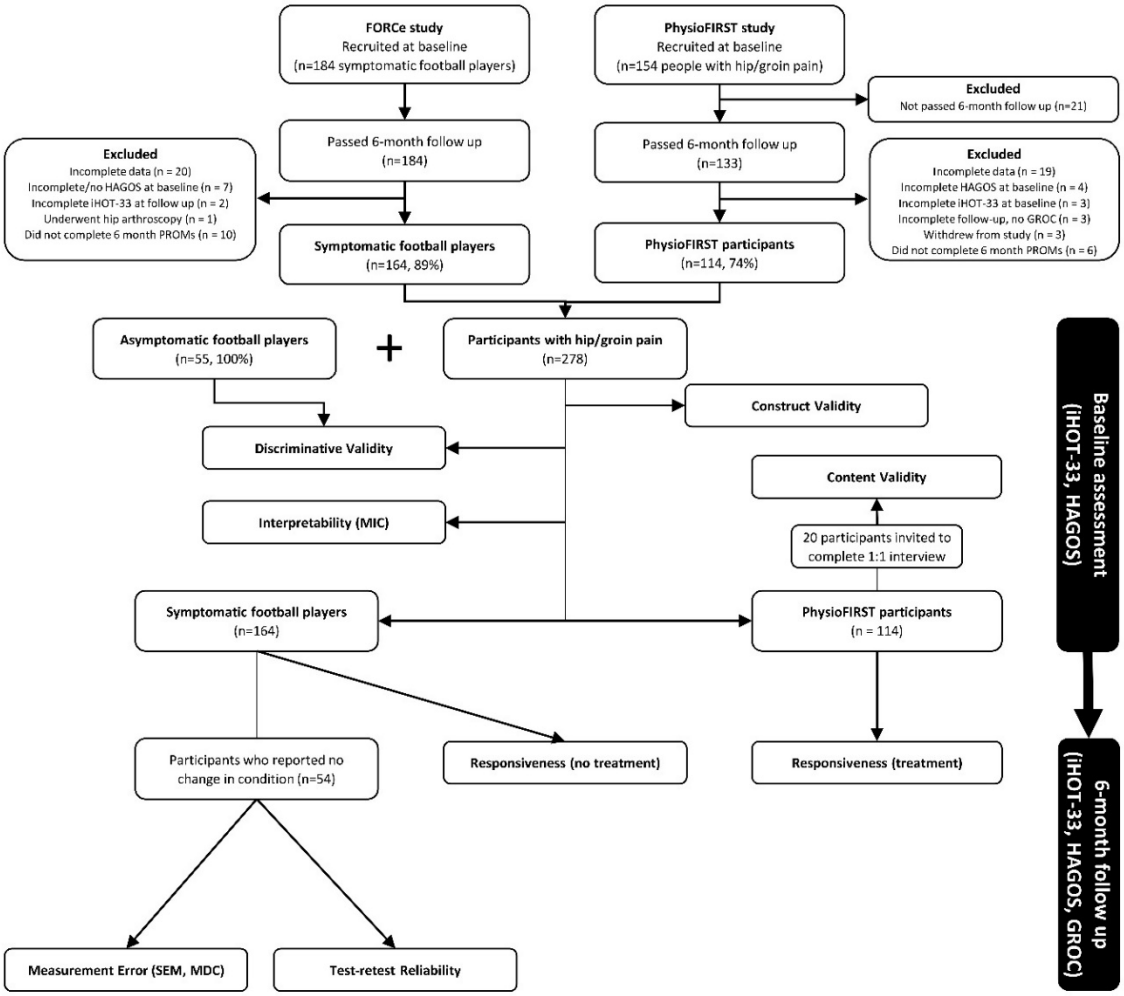


Figure 3.1. Description of participant flow and analyses undertaken.
Abbreviations: FORCe = femoroacetabular impingement and hip osteoarthritis cohort; GROC = Global Rating of Change; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool-33; MDC = minimal detectable change; MIC = minimally important change; PhysioFIRST = physiotherapist-led treatment for femoroacetabular impingement syndrome; PROMs = patient-reported outcome measures; SEM = standard error of measurement.

3.5.2 Validity

(i) Content validity

Of the 20 PhysioFIRST who were invited to complete qualitative interviews, 14 (70%) participants (5 women) agreed to participate and six did not respond to the invitation. The 14 participants who completed qualitative interviews had a median: 1) age of 27 years [IQR 16]; 2) body mass index of 22.4 [5.0]; 3) symptom duration of 36 months [96]; and 4) iHOT-Total score of 53 [34].

For the concepts of relevance, comprehensiveness, and comprehensibility, a summary of supporting quotes is provided in the supplementary information (**Section 3.8.3**). For relevance, 9/14 (64%) participants reported that all iHOT-33 items were relevant to them.

One (7%) participant (P8) felt that less than 50% of all items were relevant to their hip/groin pain experience. One (7%) participant (P11) reported that items pertaining to sport (iHOT-Sport subscale) were not relevant to them. Items concerning low-level activities in the iHOT-Symptoms subscale were considered not relevant by 4 (29%) participants (P4, P8, P9, P14). For comprehensiveness, 10 (71%) participants reported that the iHOT-33 was comprehensive and required no additional questions. Three (21%) participants reported that more questions about high-level sport tasks (e.g., running) were needed (P4, P8, P14). One participant (P11) believed the iHOT-33 needed more questions that described the location of pain. For comprehensibility, 13 (93%) participants understood all questions and instructions within the iHOT-33. One (7%) participant (P7) reported that questions in the iHOT-Social subscale (Questions 30 and 31) required more explanation. Overall, results from qualitative interviews indicated that the iHOT-33 was relevant, comprehensive, and comprehensible, and its content was valid in non-surgical patients with hip/groin pain.

(ii) Construct validity

Hypothesis testing

Construct validity for the iHOT-Total and subscale scores was confirmed, with findings largely supporting the specific hypotheses proposed (**Figure 3.2** and additional table in the supplementary information (**Section 3.8.4**)). All hypothesized strong correlations were confirmed (*r* range 0.60 to 0.76, $P<0.001$), except one correlation between the iHOT-Sport and HAGOS-Sport subscale scores ($r=0.58$, $P<0.001$).

Discriminative validity

Participants with hip/groin pain reported worse scores on the iHOT-Total and all subscales when compared to asymptomatic participants ($P<0.001$), indicating adequate discriminative validity (**Table 3.2**).

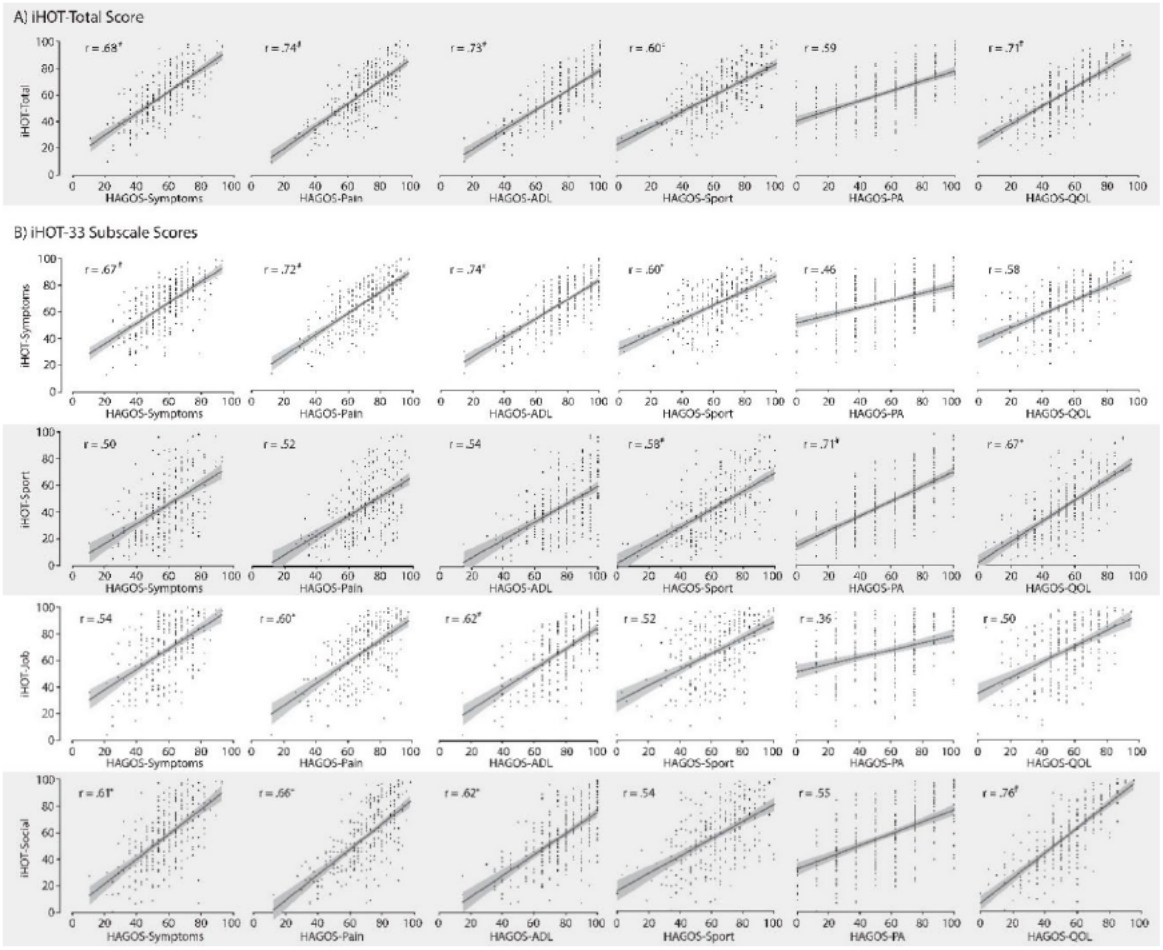


Figure 3.2. Pearson's product moment correlation coefficients (*r*) for A) iHOT-Total score and B) iHOT-33 subscale scores against HAGOS scores.

n=278 for all analyses except iHOT-Job (n=249). *P*<0.001 for all correlations. #denotes where a strong correlation (r≥0.60) was hypothesized. *denotes a strong correlation result that was not hypothesized. Abbreviations: ADL = activities of daily living; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool-33; PA = participation in physical activity; QOL = quality of life.

Table 3.2. Discriminative validity. Comparison of iHOT-33 scores between participants with hip/groin pain and asymptomatic participants.

	Hip/groin pain (n=278)	Asymptomatic participants (n=55)	*P* value
iHOT-Total	59.9 [25.6]	98.5 [2.9]	***P*<0.001***
iHOT-Symptoms	67.8 [24.5]	98.4 [3.1]	***P*<0.001***
iHOT-Sport	41.9 [32.0]	98.8 [4.3]	***P*<0.001***
iHOT-Job[a]	69.7 [32.8]	99.0 [3.6]	***P*<0.001***
iHOT-Social	56.3 [34.7]	99.1 [3.0]	***P*<0.001***

Data reported in medians and interquartile ranges with comparisons conducted using Mann-Whitney U tests. *indicates significant between-groups difference (*P*<0.05). Sample size variations: [a]n for iHOT-Job for hip/groin pain (n=249) and asymptomatic participants (n=53) (participants could opt-out of all iHOT-Job questions if they were not working). Abbreviation: iHOT = International Hip Outcome Tool.

3.5.3 Reliability

(i) Test-retest reliability

The results for test-retest reliability are contained in **Table 3.3**. Intraclass correlation coefficients ranged from 0.78 [95%CI 0.60, 0.88] for the iHOT-Job score to 0.88 for the iHOT-Social [95%CI 0.80, 0.93] and iHOT-Total [95%CI 0.79, 0.93] scores. Reliability was adequate for use in groups (≥0.80) for the iHOT-Total, iHOT-Symptoms, iHOT-Sport, and iHOT-Social scores, but not the iHOT-Job score. None of the subscales met the criteria for adequate reliability for use in individuals (≥0.90).

(ii) Measurement error

Values for the SEM ranged from 6.0 [95%CI 4.6, 7.9] for the iHOT-Total score to 9.5 [95%CI 7.3, 12.4] for the iHOT-Sport score. Minimal detectable change values for use at a group level ranged from 2.3 [95% CI 1.7, 3.0] for the iHOT-Total score to 3.7 [95%CI 2.8, 5.0] for the iHOT-Job score. For use at an individual level, MDC values ranged from 16.6 [95%CI 12.6, 21.9] for the iHOT-Total score to 26.2 [95%CI 20.1, 34.3] for the iHOT-Sports score (**Table 3.3**).

3.5.4 Responsiveness

The iHOT-Total and all subscale scores were responsive to change over 6-months in all hip/groin pain participants, except for the iHOT-Job score in participants not undertaking treatment (Symptomatic football players; **Table 3.4**). For symptomatic football players, strong correlations existed ($rho \geq 0.40$, $P < 0.05$) between iHOT-33 change scores and GROC scores for all iHOT-33 scores, except the iHOT-Job subscale ($rho = 0.27$, $P = 0.001$). For PhysioFIRST participants, all correlations were ≥0.40 ($P < 0.001$). The ES and SRM results for each iHOT-33 score are also contained in **Table 3.4**. Our hypothesis was confirmed, where participants who responded that they were “somewhat better”, “much better”, or “very much better” demonstrated larger ES and SRM for all scores when compared to participants who reported “no change” or being “somewhat worse/much worse/very much worse”.

(i) Floor and ceiling effects

Assessment of baseline data for all hip/groin pain participants demonstrated there were no floor or ceiling effects in the iHOT-Total or subscale scores (supplementary information, **Section 3.8.5**).

3.5.5 Interpretability

The MIC values for participants with hip/groin pain were calculated as: iHOT-Total = 8.7 points; iHOT-Symptoms = 8.6 points; iHOT-Sport = 10.9 points; iHOT-Job = 10.7 points; and iHOT-Social = 11.4 points.

Table 3.3. Results of reliability assessment.

GROC score = 0 at 6-month follow-up (n=54)	Test, Mean ± SD	Retest, Mean ± SD	Change score, Mean ± SD	$ICC_{agreement}$ (95%CI)	SEM (95% CI)	$MDC_{(individual)}$ (95%CI)	$MDC_{(group)}$ (95%CI)
iHOT-Total	65.2 ± 17.2	67.5 ± 14.4	2.2 ± 11.3	0.88 (0.79, 0.93)*	6.0 (4.6, 7.9)	16.6 (12.6, 21.9)	2.3 (1.7, 3.0)
iHOT-Symptoms	69.4 ± 16.1	70.9 ± 17.8	1.4 ± 13.1	0.82 (0.70, 0.89)*	7.2 (5.6, 9.3)	19.9 (15.5, 25.7)	2.7 (2.1, 3.5)
iHOT-Sport	53.1 ± 22.7	56.8 ± 23.2	3.6 ± 17.4	0.83 (0.71, 0.90)*	9.5 (7.3, 12.4)	26.2 (20.1, 34.3)	3.6 (2.7, 4.7)
iHOT-Job[a]	69.7 ± 19.4	72.9 ± 18.2	3.2 ± 16.0	0.78 (0.60, 0.88)	9.1 (6.7, 12.3)	25.3 (18.7, 34.1)	3.7 (2.8, 5.0)
iHOT-Social	63.8 ± 23.2	66.6 ± 21.2	2.8 ± 14.3	0.88 (0.80, 0.93)*	7.7 (5.9, 9.9)	21.3 (16.2, 27.5)	2.9 (2.2, 3.7)

Reliability parameters calculated using symptomatic football players only. Change score defined as retest score (6-month time point) minus test score (baseline). Sample size variations: [a]iHOT-Job n = 46 (participants could opt-out of all iHOT-Job questions if they were not working). Abbreviations: GROC = global rating of change; ICC = intraclass correlation coefficient; iHOT = International Hip Outcome Tool; MDC = minimal detectable change; SD = standard deviation; SEM = standard error of measurement; 95%CI = 95% confidence interval. *ICC ≥0.80 indicates adequate reliability for use at the group level.

Table 3.4. Responsiveness results for hip/groin pain participants undertaking (A) no treatment or (B) physiotherapist-led treatment.

iHOT-33	**Responsiveness**						
(A) Symptomatic football players (no treatment) (n=164)	Correlation of iHOT-33 change score to GROC	Total Cohort (n=164)	'Very much worse', 'much worse' and 'somewhat worse' (n=20)	'No change' (n=54)	'Somewhat better' (n=56)	'Much better' (n=30)	'Very much better' (n=4)
	Spearman's *rho*, *P*-value	SRM, ES	SRM, ES	SRM, ES	SRM, ES	SRM, ES	SRM, ES
iHOT-Total	*rho* = 0.52, *P*<0.001	0.44, 0.37	-0.32, -0.33	0.19, 0.13	0.57, 0.33	1.60, 1.25	NC
iHOT-Symptoms	*rho* = 0.48, *P*<0.001	0.35, 0.30	-0.41, -0.35	0.11, 0.09	0.48, 0.33	1.30, 1.09	NC
iHOT-Sport	*rho* = 0.52, *P*<0.001	0.46, 0.42	-0.29, -0.37	0.21, 0.16	0.58, 0.34	1.59, 1.29	NC
iHOT-Job	*rho* = 0.27, *P*=0.001	0.30, 0.26 (n = 136)	-0.07, -0.08 (n = 18)	0.20, 0.17 (n = 46)	0.31, 0.23 (n = 49)	1.13, 0.67 (n = 21)	NC
iHOT-Social	*rho* = 0.42, *P*<0.001	0.42, 0.33	-0.11, -0.11	0.20, 0.12	0.44, 0.28	1.10, 0.95	NC
(B) PhysioFIRST participants (physiotherapist-led treatment) (n=114)	Correlation of iHOT-33 change score to GROC	Total Cohort (n=114)	'Very much worse', 'much worse' and 'somewhat worse' (n=5)	'No change' (n=12)	'Somewhat better' (n=24)	'Much better' (n=31)	'Very much better' (n=42)
	Spearman's *rho*, *P*-value	SRM, ES	SRM, ES	SRM, ES	SRM, ES	SRM, ES	SRM, ES
iHOT-Total	*rho* = 0.58, *P*<0.001	1.18, 1.29	NC	0.33, 0.19	1.00, 0.85	1.77, 1.34	1.69, 2.26
iHOT-Symptoms	*rho* = 0.48, *P*<0.001	1.04, 1.05	NC	0.13, 0.07	0.96, 0.75	1.41, 1.23	1.35, 1.71
iHOT-Sport	*rho* = 0.56, *P*<0.001	1.20, 1.50	NC	0.56, 0.33	1.13, 0.98	1.68, 1.65	1.72, 2.39
iHOT-Job	*rho* = 0.40, *P*=0.001	0.78, 0.65 (n = 100)	NC	0.19, 0.09 (n = 10)	0.61, 0.46 (n = 20)	1.19, 0.63 (n = 28)	0.98, 1.17 (n = 37)
iHOT-Social	*rho* = 0.56, *P*<0.001	1.03, 1.19	NC	0.26, 0.23	0.72, 0.78	1.30, 1.03	1.81, 1.97

Change score defined as retest score (6-month follow-up) minus test score (baseline). Abbreviations: ES = effect size; GROC = global rating of change; iHOT = International Hip Outcome Tool; NC = not calculated; SRM = standardised response mean.

3.6. Discussion

The iHOT-Total score and all subscale scores demonstrated acceptable content and construct validity for use in young- to middle-aged adults with hip/groin pain who were not seeking surgery. All iHOT-33 scores discriminated between participants with and without hip/groin pain. Reliability results demonstrated that the iHOT-Total and all subscale scores except for the iHOT-Job could be confidently used for comparisons at a group level, but not at an individual level. The iHOT-Total, iHOT-Symptoms, iHOT-Sport, and iHOT-Social scores were responsive to change over a 6-month period in people with hip/groin pain who were not seeking surgery. All iHOT-33 scores demonstrated acceptable interpretability, with MIC values of less than 12 points. Clinicians should exercise caution when monitoring change in individual patients due to large subscale MDC values that exceed corresponding MIC values.

All iHOT-33 scores demonstrate adequate content, construct, and discriminative validity for use in active adults with hip/groin pain who do not seek surgery. Qualitative assessment of content validity from the patients' perspective provided unrestricted information on the topics of relevance, comprehensiveness, and comprehensibility. While findings from qualitative interviews indicated that content of the iHOT-33 was valid for use in hip/groin pain patients treated without surgery, some participants reported items concerning activities of daily living such as walking or stair climbing were not relevant. These participants felt that the iHOT-33 did not adequately explore how hip/groin pain affected their sport performance, including training duration, intensity, or volume. The iHOT-33 was developed in a surgical setting, where some items were generated by patients seeking surgery (147) who may have reported high levels of hip/groin pain burden. However, the majority (64%) of participants who completed a 1:1 interview reported that all items (including those concerning activities of daily living) were still relevant. Less than 2% of participants reported the highest score for any subscale (ceiling effects), suggesting adequate distribution of item difficulty for use in non-surgical populations. To quantify the impact of hip/groin pain on higher-level physical activity constructs, researchers and clinicians may consider augmenting the iHOT-33 with additional tools, such as the HAGOS-Sport (148), the Nord-Trøndelag Health Study (HUNT1) questionnaire (224), or other athlete monitoring tools (225). In addition to content validity, all iHOT-33 scores demonstrated acceptable construct validity in our hip/groin pain participants. The HAGOS provided a valid and reliable comparator to measure construct validity. Our findings

complement the original assessment of the iHOT-Total score in patients seeking surgery (147). Combined, our content and construct validity results indicate that researchers and clinicians can be confident that all iHOT-33 scores suitably assess the constructs they were intended to measure.

All iHOT-33 scores except for the iHOT-Job score demonstrated adequate reliability for comparison of groups, but not individuals. In the clinical setting, PROM scores are typically used to monitor change in the condition of an individual patient. For this purpose, clinicians should appreciate the measurement error of the iHOT-33 scores, as described by the SEM and MDC values. We identified large MDC values for measurement at an individual level, a finding that is typical of many PROM studies (147, 148, 156). Clinicians should exercise caution when interpreting iHOT-33 change scores from an individual patient in the clinical setting, as large change scores are required to exceed the measurement error of the scores. There are many possible reasons for the iHOT-Job having lower reliability in our cohort, most likely that our sample size (n=46) for this subscale was considerably lower than the sample size for the other subscales. Participants can opt out of one or all (four) items if they do not undertake paid employment, which may reflect that our younger participants may be studying or not employed. Younger participants might also be more likely to engage in transient work or change jobs between baseline testing and 6-month follow-up, impacting the reliability of this subscale. The employment status of young and middle-aged patients with hip/groin pain should be considered when using this subscale score.

Almost all iHOT-33 scores were responsive to change over a 6-month period in patients who had undertaken physiotherapist-led treatment or no treatment. The lower responsiveness of the iHOT-Job score in symptomatic football players might be attributed to the same reasons for its lower reliability. When combined with the original findings of Mohtadi et al. (2012) (147), all iHOT-33 scores except for the iHOT-Job can be confidently used to measure change in the condition of patients undertaking non-surgical or surgical treatment and those not undertaking treatment, over a 6-month period. Other studies may choose to assess responsiveness of the iHOT-33 over other timeframes, such as 12 or 24 months. We report MIC values for non-surgical patients with hip/groin pain ranging from 8 to 12 points for all iHOT-33 scores. Our MIC values exceeded the corresponding MDC values, meaning that clinically important changes (i.e., our MIC values) were greater than the random error of the measurements. Importantly, our MIC values likely represent a “true” change (226). Our MIC value for the iHOT-Total score (8.7) was greater than the

6.3 points identified during initial interpretability assessment in hip arthroscopy patients (147). The reason for this difference is uncertain; however, the original methods used to determine the MIC were unclear and the sample size of the hip arthroscopy cohort (n = 27) was considerably smaller than our sample (222). We suggest that those using the iHOT-33 err on the side of caution and consider MIC values of 8 to 12 points when interpreting results or calculating sample sizes for future research, increasing confidence that these values represent an important change to people with hip/groin pain.

This study has numerous strengths and limitations that should be discussed. By following the COSMIN guidelines, we rigorously assessed the psychometric properties of the iHOT-33 in the largest reported cohort of hip/groin pain patients not seeking surgery. We included people with a wide variety of athletic function, where some participants undertook physiotherapist-led treatment and others received no treatment. Baseline HAGOS scores in our hip/groin pain cohort were comparatively higher (better) than scores from patients enrolled in the Danish Hip Arthroscopy Registry (99), indicating less self-reported burden in our cohort who were not seeking surgery. Our two hip/groin pain groups varied in level of sports participation, age, and gender, which may have affected some of our results. However, we believe the variability of the combined cohort increases the generalizability of the findings and reflects the broad spectrum of people seeking non-surgical treatment for hip/groin pain. Due to the number of participants who undertook a 1:1 interview, it is possible that sampling bias may affect the generalizability of content validity findings. Future studies using a larger sample size and/or quantifiable methods to assess content validity may confirm or refute our results; however, positive findings in other psychometric properties likely support our overall finding that content of the iHOT-33 is valid in patients treated without surgery. While discriminative validity was adequate, the asymptomatic participants used in this analysis were on average two years younger than the hip/groin pain cohort; however, it is unlikely, but possible, that this statistically significant difference in age impacts the overall finding. The 6-month test-retest period used for the reliability assessment is a potential limitation. While this is a clinically acceptable timeframe to monitor and treat hip/groin pain patients (155, 213), recall bias may have affected the GROC scoring. Despite this, our reliability findings for all scores were largely consistent with the study by Hinman et al. (156), who used a 1-2 week test-retest period in patients undertaking surgery and/or physiotherapist-led care. Further, it is recommended that the reliability of a PROM be assessed in the clinical context in which it would be used (136). Our findings demonstrate that the iHOT-33 scores are reliable over a 6-month period. The

use of the GROC as an overall measure of participants' condition may have affected responsiveness for the iHOT-33 subscale scores. While GROC scores that more directly assess the underlying subscale construct may increase responsiveness, our strong correlations indicated that all iHOT-33 scores were responsive to overall condition change. It is possible that some symptomatic football players undertook self-directed treatment, potentially affecting calculated values for SRM and effect size. Our retrospective study design only included participants who had completed all relevant PROMs at baseline and 6-month follow-up, introducing the possibility of selection bias in our cohort. Methods to determine MIC remain controversial (227), and our calculations using the distribution method (223) could be debated (136). Future studies may consider using an anchor-based method (136) that includes anchor questions relating to the magnitude of change and the perceived "importance" of the change.

3.7. Conclusion

The iHOT-Total and all subscale scores are valid for use in hip/groin pain patients not seeking surgery. All scores were reliable at group level and responsive over a period of six months, except for the iHOT-Job. Responsiveness was demonstrated in patients completing physiotherapist-led treatment and in patients with hip/groin pain not undertaking treatment. The iHOT-33 is a valid and largely reliable self-reported measure of hip/groin-related QOL in patients not seeking surgery; however, clinicians should consider the large MDC values of all scores when monitoring change in individual patients in the clinical setting.

3.8. Supplementary information

3.8.1 COSMIN recommended sample sizes for studies assessing measurement properties of PROM scores

Psychometric property	COSMIN recommended sample size (highest rating)	Our study sample size	Study COSMIN rating (0-4)
Content validity (qualitative design)	≥7	n=14	Very good (4)
Construct validity (hypothesis testing)	≥100	n=278	Very good (4)
Reliability	≥100	n=54	Adequate (3)
Responsiveness	≥50	n=164 and n=114	Very good (4)

COSMIN rating from 0 to 4 (1 = inadequate, 2 = doubtful, 3 = adequate, 4 = very good) provides a general assessment of psychometric property study protocols. Abbreviation: COSMIN = Consensus-based standards for the selection of health measurement instruments; PROM = patient-reported outcome measure.

3.8.2 Adherence to COSMIN guidelines in this study

COSMIN Recommendation	Location in Text	COSMIN rating for our study (1-4)
General		
1) Provide a clear research aim, including (A) the name and version of the PROM, (B) the target population, and (C) the measurement properties of interest	Introduction	Very good (4)
2) Provide a clear description of the construct to be measured	Introduction	Very good (4)
3) Provide a clear description of the development process of the PROM, including a description of the target population for which the PROM was developed.	Introduction	Very good (4)
4) The origin of the construct should be clear: provide a theory, conceptual framework (i.e., reflective or formative model) or disease model used or clear rationale to define the construct to be measured	N/A (reviewing established PROM)	N/A (reviewing established PROM)
5) Provide a clear description of the structure of the PROM (i.e., the number of items and subscales included in the PROM, instructions given and response options) and its scoring algorithm	Methods – Testing procedure	Very good (4)
6) Provide a clear description of existing evidence on the quality of the PROM	Introduction and Methods	Very good (4)
7) Provide a clear description of the context of use (i.e., the intended application of the PROM).	Introduction (paragraph 3)	Very good (4)
8) Provide a clear description of in- and exclusion criteria to select patients, e.g., in terms of disease condition and characteristics like age, gender, language or country, and setting (e.g., general population, primary care or hospital/rehabilitation care)	Methods (participants) and Results	Very good (4)
9) Provide a clear description of the method used to select the patients for the study (e.g., convenience, consecutive, or random)	Methods - Participants	Very good (4)
10) Describe whether the selected sample is representing the target population in which the PROM will be used in terms of age, gender, important disease characteristics (e.g., severity, status, duration)	Results (Table 1)	Very good (4)
Content Validity		
1) From the perspective of the patients: use an appropriate method for assessing (A) the relevance of each item for the patients' experience with the condition, AND (B) the comprehensiveness of the PROM, AND (C) the comprehensibility of the PROM instructions, items, response options, and recall period	Methods – Content validity	Very good (4)
2) From the perspective of professionals: use an appropriate method for assessing (A) the relevance of each item for the construct of interest, AND (B) the comprehensiveness of the PROM	N/A (patients only as not generating new items)	N/A
3) Include professionals from all relevant disciplines	N/A (patients only as not generating new items)	N/A
4) Evaluate each item in an appropriate number of patients or professionals (for qualitative studies (n≥7)).	Results (n=14)	Very good (4)
5) Use skilled group moderators or interviewers	Methods – Content validity	Adequate (3)
6) Base the group meetings or interviews on an appropriate topic or interview guide	Methods – Content validity (3 themes)	Very good (4)
7) Record and transcribe verbatim the group meetings or interviews	Methods – Content validity	Very good (4)
8) Use an appropriate approach to analyse the data	Methods – Content validity – coding by 2 reviewers under the 3 themes	Very good (4)
9) Involve at least two researchers in the analysis	Methods	Very good (4)

Structural validity	Not assessed as we tested the iHOT-33 in its current form	N/A
Internal consistency	Not assessed as structural validity not assessed	N/A
Cross-cultural validity	N/A	N/A
Measurement error and reliability		
1) Use at least two measurements	Methods – Reliability	Very good (4)
2) Ensure that the administrations will be independent	Methods – Reliability	Very good (4)
3) Ensure that the patients will be stable in the interim period on the construct to be measured	Methods (reliability) and Results	Very good (4)
4) Use an appropriate time interval between the two measurements, which is long enough to prevent recall, and short enough to ensure that patients remain stable	Methods – Reliability	Very good (4)
5) Ensure that the test conditions will be similar for the measurements (e.g., type of administration, environment, instructions)	Methods – Reliability	Very good (4)
6) Perform the analysis in a sample with an appropriate number of patients (taking into account expected number of missing values)	Methods (reliability) and Results (n=54)	Adequate (3) (N = 50-99)
For measurement error:		
7) For continuous scores: calculate the Standard Error of Measurement (SEM), Smallest Detectable Change (SDC) or Limits of Agreement (LoA)	Methods (reliability) and Results	Very good (4)
8) For dichotomous/nominal/ordinal scores: calculate the percentage (positive and negative) agreement	N/A	N/A
9) Provide a clear description of how missing items will be handled	N/A (no missing data)	N/A
For reliability:		
10) For continuous scores: calculate an intraclass correlation coefficient (ICC)	Methods (reliability) and Results	Very good (4)
11) For dichotomous/nominal/ordinal scores: calculate kappa	N/A	N/A
12) For ordinal scores: calculate a weighted kappa	N/A	N/A
13) Provide a clear description of how missing items will be handled	N/A	N/A
Criterion validity	N/A	N/A
Hypothesis testing for construct validity		
1) Formulate hypotheses about expected relationships between the PROM under study and other outcome measurement instrument(s)	Methods – Construct validity	Very good (4)
2) Provide a clear description of the construct(s) measured by the comparator instrument(s)	Methods – Construct validity	Very good (4)
3) Use comparator instrument(s) with sufficient measurement properties	Methods – Construct validity	Very good (4)
4) Perform the analysis in a sample with an appropriate number of patients (taking into account expected number of missing values)	Methods (construct validity) and results	Very good (4)
5) Use an appropriate time schedule for assessments of the PROM of interest and comparison instruments	Methods (construct validity) and results	Very good (4)
6) Use statistical methods that are appropriate for the hypotheses to be tested	Methods – Construct validity	Very good (4)
7) Provide a clear description of how missing items will be handled	N/A	N/A

Responsiveness		
1) Formulate hypotheses about expected relationships between the change scores on the PROM under study and (change scores on) other outcome measurement instrument(s)	Methods – Responsiveness	Very good (4)
2) Provide a clear description of the construct(s) measured by the comparator instrument(s)	Methods – Testing procedure	Very good (4)
3) Provide information that the measurement properties of the comparator instrument(s) are sufficient	Methods – Testing procedure	Very good (4)
4) Use an appropriate time schedule for assessments of PROM of interest and comparison instruments	Methods – Testing procedure	Very good (4)
5) Use an appropriate time interval between first and second measurements	Methods – Testing procedure	Very good (4)
6) Describe anything likely to occur in the interim period (e.g., intervention, other relevant events)	Methods – Testing procedure	Very good (4)
7) Ensure that a proportion of the patients is likely to change (i.e., improvement or deterioration) on the construct to be measured	Methods (Participants, Testing procedure) and results (Table 5)	Very good (4)
8) Perform the analysis in a sample with an appropriate number of patients (taking into account expected number of missing values)	Results (Table 5)	Very good (4)
9) Ensure that the statistical methods are adequate for the hypotheses to be tested	Methods – Responsiveness	Very good (4)
10) Provide a clear description of how missing items will be handled	N/A	N/A

COSMIN rating from 0 to 4 (1 = inadequate, 2 = doubtful, 3 = adequate, 4 = very good) provides a general assessment of psychometric property study protocols. Abbreviations: COSMIN = Consensus-based standards for the selection of health measurement instruments; iHOT = International Hip Outcome Tool; N/A = not appropriate; PROM = patient-reported outcome measure.

3.8.3 Supporting quotes from content validity assessment

Theme 1: Relevance
Q1: "…they're all pretty relevant." *(P2)*
Q2: "I do a lot of running and things like that, so things like walking around or stepping over an obstacle… isn't really when I experience my pain. So yeah I suppose those symptoms aren't super relevant. And then some of the lighter exercise or activities don't really invoke any pain." *(P4)*
Q3: "Look my hip pain is not at the level where things like walking up and down stairs, or... lying on my side effects it. But… questions that may not be relevant to me, but may be relevant to someone who has more severe hip pain." *(P9)*
Q4: "Um most of them were sort of not relevant - well at least half of them - because they seemed to be for people who are more crippled, than say develop performance, which I guess is what I'm trying to do." *(P8)*
Q5: "Some of them had a bit of an assumption that you like played sports and that sort of thing… which doesn't necessarily apply to me." *(P11)*
Theme 2: Comprehensiveness
Q6: "… good job covering all the bits that I would have certainly thought of. And the difficulties that I tend to have." *(P7)*
Q7: "It's pretty comprehensive, there's 33 questions. I think there's enough there." *(P2)*
Q8: "I thought it was pretty thorough." *(P9)*
Q9: "There didn't seem to be many questions verbalising where the pain was specifically, even though it was coming from the hip. Yeah I can end up with a really sore lower back as a result of the hip pain." *(P11)*
Q10: "...for my running… how it affected training load and intensity of sessions… it's not very specific to that, but I didn't really expect it to be." *(P4)*
Q11: "There's not much about the level of activity that causes (pain)… When I start even low-grade running again, I sort of get pains." *(P8)*
Theme 3: Comprehensibility
Q12: "No, it was clear." *(P1)*
Q13: "Yes, one... needs a little bit more explanation to me. The way I perceive it, which is question 30… *(P7)* (Question 30: *How difficult is it for you to release tension and stress because of your hip?)*
Q14: Even 31 probably doesn't make a lot sense, if I was discouraged, discouraged in playing sport or... playing with children... or lifting up children or– discouraged in what– I think that's a little bit vague for me personally." *(P7)* *(Question 31: How discouraged are you because of your hip problem?)*

3.8.4 Construct validity hypotheses and results

iHOT-33 subscale	Construct measured	Hypothesized strong relationship with HAGOS score	Result (*r* value)	Hypothesis confirmed	Strong correlation identified but not hypothesised (*r* value)
iHOT-Total	Hip-related quality of life	HAGOS-Symptoms	$r = 0.68$	Yes	HAGOS-Sport; $r = 0.60$
		HAGOS-Pain	$r = 0.74$	Yes	HAGOS-QOL; $r = 0.71$
		HAGOS-QOL	$r = 0.73$	Yes	
iHOT-Symptoms	Pain, symptoms, and function during ADLs	HAGOS-Symptoms	$r = 0.67$	Yes	HAGOS-ADL; $r = 0.74$
		HAGOS-Pain	$r = 0.72$	Yes	HAGOS-Sport; $r = 0.60$
iHOT-Sport	Sports participation and performance	HAGOS-Sport	$r = 0.58$	No	HAGOS-QOL; $r = 0.67$
		HAGOS-PA	$r = 0.71$	Yes	
iHOT-Job	Participation in employment and occupational function	HAGOS-ADL	$r = 0.62$	Yes	HAGOS-Pain; $r = 0.60$
iHOT-Social	Cognitive-emotional response to hip/groin pain	HAGOS-QOL	$r = 0.76$	Yes	HAGOS-Symptoms; $r = 0.61$ HAGOS-Pain; $r = 0.66$ HAGOS- ADL; $r = 0.62$

All reported Pearson product moment correlation coefficients (*r* values) have a corresponding *P* value of <0.001. Abbreviations: ADL = activities of daily living; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool 33; PA = participation in physical activity; QOL = quality of life.

3.8.5 Floor and ceiling effects

iHOT subscale (n=278)	Floor (n with lowest score) (%)	Ceiling (n with highest score) (%)
iHOT-Total	2 (<1%)	0 (0%)
iHOT-Symptoms	0 (0%)	1 (<1%)
iHOT-Sport	2 (<1%)	2 (<1%)
iHOT-Job (n=249)	0 (0%)	6 (2%)
iHOT-Social	1 (<1%)	2 (<1%)

Data presented as count (proportions). Abbreviation: iHOT = International Hip Outcome Tool.

PART B: SELF-REPORTED BURDEN IN FOOTBALL PLAYERS WITH HIP AND/OR GROIN PAIN

Chapter 4. Self-reported burden of hip and/or groin pain in competitive football players. A cross-sectional study of 239 sub-elite players.

4.1. Preface

As described in **Chapter 1**, little is known about the burden of hip/groin pain in football players with current symptoms (4). Findings from **Chapter 3** afford the use of the iHOT-33 to assess self-reported burden in football players with hip/groin pain. This chapter aimed to describe the burden of hip/groin in symptomatic football players across the domains of the iHOT-33 and HAGOS.

4.2. Abstract

Background: Knowledge of self-reported hip/groin burden in active football players is very limited.

Methods: Symptomatic (hip/groin pain) and asymptomatic football (football and Australian football) players completed the iHOT-33 and HAGOS. Between-group comparisons of iHOT-33 and HAGOS scores were made using beta-regression models. Relationships between PROM scores (dependent variable) and symptom group (independent variable) were analysed unadjusted and adjusted for the covariates of age, sex, and body mass index. Pseudo R^2 values quantified the strength of modelled relationships. Between-group comparisons of individual items were made with Mann-Whitney U tests.

Results: 184 symptomatic football players (146 men, 38 women) and 55 asymptomatic players (41 men and 14 women) were recruited. Symptomatic football players reported lower (i.e., worse) scores for all iHOT-33 and HAGOS subscales and individual items when compared to asymptomatic players ($P \leq 0.01$), with the lowest scores recorded for the iHOT-Sport and HAGOS-QOL subscales (45 [IQR 29] and 60 [IQR 20], respectively). Pseudo R^2 values for univariable models ranged from 0.41 to 0.84. Symptomatic women reported worse HAGOS-Pain scores only when compared to men (median score difference = 4-points, $P<0.01$).

Conclusion: Despite being capable of football competition, symptomatic players reported substantial hip/groin burden. Greater physical burden was reported during high-impact sporting tasks than activities of daily living, warranting further investigation of the mechanisms of these perceived difficulties. Concerns about worsening hip/groin pain and restricted sports participation were evident in symptomatic football players, highlighting the psychosocial burden of hip/groin pain in active football players. Subtle differences existed between men and women for individual items, potentially warranting future investigation.

Key Terms: Hip, Femoroacetabular Impingement Syndrome, Football, Soccer, Patient Reported Outcome Measures, Rehabilitation

4.3. Introduction

Hip/groin conditions are common in football players, accounting for up to 19% of all time-loss injuries (27-30, 32). However, seasonal prevalence of non-time-loss hip/groin pain may be as high as 59% in active sub-elite players (3-5). Longstanding hip/groin pain can be multifactorial, where intra-articular (i.e., hip-related pain) conditions and clinical groin pain entities co-exist (30, 33, 38), and may be associated with positions of hip impingement (45). More recent studies of football players provide a better understanding of the severity of non-time-loss hip/groin pain (1, 4, 5) and its negative impact on performance (3); however, most reports of severity have included an unknown mix of players with previous or current hip/groin pain (1, 5). Since longstanding hip/groin pain and impaired sport performance can lead an athlete to cease sports participation and seek surgery (146), understanding the self-reported physical and non-physical (e.g., psychosocial) impacts (i.e., burden) of hip/groin pain in active football players may provide insights for treatments to enhance recovery and/or delay the need for surgery.

Patient-reported outcome measures designed and evaluated for active adults can quantify hip/groin burden in competitive football players (144, 145, 228). Subscale scores for the iHOT-33 (147) and HAGOS (148) evaluate various domains of hip/groin burden, and are valid, reliable, and recommended for use in active adults not seeking surgery (144, 228). Knowledge of burden in domains other than pain or symptoms, such as perceived impairments to physical function and sports participation, might inform interventions for football players with hip/groin pain.

Hip/groin pain is burdensome in people seeking surgical opinion, with reports of lower physical activity and worse QOL when compared to pain-free populations (229-231). People seeking surgery may represent those with worse hip/groin symptoms and functional impairment; thus, findings from these populations may not be relevant for symptomatic football players who are still capable of training and match play. Knowledge of self-reported burden in football players with current hip/groin pain is limited (4). Symptomatic players have reported impaired physical function during sport when compared to asymptomatic players, where those with time-loss and non-time-loss injuries were equally impaired (4). It is unknown if such differences exist between female football players with and without hip/groin pain, nor whether self-reported burden differs between symptomatic men and women.

Therefore, the aims of this study were to: (i) quantify the burden of hip/groin pain by comparing iHOT-33 and HAGOS subscale scores between football players with and without hip/groin pain; (ii) explore sex-dependent differences in the patient-reported burden of hip/groin pain; and (iii) explore individual items of the iHOT-33 and HAGOS to further describe the burden of hip/groin pain.

4.4. Methods

4.4.1 Study design and recruitment

This study investigated 18- to 50-year-old competitive football (football and Australian football) players with and without hip/groin pain. Data for this study were collected as part of the baseline assessment for the FORCe study (130), a longitudinal study investigating changes in hip joint structure and symptoms over time (**Section 2.2**). Ethics approvals and the methods used to recruit participants were reported earlier in this thesis (**Section 2.2.2** and **Section 2.2.3**, respectively).

4.4.2 Study participants

(i) Football players with hip/groin pain (symptomatic players)

Eligibility criteria for symptomatic football players are presented in **Table 2.1**. Briefly, symptomatic football players needed to report greater than six months of activity-related hip/groin pain and have a positive flexion-adduction-internal rotation (FADIR) test. Symptomatic football players were excluded if they had radiographic hip OA (KL grade ≥2) or reported a history of significant pathological hip condition or hip or pelvis surgery.

(ii) Football players without hip/groin pain (asymptomatic players)

Eligibility criteria for asymptomatic players are presented in **Table 2.2**. Briefly, asymptomatic players were eligible if they reported no prior history of hip/groin pain and had a negative FADIR test. Exclusion criteria were similar to those of the symptomatic players, except asymptomatic players were excluded if they reported prior major lower-limb surgery (e.g., knee reconstruction).

4.4.3 Primary outcomes

All football players completed the iHOT-33 and HAGOS questionnaires in hard-copy paper format or via CheckWare (CheckWare AS, Trondheim, Norway), an online platform for electronic data capture and storage. Demographic and anthropometric data including age, sex, weight, height, and self-reported symptom duration were also collected as part of the larger assessment.

(i) The International Hip Outcome Tool-33 (iHOT-33)

The iHOT-33, which was described in **Section 1.9.1**, measures hip-related burden for the most symptomatic hip in the preceding month. Study 1 (**Chapter 3**) of this thesis found that the iHOT-33 scores (including the iHOT-Total and all subscale scores) were valid for assessing hip/groin burden in active football players. All iHOT-33 scores, except for the iHOT-Job, were reliable at the group level, with SEM values for all scores ranging from 6.0 to 9.5 points [95%CI: 4.6, 12.4].

(ii) The Copenhagen Hip and Groin Outcome Score (HAGOS)

The HAGOS, which was described in **Section 1.9.2**, evaluates hip/groin burden at a per-person level over the preceding week. The six HAGOS subscale scores are valid and reliable for use in active adults with hip/groin pain not seeking surgery (148). All subscale scores have adequate reliability (ICC values ranging from 0.82 to 0.91 [95%CI: 0.68, 0.95]), with SEM scores ranging from 6.4 to 12.2 points [95%CI: 5.0, 16.2] (148). For individual items, moderate-to-extreme severity has been defined as an individual item score of greater than one (232).

4.4.4 Statistical analysis

Data were assessed for normality using boxplots and the Shapiro-Wilk analysis. Demographic data and PROM scores were summarised using means and SDs or medians and IQRs as appropriate. Data were stratified according to symptom group (symptomatic or asymptomatic) and sex. For demographic data, between-group comparisons were made for: 1) symptomatic and asymptomatic men; 2) symptomatic and asymptomatic women; and 3) symptomatic men and women. Mann-Whitney U tests were used to analyse all demographic variables, except for sports participation where Chi square tests were used.

For the first two aims of the study, the iHOT-Total score and each subscale score of the iHOT-33 and HAGOS were analysed separately. Beta-regression models were used to describe the relationship between each PROM score (dependent variable) and symptom group (independent variable). As PROM scores are anchored by values of 0 and 100, they may not be appropriately modelled using linear regression that assumes continuous trajectories beyond those values. Beta-regressions provide an alternative method to model rates or proportions (i.e., values between 0 and 1) (233), where no observations can take on values of exactly 0 or 1. To compress the data so no observations were exactly 0 or 1, PROM scores were transformed to a proportion (/1) using the following formula $y'' = [y'(n-1)+0.5]/n$ (where, n = sample size, y' = PROM observation, y'' = transformed PROM score (/1)) (234). The potential covariates of age, sex, and BMI were also considered. Separate univariable models were built for the independent variable (symptom group) and covariates (age, sex, BMI) to describe their crude relationship with each PROM score. The continuous variables of age and BMI were examined for potential polynomial relationships and significant relationships were carried through to multivariable models. Based on consensus from investigators and results of crude analyses, separate multivariable models were built by sequentially adding the covariates of age, sex, and BMI to the independent variable (symptom group). Interaction effects between covariates and the independent variable were examined and dropped if not significant. The model with the lowest Akaike's Information Criterion (AIC; an indicator of model fit with penalty for complexity) was used to guide selection of the final model. Pseudo R^2 values were used to quantify the strength of modelled relationships. All analyses were performed with the betareg R statistical software package (v 3.1-2) (235).

For the third aim, Mann-Whitney U tests were used to compare individual item scores between 1) symptomatic and asymptomatic men; 2) symptomatic and asymptomatic women; and 3) symptomatic men and women. Statistical analyses for demographic variables and individual items were completed using SPSS version 25 software (SPSS Inc, Chicago, Illinois, USA). Level of significance was set at 0.05 for all analyses.

4.5. Results

4.5.1 Participants

Of the 539 symptomatic football players screened, 184 with hip/groin pain (146 men and 38 women) fulfilled our eligibility criteria and were included (**Figure 2.1**). For the asymptomatic players, 110 were initially screened and 55 (41 men and 14 women) were included (**Figure 2.2**). Demographic characteristics and results of between-group comparisons of interest are summarised in **Table 4.1**. Symptomatic women had lower BMI and reported shorter symptom duration than symptomatic men ($P<0.05$).

Table 4.1. Demographic characteristics of symptomatic and asymptomatic football players.

	MEN			WOMEN			
	Symptomatic (n=146)	**Asymptomatic (n=38)**	***P* value**	**Symptomatic (n=41)**	**Asymptomatic (n=14)**	***P* value**	**Symptomatic men vs women (*P* value)**
Age (years)	28 ± 6 27 [7]	28 ± 6 27 [8]	0.44	27 ± 6 26 [7]	26 ± 4 26 [7]	0.45	0.63
Height (m)	1.81 ± 0.06 1.81 [0.09]	1.82 ± 0.08 1.81 [11]	0.85	1.67 ± 0.07 1.66 [0.09]	1.68 ± 0.07 1.67 [0.08]	0.66	**<0.01***
Weight (kg)	82.0 ± 10.6 79.9 [12.7]	82.2 ± 11.6 82.2 [15.8]	0.51	64.9 ± 11.3 62.8 [11.2]	65.4 ± 10.5 64.6 [19.2]	0.80	**<0.01***
BMI ($kg \cdot m^{-2}$)	25.0 ± 3.0 24.5 [3.1]	24.9 ± 2.8 24.8 [4.1]	0.92	23.2 ± 3.4 22.7 [3.1]	23.1 ± 3.4 22.6 [4.3]	0.98	**<0.01***
Symptom duration (months)[a]	47 ± 50 30 [42]	NA	NA	28 ± 24 24 [26]	NA	NA	**0.02***
Soccer player	71 (49%)	26 (63%)	0.09	22 (58%)	4 (29%)	0.06	0.31

Significant between-group differences ($P<0.05$) indicated by **bold***. Data for continuous variables presented as mean ± standard deviation or median [interquartile range]. The final row reports the number (and proportion) of soccer players in each symptomatic group. *P*-value for the between-group comparison of symptomatic men and symptomatic women reported in the final column. Sample size variations: [a]=145 symptomatic men and 37 symptomatic women. Abbreviations: BMI = body mass index; NA = not assessed.

4.5.2 Summary of primary outcomes

A summary of iHOT-33 and HAGOS scores stratified by symptom group and sex is provided in the supplementary information (**Section 4.8.1**).

(i) iHOT-33

For the iHOT-Total score and all iHOT-33 subscales, boxplots in **Figure 4.1** demonstrate the distribution of data for symptomatic and asymptomatic football players. Both symptomatic men and women reported the lowest (i.e., worst) median group scores for the iHOT-Sport subscale (45 [IQR 21] and 45 [IQR 32], respectively).

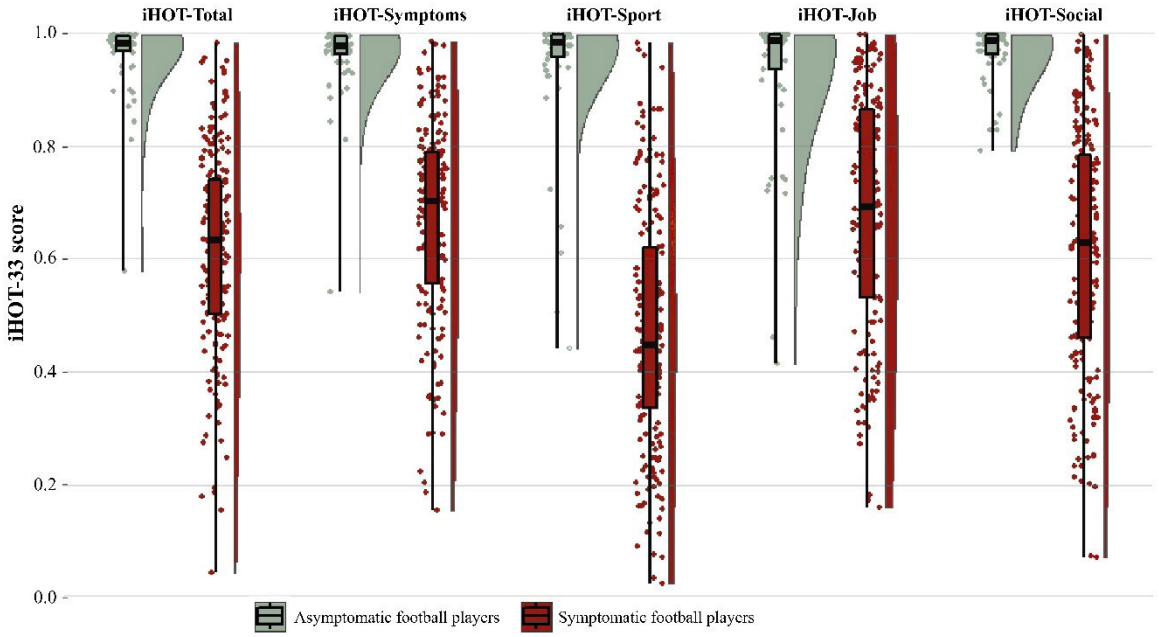


Figure 4.1. International Hip Outcome Tool-33 (iHOT-33) total scores and subscale scores (as a proportion out of 1) for symptomatic and asymptomatic football players.
Box plots indicate the median, interquartile range (25/75th centiles), maximum, and minimum values. Dots represent individual data points. Violin plots (to the right of the box plots) indicate the distribution of the data.

(ii) HAGOS

Scores for the HAGOS subscales are summarised in **Figure 4.2**. Symptomatic women reported the lowest median score on the HAGOS-Symptoms subscale (57 [IQR 23]), whilst the HAGOS-QOL was the lowest for men (60 [IQR 25]).

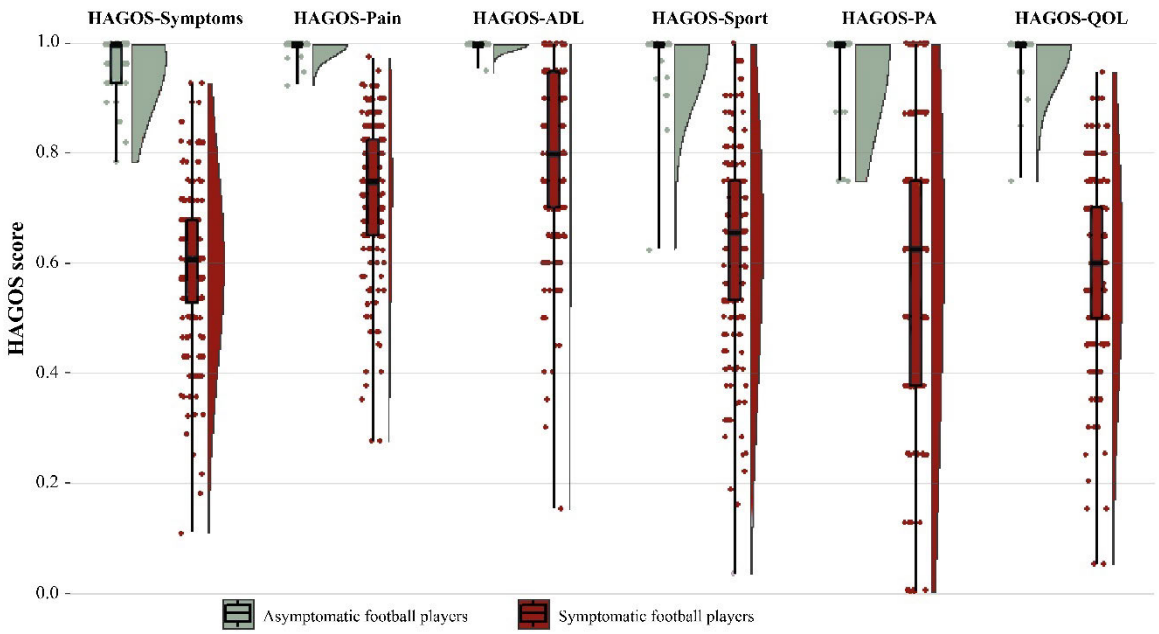


Figure 4.2. Copenhagen Hip and Groin Outcome Score (HAGOS) subscale scores (as a proportion out of 1) for asymptomatic and symptomatic football players.
Box plots indicate the median, interquartile range (25/75th centiles), maximum and minimum values. Dots represent individual data points. Violin plots (to the right of the box plots) indicate the distribution of the data. Abbreviations: ADL = activities of daily living; PA = participation in physical activity; QOL = quality of life.

4.5.3 Between-group comparisons – Subscale scores

Results for univariable and multivariable regression models are presented in the supplementary information (**Section 4.8.2**).

(i) Univariable relationships

Symptomatic football players reported lower (i.e., worse) median scores for all iHOT-33 and HAGOS subscales when compared to asymptomatic players (P<0.01). For six univariable models (iHOT-Total score, iHOT-Sport, iHOT-Job, iHOT-Social, HAGOS-Sport, and HAGOS-QOL) the addition of covariates did not improve the univariable relationship; thus, the simpler univariable model was retained. Pseudo R^2 values for the six univariable models ranged from 0.47 to 0.83 (**Figure 4.3**).

Significant univariable relationships existed between the covariate age^2 (age squared) and six PROM subscale scores (iHOT-Total, iHOT-Symptoms, iHOT-Social, HAGOS-Symptoms, HAGOS-Pain and HAGOS-ADL), indicating that both older and younger age were associated with lower PROM subscale scores (P<0.05). Pseudo R^2 scores ranged from 0.01 to 0.03, indicating weak relationships. No other univariable relationships existed between covariates and PROM scores.

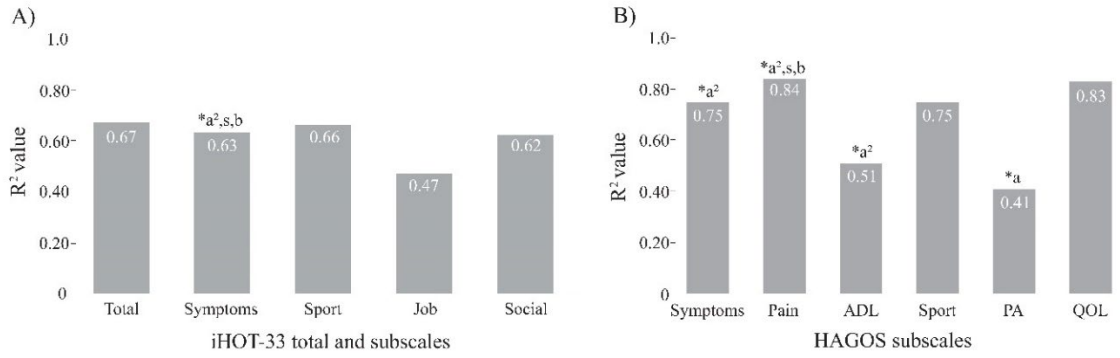


Figure 4.3. Summary of pseudo R^2 values for final iHOT-33 (A) and HAGOS (B) models. Beta-regression models described the relationship between patient-reported outcome measure subscale scores (dependent variable) and the presence of hip/groin pain (independent variable). Multivariable models that included the covariates of age (a), age squared (a^2), male sex (s), and/or body mass index (b) are denoted at the top of the relevant column. Hip/groin pain was significantly associated with all subscale scores (P<0.05). Full model details are reported in **Section 4.8.2**. Abbreviations: ADL = activities of daily living; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool-33; PA = participation in physical activity; QOL = quality of life.

(ii) Multivariable relationships

Multivariable models were selected as the final model for five subscale scores: iHOT-Symptoms (symptom group, age, sex, BMI); HAGOS-Symptoms (group, age^2); HAGOS-Pain (group, age^2, sex, BMI); HAGOS-ADL (group, age^2), and HAGOS-PA (group, age) (**Figure 4.3**). Symptom group was significantly related to PROM scores in all multivariable models, indicating that football players with hip/groin pain reported lower (worse) median scores than asymptomatic players (P<0.05). Including covariates in multivariable models had little effect on relationships between hip/groin pain and PROM scores, with pseudo R^2 values increasing by 0.01 for two subscales only (HAGOS-Symptoms and HAGOS-ADL) when compared to the pseudo R^2 values for univariable models. Full details of multivariable models are provided in the supplementary information (**Section 4.8.2**), and model statistics, including the AIC, are summarised in **Section 4.8.3**.

Covariate(s) were related to PROM scores in four multivariable models. Greater BMI was associated with lower iHOT-Symptoms and HAGOS-Pain subscale scores (P≤0.01). A polynomial relationship existed between age^2 and HAGOS-Symptoms, HAGOS-Pain, and HAGOS-ADL subscale scores (P=0.01 to 0.04); indicating that younger and older age were associated with lower scores. Sex was related to HAGOS-Pain subscale scores only, with female football players reporting lower (worse) scores than male players (P<0.01) (**Figure 4.4**).

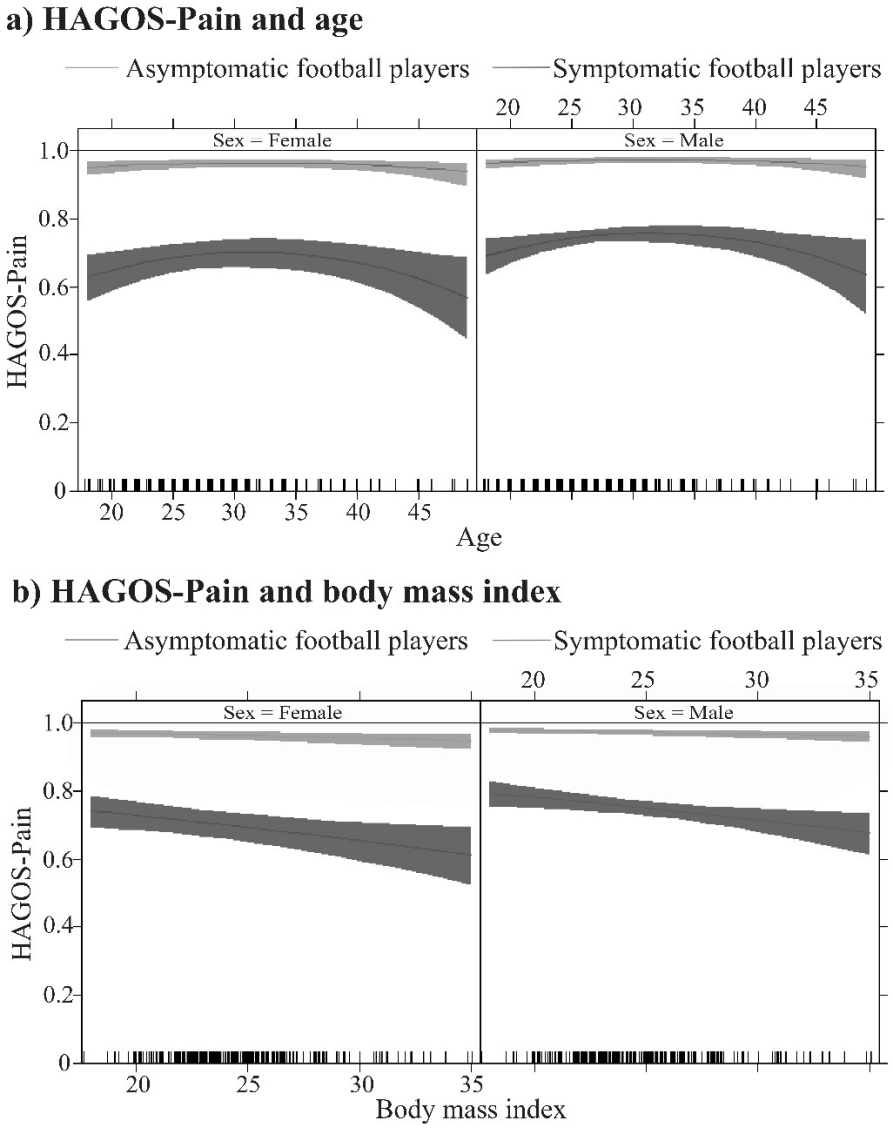


Figure 4.4. The relationship between HAGOS-Pain subscale score (as a proportion out of 1) and (A) age and (B) body mass index, stratified by sex and symptom group.
Units: Age = years; BMI = $kg \cdot m^{-2}$. Vertical lines on the x-axis represent individual data points. Abbreviation: HAGOS = Copenhagen Hip and Groin Outcome Score.

4.5.4 Between-group comparisons – Individual items

Group median scores for all items of the iHOT-33 and HAGOS are reported in the supplementary information (**Section 4.8.4**).

(i) Symptomatic vs Asymptomatic, stratified by sex

Symptomatic male and female football players reported lower group median scores on all individual items of the iHOT-33 and HAGOS than asymptomatic players of the same sex (P<0.01). Symptomatic men recorded the lowest median score on iHOT-item 19, *"How concerned are you that the pain in your hip will increase if you participate in sports or recreational activities?"* Symptomatic women recorded the lowest median score on iHOT-

item 1, *"How often does your hip/groin ache?"* For the HAGOS, symptomatic men and women recorded the lowest group median score on two items related to the frequency of hip/groin pain; including: (i) HAGOS-Symptoms item 1, *"(How frequently) Do you feel discomfort in your hip and/or groin?"* and (ii) HAGOS-QOL item 1, *"How often are you aware of your hip and/or groin problem?"*

(ii) Symptomatic men vs Symptomatic women

Symptomatic men did not record a lower median score than women for any iHOT-33 or HAGOS item.

Women reported lower median scores than men on three iHOT-33 items, including: (i) item 4 (iHOT-Symptoms subscale), *"How much pain do you have in your hip while sitting?"* (ii) item 18 (iHOT-Sport), *"How much pain do you experience in your hip after activity?"* and (iii) item 28 (iHOT-Social), *"How much trouble do you have with sexual activity because of your hip?"* (P<0.01 to 0.03).

Women reported lower median scores than men on five HAGOS items (P<0.01 to 0.04), including: (i) HAGOS-Symptoms item 7, *"How severe is your hip and/or groin stiffness after sitting, lying or resting later in the day?"* (ii) HAGOS-Pain item 6, *"What amount of hip and/or groin pain have you experienced at night while in bed (pain that disturbs your sleep)?"* (iii) HAGOS-Pain item 7, *"What amount of hip and/or groin pain have you experienced while sitting or lying?"* (iv) HAGOS-ADL item 4, *"(What degree of difficulty do you have with) Lying in bed (turning over or maintaining the same hip position for a long time)?* and HAGOS-ADL item 5, *"(What degree of difficulty do you have with) Heavy domestic duties (scrubbing floors, vacuuming, moving heavy boxes etc)?"*

4.6. Discussion

We investigated self-reported hip/groin burden in active football players with and without longstanding hip/groin pain. Symptomatic football players reported lower scores on all subscales and individual items of the iHOT-33 and HAGOS compared to asymptomatic players, with the iHOT-Sport and the HAGOS-QOL the most impaired subscales. Self-reported physical impairment appeared worse during sporting activities (HAGOS-Sport) than activities of daily living (HAGOS-ADL). The presence of hip/groin pain explained 41 to 84% of the variance in PROM scores, with football players' age, sex, and BMI having

no clinically meaningful relationship with iHOT-33 or HAGOS scores. Responses to individual PROM items suggest that our symptomatic football players reported frequent hip/groin pain and were concerned about the impact of recurrent symptoms on future sports performance and participation.

Football players with hip/groin pain reported greater difficulty performing high-impact sporting tasks than activities of daily living. Scores for the HAGOS-Sport subscale were on average 15-points lower (worse) and more strongly associated with the presence of hip/groin pain than HAGOS-ADL scores (pseudo R^2 values 0.75 and 0.51, respectively). Items of the HAGOS-Sport quantify perceived physical impairment during sport-specific tasks; where 52-58% of symptomatic football players reported moderate-to-extreme difficulty during high-speed running (SP5), explosive and agility movements (SP7), forceful movements of the leg (SP6), and positions of extreme hip movement (SP8). Interestingly, athletes who failed to return to optimal sports performance after hip arthroscopy also reported moderate-to-extreme difficulty on the same four HAGOS-Sport items (232). When our findings are combined with others (232), it is possible that perceived impairments during sport-specific tasks may represent important: (i) targets for interventions in non-surgical and post-operative treatment programmes (236), (ii) goals to be considered during collaborative rehabilitation planning, and (iii) criteria for return to sport decision-making in football players with hip/groin pain (237).

Non-physical factors might also be associated with PROM subscale scores evaluating sporting domains in football players with hip/groin pain. For example, the iHOT-Sport subscale, which appears to mostly assess an individual's sports-related cognitive-emotional response to hip/groin pain (238, 239), was the lowest scoring iHOT-33 subscale for symptomatic football players. Study 1 (**Chapter 3**) of this thesis found that iHOT-Sport scores were more strongly related to HAGOS-QOL (Pearson's r=0.67) than HAGOS-Sport scores (r=0.58) (228), indicating that the underlying constructs of the iHOT-Sport and HAGOS-Sport subscales may differ. Interestingly, the HAGOS-QOL was the lowest scoring HAGOS subscale for symptomatic players in the present study. When considered with our previous work (228), our findings suggest that sports-related cognitions and perceived QOL may be interconnected in football players with hip/groin pain. Concern about worsening hip/groin pain with continued sport participation (iHOT-33 item 19) was the lowest scoring item on the iHOT-33 in our symptomatic football players, a finding that is consistent with a study of patients 1 to 2-years post hip arthroscopy (231). Contemporary

rehabilitation and pre-surgical treatment programs might overlook the psychosocial burden of hip/groin pain in football players, with current strategies appearing to follow traditional biomedical models that encourage activity and lifestyle modifications to avoid pain (240-243). Abstaining from sports participation, and other pain avoidance strategies, may negatively impact an athlete's mood and psychological response to injury (244, 245). Instead, future work may develop and test education and rehabilitation strategies for hip/groin pain that encourage athletes to: 1) set and attain realistic sport performance goals (213), 2) demonstrate objective improvement (194, 213, 245), 3) build self-efficacy through positive feedback from clinicians and coaches (245), and 4) obtain a sense of controllability of symptoms (245).

Sex, age, and BMI were weakly associated with some PROM scores, indicating that these demographic characteristics were unlikely to have clinically meaningful effects. Female sex was associated with worse HAGOS-Pain scores, but the 4-point difference between symptomatic men and women was within the reported measurement error of the score (148). Although sex appears unrelated to self-reported hip/groin burden at a domain level, between-group comparisons for individual iHOT-33 and HAGOS items might suggest that female football players reported worse hip/groin pain after activity and with sustained postures (e.g., sitting) than men. These subtle sex-specific differences in symptom profiles, when combined with previous reports of distinct bony morphology (65, 70) and biomechanics (195, 246, 247), might indicate unique disease presentations in symptomatic men and women that could warrant further investigation. Age had a polynomial relationship with two HAGOS subscale scores (HAGOS-Symptoms and HAGOS-Pain), where older and younger age were associated with worse scores. Older age was recently found to be associated with self-reported hip pain and symptoms in a large population-based study (248). When compared to older athletes, younger athletes have previously reported increased injury stressors and limited coping strategies (249). In sub-elite football settings, it is possible that our younger players lacked the necessary social support and/or coping mechanisms to effectively manage their hip/groin pain, leading to heightened pain and symptom scores. Greater BMI was associated with worse iHOT-Symptoms and HAGOS-Pain subscale scores, suggesting that weight reduction strategies could be considered both in the clinical setting and in future intervention studies.

There are limitations that should be considered when interpreting our results. First, our symptomatic football players reported hip/groin pain that likely incorporated intra-articular

and extra-articular sources. Due to the poor specificity of the FADIR test (38, 54), the proportion of symptomatic football players with pain emanating from the hip joint is unknown. It is possible that unique symptom profiles might exist for different diagnostic (hip-related or groin pain) entities, which may have affected our findings. Second, we had a small number of women (symptomatic, n=38; asymptomatic, n=14), and may have been underpowered to detect small between-group differences. Future studies with more female participants would confirm or refute our between-sex findings. Third, we did not include self-reported measures of mood (e.g., Hospital Anxiety and Depression Scale). Non-physical factors associated with longstanding hip/groin pain may have affected PROM scores in our football players and influenced our findings, warranting further investigation in qualitative and/or quantitative studies. Last, our cohort comprised football players from two football codes. Although these sports share many similar physical demands including high speed running, agility, and kicking tasks, specific differences in competition loads and game skills (including tackling and kicking) exist. Nonetheless, time-loss hip/groin injury prevalence is similar in both football codes (29, 32) and the mixed cohort increases generalisability of the results.

Our findings may have useful clinical and research implications. First, symptomatic football players reported the most difficulty with high-impact sporting tasks. These tasks may be important treatment targets and return-to-sport criteria and could guide collaborative rehabilitation planning (194, 213), warranting further investigation in the clinical and research setting. Second, clinicians and researchers might examine the psychosocial burden of persistent hip/groin pain in football players. Our findings suggest that evaluating pain severity and/or perceived difficulties with physical activities only may underestimate the psychosocial impacts of hip/groin pain in symptomatic players. Clinicians may choose to explore the psychosocial burden of hip/groin pain more thoroughly in the subjective examination or by investigating relevant subscales of the iHOT-33 and HAGOS. Future qualitative studies might also identify other features of psychosocial burden experienced by football players. Furthermore, clinicians and researches may also use measures of psychological health, such as the Hospital Anxiety and Depression Scale (250). Concerns about worsening pain and restricted sports participation were evident in symptomatic players. Injury-related cognitions can influence behaviour and emotions, and vice versa, and may be related to rehabilitation outcomes (244). Strategies to improve individuals' self-efficacy, such as realistic collaborative goal

setting (237, 245), may improve injury and performance anxieties in football players with hip/groin pain.

4.7. Conclusion

Football players with hip/groin pain who continued to participate in training and match play reported worse scores on all iHOT-33 and HAGOS subscales and items when compared to asymptomatic football players. Symptomatic players reported greater difficulty performing high-load sporting tasks than activities of daily living; however, the mechanism of this perceived impairment warrants further investigation. Concerns about worsening hip/groin pain and restricted sports participation were evident in symptomatic football players, highlighting the psychosocial burden of hip/groin pain in active football players. Although subscale scores were similar between symptomatic men and women, subtle sex-specific differences existed for individual items, potentially warranting future investigation.

4.8. Supplementary information

4.8.1 Group median iHOT-33 and HAGOS scores stratified by sex

	Women		Men	
	Symptomatic (n=38)	**Asymptomatic (n=14)**	**Symptomatic (n=146)**	**Asymptomatic (n=41)**
iHOT-Total	66 [24] 61 ± 18	100 [2] 99 ± 2	64 [25] 63 ± 18	98 [5] 95 ± 8
iHOT-Symptoms	69 [22] 64 ± 19	99 [2] 99 ± 1	71 [23] 68 ± 17	98 [4] 96 ± 8
iHOT-Sport	45 [21] 48 ± 19	100 [2] 99 ± 2	45 [32] 48 ± 22	99 [6] 93 ± 14
iHOT-Job	70[a] [29] 70[a] ± 19	100[g] [2] 99[g] ± 2	72[b] [34] 68[b] ± 23	99[h] [4] 95[h] ±12
iHOT-Social	61 [35] 59 ± 21	100[g] [1] 99[g] ± 2	64 [34] 62 ± 22	99 [3] 98 ± 4
HAGOS-Symptoms	57[c] [25] 56[c] ± 18	100[g] [0] 99[g] ± 3	61[d] [14] 60[d] ± 13	96 [7] 96 ± 5
HAGOS-Pain	72[c] [20] 68[c] ± 16	100[g] [0] 100[g] ± 0	75[d] [20] 74[d] ± 13	100 [0] 100 ± 1
HAGOS-ADL	85[c] [28] 79[c] ± 21	100[g] [0] 100[g] ± 0	80[d] [25] 80[d] ± 15	100 [0] 100 ± 1
HAGOS-Sport	69[c] [28] 65[c] ± 21	100[g] [0] 100[g] ± 0	66[d] [22] 63[d] ± 18	100 [0] 98 ± 7
HAGOS-PA	63[c] [31] 63[c] ± 24	100[g] [0] 100[g] ± 0	63[f] [38] 61[f] ± 26	100 [0] 95 ± 9
HAGOS-QOL	60[c] [18] 60[c] ± 14	100[g] [0] 100[g] ± 0	60[d] [23] 59[d] ± 17	100 [0] 98 ± 5

Data presented as medians and interquartile ranges [IQR] and means ± standard deviations.
Sample size variations: n[a]=33 symptomatic women; n[b]=133 symptomatic men; n[c]=35 symptomatic women; n[d]=143 symptomatic men; n[f]=142 symptomatic men; n[g]=13 asymptomatic women; n[h]=40 asymptomatic men.
Abbreviations: ADL = activities of daily living; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool-33; PA = participation in physical activity; QOL = quality of life.

4.8.2 Univariable relationships and multivariable regression model statistics

PROM subscale		Beta Regression Coefficients					
		Group (Hip/groin pain)	**Age (years)**	**Age (years)^2**	**Sex (Male)**	**BMI (kg/m^2)**	**Pseudo R^2 (*P* value)**
iHOT-Total	**Univariable**	-2.22	<0.01	-2.17	-0.19	-0.02	N/A
	[95% CI]	[-2.51, -1.93]	[-0.02, 0.02]	[-4.14, -0.19]	[-0.50, 0.13]	[-0.06, 0.02]	
	(*P* value, R^2)	**(*P*<0.01, R^2=0.67)**	(*P*=0.87, R^2<0.01)	**(*P*=0.03, R^2=0.02)**	(*P*=0.25, R^2=0.01)	(*P*=0.30, R^2<0.01)	
	Multivariable	-2.22	-	-	-	-	0.67
	[95%CI]	[-2.51, -1.93]					
	(*P* value)	**(*P*<0.01)**					(*P*<0.01)
iHOT-Symptoms	**Univariable**	-2.00	<0.01	-2.31	-0.15	-0.02	N/A
	[95% CI]	[-2.29, -1.71]	[-0.02, 0.02]	[-4.23, -0.38]	[-0.45, 0.16]	[-0.06, 0.02]	
	(*P* value, R^2)	**(*P*<0.01, R^2=0.63)**	(*P*=0.99, R^2<0.01)	**(*P*=0.02, R^2=0.02)**	(*P*=0.35, R^2<0.01)	(*P*=0.24, R^2=0.01)	
	Multivariable	-2.03	0.53	-1.28	0.16	-0.04	0.63
	[95% CI]	[-2.33, -1.74]	[-1.01, 2.07]	[-2.74, 0.19]	[-0.08, 0.41]	[-0.08, -0.01]	
	(*P* value)	**(*P*<0.01)**	(*P*=0.50)	(*P*=0.09)	(*P*=0.18)	**(*P*<0.01)**	(*P*<0.01)
iHOT-Sport	**Univariable**	-2.51	<-0.01	-	-0.25	-0.02	N/A
	[95% CI]	[-2.83, -2.19]	[-0.03, 0.02]		[-0.60, 0.10]	[-0.06, 0.03]	
	(*P* value, R^2)	**(*P*<0.01, R^2=0.66)**	(*P*=0.46, R^2 < 0.01)		(*P*=0.16, R^2=0.01)	(*P*=0.52, R^2<0.01)	
	Multivariable	-2.53	-	-	-	-	0.66
	[95% CI]	[-2.83, -2.19]					
	(*P* value)	**(*P*<0.01)**					(*P*<0.01)
iHOT-Job	**Univariable**	-1.58	<0.01	-	-0.25	-0.02	N/A
	[95% CI]	[-1.91, -1.26]	[-0.02, 0.02]		[-0.59, 0.10]	[-0.07, 0.02]	
	(*P* value, R^2)	**(*P*<0.01, R^2=0.47)**	(*P*=0.96, R^2<0.01)		(*P*=0.16, R^2=0.01)	(*P*=0.28, R^2=0.01)	
	Multivariable	-1.58	-	-	-	-	0.47
	[95% CI]	[-1.91, -1.26]					
	(*P* value)	**(*P*<0.01)**					(*P*<0.01)
iHOT-Social	**Univariable**	-2.02	<0.01	-2.44	-0.09	-0.02	N/A
	[95% CI]	[-2.34, -1.71]	[-0.02, 0.02]	[-4.56, -0.33]	[-0.43, 0.24]	[-0.07, 0.02]	
	(*P* value, R^2)	**(*P*<0.01, R^2=0.62)**	(*P*=0.88, R^2<0.01)	**(*P*=0.02, R^2=0.02)**	(*P*=0.58, R^2<0.01)	(*P*=0.29, R^2<0.01)	
	Multivariable	-2.02	-	-	-	-	0.62
	[95% CI]	[-2.34, -1.71]					
	(*P* value)	**(*P*<0.01)**					(*P* < 0.01)
HAGOS-Symptoms	**Univariable**	-2.52	<0.01	-2.81	-0.14	<-0.01	N/A
	[95% CI]	[-2.80, -2.25]	[-0.02, 0.02]	[-4.72, -0.89]	[-0.46, 0.18]	[-0.05, 0.03]	
	(*P* value, R^2)	**(*P*<0.01, R^2=0.74)**	(*P*=0.90, R^2<0.01)	**(*P*<0.01, R^2=0.03)**	(*P*=0.39, R^2<0.01)	(*P*=0.60, R^2<0.01)	
	Multivariable	-2.51	0.20	-1.52	-	-	0.75
	[95% CI]	[-2.78, -2.24]	[-0.98, 1.39]	[-2.69, -0.35]			

	(*P* value)	**(*P*<0.01)**	(*P* = 0.74)	**(*P* = 0.01)**			(*P*<0.01)
HAGOS-Pain	**Univariable**	-2.37	<0.01	-2.06	-0.01	-0.02	N/A
	[95% CI]	[-2.66, -2.08]	[-0.02, 0.02]	[-3.92, -0.21]	[-0.32, 0.30]	[-0.06, 0.02]	
	(*P* value, R^2)	**(*P*<0.01, R^2=0.84)**	(*P*=0.87, R^2<0.01)	**(*P*=0.03, R^2=0.01)**	(*P*=0.95, R^2<0.01)	(*P*=0.32, R^2<0.01)	
	Multivariable	-2.43	0.12	-2.51	0.28	-0.04	0.84
	[95% CI]	[-2.72, -2.14]	[-1.12, 1.37]	[-2.68, -0.33]	[0.08, 0.49]	[-0.06, -0.01]	
	(*P* value)	**(*P*<0.01)**	(*P*=0.85)	**(*P*=0.01)**	**(*P*=0.01)**	**(*P*=0.01)**	(*P*<0.01)
HAGOS-ADL	**Univariable**	-1.39	<-0.01	-2.28	-0.14	-0.03	N/A
	[95% CI]	[-1.70, -1.08]	[-0.03, 0.01]	[-4.18, -0.38]	[-0.45, 0.18]	[-0.07, 0.01]	
	(*P* value, R^2)	**(*P*<0.01, R^2=0.50)**	(*P*=0.44, R^2<0.01)	**(*P*=0.02, R^2=0.02)**	(*P*=0.40, R^2<0.01)	(*P*=0.11, R^2=0.01)	
	Multivariable	-1.39	-1.12	-1.79	-	-	0.51
	[95% CI]	[-1.70, -1.08]	[-2.83, 0.59]	[-3.48, 0.09]			
	(*P* value)	**(*P*<0.01)**	(*P*=0.20)	**(*P*=0.04)**			(*P*<0.01)
HAGOS-Sport	**Univariable**	-2.30	<-0.01	-	-0.18	-0.02	N/A
	[95% CI]	[-2.60, -1.99]	[-0.03, 0.02]		[-0.51, 0.16]	[-0.07, 0.02]	
	(*P* value, R^2)	**(*P*<0.01, R^2=0.75)**	(*P*=0.77, R^2<0.01)		(*P*=0.30, R^2<0.01)	(*P*=0.26, R^2=0.01)	
	Multivariable	-2.30	-	-	-	-	0.75
	[95% CI]	[-2.60, -1.99]					
	(*P* value)	**(*P*<0.01)**					(*P*<0.01)
HAGOS-PA	**Univariable**	-1.59	-0.02	-	-0.25	-0.01	N/A
	[95% CI]	[-1.93, -1.24]	[-0.04, 0.01]		[-0.62, 0.12]	[-0.06, 0.03]	
	(*P* value, R^2)	**(*P*<0.01, R^2=0.41)**	(*P*=0.14, R^2=0.01)		(*P*=0.19, R^2=0.01)	(*P*=0.60, R^2<0.01)	
	Multivariable	-1.59	-0.02	-	-	-	0.41
	[95% CI]	[-1.93, -1.25]	[-0.05, <0.01]				
	(*P* value)	**(*P*<0.01)**	(*P* = 0.06)				(*P*<0.01)
HAGOS-QOL	**Univariable**	-2.71	<0.01	-	-0.19	-0.02	N/A
	[95% CI]	[-3.01, -2.42]	[-0.02, 0.02]		[-0.52, 0.15]	[-0.06, 0.02]	
	(*P* value, R^2)	**(*P*<0.01, R^2 = 0.83)**	(*P*=0.86, R^2<0.01)		(*P*=0.28, R^2<0.01)	(*P*=0.38, R^2<0.01)	
	Multivariable	-2.71	-	-	-	-	0.83
	[95% CI]	[-3.01, -2.42]					
	(*P* value)	**(*P*<0.01)**					(*P*<0.01)

R^2 indicates pseudo R^2 values. Abbreviations: Age (years)2 = squared polynomial relationship variable for age; AIC = Akaike Information Criterion; BMI = Body mass index; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool; N/A = not applicable for univariate relationship; PROM = Patient reported outcome measure. Regression coefficient interpretation: exp(B) = S/(1-S): C/(1-C); S = mean symptomatic value; C = mean control value.

4.8.3 Comparison of multivariable model statistics for all iHOT-33 and HAGOS scores

PROM Subscale	Model	Pseudo R^2	LogLik	AIC value
iHOT-Total	**Group**	**0.6684**	**186.5906**	**-367.1812**
	Group+Age^2	0.6719	187.1986	-364.3972
	Group+Age^2+Sex	0.6703	187.3119	-362.6238
	Group+Age^2+Sex+BMI	0.6687	189.7539	-365.5077
iHOT-Symptoms	Group	0.6259	191.6700	-377.3400
	Group+Age^2	0.6319	192.6705	-375.3410
	Group+Age^2+Sex	0.6294	192.9315	-373.8630
	Group+Age^2+Sex+BMI	**0.6282**	**196.4025**	**-378.8050**
iHOT-Sport	**Group**	**0.6584**	**141.1431**	**-276.2863**
	Group+Age^2	0.6583	142.5222	-275.0445
	Group+Age^2+Sex	0.6594	142.5828	-273.1656
	Group+Age^2+Sex+BMI	0.6584	142.7753	-271.5506
iHOT-Job	**Group**	**0.4738**	**153.3461**	**-300.6922**
	Group+Age^2	0.4776	153.7928	-297.5855
	Group+Age^2+Sex	0.4817	154.0210	-296.0420
	Group+Age^2+Sex+BMI	0.4819	154.9338	-295.8676
iHOT-Social	**Group**	**0.6234**	**165.4659**	**-324.9319**
	Group+Age^2	0.6294	166.6475	-323.2951
	Group+Age^2+Sex	0.6270	167.0910	-322.1820
	Group+Age^2+Sex+BMI	0.6284	169.1106	-324.2213
HAGOS-Symptoms	Group	0.7443	208.3742	-410.7484
	Group+Age^2	**0.7525**	**211.5967**	**-413.1935**

	Group+Age^2+Sex	0.7500	212.2715	-412.5429
	Group+Age^2+Sex+BMI	0.7494	213.3570	-412.7141
HAGOS-Pain	Group	0.8425	275.4525	-544.9050
	Group+Age^2	0.8436	277.6346	-545.2692
	Group+Age^2+Sex	0.8431	280.0161	-548.0322
	Group+Age^2+Sex+BMI	**0.8434**	**283.2164**	**-552.4329**
HAGOS-ADL	Group	0.4992	261.6932	-517.3865
	Group+Age^2	**0.5056**	**264.4613**	**-518.9226**
	Group+Age^2+Sex	0.5063	264.5685	-517.1369
	Group+Age^2+Sex+BMI	0.5121	266.4547	-518.9093
HAGOS-Sport	**Group**	**0.7456**	**193.9489**	**-381.8978**
	Group+Age	0.7461	193.9816	-379.9632
	Group+Age+Sex	0.7466	194.0153	-378.0306
	Group+Age+Sex+BMI	0.7469	195.4122	-378.8243
HAGOS-PA	Group	0.4084	125.5271	-245.0542
	Group+Age	**0.4181**	**127.1926**	**-246.3852**
	Group+Age+Sex	0.4212	127.5314	-245.0629
	Group+Age+Sex+BMI	0.4216	127.5468	-243.0936
HAGOS-QOL	**Group**	**0.8309**	**215.4163**	**-424.8327**
	Group+Age	0.8313	215.4882	-422.9763
	Group+Age+Sex	0.8318	215.5650	-421.1301
	Group+Age+Sex+BMI	0.8319	216.2959	-420.5918

Final model denoted in **bold**. Abbreviations: ADL = activities of daily living; Age^2 = polynomial relationship (squared) age; AIC = Akaike Information Criterion; BMI = body mass index; Group = Hip/groin pain group; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool; LogLik = log-likelihood; PA = participation in physical activity; PROM = Patient-reported outcome measure; Sex = Male sex. QOL = quality of life.

4.8.4 Comparison of group median scores for individual PROM items

PROM item	Symptomatic		Asymptomatic		Between-group comparison SW vs SM *P* value	Between-group comparison SW vs AW *P* value	Between-group comparison SM vs AM *P* value
	Women (n = 38) Median [IQR]	**Men (n = 149)** Median [IQR]	**Women (n = 14)** Median [IQR]	**Men (n = 41)** Median [IQR]			
iHOT-Symptoms							
Q1	32 [36]	41 [41]	99 [4]	99 [6][p]	0.22	**<0.01***	**<0.01***
Q2	37 [43]	48 [43]	100 [2]	99 [11][p]	0.14	**<0.01***	**<0.01***
Q3	72 [40]	79 [43]	100 [1]	99 [4]	0.18	**<0.01***	**<0.01***
Q4	63 [47]	78 [39]	100 [1]	100 [3]	**0.03***	**<0.01***	**<0.01***
Q5	64 [36]	73 [42]	100 [3]	99 [5]	0.11	**<0.01***	**<0.01***
Q6	78 [30]	74 [40]	100 [0]	99 [5]	0.77	**<0.01***	**<0.01***
Q7	85 [34]	83 [33]	100 [1]	99 [4]	0.83	**<0.01***	**<0.01***
Q8	84 [38]	84 [32]	100 [3]	99 [4]	0.17	**<0.01***	**<0.01***
Q9	81 [30]	80 [32]	100 [2]	99 [5]	0.98	**<0.01***	**<0.01***
Q10	77 [44]	82 [31]	100 [3]	99 [4]	0.38	**<0.01***	**<0.01***
Q11	79 [35]	82 [37]	100 [3]	99 [4]	0.78	**<0.01***	**<0.01***
Q12	71 [35]	78 [40]	100 [3]	99 [3]	0.17	**<0.01***	**<0.01***
Q13	90 [31]	82 [36]	100 [1]	100 [2]	0.10	**<0.01***	**<0.01***
Q14	51 [50]	67 [45]	100 [2]	99 [6]	0.06	**<0.01***	**<0.01***
Q15	88 [33]	82 [37]	100 [3]	99 [3]	0.12	**<0.01***	**<0.01***
Q16	54 [46]	56 [29]	100 [1]	99 [4][p]	0.48	**<0.01***	**<0.01***
iHOT-Sport							
Q17	38 [43]	35 [49]	100 [2]	97 [10]	0.90	**<0.01***	**<0.01***
Q18	37 [29]	42 [35]	100 [3]	99 [5]	**0.03***	**<0.01***	**<0.01***
Q19	33 [39]	32 [39]	100 [2]	99 [6]	0.77	**<0.01***	**<0.01***
Q20	79 [32]	72 [45]	100 [3]	99 [5]	0.20	**<0.01***	**<0.01***
Q21	49 [53][a]	42 [48][b]	100 [3]	99 [3]	0.63	**<0.01***	**<0.01***
Q22	51 [46]	49 [52]	100 [3]	99 [4]	0.60	**<0.01***	**<0.01***
iHOT-Job							
Q23	80 [32][c]	80 [43][d]	100 [1][k]	99 [5][n]	0.77	**<0.01***	**<0.01***
Q24	52 [49][e]	58 [43][f]	100 [3][m]	99 [4][p]	0.45	**<0.01***	**<0.01***

Q25	74 [44][e]	74 [49][f]	100 [2][m]	99 [5][p]	0.65	**<0.01***	**<0.01***
Q26	89 [30][e]	82 [39][f]	100 [2][m]	99 [5][p]	0.34	**<0.01***	**<0.01***
iHOT-Social							
Q27	45 [54]	39 [54]	100 [1]	99 [3]	0.57	**<0.01***	**<0.01***
Q28	73 [55][e]	85 [29][g]	100 [2]	99 [3]	**<0.01***	**<0.01***	**<0.01***
Q29	56 [43]	55 [47]	100 [3]	99 [4]	0.37	**<0.01***	**<0.01***
Q30	73 [43]	75 [46]	100 [3]	99 [3]	0.84	**<0.01***	**<0.01***
Q31	67 [39]	69 [48]	100 [3]	99 [3]	0.64	**<0.01***	**<0.01***
Q32	85 [32][h]	96 [21][j]	100 [2][m]	99 [3][q]	0.06	**<0.01***	**<0.01***
Q33	66 [42]	57 [45]	100 [2]	99 [3]	0.74	**<0.01***	**<0.01***
HAGOS-Symptoms							
S1	3 [1][n]	3 [1][r]	0 [0][m]	0 [1]	0.27	**<0.01***	**<0.01***
S2	2 [2][n]	2 [2][r]	0 [0][m]	0 [1]	0.12	**<0.01***	**<0.01***
S3	2 [1][n]	2 [2][r]	0 [0][m]	0 [1]	0.93	**<0.01***	**<0.01***
S4	1 [1][n]	1 [1][r]	0 [0][m]	0 [0]	0.12	**<0.01***	**<0.01***
S5	2 [2][n]	2 [1][r]	0 [0][m]	0 [0]	0.90	**<0.01***	**<0.01***
S6	1 [1][n]	1 [1][r]	0 [0][m]	0 [0]	0.93	**<0.01***	**<0.01***
S7	2 [1][n]	1 [1][r]	0 [0][m]	0 [0]	**0.04***	**<0.01***	**<0.01***
HAGOS-Pain							
P1	3 [1][n]	2 [1][r]	0 [0][m]	0 [0]	0.37	**<0.01***	**<0.01***
P2	2 [1][n]	2 [1][r]	0 [0][m]	0 [0]	0.97	**<0.01***	**<0.01***
P3	1 [2][n]	1 [1][r]	0 [0][m]	0 [0]	0.82	**<0.01***	**<0.01***
P4	2 [1][n]	1 [1][r]	0 [0][m]	0 [0]	0.08	**<0.01***	**<0.01***
P5	1 [2][e]	1 [1][r]	0 [0][m]	0 [0]	0.24	**<0.01***	**<0.01***
P6	1 [2][n]	0 [1][r]	0 [0][m]	0 [0]	**<0.01***	**<0.01***	**<0.01***
P7	1 [1][n]	1 [2][r]	0 [0][m]	0 [0]	**<0.01***	**<0.01***	**<0.01***
P8	0 [1][n]	0 [1][r]	0 [0][m]	0 [0]	0.66	**<0.01***	**<0.01***
P9	1 [1][n]	0 [1][r]	0 [0][m]	0 [0]	0.21	**<0.01***	**<0.01***
P10	1 [1][n]	1 [1][r]	0 [0][m]	0 [0]	0.74	**<0.01***	**<0.01***
HAGOS-ADL							
A1	1 [1][n]	1 [1][r]	0 [0][m]	0 [0]	0.70	**<0.01***	**<0.01***
A2	1 [2][n]	1 [1][r]	0 [0][m]	0 [0]	0.72	**<0.01***	**<0.01***
A3	0 [1][n]	1 [1][r]	0 [0][m]	0 [0]	0.09	**<0.01***	**<0.01***
A4	1 [2][n]	1 [1][r]	0 [0][m]	0 [0]	**0.04***	**<0.01***	**<0.01***

A5	1 [1][n]	1 [0][r]	0 [0][m]	0 [0]	**0.04***	**<0.01***	**<0.01***
HAGOS- Sport							
SP1	1 [1][n]	1 [1][r]	0 [0][m]	0 [0]	0.48	**<0.01***	**<0.01***
SP2	1 [1][n]	1 [1][r]	0 [0][m]	0 [0]	0.74	**<0.01***	**<0.01***
SP3	1 [1][n]	2 [1][r]	0 [0][m]	0 [0]	0.21	**<0.01***	**<0.01***
SP4	0 [1][n]	1 [1][r]	0 [0][m]	0 [0]	0.41	**<0.01***	**<0.01***
SP5	1 [1][n]	2 [1][r]	0 [0][m]	0 [0]	0.60	**<0.01***	**<0.01***
SP6	2 [1][n]	2 [1][r]	0 [0][m]	0 [0]	0.65	**<0.01***	**<0.01***
SP7	1 [1][n]	2 [1][r]	0 [0][m]	0 [0]	0.30	**<0.01***	**<0.01***
SP8	2 [1][n]	2 [1][r]	0 [0][m]	0 [0]	0.64	**<0.01***	**<0.01***
HAGOS-PA							
PA1	1 [1][n]	1 [1][s]	0 [0][m]	0 [0]	0.70	**<0.01***	**<0.01***
PA2	2 [2][n]	2 [2][s]	0 [0][m]	0 [0]	0.69	**<0.01***	**<0.01***
HAGOS-QOL							
Q1	3 [1][n]	3 [1][r]	0 [0][m]	0 [0]	0.73	**<0.01***	**<0.01***
Q2	1 [1][n]	1 [2][r]	0 [0][m]	0 [0]	0.23	**<0.01***	**<0.01***
Q3	1 [1][n]	1 [1][r]	0 [0][m]	0 [0]	0.98	**<0.01***	**<0.01***
Q4	1 [2][n]	1 [1][r]	0 [0][m]	0 [0]	0.94	**<0.01***	**<0.01***
Q5	2 [1][n]	2 [2][r]	0 [0][m]	0 [0]	0.94	**<0.01***	**<0.01***

*indicates significant between-group difference ($P<0.05$). Sample size variations: $n^a=36$; $n^b=144$; $n^c=18$; $n^d=84$; $n^e=33$; $n^f=133$; $n^g=139$; $n^h=13$; $n^j=81$; $n^k=12$; $n^m=13$; $n^n=35$; $n^p=40$; $n^q=38$; $n^r=143$, $n^s=142$. Abbreviations: ADL = activities of daily living; AM = asymptomatic men; AW = asymptomatic women; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT = International Hip Outcome Tool; IQR = interquartile range; PROM = patient reported outcome measure; SM = symptomatic men; SW = symptomatic women.

Chapter 5. Does femoroacetabular impingement syndrome affect self-reported burden in football players with hip and/or groin pain?

5.1. Preface

Findings from **Chapter 4** identified that hip/groin pain is burdensome in symptomatic football players. As indicated in **Chapter 1**, hip/groin pain may emanate from various intra- and extra-articular (hip-related) sources, with certain hip-related conditions (e.g., FAI syndrome) indicators for surgery in those with longstanding symptoms (251). Identifying a unique profile of self-reported burden in those with FAI syndrome might assist the development of targeted interventions, preventing or delaying the need for surgery in some individuals. This chapter aimed to compare self-reported burden in football players with and without FAI syndrome and examine whether chondrolabral conditions mediated the effect of FAI syndrome on PROM scores.

Chapter 5 contains an edited version of the following accepted publication:

Scholes MJ, Kemp JL, Mentiplay BF, Heerey JJ, Agricola R, Semciw AI, Souza RB, Link T, Majumdar S, King MG, Lawrenson PR, Crossley, KM. Does femoroacetabular impingement syndrome affect self-reported burden in football players with hip and groin pain? A cross-sectional study of 165 symptomatic sub-elite players. *Sports Health: A Multidisciplinary Approach*. 2022. Accepted for publication. doi:10.1177/19417381221076141

All edits of the accepted manuscript are grammatical, to improve clarity and facilitate consistency throughout this thesis. No amendments or additions have been made to the results.

5.2. Abstract

Background: It is unknown if football players with FAI syndrome report worse burden than those with other causes of hip/groin pain, and to what extent this is mediated by cartilage defects and labral tears.

Hypothesis: Football players with FAI syndrome would report worse burden than other symptomatic players, with the effect partially mediated by cartilage defects and/or labral tears.

Study design: Case-control study.

Level of evidence: Level 4.

Methods: Football (football and Australian football) players (n=165, 35 women) with hip/groin pain (≥6months and positive flexion-adduction-internal rotation test) were recruited. Participants completed two PROMS (iHOT-33 and HAGOS) and underwent hip radiographs and MRI. Femoroacetabular impingement syndrome was determined to be present when cam and/or pincer morphology were present. Cartilage defects and labral tears were graded as present or absent using MRI. Linear regression models investigated relationships between FAI syndrome (dichotomous independent variable) and PROM scores (dependent variables). Mediation analyses investigated the effect of cartilage defects and labral tears on these relationships.

Results: Femoroacetabular impingement syndrome was not related to PROM scores (unadjusted *b*-values ranged from -4.693 (*P*=0.23) to 0.337 (*P*=0.93)) and cartilage defects and/or labral tears did not mediate its effect (*P*=0.22 to 0.97).

Conclusion: Football players with FAI syndrome did not report worse burden than those with other causes of hip/groin pain. Cartilage defects and/or labral tears did not explain the effect of FAI syndrome on reported burden.

Clinical relevance: Femoroacetabular impingement syndrome, cartilage defects, and labral tears were prevalent but unrelated to reported burden in symptomatic football players.

Keywords:
Cam morphology, Magnetic resonance imaging, Patient-reported outcomes, Rehabilitation

5.3. Introduction

Hip/groin injuries are common in football players, accounting for 10-19% of all time-loss injuries (27, 28, 30, 32). Up to 53% of sub-elite players can complain of hip/groin pain per season (4), and those with prolonged symptoms (>6 weeks) report worse burden than players with shorter symptom duration (5). To aid with diagnosis and treatment planning, classification of hip-related pain into the following conditions was recently recommended (38): (1) FAI syndrome (defined by the presence of cam and/or pincer morphology); (2) acetabular dysplasia and/or hip instability; and (3) other conditions without distinct bony morphology, including labral, chondral, and/or ligamentum teres conditions. Femoroacetabular impingement syndrome can cause hip/groin pain in football players (6, 131) and has been associated with features of early hip OA (i.e., cartilage defects and labral tears) in patients undertaking hip arthroscopy (60, 252). Cartilage defects and labral tears might represent a causal pathway for hip/groin pain and symptoms in FAI syndrome (38, 45, 47). Quantifying the extent that cartilage defects and labral tears mediate self-reported hip/groin burden could improve understanding of the pathogenesis of FAI syndrome.

Femoroacetabular impingement syndrome is burdensome in patients seeking surgery, reducing sports participation and QOL (99, 229, 231). It is unknown whether people with FAI syndrome who do not seek surgery report worse burden than those with other causes of hip/groin pain. Football players require considerable hip function and ROM during sport performance. As players with large cam morphology (alpha angle ≥78°) are more likely to report hip/groin pain than those without (253), it is possible that relationships between FAI syndrome and reported burden may exist in symptomatic football players. Understanding the effect of FAI syndrome, cartilage defects, and labral tears on reported burden may assist with discerning the importance of these findings in young athletic adults and prioritising treatment approaches.

Therefore, the primary aim of this study was to investigate the relationship between FAI syndrome presence and self-reported burden in football players with hip/groin pain and a positive FADIR test, using the iHOT-33 (147) and HAGOS(148). Our secondary aim was to investigate the extent to which cartilage defects and labral tears mediated the effect of FAI syndrome on PROM scores.

5.4. Methods

5.4.1 Study design

This case-control study investigated 18- to 50-year-old sub-elite football (football and Australian football) players with hip/groin pain. Data were collected as part of the larger baseline assessment for the FORCe study (130, 131, 183), an ongoing prospective study investigating change in hip joint structure and symptoms over time (**Section 2.2**). Ethics approval was obtained from the La Trobe University Human Ethics Committee (HEC015-019) and the University of Queensland Human Ethics Committee (2015000916). Written informed consent was obtained prior to data being collected. This study was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines (254).

5.4.2 Participants

Football players with hip/groin pain who were participating in structured, sub-elite (non-professional) competitions in greater Melbourne and Brisbane, Australia, were recruited. For inclusion, participants needed to: 1) complete at least two football sessions (training/matches) per week; 2) report more than six months of gradual-onset, activity-related hip (anterior/lateral/posterior) and/or groin pain (average pain ≥3 and ≤8 on a numerical pain rating scale during football); and 3) have a positive FADIR pain provocation test. Exclusion criteria for football players with hip/groin pain are provided in **Table 2.1**. Briefly, football players with hip/groin pain were excluded if they had: 1) radiographic hip OA defined by a KL score ≥2 (188); 2) undergone hip or pelvic surgery; 3) acetabular dysplasia defined by a LCEA of <20° in the investigated hip (255); or 4) reported a history of significant hip condition (e.g., hip fracture, congenital dislocation of the hip).

5.4.3 Procedures

Football players were recruited through print, electronic, and social media advertisements to football clubs and leagues and direct advertisements to and within sports medicine and physiotherapy clinics. Following screening to confirm eligibility, participants attended La Trobe University or University of Queensland for testing between August 2015 and August 2018. Participant characteristics (age, sex, height, mass, football code, and duration of

symptoms) were recorded. Radiographs and MRI scans were undertaken at radiology clinics in Melbourne (Imaging @ Olympic Park) and Brisbane (Q-Scan), Australia.

5.4.4 Patient-reported outcome measures

Participants completed the iHOT-33 and HAGOS in hard-copy format or via CheckWare (CheckWare, AS, Trondheim, Norway), an online data capture and storage platform. The iHOT-33 and HAGOS are self-reported questionnaires recommended for assessing young- to middle-aged adults with hip/groin pain (144, 145, 228).

The iHOT-33 has been described in **Section 2.2.7**. Briefly, the iHOT-33 consists of 33 items scored on a visual analogue scale from 0 (worst possible score) to 100 (best possible score) and measures hip-related QOL in the most symptomatic hip in the preceding month (147). The iHOT-Total score was calculated as the sum of all item scores divided by the total number of items answered. Scores (from 0-100) were also calculated for the four subscales (iHOT-Symptoms, iHOT-Sport, iHOT-Job, and iHOT-Social) by summing the subscale item scores and dividing by the number of subscale items answered. The iHOT-33 scores are reliable (ICC values ranging from 0.78 to 0.88 [95%CI 0.60, 0.93]), with SEM values ranging from 6.0 to 9.5 [95%CI 4.6, 12.4] (**Chapter 3**) (228).

The HAGOS has been described in **Section 2.2.7**. Briefly, the HAGOS measures hip-related QOL at a per-person level and was developed and validated in active adults, including football players (148). The six HAGOS subscale scores range from 0 (worst possible score) to 100 (best possible score) and explore the following dimensions of hip/groin burden: symptoms (HAGOS-Symptoms), pain (HAGOS-Pain), physical function in activities of daily living (HAGOS-ADL), physical function during sport and recreational activities (HAGOS-Sport), participation in physical activities (HAGOS-PA), and hip and/or groin related quality of life (HAGOS-QOL). The HAGOS subscale scores are reliable (ICCs range from 0.82 to 0.91 [95%CIs 0.68, 0.95]), with SEM values ranging from 6.4 to 12.2 [95%CI 5.0, 16.2]) (148).

5.4.5 Radiographs

Participants underwent a supine AP and Dunn 45° radiograph of each hip according to standardised protocols (130). One blinded assessor (JJH) determined the presence of bony hip morphology (cam and pincer morphology) with quantitative methods (121), as detailed in **Appendix R**. Briefly, a point set was placed on predetermined locations on the surface of the femur and acetabulum with statistical shape modelling software (ASM toolkit, Manchester University, Manchester, UK). The alpha angle and LCEA were then calculated using MATLAB software v7.1.0 (MathWorks Inc, Natick, Massachusetts, USA). Moderate-to-good intra- (ICC alpha angle Dunn = 0.93; LCEA = 0.94) and inter-rater reliability (ICC alpha angle Dunn = 0.93; LCEA = 0.63) were demonstrated for bony hip morphology measures (131).

(i) Cam morphology

The Dunn 45° radiograph was used to quantify the extent of femoral head-neck asphericity (57, 60), as it best visualises the anterosuperior head-neck region (63, 256) where asphericity is most often observed (61, 63). Cam morphology was determined to be present if an alpha angle of ≥60° on the Dunn 45° radiograph was recorded (63, 121).

(ii) Pincer morphology

The LCEA was measured using the AP radiograph and determined the presence of pincer morphology and acetabular dysplasia (63, 74). A LCEA of ≥40° and <20° defined the presence of pincer morphology and acetabular dysplasia, respectively (63, 74). Football players with acetabular dysplasia (LCEA <20°) were excluded from this study (255).

5.4.6 Femoroacetabular impingement syndrome

Femoroacetabular impingement syndrome was defined as the presence of hip/groin pain, a positive FADIR test, and cam and/or pincer morphology on radiographs (74, 121, 257).

5.4.7 Magnetic resonance imaging acquisition and assessment

Football players underwent an unenhanced 3.0T MRI (Phillips Ingenia, The Netherlands). Each participant was positioned in supine, with positioning aids used to maintain each hip

in internal rotation and neutral abduction/adduction. A 32-channel torso coil was placed over the hips and pelvis, with right and left hips imaged independently. The MRI protocol included three sequences: coronal PD SPAIR, sagittal PD SPAIR, and oblique PD SPAIR.

All MRI scans were evaluated by a single experienced and trained musculoskeletal radiologist (Dr Ramya Srinivasan), who was blinded to bony hip morphology and PROM scores. The SHOMRI (87) was used to evaluate cartilage defects and labral tears, key features of early hip OA (87, 105, 186). Cartilage defects were assessed in six femoral and four acetabular subregions and graded from 0 to 2 (0=no defect, 1=partial defect, or 2=full thickness defect). Labral tears were assessed in four acetabular subregions and graded from 0 to 5 (0=normal or normal variant, 1=abnormal signal or fraying, 2=simple tear, 3=labrocartilage separation, 4=complex tear, or 5=maceration). For our analyses, a dichotomous (present/absent) "cartilage defect and/or labral tear" variable was used. This variable was considered present when a: 1) partial or full thickness (grade 1 or 2) cartilage defect; and/or 2) simple (grade 2) labral tear or higher was identified in at least one subregion. Intra-observer agreement for cartilage defect and labral tear grading (dichotomous scoring) had prevalence adjusted bias adjusted kappa values of 0.76 (kappa 0.66) and 0.80 (kappa 0.77), respectively (183).

5.4.8 Data management

Each participant's most symptomatic hip was defined on the iHOT-33 (by answering the introductory iHOT-33 question, *"which (hip) gives you the most trouble?"*) and used for analyses. Six participants (three with FAI syndrome and three without) did not have useable iHOT-33 scores and another six participants (three with FAI syndrome and three without) did not complete the HAGOS; they were removed from the respective analyses.

5.4.9 Statistical analysis

Data were assessed for normality using boxplots and Shapiro-Wilk analyses. Continuous demographic data were summarised using means and SD or medians and IQR values, as appropriate. Linear regression models were used for each study aim. Prior to interpreting results, models were assessed for violations of assumptions. Residual scatter plots were used to assess linearity and homoscedasticity, and variance inflation factor (VIF) statistics

>10 indicated problematic multicollinearity (258). Normality of regression model residuals were assessed using residual scatter plots and Shapiro-Wilk analyses.

(i) Primary aim – FAI syndrome (linear relationships, dichotomous variable)

Linear regression models were used to assess the relationships between FAI syndrome presence (dichotomous independent variable) and PROM scores (dependent variable, score of 0 to 100). Relationships were analysed unadjusted and adjusted for the covariates of age, sex, and BMI, and pseudo R^2 values quantified the strength of modelled relationships. For adjusted (multivariable) linear regression models, interaction effects between FAI syndrome and covariates were examined by adding interaction terms individually to each model. Interaction terms were removed if not significant (P>0.05). As PROM scores were anchored by values of 0 and 100, they may not always be optimally modelled using linear regression. Arcsin transformation of the dependent variables (PROM scores) can be used to stabilize variance and minimise bias in models (259). Sensitivity analyses using models with arcsin-transformed PROM scores are described in the supplementary information (**Section 5.8.1**).

(ii) Secondary aim - Mediation analyses

Cartilage defects and labral tears may be sequalae of FAI syndrome, representing a possible causal pathway between FAI syndrome and reported hip/groin burden. Mediation analyses were used to assess if the relationships between FAI syndrome presence and PROM scores were mediated by the presence of cartilage defects and/or labral tears (dichotomous mediator variable). **Figure 5.1** describes the direct and indirect causal pathways defined for the mediation analyses. For mediation to occur, cartilage defects and/or labral tears must be related to FAI syndrome presence (Path A) and PROM scores (Path B) (260). Sensitivity analyses controlled for the effects of the covariates of age, sex, and BMI during mediation analyses (causal pathways described in **Section 5.8.2**). If including covariates did not alter statistical significance of the indirect effect, the results of the simplified mediation analysis were retained. Secondary sensitivity analyses assessed if the direct and indirect effects of FAI syndrome presence on PROM scores were moderated by sex (causal pathways described in **Section 5.8.2**). *Post hoc* sensitivity analyses investigated cartilage defect presence as the mediator variable, to assess for the potential wash out of mediation effects by combining two variables (cartilage defects and labral tears) (**Section 5.8.3**).

Statistical analyses were completed using SPSS version 26 (SPSS Inc, Chicago, Illinois, USA) and the general analyses for linear models and advanced mediation models modules in Jamovi version 1.6.16.0 (The jamovi project, Sydney, Australia). Level of significance was set at 0.05.

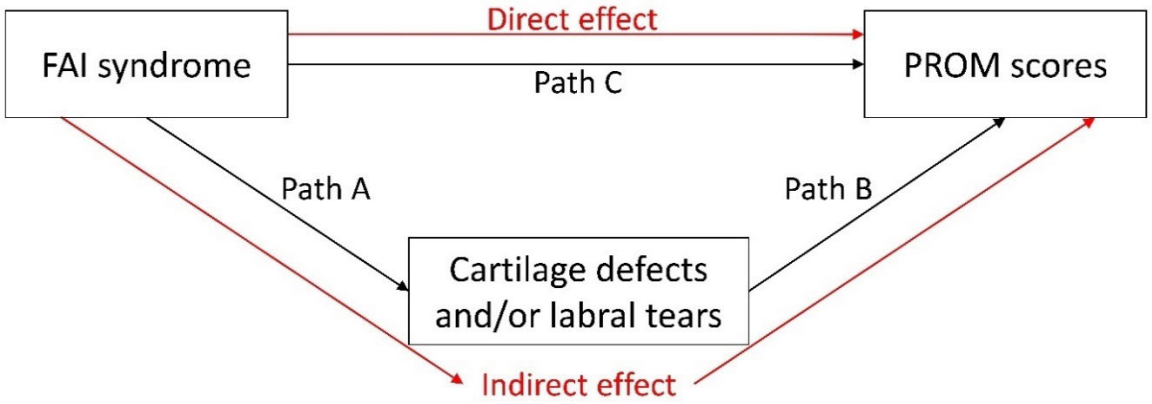


Figure 5.1. Direct and indirect causal pathways defined for mediation analyses.
Model of the potential mediating effect of cartilage defects and/or labral tears on the relationship between femoroacetabular impingement (FAI) syndrome presence and patient-reported outcome measure (PROM) scores.

5.5. Results

5.5.1 Participant recruitment and demographic characteristics

A summary of participant recruitment is provided in **Figure 5.2**. Of the 539 football players with hip/groin pain screened, 165 players (35 women, 130 men) fulfilled the eligibility criteria and were included in this study. Demographic data and PROM scores are summarised in **Table 5.1** and **Table 5.2**, respectively. Femoroacetabular impingement syndrome was identified in 114 (69%) players (pincer-type = 4 (0 women); mixed-type = 10 (1 woman); cam-type = 100 (8 women)). Cartilage defects and/or labral tears were identified in 129 (78%, 24 female) players (players with FAI syndrome = 95 (83%); players without FAI syndrome = 34 (66%)). Seventeen football players (10% of cohort) had neither FAI syndrome nor any cartilage defects or labral tears.

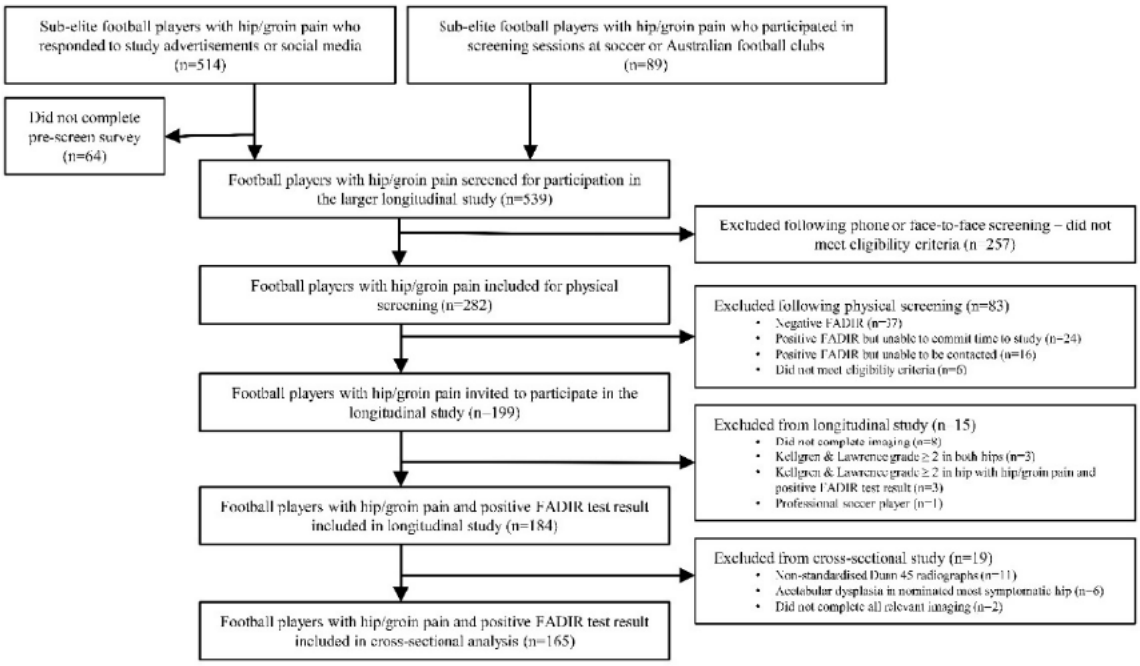


Figure 5.2. Participant flow for football players with hip/groin pain.
Abbreviation: FADIR = flexion-adduction-internal rotation

Table 5.1. Demographic characteristics of football players with hip/groin pain.

	Total Cohort (n=165)
Sex (female)	35 (21%)
Age (years)	26 [7]
Body mass index (kg·m^{-2})	24.1 [3.4]
Symptom duration (months)	24 [33]
Soccer player	77 (47%)
FAI syndrome	114 (69%)
Cartilage defect (≥grade 1)	83 (50%)
Labral tear (≥grade 2)	115 (70%)
Cartilage defect and/or labral tear	129 (78%)
KL grade 0	157 (95%)

Data presented as medians and interquartile ranges [IQRs] or count and proportions (%). Reported proportions of femoroacetabular impingement (FAI) syndrome and intra-articular findings (cartilage defects and/or labral tears) for participants included hip only. Abbreviations: FAI = femoroacetabular impingement; IQR = interquartile range; KL = Kellgren and Lawrence grade.

Table 5.2. iHOT-33 and HAGOS scores for football players with hip/groin pain.

	Total Cohort (n=165)	FAI Syndrome (n=114)	Non-FAI Syndrome (n=51)
iHOT-Total[a]	63 [23]	62 [23]	66 [20]
iHOT-Symptoms[a]	70 [23]	69 [24]	72 [20]
iHOT-Sport[a]	45 [27]	46 [31]	44 [18]
iHOT-Job[b]	72 [34]	72 [38]	71 [28]
iHOT-Social[a]	63 [32]	62 [32]	65 [31]
HAGOS-Symptoms[c]	61 [14]	61 [14]	59 [23]
HAGOS-Pain[c]	75 [18]	75 [18]	75 [20]
HAGOS-ADL[c]	80 [20]	80 [20]	80 [25]
HAGOS-Sport[c]	66 [25]	63 [25]	66 [26]
HAGOS-PA[d]	63 [38]	63 [38]	63 [28]
HAGOS-QOL[c]	60 [20]	60 [25]	60 [16]

Data presented as medians and interquartile ranges [IQRs]. Sample size variations: [a]n=159 (FAI syndrome n=111, non-FAI syndrome n=48); [b]n=145 (FAI syndrome n=101, non-FAI syndrome n=44); [c]n=158 (FAI syndrome n=110, non-FAI syndrome n=48). Abbreviations: ADL = activities of daily living; FAI = femoroacetabular impingement; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool-33; IQR = interquartile range; PA = participation in physical activity; QOL = quality of life.

5.5.2 Primary study aim – FAI syndrome (linear relationships, dichotomous variable)

Table 5.3A and Table 5.3B present the unadjusted and adjusted relationships between FAI syndrome and iHOT-33 and HAGOS scores, respectively. Femoroacetabular impingement syndrome was not related to PROM scores in any models (unadjusted *b*-values ranged from -4.693 ([95%CI -12.621, 3.090], *P*=0.24) to 0.337 ([95%CI -6.915, 7.588], *P*=0.93)). Pseudo R^2 values for unadjusted linear models ranged from 0.017 to <0.001. Sensitivity analyses using arcsin-transformed dependent variables confirmed the findings of the untransformed linear models (**Section 5.8.2**).

5.5.3 Secondary study aim - Mediation analyses

Cartilage defects and/or labral tears did not mediate the effect of FAI syndrome on PROM scores (unadjusted indirect effect estimates ranged from -0.167 ([95%CI -1.181, 0.847], *P*=0.75) to 0.825 ([95%CI -0.898, 2.548], *P*=0.35)). Results of mediation analyses are presented in **Table 5.4**. Sensitivity analyses confirmed that relationships were not moderated by sex. Sensitivity analyses investigating cartilage defects as the mediator variable confirmed the results of the main mediation analysis (**Section 5.8.3**).

Table 5.3A. Relationships between femoroacetabular impingement syndrome presence and iHOT-33 scores.

N=159		iHOT-Total		iHOT-Symptoms		iHOT-Sport		iHOT-Job[a]		iHOT-Social	
Model		Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted
		R^2 = 0.001	R^2 = 0.065 (P = 0.034)	R^2 <0.001	R^2 = 0.071 (P = 0.022)	R^2 <0.001	R^2 = 0.059 (P = 0.051)	R^2 = 0.010	R^2 = 0.035 (P = 0.289)	R^2 = 0.004	R^2 = 0.051 (P = 0.087)
FAI Syndrome	b-value	-1.428	-2.385	-0.975	-2.630	0.337	1.438	-4.693	-3.880	-3.047	-4.606
	95%CI	(-7.315, 4.459)	(-8.932, 4.162)	(-7.000, 5.051)	(-9.307, 4.048)	(-6.915, 7.588)	(-6.647, 9.523)	(-12.475, 3.090)	(-12.621, 4.861)	(-10.381, 4.286)	(-12.833, 3.622)
	P value	P = 0.633	P = 0.473	P = 0.750	P = 0.438	P = 0.927	P = 0.726	P = 0.235	P = 0.382	P = 0.413	P = 0.271

Table 5.3B. Relationships between femoroacetabular impingement syndrome presence and HAGOS scores.

N=159		HAGOS-Symptoms		HAGOS-Pain		HAGOS-ADL		HAGOS-Sport		HAGOS-PA[b]		HAGOS-QOL	
Model		Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted
		R^2 = 0.002	R^2 = 0.050 (P = 0.107)	R^2 <0.001	R^2 = 0.086 (P = 0.062)	R^2 = 0.002	R^2 = 0.033 (P = 0.260)	R^2 = 0.003	R^2 = 0.026 (P = 0.398)	R^2 = 0.005	R^2 = 0.020 (P = 0.538)	R^2 = 0.017	R^2 = 0.055 (P = 0.068)
FAI Syndrome	b-value	-1.345	-3.605	0.106	-2.919	-1.484	-2.245	-2.245	-2.185	-3.996	-3.920	-4.488	-4.519
	95%CI	(-6.248, 3.558)	(-9.042, 1.832)	(-4.525, 4.736)	(-7.945, 2.107)	(-7.059, 4.092)	(-8.474, 3.984)	(-8.483, 3.992)	(-9.187, 4.816)	(-12.832, 4.839)	(-13.869, 6.029)	(-9.949, 0.974)	(-10.598, 1.560)
	P value	P = 0.589	P = 0.192	P = 0.964	P = 0.253	P = 0.600	P = 0.478	P = 0.478	P = 0.538	P = 0.373	P = 0.438	P = 0.107	P = 0.144

R^2 indicates pseudo R^2 values. Adjusted models controlled for age, sex, and body mass index. Abbreviations: ADL = activities of daily living; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool-33; PA = participation in physical activities; QOL = quality of life; 95%CI = 95% confidence interval. Sample size: [a]n=151; [b]n=158.

Table 5.4. Results of mediation analyses investigating proposed causal pathways between FAI syndrome and PROM scores.

	Total effect		Direct effect		Indirect effect		Proportion mediated
	Effect estimate (95%CI)	P value	Effect estimate (95%CI)	P value	Effect estimate (95%CI)	P value	
iHOT-Total	-1.428 (-7.251, 4.395)	0.631	-1.869 (-7.773, 4.034)	0.535	0.442 (-0.743, 1.627)	0.465	N/A
iHOT-Symptoms	-0.975 (-6.935, 4.986)	0.749	-1.366 (-7.412, 4.679)	0.658	0.392 (-0.808, 1.591)	0.522	N/A
iHOT-Sport	0.337 (-6.836, 7.510)	0.927	-0.374 (-7.637, 6.888)	0.920	0.711 (-0.792, 2.214)	0.354	N/A
iHOT-Job[a]	-4.693 (-12.382, 2.997)	0.232	-4.724 (-12.561, 3.112)	0.237	0.032 (-1.607, 1.671)	0.970	N/A
iHOT-Social	-3.047 (-10.301, 4.207)	0.410	-3.325 (-10.689, 4.039)	0.376	0.277 (-1.151, 1.706)	0.704	N/A
HAGOS-Symptoms	-1.345 (-6.195, 3.505)	0.587	-1.186 (-6.099, 3.727)	0.636	-0.159 (-1.052, 0.734)	0.727	N/A
HAGOS-Pain	0.106 (-4.475, 4.686)	0.964	0.008 (-4.633, 4.649)	0.997	0.098 (-0.740, 0.936)	0.819	N/A
HAGOS-ADL	-1.484 (-6.999, 4.031)	0.598	-1.316 (-6.903, 4.270)	0.644	-0.167 (-1.181, 0.847)	0.746	N/A
HAGOS-Sport	-2.245 (-8.415, 3.925)	0.476	-2.298 (-8.550, 3.954)	0.471	0.053 (-1.071, 1.177)	0.926	N/A
HAGOS-PA[b]	-3.996 (-12.735, 4.743)	0.370	-4.821 (-13.644, 4.001)	0.284	0.825 (-0.898, 2.548)	0.348	N/A
HAGOS-QOL	-4.488 (-9.890, 0.915)	0.103	-5.196 (-10.636, 0.244)	0.061	0.708 (-0.440, 1.857)	0.227	N/A

N/A indicates that the effect of femoroacetabular impingement (FAI) syndrome on patient-reported outcome measure (PROM) scores was not mediated by cartilage defects and/or labral tears (indirect causal pathway was not statistically significant, P>0.05). Sample size variations: [a]n=151; [b]n=158. Abbreviations: ADL = activities of daily living; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool-33; PA = participation in physical activity; QOL = quality of life; 95%CI = 95% confidence interval.

5.6. Discussion

In our study of sub-elite football players with hip/groin pain and a positive FADIR test, football players with FAI syndrome did not report worse burden than those with other causes of hip/groin pain. Cartilage defects and/or labral tears were not associated with lower PROM scores (i.e., worse hip/groin burden) and did not mediate the effect of FAI syndrome on reported burden, based on iHOT-33 and HAGOS scores.

Symptomatic football players classified as having FAI syndrome did not describe worse hip/groin burden than those without, adding to the diagnostic challenge for clinicians (38, 54). The diagnostic utility of hip joint physical tests is limited, with clinical tests lacking specificity and acting as screening tools to rule out intra-articular conditions (36, 54, 55). Magnetic resonance imaging identified a high prevalence of cartilage defects and labral tears in our football players with hip/groin pain; however, they were not associated with worse reported burden when compared to players without these findings. The immediate clinical value of diagnosing FAI syndrome, cartilage defects, and labral tears is unclear, considering their absent relationship with reported burden. Prospective studies are needed to investigate if these imaging-based diagnoses can identify those who develop worse hip/groin pain, function, and QOL over time. Classifying FAI syndrome using contemporary threshold values for cam or pincer morphology explained less than 1.7% of the variance in PROM scores in our football players with hip/groin pain. Other physical features might contribute to reported burden in hip/groin pain in football players, including other bony and soft tissue hip morphological features (183), physical impairments (52), and/or biomechanics (126). As the iHOT-33 and HAGOS are self-reported measures that quantify patients' perceptions of their hip/groin burden, scores may also be influenced by non-physical (e.g., psychological, social, contextual) factors (238, 244). Non-physical factors might explain more of the variance in reported burden than imaging findings alone and warrant further investigation. These factors may also influence the success of treatments that address imaging findings (cam morphology, cartilage defects, and/or labral tears) (261), indicating that better understanding of the mechanisms of these treatments is needed.

Football players with cam morphology, cartilage defects, and/or labral tears did not report worse burden than symptomatic football players with a positive FADIR test and without

these imaging features. Our findings are consistent with those of van Klij et al. (2020) (253) who reported that cam morphology was not related to HAGOS scores in a sample of academy football players, including some (n=9) who reported hip/groin pain (253). By investigating a large cohort of football players with hip/groin pain (n=165) and avoiding dichotomising continuous PROM scores, we undertook a more robust assessment of the relationship between bony hip morphology and reported burden in symptomatic players. Cam morphology was also found unrelated to reported burden in other symptomatic populations, including middle-aged adults with self-reported hip OA (179) and patients undergoing hip arthroscopy (185). Combined with others, our results suggest that people with FAI syndrome (with an alpha angle ≥60°) do not report worse burden than people with other causes of hip/groin pain. Furthermore, we found that cartilage defects and/or labral tears did not explain the effect of FAI syndrome on reported burden, primarily due to their presence being unrelated to PROM scores. This is consistent with findings from middle-aged and older adults (87, 105) and patients undertaking hip arthroscopy (185). While a structural relationship between cam morphology and cartilage defects and labral tears is evident (59, 60), our findings suggest that other mechanisms may contribute more meaningfully to pain and symptoms in football players with FAI syndrome. Magnetic resonance imaging is frequently used to aid diagnosis in FAI syndrome patients (262), and although the presence of cartilage defects may affect treatment outcomes after hip arthroscopy (98, 263), cartilage defects and labral tears in active football players should be interpreted with caution considering their unclear relationship with reported burden and high prevalence in asymptomatic athletes (88, 264).

While our study had many methodological strengths, several limitations should be considered. First, extra-articular causes of hip/groin pain likely co-existed in our football players and contributed to self-reported burden, including lumbar and groin pain entities (33). All participants reported longstanding hip/groin pain and had a positive FADIR test; however, the low specificity (35, 54) of the FADIR test means that the proportion of football players with hip-related pain is unknown. To aid the challenging diagnostic process in hip/groin pain (38), we aimed to discern the relationship between imaging-based classifications and reported burden in a typical hip/groin pain population where various sources of nociception may have existed. Second, although the radiographic views used have demonstrated good sensitivity and specificity (265, 266) and are recommended to quantify femoral and acetabular morphology in the clinical setting (38, 267), they do not provide a 3-dimensional understanding of femoral and acetabular anatomy that can be

achieved with CT and MRI. Threshold angles for defining anterosuperior cam morphology (as visualised with the Dunn 45° radiograph) might also be higher than current recommendations (63, 64). We also acknowledge that other bony morphologies such as acetabular retroversion, femoral version, and/or femoral neck-shaft angle may co-exist, potentially contributing to mechanical impingement and influencing self-reported burden in FAI syndrome (268). Finally, cartilage defects and labral tears may be more accurately assessed with contrast-enhanced MRI (112), but this procedure has increased patient risk (100). We used high-resolution, unenhanced 3T MRI which has demonstrated similar accuracy to contrast-enhanced MRI for assessing identifying cartilage defects and labral tears (103). As grading of hip MRIs was completed by one trained musculoskeletal radiologist, cartilage defects and labral tears may be over- or under-reported (misclassification bias); potentially affecting the investigated relationships. The relationship between cartilage defect or labral tear severity and self-reported burden was not investigated; however, moderate inter-rater reliability may limit semi-quantitative MRI scoring methods (87, 105, 186, 267).

5.7. Conclusion

Football players with FAI syndrome did not report worse hip/groin pain burden those with other causes of hip/groin pain. Cartilage defects and labral tears did not mediate the effect of FAI syndrome on PROM scores. Defining the presence of FAI syndrome, cartilage defects, and/or labral tears did not explain reported burden in football players with hip/groin pain, raising questions about the immediate usefulness of these clinical classifications.

5.8. Supplementary information

5.8.1 Sensitivity analyses – Arcsin-transformed linear models

As the data were bound by scores of 0 and 100, arcsin transformation of PROM scores (dependent variables) was completed using formula $Y'' = 2\sin^{-1}\sqrt{Y'}$ (where, y' = PROM observation, y'' = transformed PROM score).

(i) Relationships between FAI syndrome and iHOT-33 scores.

N=159		iHOT-Total		iHOT-Symptoms		iHOT-Sport		iHOT-Job[a]		iHOT-Social	
Model		**Unadjusted** R^2 <0.001	**Adjusted** R^2 = 0.066 (P = 0.032)	**Unadjusted** R^2 <0.001	**Adjusted** R^2 = 0.071 (P = 0.022)	**Unadjusted** R^2 <0.001	**Adjusted** R^2 = 0.055 (P = 0.067)	**Unadjusted** R^2 = 0.008	**Adjusted** R^2 = 0.036 (P = 0.276)	**Unadjusted** R^2 = 0.002	**Adjusted** R^2 = 0.052 (P = 0.084)
FAI syndrome	b-value	-0.560	-1.209	-0.352	-1.406	0.270	0.825	-2.881	-2.369	-1.343	-2.433
	95%CI	(-4.330, 3.210)	(-5.397, 2.980)	(-4.287, 3.583)	(-5.765, 2.953)	(-4.401, 4 940)	(-4.393, 6.044)	(-8.282, 2.520)	(-8.425, 3.688)	(-6.189, 3.504)	(-7.863, 2.996)
	P value	*P* = 0.769	*P* = 0 570	*P* = 0.860	*P* = 0.525	*P* = 0.909	*P* = 0.755	*P* = 0.293	*P* = 0.441	*P* = 0.585	*P* = 0.377

(ii) Relationships between FAI syndrome and HAGOS scores.

N=159		HAGOS-Symptoms		HAGOS-Pain		HAGOS-ADL		HAGOS-Sport		HAGOS-PA[b]		HAGOS-QOL	
Model		**Unadjusted** R^2 = 0.002	**Adjusted** R^2 = 0.050 (P = 0.091)	**Unadjusted** R^2 <0.001	**Adjusted** R^2 = 0.084 (P = 0.009)	**Unadjusted** R^2 = 0.002	**Adjusted** R^2 = 0.030 (P = 0.316)	**Unadjusted** R^2 = 0.002	**Adjusted** R^2 = 0.025 (P = 0.411)	**Unadjusted** R^2 = 0.006	**Adjusted** R^2 = 0.020 (P = 0.530)	**Unadjusted** R^2 = 0.015	**Adjusted** R^2 = 0.052 (P = 0.085)
FAI Syndrome	b-value	-0.865	-2.265	0.009	-1.931	-1.357	-1.313	-1.199	-1.278	-3.250	-2.933	-2.701	-2.758
	95%CI	(-3.894, 2.165)	(-5.620, 1.091)	(-3.058, 3.076)	(-5.263, 1.402)	(-5.934, 3.221)	(-6.437, 3.811)	(-5.298, 2.899)	(-5.877, 3.322)	(-10.068, 3.567)	(-10.610, 4.745)	(-6.140, 0.739)	(-6.590, 1.075)
	P value	*P* = 0.574	*P* = 0.184	*P* = 0.995	*P* = 0 254	*P* = 0 559	*P* = 0.613	*P* = 0.564	*P* = 0.584	*P* = 0.348	*P* = 0.425	*P* = 0 123	*P* = 0.157

R^2 indicates pseudo R^2 values. Adjusted = multivariable model estimates adjusted for age, sex, and body mass index. Sample size variations: n^a=151; n^b=158; *indicates P<0.05. Abbreviations: ADL = activities of daily living; FAI = femoroacetabular impingement; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool-33; PA = participation in physical activity; PROM = patient-reported outcome measure; QOL = quality of life; 95%CI = 95% confidence interval.

5.8.2 Representation of models for mediation analyses (sensitivity analyses)

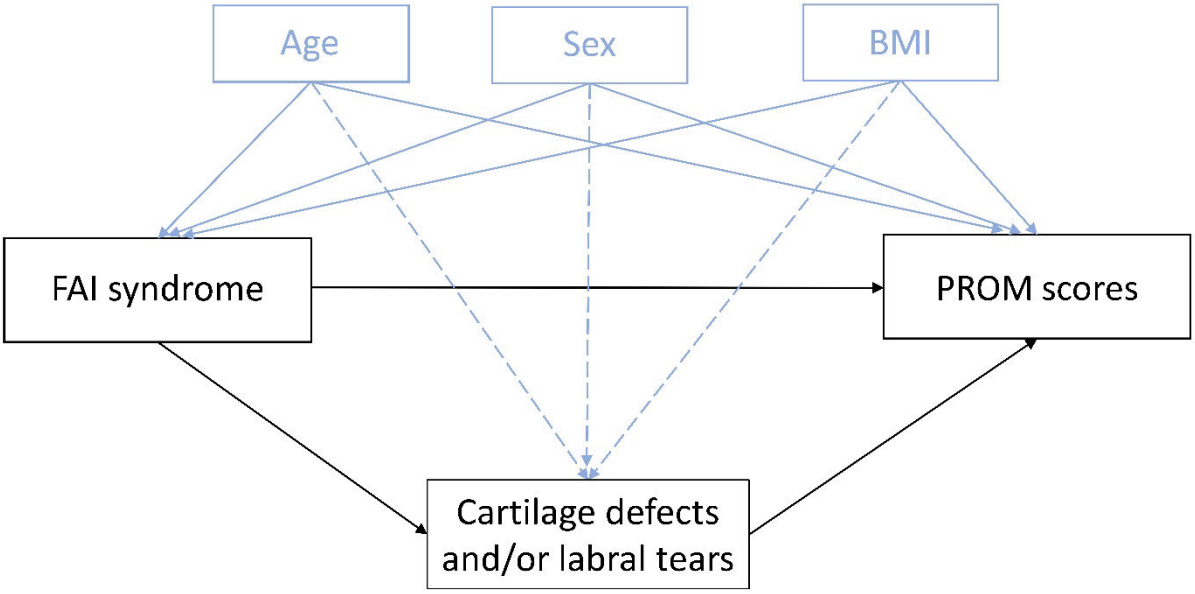


Figure A. Model of the potential effect of covariates (age, sex, and body mass index (BMI)) on the proposed indirect and direct relationships between femoroacetabular impingement (FAI) syndrome presence and patient-reported outcome measure (PROM) scores.

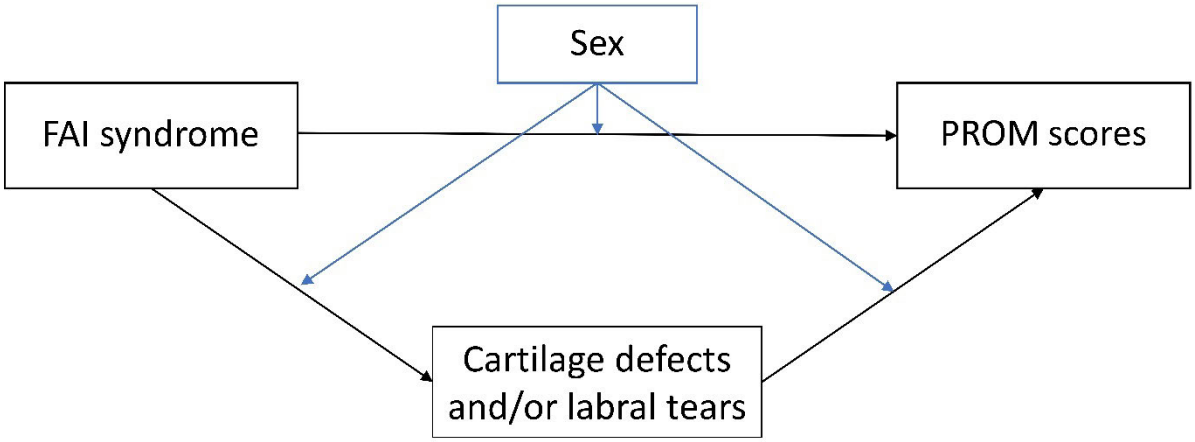


Figure B. Model of the potential moderating effect of sex on the proposed direct and indirect relationships between femoroacetabular impingement (FAI) syndrome presence and patient-reported outcome measure (PROM) scores.

5.8.3 Results of sensitivity analyses (cartilage defect presence as mediator variable)

	Total effect		Direct effect		Indirect effect		Proportion mediated
(n=159)	**Effect estimate (95% CI)**	***P***	**Effect estimate (95% CI)**	***P***	**Effect estimate (95% CI)**	***P***	
iHOT-Total	-1.428 (-7.251, 4.395)	0.631	-2.359 (-8.411, 3.693)	0.445	0.816 (-0.853, 2.484)	0.338	N/A
iHOT-Symptoms	-0.975 (-6.935, 4.986)	0.749	-2.147 (-8.322, 4.027)	0.495	0.776 (-0.918, 2.470)	0.369	N/A
iHOT-Sport	-0.337 (-6.836, 7.510)	0.927	-0.493 (-7.956, 6.970)	0.897	0.989 (-1.066, 3.044)	0.346	N/A
iHOT-Job[a]	-4.693 (-12.382, 2.997)	0.232	-5.281 (-13.324, 2.763)	0.198	0.835 (-1.456, 3.126)	0.475	N/A
iHOT-Social	-3.047 (-10.301, 4.207)	0.410	-3.676 (-11.224, 3.871)	0.340	0.924 (-1.143, 2.991)	0.381	N/A
HAGOS-Symptoms	-1.345 (-6.195, 3.505)	0.587	-1.062 (-6.092, 3.968)	0.679	-0.010 (-1.303, 1.284)	0.988	N/A
HAGOS-Pain	0.106 (-4.475, 4.686)	0.964	-0.190 (-4.942, 4.563)	0.938	-0.456 (-0.795, 1.706)	0.475	N/A
HAGOS-ADL	-1.484 (-6.999, 4.031)	0.598	-1.625 (-7.353, 4.104)	0.578	0.310 (-1.174, 1.794)	0.682	N/A
HAGOS-Sport	-2.245 (-8.415, 3.925)	0.476	-2.723 (-9.090, 3.645)	0.402	1.008 (-0.730, 2.747)	0.256	N/A
HAGOS-PA[b]	-3.996 (-12.735, 4.743)	0.370	-5.394 (-14.440, 3.651)	0.242	1.683 (-0.879, 4.244)	0.198	N/A
HAGOS-QOL	-4.488 (-9.890, 0.915)	0.103	-5.570 (-11.143, 0.002)	0.050	1.214 (-0.382, 2.810)	0.136	N/A

N/A indicates that the effect of FAI syndrome on iHOT-33 and HAGOS scores was not mediated by cartilage defects (indirect causal pathway was not statistically significant (P>0.05)). Sample size variations: n^a=151; n^b=158. Abbreviations: ADL = activities of daily living; FAI = femoroacetabular impingement; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT = International Hip Outcome Tool-33; PA = participation in physical activity; QOL = quality of life.

Chapter 6. Are cam morphology size and location associated with self-reported burden in football players with FAI syndrome?

6.1. Preface

Chapter 5 identified that football players with FAI syndrome did not report worse burden than football players with other sources of hip/groin pain (269). Using a 60° threshold value to dichotomise the continuous alpha angle allowed us to compare individuals with and without FAI syndrome, but the effects of cam morphology size warrant further investigation. In addition, cam morphology was assessed from a single radiographic view. Superior and anterosuperior cam morphology can be assessed using the AP and Dunn 45° radiographs, respectively, where differing cam morphology location may alter the potential for impingement with the acetabulum during football-specific tasks. This chapter investigated whether self-reported burden was associated with cam morphology size and location in football players with FAI syndrome.

Chapter 6 contains an edited version of the following accepted publication:

Scholes MJ, Kemp JL, Mentiplay BF, Heerey JJ, Agricola R, King MG, Semciw AI, Lawrenson PR, Crossley KM. Are cam morphology size and location associated with self-reported burden in football players with FAI syndrome? *Scandinavian Journal of Medicine & Science in Sports*. 2022;34(4):737-753. doi: 10.1111/sms.14119.

All edits of the accepted manuscript are grammatical, to improve clarity and facilitate consistency throughout this thesis. No amendments or additions have been made to the results.

6.2. Abstract

Cam morphology size and location might affect the severity of reported burden in people with FAI syndrome. We investigated the relationship between cam morphology size (i.e., alpha angle) and self-reported hip/groin burden (i.e., scores for the iHOT-33 and HAGOS), examined separately for the AP and Dunn 45° radiographs in football players with FAI syndrome. In total, 118 (12 female) sub-elite football (football or Australian football) players with FAI syndrome with cam morphology (alpha angle ≥60°) participated. One blinded assessor quantified superior and anterosuperior cam morphology size by measuring alpha angles for the AP and Dunn 45° radiographs, respectively. Linear regression models investigated relationships between alpha angle (continuous independent variable, measured separately for the AP and Dunn 45° radiographs) and iHOT-33 and HAGOS scores (dependent variables). Larger anterosuperior cam morphology (seen on the Dunn 45° radiograph) was associated with lower (i.e., worse) scores for the iHOT-Total, iHOT-Symptoms, iHOT-Job, and iHOT-Social subscales (unadjusted estimate range -0.553 to -0.319 [95%CI -0.900, -0.037], *P*=0.002 to 0.027), but not the iHOT-Sport (*P*=0.459) nor any HAGOS scores (*P*=0.110 to 0.802). Superior cam morphology size (measured using the AP radiograph) was not associated with any iHOT-33 or HAGOS scores (*P*=0.085 to 0.975). Larger anterosuperior cam morphology may be more relevant to pain and symptoms in football players with FAI syndrome than superior cam morphology, warranting investigation of its effects on reported burden and hip disease over time.

Keywords: Femoroacetabular impingement syndrome, Cam morphology, Rehabilitation, Hip-related pain, Patient-reported outcome measure, Hip joint, Football.

6.3. Introduction

Femoroacetabular impingement syndrome is a cause of hip/groin pain in football players (6, 131) and may contribute to their greater lifetime risk of hip OA when compared to controls (123). Diagnosis of FAI syndrome requires symptoms, clinical signs, and imaging evidence of cam and/or pincer morphology (38, 63). Primary cam morphology is determined by an alpha angle threshold value of 60° (63, 64, 210), and has been associated with chondrolabral pathology (59, 60), lower hip ROM (52, 253), and the development of hip OA (121). However, symptomatic adults with and without cam morphology report similar patient reported outcome measure scores (179, 269), indicating a less certain relationship between cam morphology and reported burden in people with hip/groin pain.

Defining FAI syndrome using an alpha angle threshold value (i.e., ≥60°) may not identify the potential effect of cam morphology size on self-reported hip/groin burden severity. A dose-response relationship was observed between cam morphology size and hip joint physical findings, where people with large cam morphology (alpha angle ≥78°) had worse chondrolabral pathology (59, 60) and lesser hip ROM (253) when compared to those with cam morphology (alpha angles 60-78°). However, it is not known if a similar relationship exists between cam morphology and self-reported pain and symptoms in people with FAI syndrome. Cam morphology size might affect reported burden in football players with FAI syndrome, as they require considerable hip function and ROM during their sporting activities.

The anatomical location of cam morphology may also affect reported burden in people with FAI syndrome. Anteroposterior pelvis and Dunn 45° radiographs visualise cam morphology at the superior and anterosuperior femoral head-neck junction, respectively, and together are recommended as the first line assessment for patients with suspected FAI syndrome (38, 63). Larger superior cam morphology (seen on AP radiograph) has been associated with worsening hip joint disease over time (121, 210); however, maximum alpha angles mostly occur in the anterosuperior femoral head-neck (63, 256, 265, 270), where Dunn 45° radiographs may more accurately quantify cam morphology size (256). Discerning the impacts of both cam morphology location and size on the severity of reported burden could inform future prospective studies of hip joint disease and guide treatments for football players with FAI syndrome.

Therefore, the primary aim of this study was to investigate the relationship between cam morphology size (i.e., continuous alpha angle) and self-reported hip/groin burden (i.e., scores for the iHOT-33 and the HAGOS), examined separately for the AP and Dunn 45° radiographs in football players with FAI syndrome.

6.4. Methods

6.4.1 Study design and participants

Participants in this study were a subset of a larger prospective cohort study of 18- to 50-year-old sub-elite (non-professional) football (football or Australian football) players with hip/groin pain who continued to participate in competitive sport (130). Briefly, for inclusion in the larger cohort, football players were required to report more than six months of hip/groin pain and have a positive FADIR test. Football players with hip/groin pain were excluded if they had: 1) radiographic hip OA defined by a KL score of ≥2 (188); 2) undergone hip or pelvic surgery; or 3) reported a history of significant hip condition (e.g., hip fracture or congenital dislocation of the hip). To be included in this cross-sectional study, participants from the larger cohort needed to have cam morphology (defined by an alpha angle of ≥60° using the supine AP or Dunn 45° radiograph (63, 121)) and be free from acetabular dysplasia (defined by a LCEA of <20° using the supine AP radiograph (121, 269)). Ethics approval was obtained from the La Trobe University Human Ethics Committee (HEC015-019) and the University of Queensland Human Ethics Committee (2015000916). Written informed consent was obtained prior to participation in the study.

6.4.2 Procedures

Football players with hip/groin pain attended La Trobe University or University of Queensland for testing between August 2015 and August 2018. Participant characteristics (e.g., age, sex, height, body mass, football code, and duration of symptoms) were recorded. Radiographs were undertaken at radiology clinics in Melbourne (Imaging @ Olympic Park) and Brisbane (Q-Scan), Australia. Participants completed the iHOT-33 and HAGOS, two self-reported questionnaires that are recommended for assessing active adults with hip/groin pain (144, 148, 228). The iHOT-33 measures five dimensions of hip/groin burden: 1) hip-related quality of life (iHOT-Total); 2) symptoms and functional limitations (iHOT-Symptoms); 3) sport and recreational activities (iHOT-Sport); 4) job-related

concerns (iHOT-Job); and 5) social, emotional, and lifestyle concerns (iHOT-Social). The HAGOS explores six dimensions of hip/groin burden: symptoms (HAGOS-Symptoms), pain (HAGOS-Pain), physical function in activities of daily living (HAGOS-ADL), physical function during sport and recreational activities (HAGOS-Sport), participation in physical activities (HAGOS-PA), and hip and/or groin-related quality of life (HAGOS-QOL). Scores for the iHOT-33 and HAGOS have acceptable validity and reliability in active adults with hip/groin pain (148, 228).

6.4.3 Radiographs

Participants underwent a supine AP and Dunn 45° radiograph of each hip according to standardised protocols (130) to determine eligibility for the study and quantify femoral head-neck asphericity (63, 121). One blinded assessor (JJH) determined the presence of cam and pincer morphology using quantitative methods (121), as detailed in **Section 2.2.9**. Briefly, a point set was placed on predetermined locations on the surface of the femur and acetabulum with statistical shape modelling software (ASM toolkit, Manchester University, Manchester, UK). The alpha angle and LCEA were then calculated using MATLAB software v7.1.0 (MathWorks Inc, Natick, Massachusetts, USA), with the alpha angle calculated separately for the AP and Dunn 45° radiographs. An LCEA ≥40° on the AP radiograph defined the presence of global pincer morphology (63, 74). As all participants in this study had hip/groin pain and cam morphology, those with global pincer morphology were determined to have FAI syndrome with mixed morphology (15, 74, 121, 257), whilst all other participants had FAI syndrome with cam morphology (15, 74, 121, 257). Excellent intra-observer reliability (ICC alpha angle AP = 0.92; alpha angle Dunn = 0.93; LCEA = 0.94) and moderate-to-good inter-observer reliability (ICC alpha angle AP = 0.76; alpha angle Dunn = 0.93; LCEA = 0.63) were demonstrated for bony hip morphology measures (131). Methods for determining intra-observer (JJH) and inter-observer (JJH and RA) reliability have been described previously (**Section 2.2.9**) (131).

6.4.4 Data management

Participants defined their most symptomatic hip on the iHOT-33 (reported from the question, *"which (hip) gives you the most trouble?"*) and this hip was used for analyses. Three participants did not have useable iHOT-33 scores (i.e., their reported most symptomatic hip from the iHOT-33 did not meet the inclusion criteria of a positive FADIR

test result) and another three did not complete the HAGOS; these six participants were removed from the respective analyses.

6.4.5 Statistical analysis

Data were assessed for normality using boxplots and Shapiro-Wilk analyses. Continuous demographic data were summarised using means and SDs or medians and IQR values, as appropriate. Linear regression models investigated the relationships between alpha angle (continuous independent variable, measured separately using AP and Dunn 45° radiographs) and PROM scores (dependent variable, HAGOS and iHOT-33 scores of 0 to 100). Prior to interpreting results, models were assessed for violations of assumptions. Residual scatter plots assessed linearity and homoscedasticity, and VIF statistics >10 indicated problematic multicollinearity (258). Normality of regression model residuals were assessed using residual scatter plots and Shapiro-Wilk analyses. Relationships between alpha angle and PROM scores were analysed unadjusted and adjusted for the covariates of age, sex, and BMI. Pseudo R^2 values quantified the strength of modelled relationships. For adjusted (multivariable) linear regression models, interaction effects between sex and alpha angle (sex*alpha angle) were examined and removed if not significant. Due to the relatively small number of female football players compared to men, modelled relationships for women may have been unduly influenced by individual participants. Therefore, models with significant sex*alpha angle interaction terms (P<0.05) were examined for data outliers using boxplots and residual scatter plots. If removing data outlier(s) from affected linear regression models nullified the sex*alpha angle interaction term (i.e., P>0.05), then the influential case(s) were removed from the main analysis. Sensitivity analyses involving men only were then undertaken to validate the findings of the main analysis. If the statistical significance of the interaction term was unchanged after removing data outliers (i.e., P<0.05), then all available data were stratified by sex and linear regression models were built for men and women separately. As iHOT-33 and HAGOS scores are anchored by values of 0 and 100 they may not always be optimally modelled using linear regression. To validate the results of our main analysis, we conducted sensitivity analyses using models with arcsin-transformed (259) iHOT-33 and HAGOS scores. The method for transforming the dependent variables is described in the supplementary information (**Section 6.8.1**). Statistical analyses were completed using the General Analyses for Linear Models module in Jamovi version 1.8.1.0 (The jamovi project, Sydney, Australia). Level of significance was set at 0.05.

6.5. Results

In total, 118 football players (12 women) with FAI syndrome were included in this study. **Figure 6.1** summarises participant recruitment and flow. Demographic characteristics of football players with FAI syndrome are summarised in **Table 6.1**.

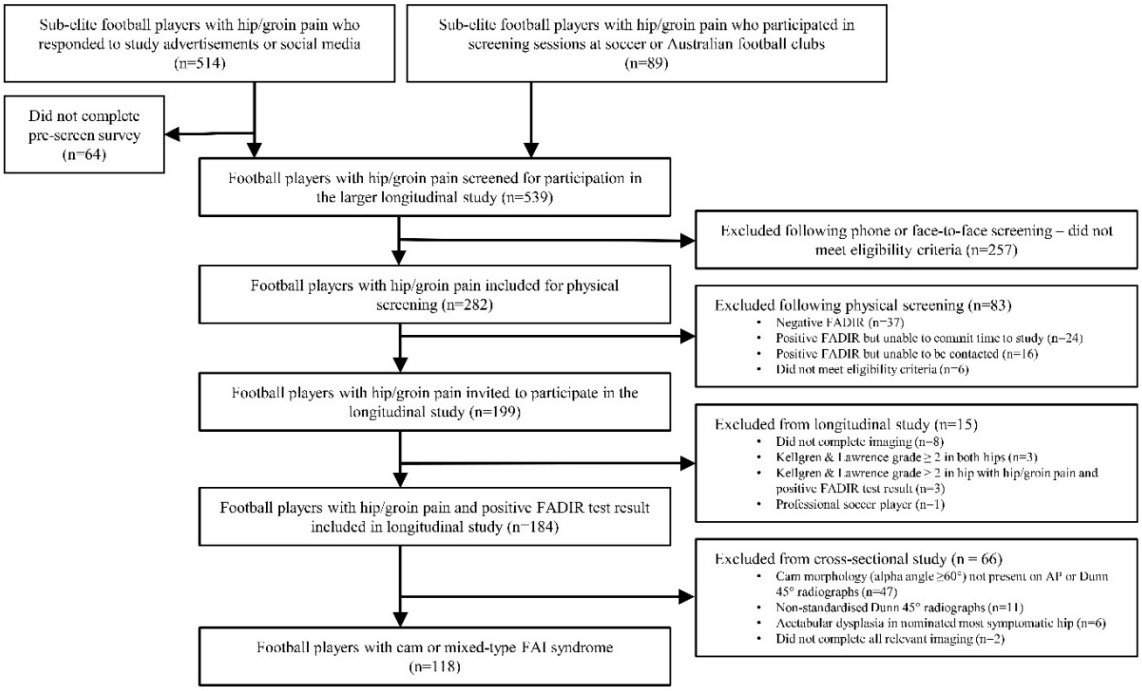


Figure 6.1. Participant flow for football players with FAI syndrome.
Abbreviations: AP = anteroposterior pelvis; FADIR = flexion-adduction-internal rotation; FAI = femoroacetabular impingement.

Table 6.1. Demographic characteristics of football players with FAI syndrome.

	All participants (n=118)		**Cam morphology using Dunn 45° radiograph (n=110)**		**Cam morphology using AP pelvis radiograph (n=77)**	
	Women (n=12)	Men (n=106)	Women (n=9)	Men (n=101)	Women (n=8)	Men (n=69)
Age (years)	24 [7]	26 [6]	23 [5]	26 [6]	24 [10]	26 [6]
Body mass index (kg·m^{-2})	22.4 [2.4]	24.5 [2.7]	22.9 [2.9]	24.4 [2.7]	22.4 [1.8]	24.4 [2.7]
Symptom duration (months)	18 [30]	24 [32]	24 [38]	24 [33]	14 [12]	30 [41]
Soccer player	5 (42%)	43 (41%)	4 (44%)	40 (40%)	3 (38%)	28 (41%)
KL grade 0	12 (100%)	98 (92%)	9 (100%)	93 (92%)	8 (100%)	63 (91%)
FAI syndrome – Mixed	1 (8%)	10 (9%)	1 (11%)	9 (9%)	1 (13%)	7 (10%)
Alpha angle (degrees)	-	-	67.5 [13.2]	77.9 [15.1]	77.0 [3.7]	77.0 [13.2]
Cam morphology using both radiographic views	5 (42%)	64 (60%)	-	-	-	-
Cam morphology using Dunn 45° view only	4 (33%)	37 (35%)	-	-	-	-
Cam morphology using AP pelvis view only	3 (25%)	5 (5%)	-	-	-	-

Data presented as medians and interquartile ranges [IQR] or counts and proportions (%). Cam morphology determined to be present for each radiographic projection when alpha angle ≥60° was recorded. "FAI syndrome – Mixed" indicates femoroacetabular impingement syndrome with mixed morphology. Abbreviations: AP = anteroposterior, FAI = femoroacetabular impingement; KL = Kellgren and Lawrence (188), - = not applicable.

6.5.1 Linear models, Dunn 45° radiograph

Results for linear regression models (unadjusted and adjusted) for the Dunn 45° radiograph are presented in **Table 6.2**. Larger alpha angles were associated with lower (i.e., worse) scores for the iHOT-Total, iHOT-Symptoms, iHOT-Job, and iHOT-Social subscales (unadjusted estimate range -0.553 to -0.319 [95%CI -0.900, -0.037], *P*=0.002 to 0.027). Adjusted model estimates found that for every 10° increase in alpha angle above 60°, iHOT-33 scores decreased by 3.7 points (iHOT-Total), 3.5 points (iHOT-Symptoms), 4.9 points (iHOT-Job), and 5.8 points (iHOT-Social) (**Figure 6.2**). Alpha angles were not associated with the iHOT-Sport score (*P*=0.459) nor any HAGOS scores (*P*=0.110 to 0.802).

6.5.2 Linear models, AP radiograph

The results for linear regression models for the AP radiograph are presented in **Table 6.3**. Alpha angles measured using the AP radiograph were not associated with any iHOT-33 or HAGOS scores (*P*=0.085 to 0.975).

Table 6.2. Relationships between alpha angle and iHOT-33 and HAGOS scores using Dunn 45° radiograph.

A) iHOT-33

N=110[a]		iHOT-Total		iHOT-Symptoms		iHOT-Sport		iHOT-Job[b]		iHOT-Social	
Model		Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted
		$R^2 = 0.055$	$R^2 = 0.12$ ($P = 0.010$)	$R^2 = 0.046$	$R^2 = 0.125$ ($P = 0.008$)	$R^2 = 0.005$	$R^2 = 0.098$ ($P = 0.032$)	$R^2 = 0.059$	$R^2 = 0.090$ ($P = 0.067$)	$R^2 = 0.087$	$R^2 = 0.129$ ($P = 0.006$)
Cam size	b-value	-0.349	-0.374	-0.319	-0.349	-0.138	-0.147	-0.473	-0.487	-0.553	-0.577
	95%CI	(-0.630, -0.069)	(-0.650, -0.097)	(-0.601, -0.037)	(-0.626, -0.073)	(-0.504,0.229)	(-0.505, 0 210)	(-0.856, -0.090)	(-0.879, -0.096)	(-0.900, -0.206)	(-0.923, -0.230)
	P value	$P = 0.015$	$P = 0.009$	$P = 0.027$	$P = 0.014$	$P = 0.459$	$P = 0.416$	$P = 0.016$	$P = 0.015$	$P = 0.002$	$P = 0.001$

B) HAGOS

N=110[a]		HAGOS-Symptoms		HAGOS-Pain		HAGOS-ADL		HAGOS-Sport		HAGOS-PA[c]		HAGOS-QOL	
Model		Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted
		$R^2 = 0.024$	$R^2 = 0.096$ ($P = 0.034$)	$R^2 = 0.003$	$R^2 = 0.126$ ($P = 0.008$)	$R^2 = 0.007$	$R^2 = 0.056$ ($P = 0.205$)	$R^2 = 0.011$	$R^2 = 0.028$ ($P = 0$ 569)	$R^2 < 0.001$	$R^2 = 0.022$ ($P = 0.629$)	$R^2 = 0.022$	$R^2 = 0.061$ ($P = 0.168$)
Cam size	b-value	-0.173	-0.192	-0.057	-0.081	-0.113	-0.135	-0.162	-0.175	-0.057	-0.071	-0.214	-0.231
	95%CI	(-0.387, 0.040)	(-0.402, 0.018)	(-0.269, 0.155)	(-0.284, 0.123)	(-0.379, 0.153)	(-0.401, 0.131)	(-0.465, 0.141)	(-0.483, 0.132)	(-0.502, 0.389)	(-0.524, 0.381)	(-0.493, 0.065)	(-0.510, 0.049)
	P value	$P = 0.110$	$P = 0.072$	$P = 0.595$	$P = 0.434$	$P = 0.402$	$P = 0.316$	$P = 0.291$	$P = 0.260$	$P = 0.802$	$P = 0.754$	$P = 0.131$	$P = 0.105$

R^2 indicates pseudo R^2 values. Adjusted models controlled for covariates of age, sex, and body mass index. Sample size variations: n^a=107 (unless otherwise indicated), n^b=97, n^c=106. Abbreviations: ADL = activities of daily living; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool-33; PA = participation in physical activity; QOL = quality of life; 95%CI = 95% confidence interval.

Table 6.3. Relationships between alpha angle and iHOT-33 and HAGOS scores using anteroposterior pelvis radiograph.

A) iHOT-33

N=77[a]		iHOT-Total		iHOT-Symptoms		iHOT-Sport		iHOT-Job[b]		iHOT-Social[c]	
Model		Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted
		$R^2 = 0.004$	$R^2 = 0.007$ ($P = 0.974$)	$R^2 = 0.003$	$R^2 = 0.016$ ($P = 0.891$)	$R^2 = 0.002$	$R^2 = 0.024$ ($P = 0.787$)	$R^2 = 0.027$	$R^2 = 0.028$ ($P = 0.768$)	$R^2 = 0.024$	$R^2 = 0.038$ ($P = 0.594$)
Cam size	b-value	-0.103	-0.100	-0.100	-0.084	0.096	0.067	-0.370	-0.383	-0.327	-0.293
	95%CI	(-0.499, 0 293)	(-0.509, 0.310)	(-0.501, 0.302)	(-0.497, 0.329)	(-0.450, 0.642)	(-0.492, 0.626)	(-0.917, 0.177)	(-0.953, 0.188)	(-0.817, 0.164)	(-0.798, 0.213)
	P value	$P = 0.606$	$P = 0.629$	$P = 0.623$	$P = 0.687$	$P = 0.727$	$P = 0.813$	$P = 0$ 181	$P = 0.185$	$P = 0.189$	$P = 0.252$

B) HAGOS

N=77[d]		HAGOS-Symptoms		HAGOS-Pain		HAGOS-ADL		HAGOS-Sport		HAGOS-PA[e]		HAGOS-QOL	
Model		Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted
		$R^2 < 0.001$	$R^2 = 0.027$ ($P = 0.753$)	$R^2 = 0.003$	$R^2 = 0.074$ ($P = 0.260$)	$R^2 < 0.001$	$R^2 = 0.018$ ($P = 0.869$)	$R^2 < 0.001$	$R^2 = 0.006$ ($P = 0$ 981)	$R^2 = 0.003$	$R^2 = 0.027$ ($P = 0.764$)	$R^2 = 0.007$	$R^2 = 0.018$ ($P = 0.869$)
Cam size	b-value	-0.041	-0.013	-0.073	-0.074	0.007	0.008	0.007	0.006	0.155	0.151	0.152	0.176
	95%CI	(-0.360, 0.279)	(-0.339, 0.313)	(0.374, 0 228)	(-0.374, 0.226)	(-0.389, 0.403)	(-0.398, 0.414)	(-0.432, 0.446)	(-0.446, 0.458)	(-0.514, 0.825)	(-0.539, 0.841)	(-0.282, 0.586)	(-0.270, 0.622)
	P value	$P = 0.801$	$P = 0.938$	$P = 0.629$	$P = 0.622$	$P = 0.973$	$P = 0.968$	$P = 0.975$	$P = 0.979$	$P = 0.645$	$P = 0.663$	$P = 0.486$	$P = 0.434$

R^2 indicates pseudo R^2 values. Adjusted models controlled for covariates of age, sex, and body mass index. Sample size variations: n^a=74 (unless otherwise indicated); n^b=68; n^c=75; n^d=73 (unless otherwise indicated); n^e=72. Abbreviations: ADL = activities of daily living; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool-33; PA = participation in physical activity; QOL = quality of life; 95%CI = 95% confidence interval.

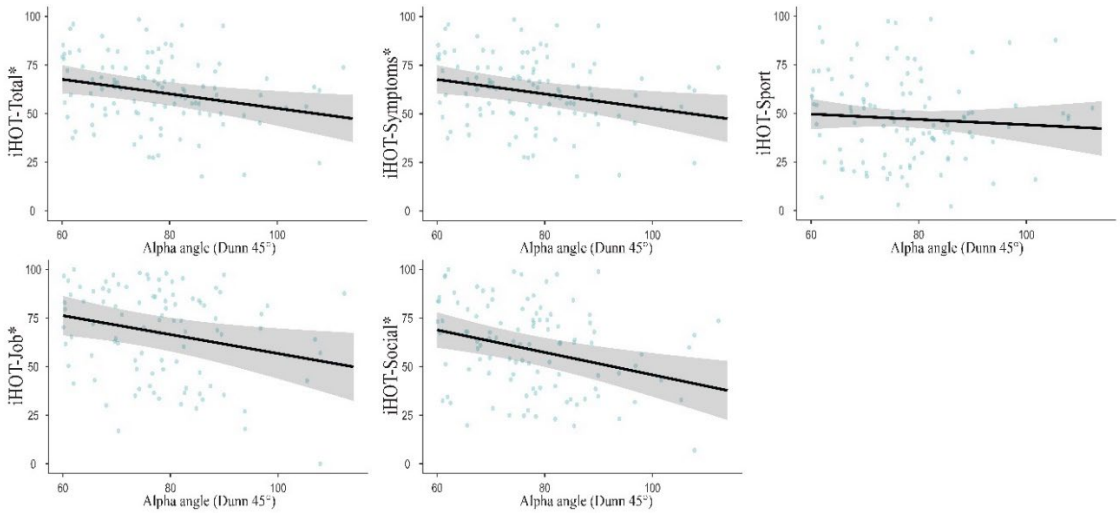


Figure 6.2. Adjusted relationships between iHOT-33 subscale scores and alpha angles (Dunn 45° radiograph) in football players with FAI syndrome.
Alpha angle measured in degrees using the Dunn 45° radiograph. *indicates significant relationship (P<0.05).
Abbreviations: FAI = femoroacetabular impingement; iHOT-33 = International Hip Outcome Tool-33.

6.5.3 Sensitivity analyses

There were significant sex*alpha angle interaction effects for all linear models involving the AP radiograph (except iHOT-Job and iHOT-Social). Larger alpha angles were associated with worse burden in women but not men due to one influential female case (see figures in **Section 6.8.2**). Therefore, data for this one female participant was removed from the main analysis (for affected AP models only), nullifying the significant sex*alpha angle interaction terms. Sensitivity analyses undertaken in men only confirmed the findings of the main analysis (**Section 6.8.3**), indicating that our inclusion of women in the main analysis did not alter the statistical significance of the models. Sensitivity analyses with arcsin-transformed dependent variables also confirmed the findings of the main analysis (**Section 6.8.1**), indicating that the distribution of PROM scores did not affect the modelled relationships.

6.6. Discussion

We investigated the relationships between alpha angle (measured separately using the AP and Dunn 45° radiographs) and iHOT-33 and HAGOS scores in active football players with FAI syndrome with cam or mixed morphology. Football players with larger cam morphology reported worse iHOT-Total, iHOT-Symptoms, iHOT-Job, and iHOT-Social scores when alpha angle was measured using the Dunn 45° radiograph, but not the AP. Larger anterosuperior cam morphology, as visualised using the Dunn 45° radiograph, may

be more relevant for self-reported burden in football players with FAI syndrome than superior (AP visualised) cam morphology.

We found a location-specific relationship between cam morphology size and reported hip/groin burden in football players with FAI syndrome. Maximum alpha angle measurements are frequently observed at the anterosuperior region of the femoral head-neck junction (63, 256, 265, 270), where larger and more anterior cam morphology have been found to impinge the acetabulum at smaller degrees of hip flexion (271). Whilst mechanical impingement between the femoral neck and acetabulum may increase hip joint stresses (272), restrict ROM (253, 273), and cause chondrolabral pathology (59, 60), the effect of cam morphology on reported burden has been less certain. Cam morphology presence (179, 269) and size (131, 177, 178) have been unrelated to PROM scores in various symptomatic populations, including those undergoing hip arthroscopy (177, 178), adults with self-reported hip OA (179), and football players with hip/groin pain (131, 269). Our findings, which contrast previous reports investigating cam morphology size (131, 177), might be explained in part by our location-specific analysis (177) and more homogenous cohort (131, 177). By only including football players with FAI syndrome with alpha angles ≥60°, cam morphology was more likely to be relevant for participants' clinical presentation when compared to symptomatic football players (or other populations) with alpha angles <60° (15, 63, 64). Consistent with our findings, anterosuperior located cam morphology optimally discriminated between people undergoing surgery for hip pain and pain-free people, compared to other femoral head-neck regions (270, 274). Larger anterosuperior cam morphology, therefore, might be related both to the presence and severity of hip/groin pain; however, the cross-sectional nature of our study and others (270, 274) means that determining causality remains elusive. Our findings support calls for prospective studies to understand the effect of anterosuperior cam morphology size on reported burden and joint disease over time (38, 121), particularly in high-impact athletes who may be at greater risk of hip OA (123).

Modest relationships between anterosuperior cam morphology size and iHOT-33 scores suggests that factors other than cam morphology may influence self-reported burden in football players with FAI syndrome. It is unclear why relationships were limited to the iHOT-33 only, considering that the HAGOS and iHOT-33 examine equivalent dimensions of hip/groin pain (228) and share many similar questions (275). Differences in the scoring (ordinal vs continuous and per-person vs per-hip) and/or unique questions within the iHOT-

33 may have influenced the scores, and hence the relationships with cam morphology size. Although relationships existed for most iHOT-33 scores, model estimates determined that alpha angle differences of more than 20° would be required to manifest as clinically important score differences between our football players (228), and smaller alpha angle differences were less likely to be meaningful. Furthermore, small pseudo R^2 values for univariable models found that only 4.6% to 8.7% of the variance in iHOT-33 scores was explained by alpha angle, indicating that the severity of pain, symptoms, and functional impairment reported by our football players was mostly impacted by factors other than anterosuperior cam morphology size. These coexisting factors may be distinct from the sequalae of cam morphology and could include, for example, physical impairments such as strength deficits (52) or altered biomechanics (126). Other bony morphological features (e.g., acetabular, femoral, and spinopelvic morphologies) have partially explained the presence of hip/groin pain in those undergoing surgery when compared to pain-free people (270), and greater understanding of the relationships between these imaging findings and the presence of pain and the severity of reported burden are needed in high-impact athletes. Non-physical (e.g., psychosocial, contextual) factors (244) can moderate relationships between physical findings and reported burden. For example, pre-operative mental health status, but not the severity of intra-operative findings, was related to reported burden in people undergoing hip arthroscopy (178, 185). Self-reported treatment outcomes may too be influenced by other physical and non-physical factors, with post-operative alpha angles or the magnitude of bony resection rarely related to PROM scores following femoral head-neck osteochondroplasty (176). Our findings suggest that football players with larger anterosuperior cam morphology may be at risk of worse hip/groin pain and symptoms; however, they do not imply that surgical treatment to address bony morphology will improve reported burden. Larger cam morphology might moderate the effectiveness of exercise-based rehabilitation (241), but full-scale studies are needed to understand this potential relationship. To improve treatment selection and outcomes for football players with FAI syndrome, improved knowledge of the natural history of reported hip/groin burden and the mechanisms of non-surgical and surgical treatments are needed.

There are limitations that should be considered when interpreting our results. First, AP and Dunn 45° radiographs do not provide three-dimensional visualisation of the femoral head-neck junction, potentially leading to under or over-reporting of cam morphology size (misclassification bias). However, alpha angles recorded using AP and Dunn 45° radiographs have previously demonstrated adequate correlation with CT (ICC=0.64-0.69

for AP radiograph at 12-1 o'clock positions, and 0.68 for Dunn 45° radiograph at 1-2 o'clock) (266) and MRI (Pearson's correlation coefficient=0.63 for AP radiograph at 12 o'clock, and 0.73-0.77 for Dunn 45° at 1-2 o'clock) (256, 265). Second, impingement between the femoral head-neck junction and the acetabulum may be more likely in individuals with smaller femoral antetorsion angles (63), potentially altering the relationship between cam morphology size and self-reported burden in our football players with FAI syndrome. Third, global pincer morphology was defined using the LCEA; however, other pincer morphologies (e.g., global or focal retroversion) may have existed (63) and affected investigated relationships. Fourth, the low specificity of the FADIR test to detect hip-related pain (55) means that hip/groin pain in some of our football players may not have been due to FAI syndrome, despite the presence of cam morphology. Extra-articular groin pain entities (33) and lumbar conditions may have contributed to hip/groin pain in our football players and affected modelled relationships. Fifth, the small number of women we investigated means that we were likely underpowered to determine if relationships between alpha angle and reported burden were dependent on sex. Whilst sensitivity analyses confirmed our findings in men, studies with more women are needed to confirm or refute a potential sex-specific negative relationship between superior cam morphology and reported burden. Sixth, our findings may be specific to football players, and further investigation of other patient populations with FAI syndrome (e.g., non-athletes and athletes from other sports) are needed to identify if similar location-specific relationships exist.

6.7. Conclusion

Alpha angle measured using the Dunn 45° radiograph, but not the AP, was modestly related to worse iHOT-33 scores in football players with FAI syndrome with cam morphology. Larger anterosuperior (Dunn 45°) cam morphology may be more relevant to pain and symptoms in football players with FAI syndrome than superior (AP) cam morphology. Further prospective studies are needed to examine the effect of larger anterosuperior cam morphology on reported burden and structural hip disease over time.

Perspective

We found that larger anterosuperior, but not superior, cam morphology was modestly associated with worse self-reported pain and symptoms in football players with FAI syndrome. Cam morphology presence, defined by an alpha angle threshold value of 60°,

has previously been unrelated to reported burden in people with hip/groin pain (179, 269); however, our findings indicate that larger cam morphology may be more relevant. Our findings are consistent with previous reports of a dose-response relationship between cam morphology and physical findings, where those with larger cam morphology had worse chondrolabral pathology (59, 60) and restricted ROM (253). It is unclear why football players with larger cam morphology reported worse perceived impairment to physical function than those with smaller cam morphology, warranting future investigation of the relationship between cam morphology size and hip joint biomechanics during sporting tasks. The modest strength of our modelled relationships indicated that the severity of reported burden in football players with FAI syndrome was mostly impacted by factors other than anterosuperior cam morphology size; thus, clinicians might consider the relevance of cam morphology size in relation to other physical and non-physical factors when planning treatment for football players with FAI syndrome. Our location-specific findings support calls for prospective studies that investigate the effect of anterosuperior cam morphology on hip disease in people with FAI syndrome (38, 121). Furthermore, knowledge of the mechanisms of non-surgical and surgical treatments is needed to improve treatment selection and outcomes for football players with FAI syndrome.

6.8. Supplementary information

6.8.1 Sensitivity analyses – Arcsin-transformed linear models

As the data were bound by scores of 0 and 100, arcsin transformation of patient reported outcome measure (PROM) scores (dependent variables) was completed using formula $Y'' = 2\sin^{-1}\sqrt{Y'}$ (where, y' = PROM observation, y'' = transformed PROM score).

(i) Relationship between cam morphology size (Dunn 45° radiograph) and iHOT-33 and HAGOS scores.

A) iHOT-33

N=110[a]		iHOT-Total		iHOT-Symptoms		iHOT-Sport		iHOT-Job[b]		iHOT-Social	
Model		Unadjusted $R^2 = 0.055$	Adjusted $R^2 = 0.121$ ($P = 0.010$)	Unadjusted $R^2 = 0.046$	Adjusted $R^2 = 0.123$ ($P = 0.009$)	Unadjusted $R^2 = 0.004$	Adjusted $R^2 = 0.089$ ($P = 0.047$)	Unadjusted $R^2 = 0.071$	Adjusted $R^2 = 0.100$ ($P = 0.044$)	Unadjusted $R^2 = 0.089$	Adjusted $R^2 = 0.134$ ($P = 0.005$)
Cam size	b-value	-0.226	-0.243	-0.210	-0.230	-0.082	-0.090	-0.358	-0.371	-0.372	-0.391
	95%CI	(-0.407, -0.045)	(-0.422, -0.064)	(-0.395, -0.024)	(-0.412, -0.048)	(-0.321, 0.158)	(-0.324, 0 145)	(-0.621, -0.094)	(-0.640, -0.101)	(-0.603, -0.141)	(-0.621, -0.160)
	P value	$P = 0.015$	$P = 0.008$	$P = 0.027$	$P = 0.014$	$P = 0.500$	$P = 0.449$	$P = 0.008$	$P = 0.008$	$P = 0.002$	$P = 0.001$

B) HAGOS

N=110[a]		HAGOS-Symptoms		HAGOS-Pain		HAGOS-ADL		HAGOS-Sport		HAGOS-PA[c]		HAGOS-QOL	
Model		Unadjusted $R^2 = 0.022$	Adjusted $R^2 = 0.095$ ($P = 0.036$)	Unadjusted $R^2 = 0.002$	Adjusted $R^2 = 0.124$ ($P = 0.009$)	Unadjusted $R^2 = 0.007$	Adjusted $R^2 = 0.053$ ($P = 0.232$)	Unadjusted $R^2 = 0.014$	Adjusted $R^2 = 0.035$ ($P = 0.455$)	Unadjusted $R^2 = 0.002$	Adjusted $R^2 = 0.022$ ($P = 0.684$)	Unadjusted $R^2 = 0.021$	Adjusted $R^2 = 0.059$ ($P = 0.183$)
Cam size	b-value	-0.101	-0.113	-0.030	-0.045	-0.092	-0.109	-0.124	-0.136	-0.076	-0.093	-0.134	-0.145
	95%CI	(-0.233, 0.031)	(-0.243, 0.017)	(-0.171, 0.111)	(-0.180, 0.091)	(-0.306, 0.122)	(-0.323, 0.105)	(-0.324, 0.076)	(-0.339, 0.066)	(-0.421, 0.269)	(-0.443, 0.258)	(-0.311, 0.042)	(-0.322, 0.033)
	P value	$P = 0.131$	$P = 0.087$	$P = 0.677$	$P = 0.514$	$P = 0.397$	$P = 0.315$	$P = 0.221$	$P = 0.185$	$P = 0.664$	$P = 0.601$	$P = 0.134$	$P = 0.109$

R^2 indicates pseudo R^2 values. Adjusted models controlled for the effect age, sex, and body mass index. Sample size variations: n[a]=107 (unless otherwise indicated), n[b]=97, n[c]=106. Abbreviations: ADL = activities of daily living; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool 33; PA = participation in physical activity; QOL = quality of life.

(ii) Relationship between cam morphology size (Anteroposterior pelvis radiograph) and iHOT-33 and HAGOS scores.

A) iHOT-33

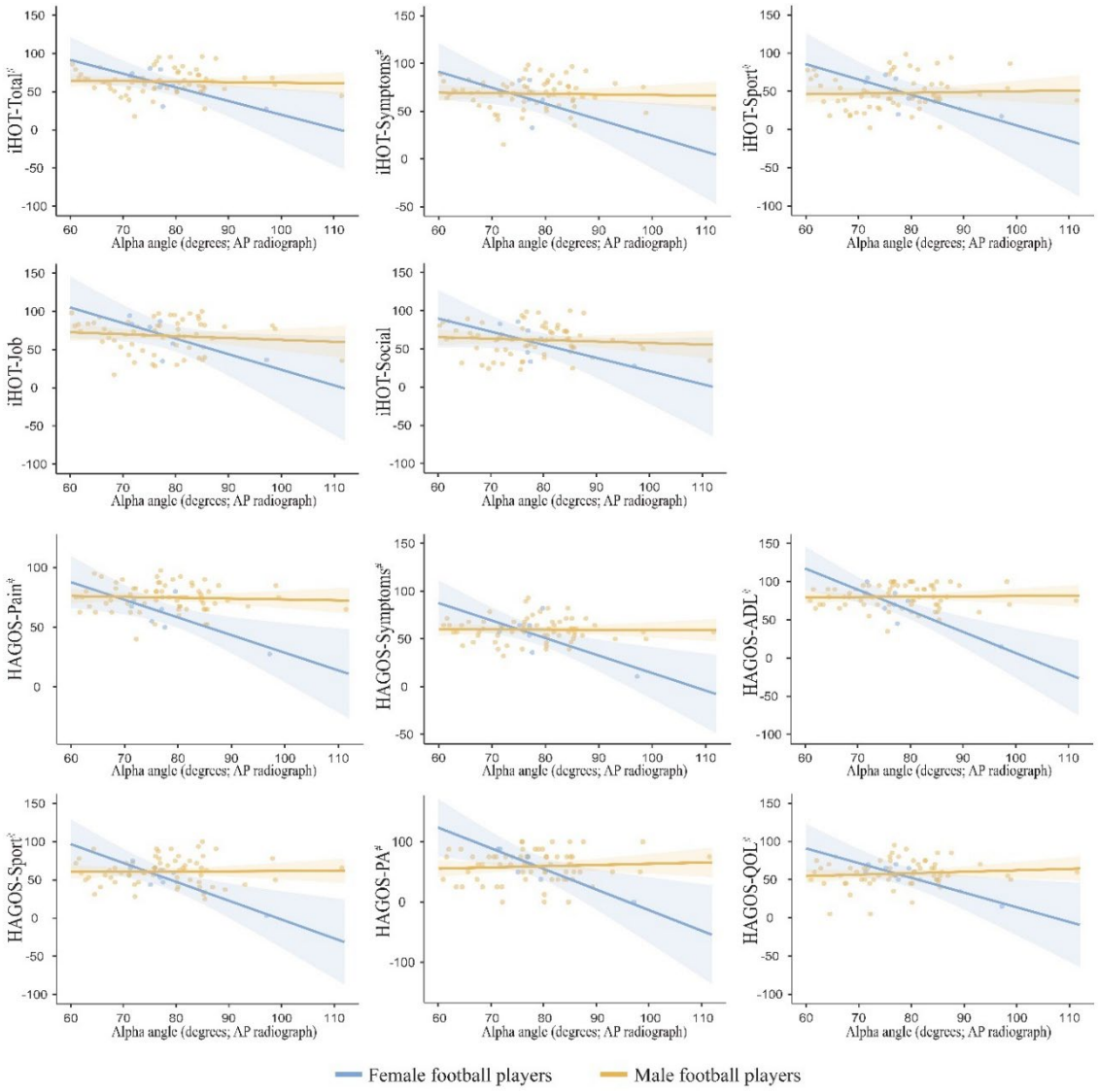
N=77[a]		iHOT-Total		iHOT-Symptoms		iHOT-Sport		iHOT-Job[b]		iHOT-Social[c]	
Model		Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted
		$R^2 = 0.002$	$R^2 = 0.007$ ($P = 0.974$)	$R^2 = 0.002$	$R^2 = 0.015$ ($P = 0.898$)	$R^2 = 0.003$	$R^2 = 0.023$ ($P = 0.803$)	$R^2 = 0.020$	$R^2 = 0.023$ ($P = 0.830$)	$R^2 = 0.016$	$R^2 = 0.035$ ($P = 0.635$)
Cam size	b-value	-0.050	-0.049	-0.048	-0.038	0.078	0.058	-0.219	-0.227	-0.182	-0.159
	95%CI	(-0.309, 0 208)	(-0.316, 0.218)	(-0.314, 0.218)	(-0.312, 0.235)	(-0.277, 0.434)	(-0.306, 0.422)	(-0.590, 0.153)	(-0.615, 0.160)	(-0.511, 0.148)	(-0.498, 0.180)
	P value	$P = 0.698$	$P = 0.714$	$P = 0.721$	$P = 0.781$	$P = 0.662$	$P = 0.752$	$P = 0\ 244$	$P = 0.245$	$P = 0.275$	$P = 0.352$

B) HAGOS

N=77[d]		HAGOS-Symptoms		HAGOS-Pain		HAGOS-ADL		HAGOS-Sport		HAGOS-PA[e]		HAGOS-QOL	
Model		Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted
		$R^2 < 0.001$	$R^2 = 0.027$ ($P = 0.753$)	$R^2 = 0.005$	$R^2 = 0.078$ ($P = 0.231$)	$R^2 = 0.003$	$R^2 = 0.019$ ($P = 0.856$)	$R^2 < 0.001$	$R^2 = 0.006$ ($P = 0\ 982$)	$R^2 = 0.006$	$R^2 = 0.022$ ($P = 0.818$)	$R^2 = 0.008$	$R^2 = 0.020$ ($P = 0.848$)
Cam size	b-value	-0.024	-0.006	-0.061	-0.061	0.084	0.083	0.028	0.025	0.170	0.169	0.108	0.124
	95%CI	(-0.221, 0.174)	(-0.208, 0.195)	(-0.269, 0.147)	(-0.268, 0.145)	(-0.261, 0.430)	(-0.271, 0.438)	(-0.261, 0.318)	(-0.273, 0.324)	(-0.340, 0.679)	(-0.357, 0.696)	(-0.172, 0.388)	(-0.163, 0.412)
	P value	$P = 0.812$	$P = 0.950$	$P = 0.558$	$P = 0.555$	$P = 0.628$	$P = 0.640$	$P = 0.845$	$P = 0.866$	$P = 0.509$	$P = 0.523$	$P = 0.443$	$P = 0.391$

R^2 indicates pseudo R^2 values. Sample size variations: n^a=74 (unless otherwise indicated); n^b=68; n^c=75; n^d=73 (unless otherwise indicated); n^e=72. Abbreviations: ADL = activities of daily living; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool 33; PA = participation in physical activity; QOL = quality of life; 95%CI = 95% confidence interval.

6.8.2 Sex-by-alpha angle interaction effects for linear models when alpha angle was measured with the AP radiograph



#denotes linear models with significant sex*alpha angle interaction term (P<0.05). Abbreviations: AP = anteroposterior pelvis, ADL = activities of daily living; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT = International Hip and Groin Outcome Score; PA = participation in physical activity; QOL = quality of life.

6.8.3 Results of sensitivity analyses investigating male football players with FAI syndrome only

(i) Relationship between cam morphology size (Dunn 45° radiograph) and iHOT-33 and HAGOS scores in men only.

A) iHOT-33

N=101[a]		iHOT-Total		iHOT-Symptoms		iHOT-Sport		iHOT-Job[b]		iHOT-Social	
Model		Unadjusted $R^2 = 0.045$	Adjusted $R^2 = 0.114$ ($P = 0.010$)	Unadjusted $R^2 = 0.042$	Adjusted $R^2 = 0.114$ ($P = 0.010$)	Unadjusted $R^2 = 0.002$	Adjusted $R^2 = 0.101$ ($P = 0.018$)	Unadjusted $R^2 = 0.047$	Adjusted $R^2 = 0.084$ ($P = 0.057$)	Unadjusted $R^2 = 0.071$	Adjusted $R^2 = 0.116$ ($P = 0.007$)
Cam size	b-value	-0.317	-0.339	-0.305	-0.325	-0.090	-0.121	-0.424	-0.448	-0.500	-0.518
	95%CI	(-0.612, -0.023)	(-0.627, -0.052)	(-0.601, -0.009)	(-0.614, -0.037)	(-0.478, 0.298)	(-0.493, 0 252)	(-0.829, -0.018)	(-0.852, -0.044)	(-0.867, -0.133)	(-0.880, -0.155)
	P value	$P = 0.035$	$P = 0.021$	$P = 0.044$	$P = 0.027$	$P = 0.647$	$P = 0.523$	$P = 0.041$	$P = 0.030$	$P = 0.008$	$P = 0.006$

B) HAGOS

N=101[a]		HAGOS-Symptoms		HAGOS-Pain		HAGOS-ADL		HAGOS-Sport		HAGOS-PA[c]		HAGOS-QOL	
Model		Unadjusted $R^2 = 0.022$	Adjusted $R^2 = 0.064$ ($P = 0.098$)	Unadjusted $R^2 = 0.004$	Adjusted $R^2 = 0.118$ ($P = 0.008$)	Unadjusted $R^2 = 0.005$	Adjusted $R^2 = 0.046$ ($P = 0.213$)	Unadjusted $R^2 = 0.010$	Adjusted $R^2 = 0.030$ ($P = 0.409$)	Unadjusted $R^2 < 0.001$	Adjusted $R^2 = 0.020$ ($P = 0.594$)	Unadjusted $R^2 = 0.018$	Adjusted $R^2 = 0.054$ ($P = 0.153$)
Cam size	b-value	-0.155	-0.155	-0.069	0.069	-0.092	-0.095	-0.151	-0.154	-0.049	-0.075	-0.193	-0.202
	95%CI	(-0.366, 0.056)	(-0.364, 0.054)	(-0.283, 0.144)	(-0.272, 0.135)	(-0.354, 0.169)	(-0.355, 0.164)	(-0.459, 0.156)	(-0.462, 0.155)	(-0.512, 0.414)	(-0.540, 0.390)	(-0.485, 0.099)	(-0.492, 0.088)
	P value	$P = 0.148$	$P = 0.144$	$P = 0.521$	$P = 0.503$	$P = 0.485$	$P = 0.468$	$P = 0.331$	$P = 0.325$	$P = 0.834$	$P = 0.750$	$P = 0.192$	$P = 0.169$

R^2 indicates pseudo R^2 values. Sample size variations: n^a= 98 (unless otherwise indicated), n^b=89, n^c=97. Abbreviations: ADL = activities of daily living; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool 33; PA = participation in physical activity; QOL = quality of life.

(ii) Relationship between cam morphology size (AP radiograph) and iHOT-33 and HAGOS scores in men only.

A) iHOT-33

N=69[a]		iHOT-Total		iHOT-Symptoms		iHOT-Sport		iHOT-Job[b]		iHOT-Social	
Model		**Unadjusted** $R^2 = 0.002$	**Adjusted** $R^2 = 0.007$ ($P = 0.924$)	**Unadjusted** $R^2 = 0.003$	**Adjusted** $R^2 = 0.010$ ($P = 0.889$)	**Unadjusted** $R^2 = 0.004$	**Adjusted** $R^2 = 0.028$ ($P = 0.609$)	**Unadjusted** $R^2 = 0.011$	**Adjusted** $R^2 = 0.015$ ($P = 0.840$)	**Unadjusted** $R^2 = 0.010$	**Adjusted** $R^2 = 0.021$ ($P = 0.715$)
Cam size	b-value	-0.078	-0.084	-0.088	-0.074	0.142	0.083	-0.232	-0.225	-0.212	-0.198
	95%CI	(-0.476, 0 320)	(-0.493, 0.325)	(-0.493, 0.317)	(-0.490, 0.342)	(-0.416, 0.700)	(-0.486, 0.651)	(-0.804, -0.340)	(-0.846, 0.335)	(-0.725, 0.300)	(-0.723, 0.328)
	P value	$P = 0.697$	$P = 0.683$	$P = 0.667$	$P = 0.723$	$P = 0.613$	$P = 0.772$	$P = 0.420$	$P = 0.390$	$P = 0.411$	$P = 0.455$

B) HAGOS

N=69[c]		HAGOS-Symptoms		HAGOS-Pain		HAGOS-ADL		HAGOS-Sport		HAGOS-PA[d]		HAGOS-QOL	
Model		**Unadjusted** $R^2 = 0.001$	**Adjusted** $R^2 = 0.018$ ($P = 0.765$)	**Unadjusted** $R^2 = 0.006$	**Adjusted** $R^2 = 0.033$ ($P = 0.555$)	**Unadjusted** $R^2 < 0.001$	**Adjusted** $R^2 = 0.015$ ($P = 0.815$)	**Unadjusted** $R^2 < 0.001$	**Adjusted** $R^2 = 0.007$ ($P = 0\ 936$)	**Unadjusted** $R^2 = 0.007$	**Adjusted** $R^2 = 0.016$ ($P = 0.810$)	**Unadjusted** $R^2 = 0.009$	**Adjusted** $R^2 = 0.014$ ($P = 0.831$)
Cam size	b-value	-0.049	-0.027	-0.096	-0.071	0.026	0.049	0.018	0.035	0.228	0.220	0.170	0.186
	95%CI	(-0.370, 0.272)	(-0.354, 0.301)	(-0.396, 0.204)	(-0.375, 0.234)	(-0.369, 0.421)	(-0.354, 0.452)	(-0.440, 0.475)	(-0.434, 0.503)	(0.464, 0.919)	(-0.494, 0.934)	(-0.286, 0.626)	(-0.282, 0.653)
	P value	$P = 0.762$	$P = 0.871$	$P = 0.524$	$P = 0.645$	$P = 0.896$	$P = 0.809$	$P = 0.938$	$P = 0.883$	$P = 0.513$	$P = 0.540$	$P = 0.458$	$P = 0.430$

R^2 indicates pseudo R^2 values. Sample size variations: n^a=67 (unless otherwise indicated); n^b=61; n^c=66 (unless otherwise indicated); n^d=65. Abbreviations: ADL = activities of daily living; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT-33 = International Hip Outcome Tool 33; PA = participation in physical activity; QOL = quality of life; 95%CI = 95% confidence interval.

PART C: RUNNING BIOMECHANICS IN FOOTBALL PLAYERS WITH HIP AND/OR GROIN PAIN

Chapter 7. Biomechanical data collection

7.1. Preface

This chapter outlines the methods used for collecting and processing biomechanical data used for this thesis. Throughout my PhD, I underwent extensive training in biomechanical data collection and processing from three experienced post-doctoral research fellows (Dr Benjamin Mentiplay, Dr Anthony Schache, and Dr Matthew King). I was the primary person collecting data for approximately two-thirds (n>100) of the biomechanical testing sessions that assessed running, and individually processed all maker trajectory and GRF data for the running trials (≥8 running trials per participant, >116 participants).

This chapter will be referenced throughout chapters eight and nine, which include studies of running biomechanics in the FORCe study participants.

7.2. Set-up and data collection

7.2.1 Participant set-up

Biomechanical data were collected at the La Trobe University Gait Laboratory in Melbourne, Australia. Participants wore running shorts (and a singlet or crop top for women) and Teva Original Universal sandals (Deckers Brands, Goleta, USA). The sandals permitted adequate exposure of anatomical bony landmarks for marker placement and ensured that footwear was consistent between participants. Forty-nine small (14mm) reflective markers (B & L engineering, Albion, Australia) were placed on the participant's skin at specific anatomical landmarks according to a published protocol (130) **(Figure 7.1)**. For the trunk and upper limbs, markers were placed on the C7 spinous process, acromioclavicular joint, lateral epicondyle of the humeri, and the posterior line of the wrists. A thermoplastic plate with four markers was affixed to the participant's pelvis using a belt positioned at the height of the posterior iliac spine. An additional marker was placed on the belt at each anterior superior iliac spine. For the lower limbs and feet, markers were placed on the medial and lateral femoral epicondyles, medial and lateral malleoli, 5th and 1st metatarsal heads, and the great toes. Four additional segment tracking markers were placed on each thigh (two anterior, two lateral), three on the shank (two anterior, one lateral), and two on the midfoot (one superior, one lateral). Participant set-up for male participants is demonstrated in **Figure 7.2**.

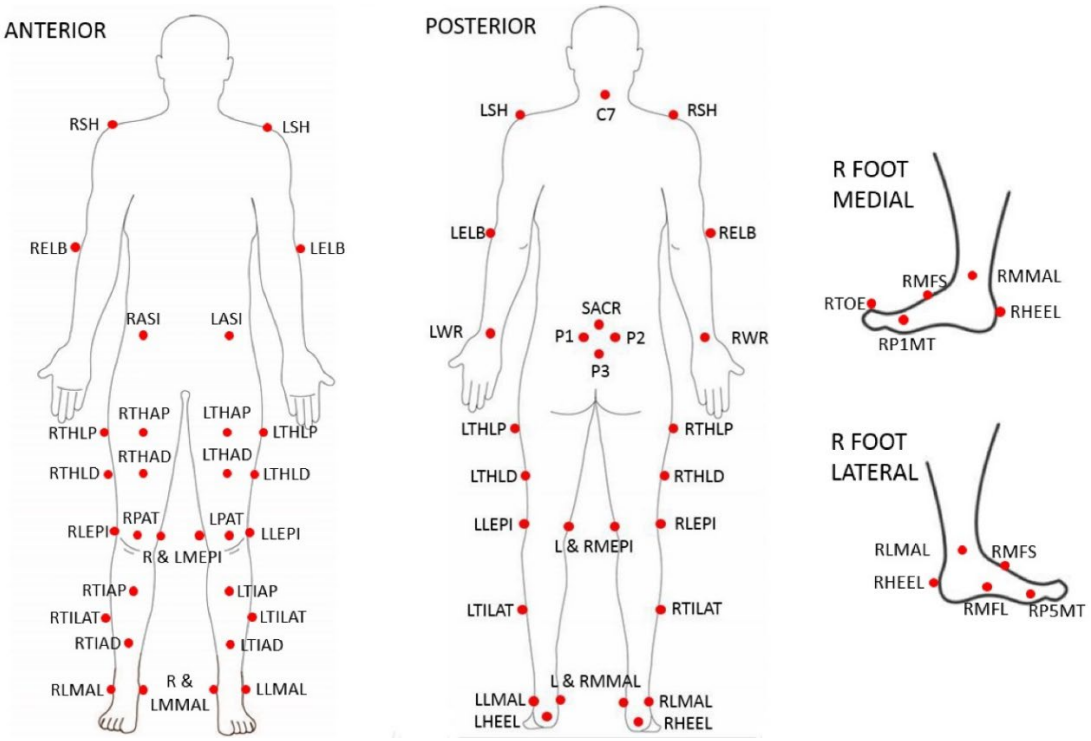


Figure 7.1. Location of markers on participants' body.
Marker names and descriptions are listed in **Appendix S**. Figure sourced from Crossley et al. (2018) (130).

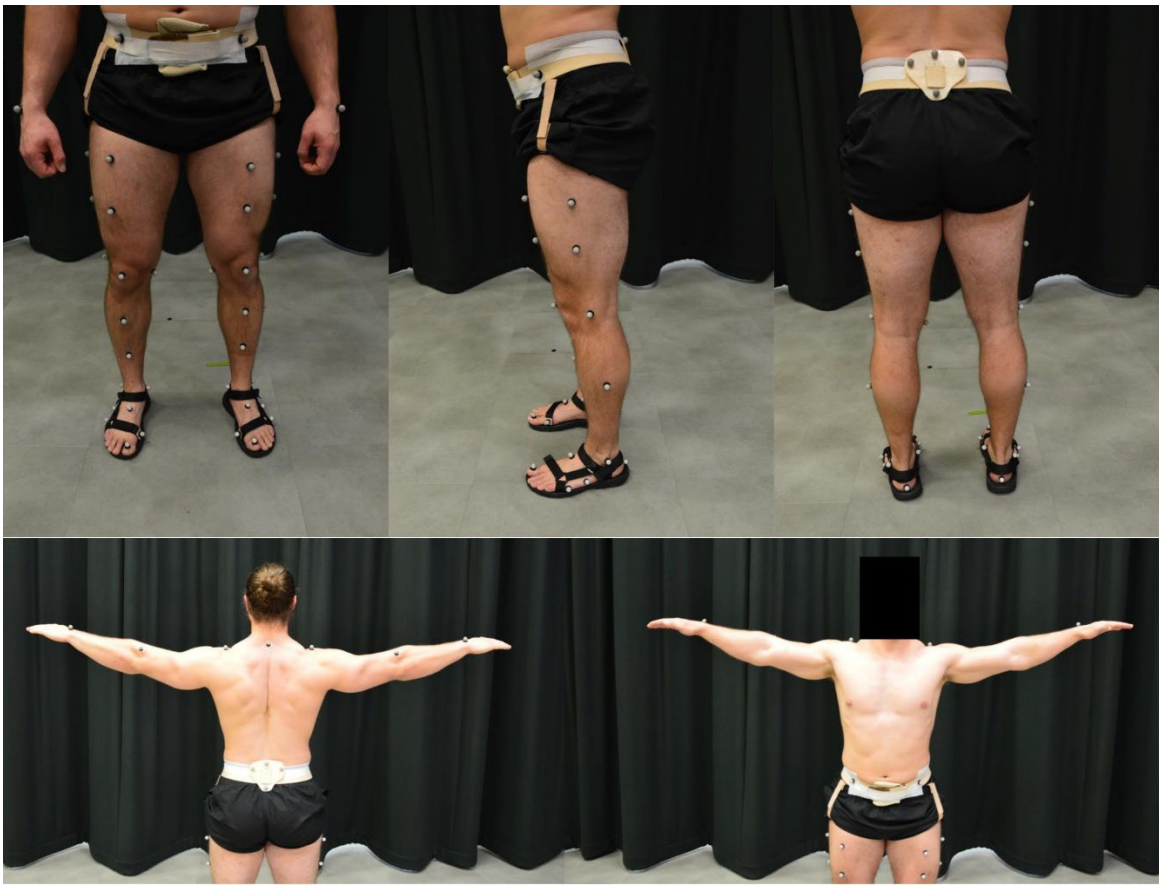


Figure 7.2. Participant set-up for male football players with hip/groin pain.
Figure sourced from King (2020) (191).

7.2.2 Gait laboratory set-up

A 10-camera opto-reflective motion capture system (Vicon Motion Systems Ltd, Oxford, UK) recorded marker trajectories at a sampling rate of 100 hertz (Hz). Ground reaction force data were recorded at a sampling rate of 1000 Hz using either a large (1200mm x 600mm) or small (600mm x 400mm) force plate (Advanced Mechanical Technology Inc., Watertown, USA) embedded in the laboratory floor **(Figure 7.3)**. Marker trajectories and raw GRF data were simultaneously recorded using Vicon Nexus version 1.8.5 (Vicon Motion Systems Ltd, Oxford, UK), except for nine control participants when version 2.10.0 was used.

Figure 7.3. Laboratory set up for biomechanical data collection.
Figure sourced from King (2020) (191).

7.2.3 Static calibration trial

Prior to completing overground running trials, a static calibration trial was captured to calculate anthropometric properties and estimate joint centre locations for each participant. Participants were instructed to stand stationary, with feet shoulder width apart and shoulders elevated to 90° abduction for three seconds while the trial was captured **(Figure 7.4)**. Once the static calibration trial was completed, markers placed on the medial femoral condyles and medial malleoli were removed to avoid interference with participants' natural running pattern.

Figure 7.4. Static calibration trial.
Figure adapted from King (2020) (191).

7.2.4 Overground running trials

For the overground running trials, participants were instructed to run at a constant pace through the calibrated measurement volume in the centre of the laboratory. As the gait laboratory is approximately 60m long, participants were not restricted in their acceleration or deceleration distances. Timing gates, placed 5m apart and spanning the centre of the measurement volume, were used to determine the participants running speed for each trial. A successful trial was defined by whole-foot force plate contact at a running speed of 3-3.5m·s^{-1}. Participants were provided with verbal feedback immediately after each trial to assist with reproducing the designated running speed. Familiarisation trials were undertaken until the participant successfully achieved the designated running speed with a valid foot contact on the force plate. At least four successful trials were captured for each limb.

7.3. Biomechanical data processing

Marker trajectories and GRF data were processed using Vicon Nexus software (Vicon Motion Systems Pty Ltd, Oxford, UK). The start and end of the stance phase was defined

by initial contact and toe-off, respectively (**Figure 7.5**). Initial contact was defined as the first frame when the raw vertical GRF exceeded 20N, whereas toe-off was defined as the first frame when the raw vertical GRF dropped below 20N. A fourth-order, low-pass Butterworth filter with zero lag and cut-off frequency of 10Hz was used to filter marker trajectories and GRF data (276). A seven-segment (pelvis; right and left thigh, right and left shank; right and left feet) biomechanical model generated in Vicon BodyBuilder software (Vicon Motion Systems Pty Ltd, Oxford, UK) was used to calculate joint angle and moment data. The hip joint centre was estimated using equations reported by Harrington et al. (2007) (277) whereas a dynamic optimisation approach was used to determine the orientation of the knee flexion-extension axis (278). Anatomical coordinate systems for each body segment of interest were consistent with published definitions (279) and are summarised in **Table 7.1**.

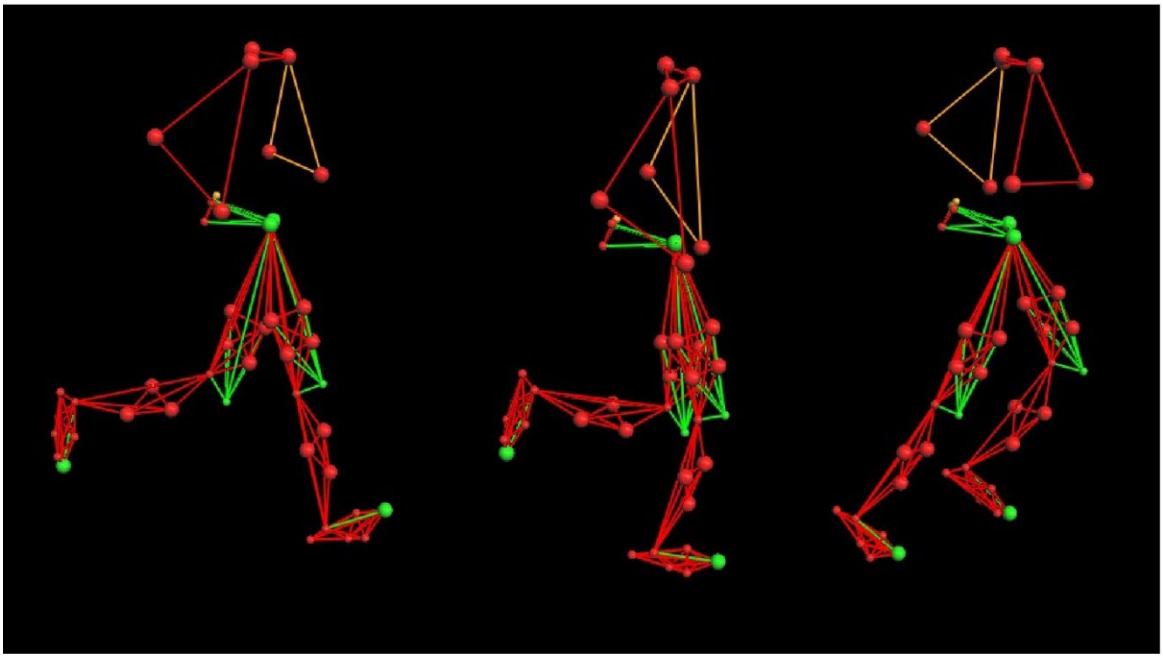


Figure 7.5. Example of reconstructed marker trajectories from right initial contact to toe-off during running.

Table 7.1. Anatomical coordinate system definitions.

Segment	Anatomical Coordinate System Definition
Pelvis	
- Origin	Midpoint between right and left anterior superior iliac spine markers
- Mediolateral axis (y)	In the direction from right to left anterior superior iliac spine markers
- Anterior-posterior axis (x)	Perpendicular to the mediolateral y-axis, in the plane containing the right and left anterior superior iliac spine and the sacral marker (where the sacral marker overlays the midpoint between both posterior superior iliac spine markers)
- Vertical axis (z)	Mutually perpendicular to x and y axes
- Virtual point	Right and left hip joint centre – defined relative to the anatomical coordinate system of the pelvis (277)
Lower-limb	
Lower-limb anatomical co-ordinate systems written with reference to the left lower-limb; marker labels and frames were adjusted and replicated on the right lower-limb as appropriate	
Femur	
- Origin	Left knee joint centre – midpoint between left medial and lateral femoral condyle markers
- Vertical axis (z)	In the direction from left knee joint centre to the left hip joint centre
- Mediolateral axis (y)	Perpendicular to the z-axis, in the plane containing the left knee and hip joint centre and left thigh lateral distal (LTHAD) marker rotated by angle ɵ about the z-axis (where ɵ is the degree of rotation needed to minimise the variance in the dynamic knee varus-valgus kinematic profile)
- Anterior-posterior axis (x)	Mutually perpendicular to the z and y axes
- Virtual points	Left knee joint centre and Left Thigh^{Rot} as outlined above
Tibia (Proximal)	
- Origin	Left ankle joint centre – defined as the midpoint between the left lateral and medial malleoli markers
- Vertical axis (z)	In the direction from left ankle joint centre to left knee joint centre
- Mediolateral axis (y)	Perpendicular to the z axis and parallel to the femur y axis when in static anatomical landmark calibration trial configuration
- Anterior-posterior axis (x)	Mutually perpendicular to the z and y axes
- Virtual points	Left ankle joint centre as defined above
Tibia (Distal)	
- Origin	Left ankle joint centre – defined as the midpoint between the left lateral and medial malleoli markers
- Vertical axis (z)	In the direction from left ankle joint centre to left knee joint centre
- Mediolateral axis (y)	Perpendicular to the z-axis in the plane containing the left knee joint centre and the left medial and lateral malleoli markers.
- Anterior-posterior axis (x)	Mutually perpendicular to the z and y axes
- Virtual points	Left ankle joint centre as defined above
Foot	
- Origin	Left ankle joint centre as defined above
- Vertical axis (z)	Defined to be parallel with the z-axis of the laboratory-based coordinate system
- Anterior-posterior axis (x)	Perpendicular to the z-axis, in the plane containing the left ankle joint centre and the mid-point between the 1st and 5th metatarsal head markers (LP1MT and LP5MT)
- Mediolateral axis (y)	Mutually perpendicular to the z and x-axes
- Virtual point	Left ankle joint centre as defined above

Anatomical coordinate systems adapted from Schache and Baker (2007) (279).

7.3.1 Joint angles

Pelvis angles were calculated with respect to a global (laboratory-based) coordinate system (280). Hip, knee, and ankle joint angles were calculated using a joint coordinate system convention (281).

7.3.2 External joint moments

External lower-limb joint moments were calculated using a standard inverse dynamics approach. Moments were normalised to body mass and presented as Newton metres per kilogram ($N \cdot m \cdot kg^{-1}$). Moments were expressed in the same non-orthogonal joint coordinate system used to calculate the hip, knee, and ankle joint angles (279).

7.3.3 Impulse of the external joint moments

The impulse of the external joint moment was calculated by taking the integral (area under the curve) of the non-time normalised moment-time curve in each plane, and presented as Newton metre seconds per kilogram ($N \cdot m \cdot s \cdot kg^{-1}$). Positive and negative integrals were summed independently to calculate the total positive and negative impulses for each external joint moment of interest.

7.3.4 Time series plots

Biomechanical variables analysed in this thesis were calculated for the stance phase only. All angle and moment data were time normalised to represent 100% of the stance phase and time series plots were generated.

Chapter 8. Running biomechanics in football players with and without hip and/or groin pain.

8.1. Preface

As identified in **Chapter 1**, knowledge of biomechanical impairments in athletes with hip/groin pain is limited. Although running is fundamental to many field sports, including football, it is unknown if running biomechanics differ in those with and without hip/groin pain. This chapter aimed to compare running biomechanics between symptomatic and asymptomatic football players, comparing men and women separately.

Chapter 8 contains an edited version of the following publication:

Scholes MJ, Crossley KM, King MG, Schache AG, Kemp JL, Semciw AI, Sritharan P, Heerey JJ, Mentiplay BF. Running biomechanics in football players with and without hip and groin pain. A cross-sectional analysis of 116 sub-elite players. *Physical Therapy in Sport*. 2021;52:312-21. doi: 10.1016/j.ptsp.2021.10.011.

All edits of the accepted manuscript are grammatical, to improve clarity and facilitate consistency throughout this thesis. No amendments or additions have been made to the results.

8.2. Abstract

Objective: Examine whether football players with hip/groin pain have impaired running biomechanics when compared to pain-free players, analysing men and women independently.

Design: Cross-sectional.

Setting: Biomechanics laboratory.

Participants: Seventy-eight (62 men, 16 women) football players with >6 months of hip/groin pain and a positive flexion-adduction-internal rotation test and 38 (25 men, 13 women) asymptomatic players.

Main outcome measures: Pelvis angles and hip, knee, and ankle joint angles and moments were analysed during the stance phase of overground running at 3-3.5m.s^{-1}. Continuous joint angle and moment data were compared between symptomatic and asymptomatic football players of the same sex using statistical parametric mapping. Joint moment impulses (area under the curve) were compared between groups using linear regression models.

Results: Symptomatic football players did not display significant differences in pelvis angles or lower-limb joint angles, moments, or moment impulses during the stance phase of running, when compared to asymptomatic players of the same sex.

Conclusion: Our large sample of football players with hip/groin pain who were still participating in competitive sport displayed similar running biomechanics to asymptomatic players. Impaired running biomechanics might exist in people with worse hip/groin pain, warranting future investigation.

Keywords: Gait analysis, Hip-related pain, Hip joint, Rehabilitation.

8.3. Introduction

Hip/groin pain is common in football players, occurring in up to half of all sub-elite players per season (4). Longstanding hip/groin pain is burdensome for football players, restricting sports performance and reducing QOL (**Chapter 4**) (5). Hip/groin pain can encompass intra-articular (i.e., hip-related) and extra-articular conditions that often co-exist (33, 38). Current evidence suggests that movement patterns in athletes with hip/groin pain may not be unique to specific pathoanatomical diagnoses (282), with group-level biomechanical impairments evident in heterogeneous symptomatic cohorts when compared to asymptomatic athletes (196, 200). Furthermore, interventions that aim to optimise movement patterns have improved outcomes in people with various hip/groin pain conditions (175, 200, 283). Despite this work, existing knowledge of whether symptomatic athletes display altered biomechanics during sporting tasks is limited (196, 200, 201).

Lower-limb biomechanics during functional tasks have been examined in people with varying degrees of hip/groin pain burden (126, 196, 200-202, 282, 284). People awaiting surgery for hip-related pain (i.e., FAI syndrome) have less sagittal plane hip excursion (285, 286) and peak hip extension (287) during the stance phase of walking when compared to pain-free individuals. In contrast, we recently found that football players with hip/groin pain who were still participating in competitive sport did not display different sagittal plane hip kinematics during walking when compared to asymptomatic players (196). It is possible that movement and joint loading impairments during relatively low-impact tasks (e.g., walking) might be limited to people with worse burden (e.g., patients seeking surgery for FAI syndrome), whereas impairments in athletes may only be revealed during high-impact tasks (126, 194, 288), or tasks that demand greater hip joint ROM (e.g., deep squatting) (289). Athletes with hip/groin pain have previously demonstrated decreased sagittal and frontal plane hip moments during lateral hopping (200), and altered frontal plane pelvis kinematics during single-leg drop landing (201) and single-leg drop jumping (196), when compared to asymptomatic athletes. Similar biomechanical impairments might exist during running in symptomatic football players. Running is fundamental to football; elite players accumulate greater distances running at speeds of $<4 m \cdot s^{-1}$ compared to sprinting (290, 291), suggesting that submaximal running might be an important contributor to match-related hip/groin loads and pain in football players. Athletes with hip/groin pain often experience

difficulty when running (232), but it is unknown if differences in running biomechanics exist between those with and without symptoms.

Sex-related differences in running biomechanics exist in healthy adults (292), and in people with patellofemoral pain (293) and iliotibial band syndrome (294). Whilst running biomechanics have not been studied in people with hip/groin pain, some subtle sex-related differences in walking biomechanics have been observed. For example, men with hip/groin pain walk with a smaller hip axial rotation excursion throughout stance (196), and smaller peak hip extension angle (195) and impulse of the hip axial rotation moment during late stance (196) when compared to asymptomatic men, whereas these differences were not observed for women (195, 196). Running might exaggerate these subtle between-group differences in men and reveal altered lower-limb biomechanics in women, providing insights for exercise-based interventions.

Therefore, the aim of this exploratory study was to compare running biomechanics between football players with and without hip/groin pain, analysing men and women independently.

8.4. Methods

8.4.1 Study design

This case-control study investigated 18- to 50-year-old competitive football (football and Australian football) players with and without hip/groin pain. Participants with hip/groin pain (symptomatic players) were a subset of the larger FORCe study investigating change in hip joint structure and symptoms over time (**Section 2.2**) (130). Ethics approvals were obtained from the La Trobe University Human Ethics Committee to investigate football players with and without hip/groin pain (HEC015-019 and HEC016-045, respectively). Data were collected between August 2015 and March 2020 and written informed consent was obtained prior to participation in the study.

8.4.2 Participants

Football players completing at least two football sessions (training/matches) per week in structured, sub-elite (non-professional) competitions in greater Melbourne, Australia, were recruited. Eligibility criteria for participants with and without hip/groin pain are described

in **Table 2.1** and **Table 2.2**, respectively. Briefly, symptomatic football players needed to report greater than six months of activity-related hip (anterior/lateral/posterior) and/or groin pain and have a positive FADIR pain provocation test. Asymptomatic control football players reported no history of hip/groin pain and had a negative FADIR test. Participants were recruited through print, electronic, and social media advertisements to football clubs and leagues and direct advertisement to sports medicine and physiotherapy clinics. A total of 116 participants were included: 78 (62 men, 16 women) symptomatic football players and 38 (25 men, 13 women) asymptomatic control football players. As the study was exploratory in nature, no formal power analysis was conducted.

8.4.3 Patient-reported outcome measures

Demographic and anthropometric data including sex, age, height, body mass, football code, and dominant kicking foot (lower-limb dominance) were recorded at the beginning of the testing session. Symptomatic football players also estimated their duration of hip/groin pain (in months) and quantified their average level of pain (0 to 10) in the last seven days using a numerical pain rating scale. Self-reported hip/groin pain burden was quantified in all participants using the iHOT-33 (147) and HAGOS (148). The iHOT-33 and HAGOS are reliable, valid, and recommended for use in active adults with hip/groin pain (144, 228).

8.4.4 Biomechanical data collection

Biomechanical data were collected at the La Trobe University Gait Laboratory. Participants wore loose-fitting shorts, a singlet/crop top for women, and Teva Original Universal sandals (Deckers Brands, Goleta, CA). The sandals allowed exposure of anatomical landmarks on the foot for marker placement. Forty-nine small (14mm) reflective markers were placed on specific anatomical landmarks according to a published protocol (130). A 10-camera opto-reflective motion capture system (Vicon Motion Systems Pty Ltd., Oxford, UK) recorded marker trajectories at a sampling rate of 100Hz. Ground reaction force data were recorded at sampling rate of 1000Hz using either a large (1200mm x 600mm) or small (600mm x 400mm) force plate (Advanced Mechanical Technology Inc., Watertown, MA, USA) embedded in the laboratory floor. Marker trajectories and GRF data were simultaneously recorded using Vicon Nexus software (Vicon Motion Systems Pty Ltd, Oxford, UK).

A static trial was used to calibrate anatomical landmarks, estimate joint centre locations, and define body segment anatomical coordinate systems. After the static trial, markers over the medial femoral epicondyles and medial malleoli were removed to avoid interference with participants' natural running pattern. For the overground running trials, participants were instructed to run at a constant pace through the calibrated measurement volume in the centre of the laboratory. No restrictions were placed on the acceleration or deceleration distances. Timing gates, placed 5m apart and spanning the centre of the measurement volume, were used to determine the participants running speed for each trial. A successful trial was defined by whole-foot force plate contact at a running speed of 3-3.5m·s^{-1}. Participants were provided with verbal feedback immediately after each trial to assist with reproducing the designated running speed. Familiarisation trials were undertaken until the participant successfully achieved the designated running speed with a valid foot contact in the middle of the force plate. At least four successful trials were captured for each limb.

8.4.5 Biomechanical data processing

Marker trajectories and GRF data were processed using Vicon Nexus software (Vicon Motion Systems Pty Ltd, Oxford, UK). The start and end of the stance phase was defined by initial contact and toe-off, respectively. Initial contact was defined as the first frame when the raw vertical GRF exceeded 20N, whereas toe-off was defined as the first frame when the raw vertical GRF dropped below 20N. A fourth-order, low-pass Butterworth filter with zero lag and cut-off frequency of 10Hz was used to filter marker trajectories and GRF data (276). A seven-segment (pelvis; right and left thigh, right and left shank; right and left feet) biomechanical model generated in Vicon BodyBuilder software (Vicon Motion Systems Pty Ltd, Oxford, UK) was used to calculate angle and moment data. The hip joint centre was estimated using equations reported by Harrington et al. (2007) (277) whereas a dynamic optimisation approach was used to determine the orientation of the knee flexion-extension axis (278). Anatomical coordinate systems for each body segment were consistent with published definitions (279). Hip, knee, and ankle joint angles were calculated using a joint coordinate system convention (281). Pelvis angles were calculated with respect to a global (laboratory-based) coordinate system (280). External lower-limb joint moments were calculated using a standard inverse dynamics approach. Moments were normalised to body mass (N·m·kg^{-1}) and were expressed in the same non-orthogonal joint coordinate system used to calculate joint angles (279, 295). External joint moment data were integrated over the stance phase to calculate the impulse (area under the curve;

$N \cdot m \cdot s \cdot kg^{-1}$). Positive and negative impulses were summed independently to calculate total positive and negative impulses for each external joint moment of interest.

8.4.6 Data management

A single lower limb was selected for analysis per participant. For the 49 (63%) symptomatic football players (eight women) where both hips met the inclusion criteria, the most symptomatic hip (reported from the iHOT-33 question, *"which (hip) gives you the most trouble?"*) was selected. The test side for each asymptomatic control football player was determined using a random line shuffle designed to match the distribution of kicking (dominant) versus non-kicking (non-dominant) lower limbs in the symptomatic group (stratified by sex). As both running speed and foot strike pattern can affect lower-limb biomechanics (295, 296), each successful trial was screened following data processing and prior to statistical analyses. Foot strike pattern was classified as "rearfoot" or "non-rearfoot" using visual inspection of reconstructed marker trajectories and confirmed with sagittal plane ankle joint angle and moment data. As the target speed for trials was assessed over 5m but biomechanical variables were analysed for the stance phase on the force plate only, screening of stance phase speed was undertaken (by dividing the anterior translation of the sacral marker during stance by stance time). Individual trials with an outlying foot strike pattern or stance speed were excluded. External joint moments and impulses were unable to be calculated for one (6%) female and three (5%) male symptomatic football players and two (8%) male asymptomatic control football players due to erroneous force plate data. In total, all participants had at least three trials for analysis, except for five (8%) symptomatic male football players who only had two. Sensitivity analyses that excluded these five participants were completed to examine the effect of including those with only two trials.

8.4.7 Data analysis

As the relationship between hip/groin pain and running biomechanics may be modified by sex, it was decided *a priori* to analyse biomechanical variables independently for men and women. Variables were explored in three anatomical planes for the pelvis and hip, and in the sagittal plane for the knee and ankle. All angle and moment data were time normalized to represent 100% of the stance phase and time series plots were generated. Mean time series plots for all variables of interest were obtained for each participant by averaging all

included trials. Group mean time series plots used for analyses were obtained by averaging relevant participant means. Normality of participant demographics, PROM scores, and impulse data were explored by visually inspecting boxplots and using Shapiro-Wilk analyses. Data were summarized using means and SDs or medians and IQRs, as appropriate. Demographic characteristics were compared between groups using Mann-Whitney U tests, independent sample t-tests, or Chi square tests as appropriate.

Continuous angle and moment data during the stance phase of running were compared between football players with and without hip/groin pain using a two-sample t-test within the statistical parametric mapping (SPM) package (spm1D v0.4, http://www.spm1D.org) conducted in Python 2.7 (Python™, Python Software Foundation). Alpha level was set at 0.05, and the statistical parametric map (SPM{t}) and critical value of *t* was calculated throughout the stance phase. For each biomechanical variable of interest, the two groups were considered significantly different from each other when SPM{t} exceeded the calculated critical value of *t*. The periods of stance in which the two groups differed were indicated on the SPM{t} trace with a corresponding *P* value. The impulses of the external joint moments were compared between symptomatic and asymptomatic football players using linear regression models adjusted for stance phase speed and foot strike pattern. These two covariates were selected based on previously demonstrated effects on lower-limb kinetics (295, 296). All statistical analysis was completed using Jamovi version 1.6.16.0 (The jamovi project, Sydney, Australia). Sensitivity analyses that excluded outlying impulse data (beyond two standard deviations from the group mean) were undertaken. Level of significance was set at 0.05.

8.5. Results

Demographic characteristics and PROM scores for football players with and without hip/groin pain are presented in **Table 8.1**, stratified by sex. Symptomatic football players reported significantly lower (worse) median PROM scores compared to asymptomatic control football players. No other between-group differences in demographic characteristics existed, except that a lesser proportion of symptomatic men played soccer when compared to asymptomatic men ($P<0.001$).

Table 8.1. Demographic characteristics of football players with and without hip/groin pain.

	WOMEN			MEN		
	Symptomatic (*n*=16)	**Asymptomatic (*n*=13)**	***P* value**	**Symptomatic (*n*=62)**	**Asymptomatic (*n*=25)**	***P* value**
Age (years)	25 [6]	26 [8]	0.91$^{\delta}$	26 [7]	27 [9]	0.33$^{\delta}$
Height (m)	1.69 ± 0.05	1.68 ± 0.07	0.69$^{\varphi}$	1.82 ± 0.06	1.83 ± 0.08	0.53$^{\varphi}$
Mass (kg)	63.2 [11.1]	63.8 [18.0]	0.75$^{\delta}$	79.5 [13.8]	84.0 [13.6]	0.12$^{\delta}$
BMI (kg·m^{-2})	22.8 [2.0]	22.1 [3.7]	0.88$^{\delta}$	24.7 [4.1]	25.2 [3.6]	0.25$^{\delta}$
Running speed (m·s^{-1})	3.6 ± 0.4	3.6 ± 0.3^{a}	0 94$^{\varphi}$	3.5 ± 0.3	3.5 ± 0.2	0.88$^{\varphi}$
Rearfoot strike pattern during running	12 (75%)	10 (77%)	0 90$^{\upsilon}$	55 (89%)	18 (72%)	0.06$^{\upsilon}$
Soccer player	2 (12.5%)	3 (23.1%)	0.45$^{\upsilon}$	8 (12.9%)	12 (48%)	<0.001$^{\upsilon}$
Symptom duration (months)	18.0 [14]	N/A	-	24.0 [42]	N/A	-
Average pain in last week (0-10)	4.0 [4]	N/A	-	4.0 [3]	N/A	-
Bilateral pain	8 (50%)	N/A	-	41 (66%)	N/A	-
Unilateral pain	8 (50%)	N/A	-	21 (34%)	N/A	-
Testing limb						
-Dominant	5 (33%)^{b}	4 (31%)	0.89$^{\upsilon}$	27 (44%)^{c}	11 (44%)	0.98$^{\upsilon}$
-Non-dominant	10 (67%)^{b}	9 (69%)	0.89$^{\upsilon}$	34 (56%)^{c}	14 (56%)	0.98$^{\upsilon}$
-Right	6 (38%)	4 (31%)	0.75$^{\upsilon}$	32 (52%)	11 (44%)	0.52$^{\upsilon}$
-Left	10 (62%)	9 (69%)	0.75$^{\upsilon}$	30 (48%)	14 (56%)	0.52$^{\upsilon}$
iHOT-Total	64 [23]^{b}	100 [2]	<0.001$^{\delta}$	62 [21]^{d}	99 [5]	<0.001$^{\delta}$
HAGOS-Symptoms	57 [15]	100 [1]	<0.001$^{\delta}$	61 [14]	100 [7]	<0.001$^{\delta}$
HAGOS-Pain	70 [25]	100 [0]	<0.001$^{\delta}$	75 [15]	100 [0]	<0.001$^{\delta}$
HAGOS-ADL	85 [21]	100 [0]	<0.001$^{\delta}$	80 [20]	100 [0]	<0.001$^{\delta}$
HAGOS-Sport	66 [27]	100 [0]	<0.001$^{\delta}$	64 [25]	100 [0]	<0.001$^{\delta}$
HAGOS-PA	69 [25]	100 [0]	<0.001$^{\delta}$	63 [25]	100 [0]	<0.001$^{\delta}$
HAGOS-QOL	65 [15]	100 [0]	<0.001$^{\delta}$	60 [19]	100 [0]	<0.001$^{\delta}$

Data presented as median [interquartile range], mean ± standard deviation, or count (%). Between group comparisons made using: Mann-Whitney U tests ($^{\delta}$), independent sample t-tests ($^{\varphi}$), or Chi square tests ($^{\upsilon}$) as appropriate. *P* value indicates statistical significance of between-group comparisons for each sex. Average pain measured using a numerical pain rating scale (0=worst possible score). Sample size variations due to missing/unusable data: n^{a}=12; n^{b}=15; n^{c}=61; and n^{d}=59. Abbreviations: ADL = activities of daily living; BMI = body mass index; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT = International Hip Outcome Tool; PA = participation in physical activities; QOL = quality of life; - = not calculated.

8.5.1 Angle and moment data

Time series plots for lower-limb joint angles and moments, including statistical parametric maps, are presented for men and women in **Figure 8.1** and **Figure 8.2**, respectively. Pelvis angles for both men and women are presented in **Figure 8.3**. No differences in angles and moments during running were identified between symptomatic and asymptomatic football players of the same sex (*P*>0.05*)*.

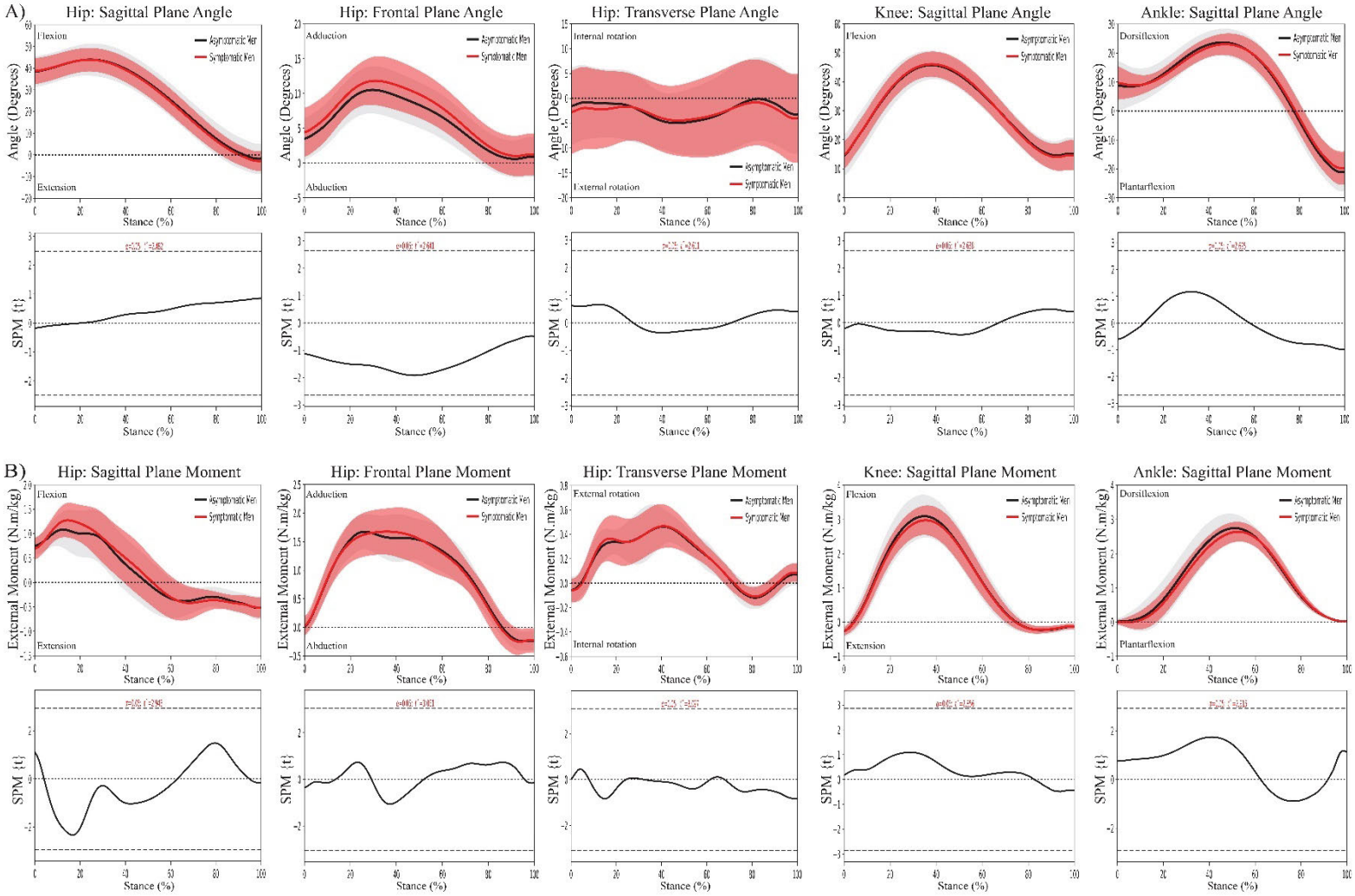


Figure 8.1. Group means and standard deviations, and statistical parametric map (SPM) traces, for lower limb joint angles (A) and external joint moments (B) in men with and without hip and/or groin pain during running.

Abbreviations: t* = critical value of t to indicate between-group difference. Sample sizes: Angle data n=62 symptomatic, n=25 asymptomatic; Moment data n=59 symptomatic, n=23 asymptomatic.

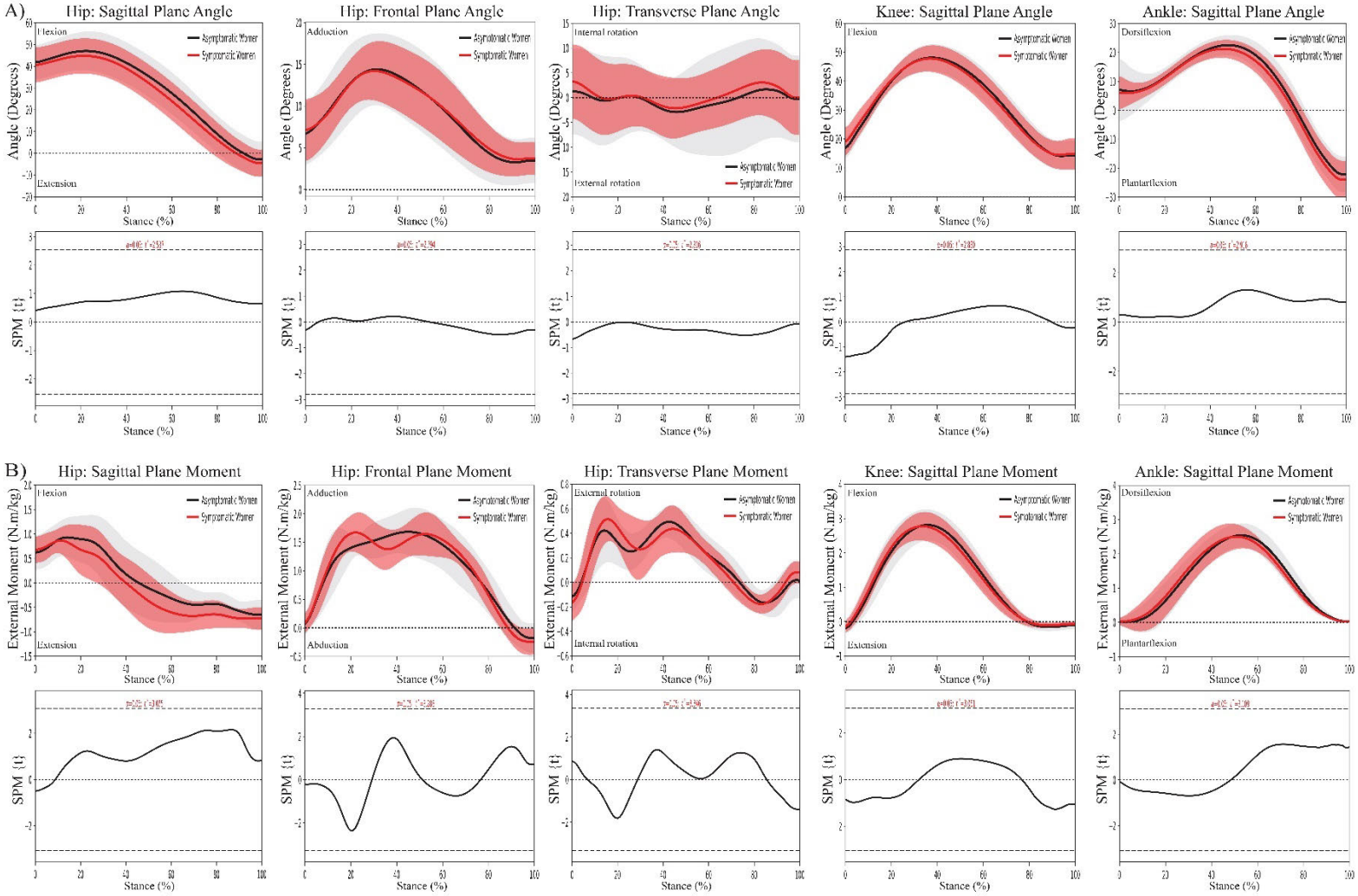


Figure 8.2. Group means and standard deviations, and statistical parametric map (SPM) traces, for lower limb joint angles (A) and external joint moments (B) in women with and without hip and/or groin pain during running.

Abbreviations: t* = critical value of t to indicate between-group difference. Sample sizes: Angle data n=16 symptomatic, n=13 asymptomatic; Moment data n=15 symptomatic, n=13 asymptomatic.

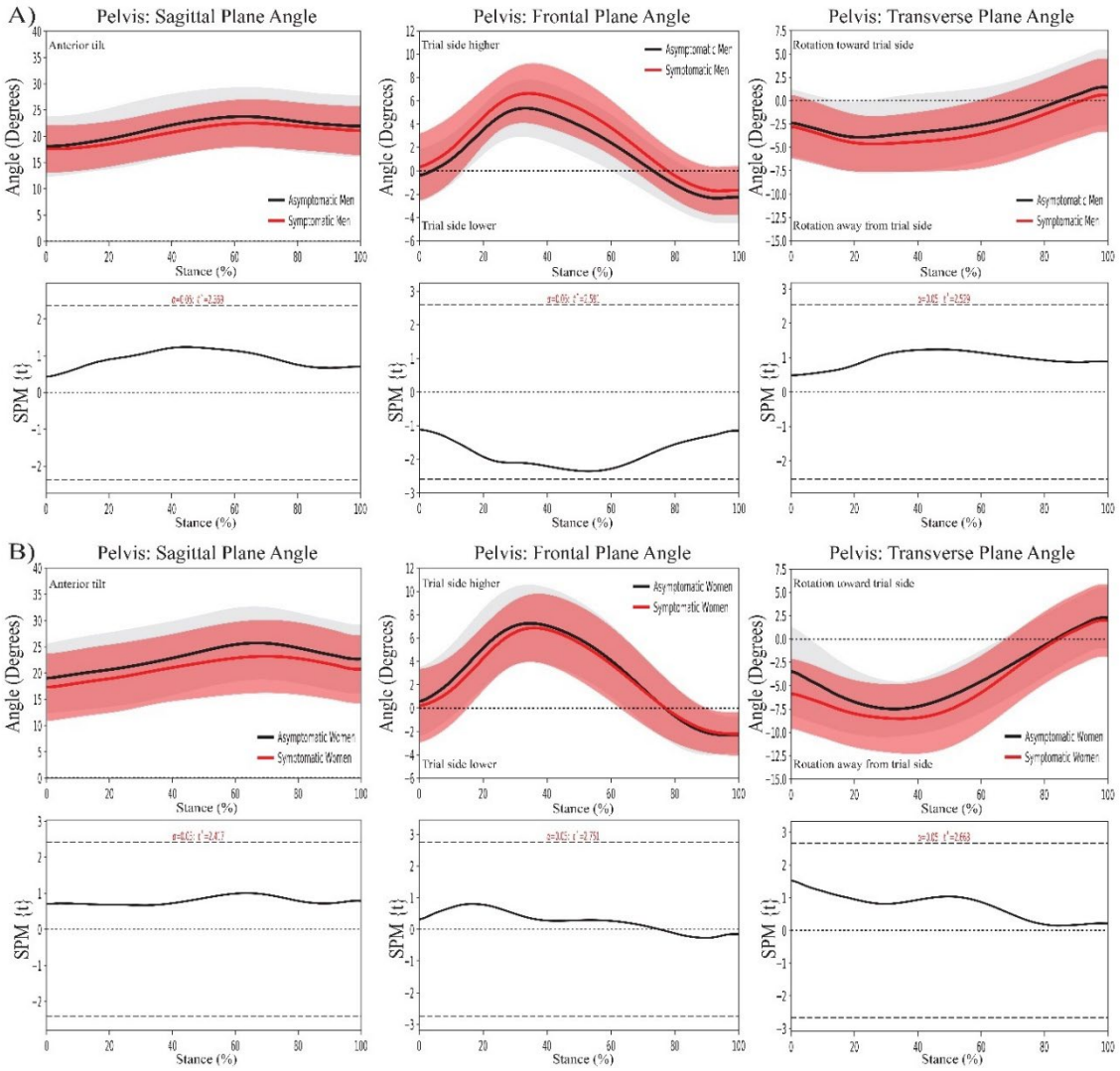


Figure 8.3. Group means and standard deviations, and statistical parametric map (SPM) traces, for pelvis angles in men (A) and women (B) with and without hip and/or groin pain during running.
Abbreviations: t* = critical value of t to indicate between-group difference.

8.5.2 Impulses of lower-limb external joint moments

The impulses of the lower-limb external joint moments during running were not different between symptomatic and asymptomatic football players, when comparing participants of the same sex **Table 8.2**.

Table 8.2. Comparison of the impulses of the lower limb external joint moments during running between football players with and without hip/groin pain.

	WOMEN			MEN		
	Symptomatic (*n*=15)[a] Mean (SD) Median [IQR]	**Asymptomatic (*n*=13)** Mean (SD) Median [IQR]	***P* value**	**Symptomatic (*n*=62)[b]** Mean (SD) Median [IQR]	**Asymptomatic (*n*=25)[c]** Mean (SD) Median [IQR]	***P* value**
Impulse of the external joint moment (N·m·s·kg^{-1}, 10^{-2})						
Hip						
Flexion	6.41 (3.61) 6.16 [5.27]	8.20 (4.55) 6 20 [6.37]	0.18	11.52 (4.91) 11.00 [5.81]	10.08 (4.10) 9.95 [4.52]	0.31
Extension	8.40 (3.93) 7.12 [4.29]	6.60 (4.51) 6.71 [6.17]	0.21	5.24 (2.72) 4.90 [3.45]	5.10 (3.85) 4.24 [4.62]	0.87
Adduction	24.87 (3.66) 24.53 [4.78]	25.20 (4.58) 25.18 [5.17]	0.92	24.92 (3.97) 25.59 [5.00]	24.79 (3.78) 24.89 [5.14]	0.86
External Rotation	5.20 (1.46) 4.54 [1.75]	5.36 (1.52) 5 39 [2.10]	0.90	5.50 (1.62) 5.38 [1.90]	5.31 (1.63) 5.16 [2.51]	0.70
Internal rotation	0.97 (0.50) 0.95 [0.55]	0.94 (0.38) 0.89 [0.53]	0.99	0.59 (0.46) 0.49 [0.45]	0.62 (0.42) 0.54 [0.54]	0.59
Knee						
Flexion	28.60 (5.45) 30.65 [7.12]	29.63 (6.96) 30.51 [7.59]	0.73	30.79 (6.75) 30.61 [9.30]	31.64 (7.92) 32.03 [9.34]	0.54
Ankle						
Dorsiflexion	27.91 (4.99) 26.71 [6.87]	28.56 (4.88) 26.98 [6.81]	0.57	30.53 (4.64) 29.90 [5.18]	31.72 (5.54) 31.65 [7.04]	0.68

Data are presented as means and standard deviations (SD) and medians and interquartile ranges [IQR]. Between-group comparisons made using linear regression models adjusted for stance velocity and foot strike pattern (rearfoot/non-rearfoot). *P* value is the statistical significance of the Group (Symptomatic/Asymptomatic) coefficient. All reported impulses are for the external joint moment. Sample size variations due to corrupt force plate data: n[a]=14; n[b]=59; n[c]=23.

8.5.3 Sensitivity analyses

Sensitivity analyses that excluded the five symptomatic men with two trials demonstrated no statistically significant results (supplementary information, **Section 8.8.1**), consistent with our primary analyses. Analyses that excluded data outliers from impulse linear models also demonstrated no statistically significant findings (**Section 8.8.2**), consistent with our primary analyses.

8.6. Discussion

This study investigated running biomechanics in sub-elite football players with and without hip/groin pain. When compared to asymptomatic football players of the same sex, symptomatic players did not display different pelvis angles or lower-limb joint angles or moments (including the impulses of the joint moments) during the stance phase of running. Although football players with hip/groin pain often experience difficulty when running (**Chapter 4**) (232), our findings suggest that it is unlikely to be due to gross alterations in their running biomechanics.

Our findings contrast with previous studies that have reported differences in lower-limb biomechanics between athletes with and without hip/groin pain during cutting (202), lateral hopping (200), single-leg drop landing (201), and single-leg drop jumping (196, 297). Although evaluating high-impact tasks has been recommended to elucidate more pronounced biomechanical differences between those with and without hip/groin pain (194, 288), we note that only modest between-group differences in lower-limb biomechanics have been observed thus far (196, 200-202). For example, when compared to their asymptomatic counterparts, athletes with longstanding groin pain performed a single-leg drop landing with 1.98° greater peak pelvic drop angle (i.e., lateral tilt of the pelvis toward the contralateral side; small effect size (r) = 0.25) (201), while football players with hip/groin pain performed the single-leg drop jump with 0.7° greater average pelvic hike (i.e., lateral tilt of the pelvis toward the ipsilateral side; small effect size (d) = 0.48) (196). Visual inspection of the data for pelvis angles during running for men (**Figure 8.3**) might suggest a (non-significant) pattern of greater average pelvic drop angle in those with hip/groin pain, when compared to asymptomatic men, but a similar trend was not observed in women. Whilst no significant differences were found between symptomatic and asymptomatic football players of the same sex, we did observe a tendency for hip/groin pain to have a sex-specific association with sagittal plane hip moments during running. More specifically, the impulse of the external hip flexion moment during early stance was approximately 10% greater for symptomatic compared to asymptomatic men (**Figure 8.1**, **Table 8.2**), whereas the opposite was observed for women (**Figure 8.2**, **Table 8.2**). Whilst the reason for this apparent contrasting response is unknown, it lends support for sex-specific analyses when investigating biomechanical impairments in people with hip/groin pain (196, 247, 297). Overall, when the results of the present study are interpreted together with those from previous studies, it seems that biomechanical differences between athletes with and without hip/groin pain may be task- (196, 200-202) and sex-specific (196, 297); however, the magnitudes of such differences are generally small and findings should be interpreted with caution.

Absence of significant between-group differences in lower limb biomechanics might be partly explained by our evaluation of straight-line running at a speed of 3-3.5m·s^{-1}. Although impaired running biomechanics have been previously observed at speeds less than 3.5m·s^{-1} in people with patellofemoral pain (298, 299), achilles tendinopathy (300, 301), and iliotibial band syndrome (294, 302), moderate speed running might have been

insufficiently challenging for active football players with hip/groin pain. Submaximal running might importantly contribute to match-related hip/groin loading (290, 291), but higher-intensity activities, such as rapidly accelerating, sprinting, and cutting to evade an opponent, may be more important for optimal football performance, and may elicit between-group differences if they exist. It is also possible that because our symptomatic football players continued to undertake training and match play, they were well exposed to high-impact tasks and thus able to tolerate running at 3-3.5$m \cdot s^{-1}$ despite their hip/groin pain. Hence, impairments may only be revealed with more challenging multiplanar tasks such as cutting, sidestepping, lateral hopping (200), or kicking (203).

Heterogeneity within our symptomatic group may have confounded our findings. Whilst our broad hip/groin pain classification reflects the diagnostic challenge faced by clinicians (33, 38), it means we investigated a heterogenous cohort that likely included many specific and potentially co-existing conditions (e.g., FAI syndrome and groin pain entities such as adductor-, iliopsoas-, pubic-, and inguinal-related pain). It is possible that different biomechanical profiles exist between these conditions. Moreover, the effect of hip/groin pain on running biomechanics may not be uniform, irrespective of the specific hip/groin pain condition. The adaptation of motor output to pain is thought to protect from further pain and injury, but the adaptation might involve increased, decreased, or re-distributed output within and/or between muscles (303). For example, three distinct movement patterns were previously observed in a cohort of athletes with hip/groin pain during a cutting task (282). These movement patterns, however, were unrelated to participants' clinical diagnoses (282), meaning that different biomechanical profiles might exist between individuals with the same hip/groin pain condition. An additional factor contributing to heterogeneity within our symptomatic group was the high prevalence of contra-lateral hip/groin pain (66% men, 50% women). Given that unilateral pain can trigger bilateral changes to motor output (303), it is likely that the observed running biomechanics variables for the test side for the majority of our symptomatic football players represented an unknown combination of ipsi- and contra-lateral hip/groin pain influences. Ultimately, the biomechanical profiles of football players with persistent hip/groin pain during running and other sporting tasks might be individualised and reflect the complex interplay between optimising functional performance versus protection from further pain/pathology.

There are limitations that should be considered when interpreting our results. First, our symptomatic football players presented with hip/groin pain that likely incorporated intra-

and extra-articular sources of pain. The presence of various hip/groin pain conditions might have contributed to data variability within this group. Whilst hip-related pain can be classified using imaging (38), determining the relevance of these conditions to an individual's hip/groin pain is complicated by the poor utility of clinical tests (38) and the high prevalence of these findings in asymptomatic football players (131, 183). Improved diagnostic utility of clinical tests and imaging may enable future studies to investigate biomechanical patterns in more homogeneous hip/groin pain cohorts. Second, only 26% of our symptomatic football players were women (n=16). Although this representation likely reflects sex-based differences in football participation rates in the community, our small sample of female players reduced our statistical power to detect between-group differences in women. Third, we did not collect self-reported pain before, during, or after participants completed their biomechanical data collection session. We were therefore unable to determine how many players experienced pain, or an increase in pain, during the running trials. Fourth, global measures of joint loading such as moments (and their respective impulses) do not provide any information about site-specific loading (127). It is therefore possible that football players with hip/groin pain exhibited subtle biomechanical impairments during running (e.g., altered pressure distribution within the hip joint) that were undetected by our global metrics. Fifth, we did not include measures of muscle electromyographic activity, which have previously disclosed differences in neuromuscular strategies between people with and without hip/groin pain during walking (304).

Our study may have useful clinical implications. For symptomatic football players who are still capable of participating in training and match play, our results suggest that an assessment of running biomechanics is unlikely to aid diagnosis or guide treatment. In those undertaking treatment programs, running may serve as a pain provocation test to monitor outcomes and guide return to sport planning, but obvious movement pattern impairments are unlikely. Ideally, football players returning to training and match play should not display gross alterations to their running biomechanical patterns, and detecting such changes in an individual might justify altering their return to sport planning.

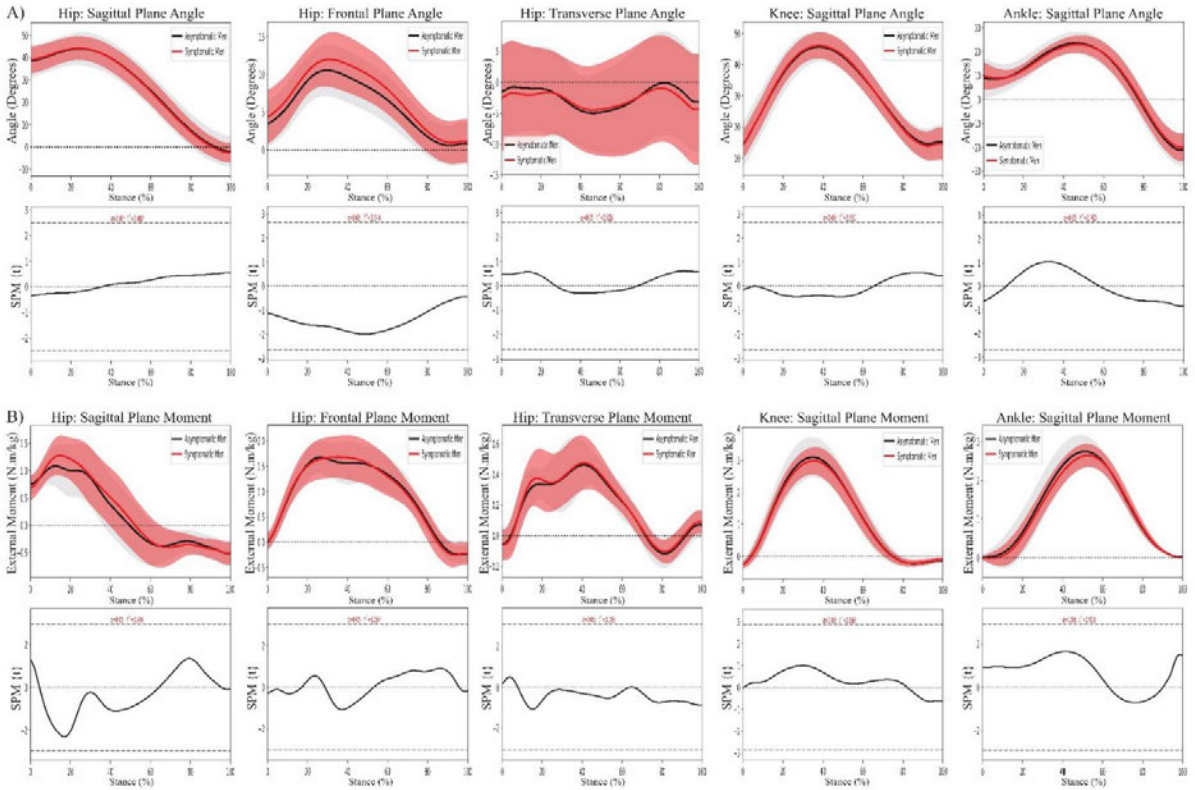
8.7. Conclusion

Football players with and without hip/groin pain did not display differences in running biomechanics, when men and women were analysed separately. Faster running may be more challenging for active football players, thus studies investigating high-speed running

may reveal biomechanical impairments in symptomatic players. Future studies should also aim to examine football players with more specific diagnostic entities and explore the role of localised impairments. For example, in athletes with FAI syndrome, investigating the relationship between running biomechanics and condition-specific features, such as pain severity and cam morphology size, might identify those with more pronounced biomechanical impairments. Running is a cyclical activity that might importantly contribute to cumulative hip joint loading in football players. Knowledge of neuromuscular activity during running in symptomatic athletes might provide insights for joint-specific loading and inform prospective studies investigating worsening hip joint pain and structure over time.

8.8. Supplementary information

8.8.1 Sensitivity analyses excluding men with two running trials only



Group means and standard deviations, and statistical parametric map (SPM) traces, for lower-limb joint angles (A) and moments (B) in men with and without hip and/or groin pain during running. Positive values for angles indicate: hip flexion, hip adduction, hip internal rotation, knee flexion, ankle dorsiflexion. Positive values for external joint moments indicate: hip flexion, hip adduction, hip external rotation, knee flexion, ankle dorsiflexion. Sample sizes: Angle data n=57 symptomatic, n=25 asymptomatic; Moment data n=55 symptomatic, n=23 asymptomatic. Abbreviations: t* = critical value of t to indicate between-group difference.

8.8.2 Between-group comparison of lower-limb external joint moment impulses (data outliers removed)

	WOMEN			MEN		
	Symptomatic (*n*=16)[a] Mean (SD)	**Asymptomatic (*n*=13)** Mean (SD)	*P* value	**Symptomatic (*n*=62)[h]** Mean (SD)	**Asymptomatic (*n*=25)[j]** Mean (SD)	*P* value
Impulse of the external joint moment (N·m·s·kg^{-1}, 10^{-2})						
Hip						
Flexion	6.41 (3.61)	8.20 (4.55)	0.18	11.15 (4.05)[d]	9.62 (3.52)[k]	0.18
Extension	-7.71 (3.00)[b]	-5.73 (3.37)[c]	0.06	4.95 (2.24)[e]	4.50 (2.61)[k]	0.40
Adduction	24.25 (2.87)[b]	25.20 (4.58)	0.60	25.10 (2.81)[f]	24.79 (3.78)	0.76
External Rotation	5 20 (1.46)	5.66 (1.10)[c]	0.50	5.50 (1.39)[g]	5.31 (1.63)	0.60
Internal rotation	-0.88 (0.35)	0.94 (0.38)	0.52	0.52 (0.31)	0.57 (0.36)[k]	0.34
Knee						
Flexion	28.60 (5.45)	29.63 (6.96)	0.73	30.49 (5.94)	31.57 (6.34)[m]	0.45
Ankle						
Dorsiflexion	27.91 (4.99)	28.56 (4.88)	0.57	30.20 (3.69)	31.72 (5.54)	0.39

Data that exceeded two standard deviations (SD) from the relevant group means were removed for sensitivity analyses. Between-group comparisons were made using linear regression models adjusted for stance speed and foot strike pattern (rearfoot/non-rearfoot). *P* value is the statistical significance of the Group (Symptomatic/Asymptomatic) coefficient within the model. All reported impulses are for the external joint moment. Sample size variations due to corrupt force plate data and removal of outliers: n[a]=15 (unless otherwise indicated); n[b]=14; n[c]=12; n[d]=58; n[e]=57; n[f]=54; n[g]=55; n[h]=56 (unless otherwise indicated); n[j]=23 (unless otherwise indicated); n[k]=22; n[m]=21.

Chapter 9. Are running biomechanics associated with self-reported burden or cam morphology size in male football players with FAI syndrome?

9.1. Preface

In people with hip/groin pain, biomechanical impairments may be more evident in those with worse burden (**Section 1.12.2**). Findings from **Chapter 8** indicated that running biomechanics did not differ between football players with and without hip/groin pain, but further investigation of those with FAI syndrome is warranted (305). As a motion-related condition, movement patterns in people with FAI syndrome might be associated with symptom severity and cam morphology size. This chapter aimed to investigate whether running biomechanics were associated with self-reported burden or cam morphology size in male football players with FAI syndrome.

9.2. Abstract

Objective: Investigate whether running biomechanics were associated with 1) self-reported burden or 2) cam morphology size in active male football players with FAI syndrome.

Setting: Biomechanics laboratory.

Participants: Forty-nine male sub-elite football (football or Australian football) players with FAI syndrome (>6 months hip/groin pain, positive FADIR test, and cam morphology (alpha angle ≥60°) with or without pincer morphology (LCEA≥40°)).

Main outcome measures: Discrete pelvis and hip joint angles during the stance phase of overground running (3-3.5ms^{-1}) were investigated for both study aims. External lower-limb joint moment impulses were investigated in the first study aim only. Self-reported burden was evaluated using the iHOT-Symptoms, iHOT-Sport, HAGOS-Symptoms, and HAGOS-Sport subscales (scores 0 to 100). For the second aim, alpha angle on the Dunn 45° radiograph determined anterosuperior cam morphology size. Linear regression models investigated relationships between running biomechanical variables of interest (dependent variables) and the independent variables of self-reported burden (each subscale separately) and cam morphology size. Relationships were investigated unadjusted and adjusted for the covariates of running speed and foot strike pattern. Pseudo R^2 values described the strength of modelled relationships.

Results: Hip joint angles during running were not associated with self-reported burden in football players with FAI syndrome. Lower (i.e., worse) HAGOS-Symptoms and HAGOS-Sport scores were weakly associated with smaller transverse plane pelvis total ROM (unadjusted estimate 0.097 [95%CI 0.021, 0.174], pseudo R^2=0.122, *P*=0.014) and external hip external rotation moment impulse (unadjusted estimate (x10^{-2}) 0.026 [95%CI <0.001, 0.051], pseudo R^2=0.086, *P*=0.048) values, respectively. Larger cam morphology was associated with smaller peak pelvic axial rotation angles at terminal stance (unadjusted estimate -0.059 [95%CI -0.166, -0.002], pseudo R^2=0.085, *P*=0.042) and greater peak hip adduction angles at midstance (adjusted estimate 0.073 [95%CI 0.002, 0.145], *P*=0.045).

Conclusion: Running biomechanics in active football player with FAI syndrome were mostly unrelated to symptom severity and cam morphology size. Whilst relationships existed, the clinical relevance of the weak associations is unclear.

Keywords: Hip joint, Gait analysis, Running, Radiography, Patient-reported outcome measures, Rehabilitation.

9.3. Introduction

Hip/groin pain is common in male football players (4, 28), with FAI syndrome more prevalent in male athletes with longstanding hip/groin pain than in female athletes (6). A motion-related condition, FAI syndrome is thought to be associated with mechanical abutment of femoral and acetabular bony morphology (45). Evidence of impaired lower-limb biomechanics in people with FAI syndrome is mostly limited to low-impact tasks (e.g., walking and single leg squatting) in those seeking surgery (126, 195, 246, 284, 306); however, these findings may not be relevant for symptomatic athletes who are still capable of sport participation.

In people with hip-related pain conditions, biomechanical impairments during functional tasks may be more pronounced in those who report worse burden. For example, people with end-stage hip OA walked with lower sagittal and frontal plane hip joint moments when compared to those with mild-to-moderate hip OA and controls (193). Hip joint offloading during walking is less evident in people with FAI syndrome than in those with end-stage hip OA, with lower hip joint moments observed in the transverse plane only when compared to controls (126). However, a recent study of people seeking surgery for FAI syndrome reported lower sagittal plane hip moments in those with worse self-reported burden (307). The relationship between biomechanical patterns and symptom severity in active football players with FAI syndrome is unknown. **Chapter 8** (305) found that running biomechanics did not differ between football players with and without hip/groin pain; thus, it is prudent to focus on those with FAI syndrome and explore relationships between running biomechanics and symptoms. From the FORCe cohort, we observed that lower (i.e., worse) iHOT-33 scores were associated with biomechanical variables during the single leg drop jump (297). It is possible that greater symptom severity might be related to lower-limb biomechanics in football players with FAI syndrome during sport-specific tasks such as running.

Hip joint bony morphology might also be associated with lower-limb biomechanical patterns in people with FAI syndrome. Large cam morphology (alpha angle >78°) was found to impinge the acetabulum at smaller hip flexion angles during clinical testing when compared to cam morphology (alpha angle 60-78°) (271); however, the relationship between cam morphology size and hip joint biomechanics during tasks such as walking and

squatting is uncertain. In people seeking surgery for FAI syndrome, larger cam morphology was associated with lesser single leg squat depth (308), but unrelated to pelvis or hip joint kinematics during walking or squatting (309). Understanding whether cam morphology size is related to running biomechanics in active football players with FAI syndrome might discern the importance of cam morphology for athletes with FAI syndrome.

Running is fundamental to most field sports. Following on from Study 5 (**Chapter 8**), which found no differences in running biomechanics between football players with and without hip/groin pain, this study will focus on those with FAI syndrome and explore the relationships of running biomechanics with PROMs and cam morphology size. Knowledge of these potential relationships might identify symptomatic players with more pronounced biomechanical impairments. As sex-specific biomechanical differences are evident in people with FAI syndrome (195) and we had insufficient people to investigate men and women separately, this chapter will focus on men only. Investigating high-functioning men with FAI syndrome may improve our understanding of the pathogenesis of the condition and inform interventions for those earlier in the disease process. Therefore, the aims of this study were to investigate the association between running biomechanics and 1) self-reported burden (using the iHOT-33 and the HAGOS) and 2) cam morphology size in male football players with FAI syndrome.

9.4. Methods

9.4.1 Study design and participants

This study investigated 18- to 50-year-old sub-elite football (football or Australian football) players with FAI syndrome who were completing at least two football sessions (training or games) per week. Participants in this study were a subset of the FORCe study (130), a prospective study investigating change in hip joint structure and symptoms over time (**Section 2.2**). Eligibility criteria for the larger FORCe study are published (130) and described in **Section 2.2.4**. Briefly, football players were required to report more than six months of hip/groin pain and have a positive FADIR pain provocation test. Football players were excluded if they: 1) had radiographic hip OA KL score ≥2 (188), 2) had undergone hip or pelvic surgery, or 3) reported a history of significant hip condition (e.g., hip fracture or congenital dislocation of the hip). To be included in this cross-sectional study, participants from the larger cohort needed to have cam morphology (defined by an alpha

angle ≥60° using the Dunn 45° radiograph (63, 269)) and be free from acetabular dysplasia (defined by a LCEA of <20° using the AP radiograph (121, 269)). Female football players were not included in this study, as few women who completed the running biomechanical data collection (305) had cam morphology (n=4). Ethics approval was obtained from the La Trobe University Human Ethics Committee (HEC015-019). Data were collected between August 2015 and August 2018, and written informed consent was obtained prior to participation in the study.

Participants attended the La Trobe University Gait Laboratory for testing, where demographic and anthropometric data including sex, age, height, body mass, football code, and dominant kicking foot (lower-limb dominance) were recorded at the beginning of the session.

9.4.2 Patient reported outcome measures

Self-reported hip/groin burden was quantified using the iHOT-33 (147) and the HAGOS (148), two PROMs that are valid and reliable for use in people with hip-related pain conditions who do not seek surgery (144, 145, 228). The iHOT-33 and HAGOS are described in **Section 2.2.7**, and the measurement properties of the iHOT-33 are reported in **Chapter 3**. Briefly, the iHOT-33 consists of four subscale scores that measure distinct dimensions of hip/groin burden, including 1) symptoms and functional limitations; 2) sport and recreational activities; 3) job-related concerns; and 4) social, emotional, and lifestyle concerns (147, 228). The HAGOS consists of six subscales, including: 1) symptoms; 2) pain; 3) physical function in activities of daily living; 4) physical function during sport and recreational activities; 5) participation in physical activity; and 6) hip and/or groin related quality of life (148). All iHOT-33 and HAGOS scores range from 0 (worst possible score) to 100 (best possible score).

9.4.3 Radiographs

Radiographs were undertaken at a private radiology clinic in Melbourne, Australia (Imaging @ Olympic Park). Participants underwent a supine AP radiograph and Dunn 45° radiograph of each hip according to standardised protocols (130). One blinded assessor (Dr Joshua Heerey) determined the presence of cam and pincer morphology using quantitative methods that have been described previously (**Section 2.2.9**, **Appendix R**) (121, 131).

Briefly, a point set was placed on predetermined locations on the surface of the femur and acetabulum with statistical shape modelling software (ASM toolkit, Manchester University, Manchester, UK). The alpha angle and LCEA were then calculated using MATLAB software v7.1.0 (MathWorks Inc, Natick, Massachusetts, USA). An alpha angle of ≥60° on the Dunn 45° radiograph and an LCEA ≥40° on the AP radiograph defined the presence of cam and pincer morphology, respectively (63, 74, 121). As all participants in this study had FAI syndrome with cam morphology, those with pincer morphology were determined to have FAI syndrome with mixed morphology (15). Moderate-to-good intra- (ICC alpha angle = 0.93; LCEA = 0.94) and inter-observer reliability (ICC alpha angle = 0.93; LCEA = 0.63) were demonstrated for bony hip morphology measures (131).

9.4.4 Biomechanical data collection and processing

Methods used to collect running biomechanics data in our football players with FAI syndrome have been published (305) and described in **Chapter 7**. Briefly, football players wore loose-fitting shorts and Teva Original Universal sandals (Deckers Brands, Goleta, CA) to allow marker placement on specific bony landmarks (130). Marker trajectories were recorded with a 10-camera opto-reflective motion capture system (Vicon Motion Systems Pty Ltd., Oxford, UK) sampling at 100Hz. Ground reaction force data were recorded at a sampling rate of 1000Hz using a force plate (Advanced Mechanical Technology Inc., Watertown, MA, USA) embedded in the laboratory floor. Marker trajectories and GRF data were simultaneously recorded using Vicon Nexus software (Vicon Motion Systems Pty Ltd, Oxford, UK). For overground running trials, participants were instructed to run at a constant pace through the calibrated measurement volume in the centre of the laboratory. Timing gates, placed 5m apart and spanning the centre of the measurement volume, were used to determine the participants running speed for each trial. A successful trial was defined by whole-foot force plate contact at a running speed of 3-3.5m·s^{-1}, with at least four successful trials recorded for each limb (305).

Marker trajectories and GRF data were processed using Vicon Nexus software (Vicon Motion Systems Pty Ltd, Oxford, UK). Data were filtered using a fourth-order, low-pass Butterworth filter with zero lag and a cut-off frequency of 10Hz (276). The start and end of the stance phase was defined by initial contact and toe-off, respectively. Initial contact was defined as the first frame when vertical GRF exceeded 20N, whereas toe-off was defined as the first frame when vertical GRF dropped below 20N (305). Lower-limb joint angle and

moment data were calculated using a seven-segment biomechanical model generated in Vicon BodyBuilder software (Vicon Motion Systems Pty Ltd, Oxford, UK). Hip, knee, and ankle joint angles were calculated using a joint coordinate system convention (281), whereas pelvis angles were calculated with respect to a global (laboratory-based) coordinate system (280). External lower-lower limb joint moments were calculated using a standard inverse dynamics approach. Moments were normalised to body mass ($N \cdot m \cdot kg^{-1}$) and expressed in the same non-orthogonal joint coordinate system used to calculate joint angles. Joint moment data were integrated over the stance phase to calculate the impulse of the external joint moment (area under the curve, $N \cdot m \cdot s \cdot kg^{-1}$), with positive and negative impulses summed independently (305).

Discrete kinematic variables (e.g., peak angle and excursion (i.e., total ROM) values) and joint moment impulses were investigated in this study. Variables were calculated for each individual trial and then averaged across the successful trials for each participant. As both running speed and foot strike pattern can affect lower-limb biomechanics (295, 296), each recorded trial was screened following data processing and prior to statistical analyses (305). Foot strike pattern was classified as "rearfoot" or "non-rearfoot" using visual inspection of reconstructed marker trajectories. Stance phase running speed was calculated by dividing the anterior translation of the sacral marker (m) during the stance phase by the stance phase time (s). Individual trials with outlying foot strike pattern or running speed were excluded (305).

9.4.5 Data management

A single lower limb was selected for analysis per participant. For participants where both hips met the inclusion criteria, the most symptomatic hip (reported from the iHOT-33 question, *"which hip gives you the most trouble?")* was selected. Two participants did not have useable iHOT-33 data (i.e., their reported "most symptomatic" hip did not meet the inclusion criteria of a positive FADIR test result) and were removed from analyses involving the iHOT-33. External joint moment impulses were unable to be calculated for three participants due to erroneous force plate data.

9.4.6 Statistical analysis

To minimise the risk of a type 1 error, PROM subscales and biomechanical variables deemed most relevant for football players were selected *a priori.* Subscales that examine sporting function (iHOT-Sport and HAGOS-Sport) were considered most important for active football players. In addition, HAGOS scores for the larger FORCe cohort in **Chapter 4** suggest that male football players report more symptoms than pain (median subscale scores 60 and 74, respectively). Hence, the iHOT-Sport, iHOT-Symptoms, HAGOS-Sport, and HAGOS-Symptoms subscales were investigated in this study. Biomechanical variables of interest were selected separately for the two aims of our study based on known biomechanical impairments in people with FAI syndrome (126). For the first aim, pelvic and hip joint excursion (i.e., total ROM) were assessed in the three anatomical planes, as well as peak angle values for hip joint flexion, extension, and adduction. External joint moment impulses were selected as kinetic variables of interest, as they consider both magnitude and duration of the moment and provide an estimate of the accumulative joint load during the stance phase (190). Joint moment impulses were assessed in the three planes of the hip, and in the sagittal plane for the knee and ankle. The second aim of this study investigated pelvis and hip joint kinematics only. As bony morphology is likely to impinge in end-of-range positions, peak angle values were examined for the three planes of the pelvis and for the sagittal and frontal planes of the hip joint. Hip joint excursion was examined for the transverse plane, owing to the absence of distinct maximum or minimum values during the stance phase of running, the wide variability of data we observed previously (305), and the low reliability of hip transverse plane kinematic data (310).

Normality of participant demographics and biomechanical variables of interest were assessed using boxplots and Shapiro-Wilk analyses. Continuous data were described using means and SDs or medians and IQRs, as appropriate. Linear regression models were used for both study aims. Relationships between PROM scores (independent variables) and biomechanical variables of interest (dependent variables) were assessed in the first study aim, whereas relationships between cam morphology size (independent variable) and kinematic variables of interest (dependent variables) were assessed in the second. For both study aims, separate linear regression models were built for each independent and dependent variable. Relationships were analysed unadjusted and adjusted for the covariates of foot strike pattern and running speed. Pseudo R^2 values described the strength of modelled relationships. Prior to interpreting results, models were assessed for violations of

assumptions. Residual scatter plots assessed linearity and homoscedasticity, and VIF >10 indicated problematic multicollinearity. Normality of regression model residuals were assessed using residual scatter plots and Shapiro-Wilk analyses. Statistical analyses were completed using the General Analyses for Linear Models module in Jamovi version 1.8.1.0 (The jamovi project, Sydney, Australia). Level of significance was set at 0.05.

9.5. Results

Forty-nine male football players with FAI syndrome participated in this study. **Figure 9.1** summarises participant recruitment and flow. Demographic characteristics, alpha angle, and PROM scores are presented in **Table 9.1**. Discrete kinematic and joint moment impulse variables are reported in **Table 9.2**.

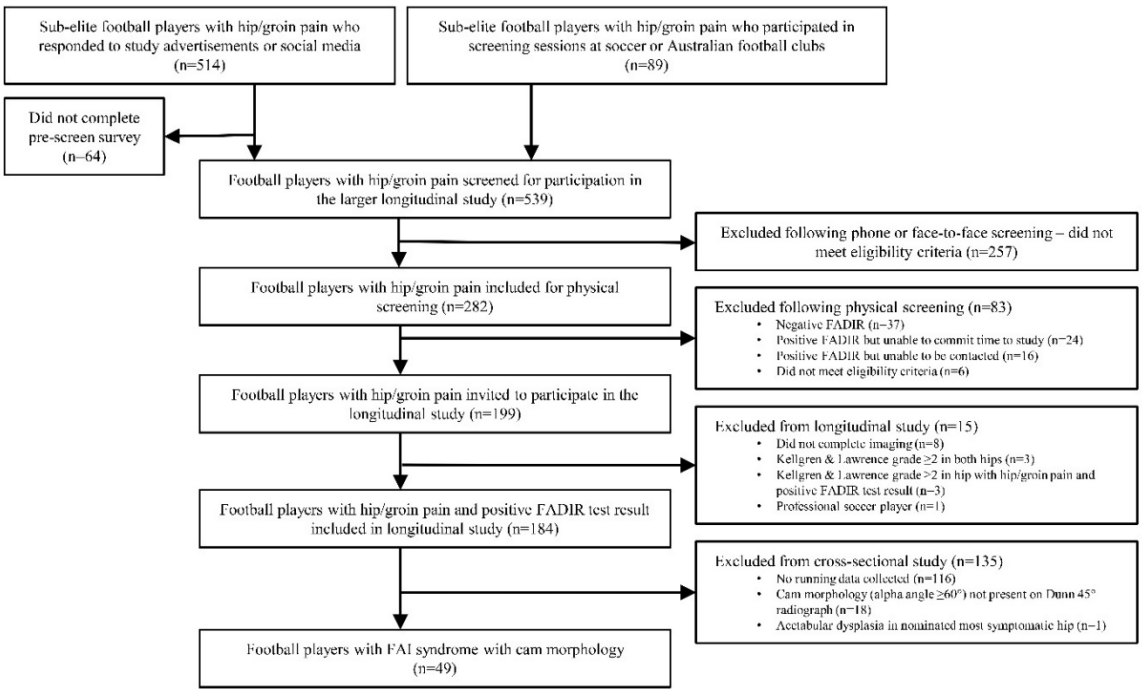


Figure 9.1. Recruitment of male football players with FAI syndrome.
Abbreviations: FADIR = flexion-adduction-internal rotation; FAI = femoroacetabular impingement.

Table 9.1. Demographic characteristics of male football players FAI syndrome.

	Male football players with FAI syndrome (n=49)
Age (years)	26 ± 5
Height (m)	1.82 ± 0.06
Mass (kg)	78.9 [12.0]
BMI ($kg \cdot m^{-2}$)	24.4 [2.7]
Soccer player	7 (14%)
Running speed ($m \cdot s^{-1}$)	3.5 ± 0.3
Rearfoot strike pattern during running	44 (90%)
Average pain in the previous week (0-10)	4.4 ± 1.7
Symptom duration (months)	24 [33][a]
Alpha angle (degrees)	77.1 [15.9]
FAI syndrome with mixed morphology	5 (10%)
Testing limb	
Dominant	19 (40%)[a]
Non-dominant	29 (60%)[a]
Left	24 (49%)
Right	25 (51%)
iHOT-Symptoms	67 [22][b]
iHOT-Sport	51 [23][b]
HAGOS-Symptoms	61 [11]
HAGOS-Sport	66 [25]

Data presented as mean ± standard deviation, median [interquartile range], or count (proportion). Alpha angle measured using the Dunn 45° radiograph. Sample size variations due to missing/unusable data: n^a=48; n^b=47. Abbreviations: BMI = body mass index; FAI = femoroacetabular impingement; HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT = International Hip Outcome Tool.

Table 9.2. Results for lower-limb biomechanical variables of interest.

	Male football players with FAI syndrome (n=49)
Pelvis kinematics (°)	
Sagittal plane	
Excursion	5.9 ± 1.9
Peak anterior tilt	23.0 ± 4.3
Frontal plane	
Excursion	9.4 ± 2.6
Peak pelvic drop	7.2 ± 2.4
Peak pelvic hitch	2.2 ± 2.2
Transverse plane	
Excursion	8.0 ± 3.3
Peak rotation away from stance leg	6.7 ± 2.9
Peak rotation toward stance leg	1.2 ± 2.6
Hip joint kinematics (°)	
Sagittal plane	
Excursion	47.3 ± 5.4
Peak hip flexion	44.2 ± 5.0
Peak hip extension	3.0 ± 4.5
Frontal plane	
Excursion	12.1 ± 3.6
Peak hip adduction	12.4 ± 3.3
Peak hip abduction	-0.3 ± 2.7
Transverse plane	
Excursion	10.3 ± 3.5
Lower-limb joint moment impulses[a] ($N \cdot m \cdot s \cdot kg^{-1} \times 10^{-2}$)	
Hip	
Flexion	11.7 ± 5.4
Extension	5.4 ± 2.5
Adduction	25.0 ± 3.5
External rotation	5.7 ± 1.5
Knee	
Flexion	31.4 ± 6.6
Ankle	
Dorsiflexion	30.5 ± 5.0

Data presented as group mean ± standard deviation. Excursion refers to total range of motion for the relevant anatomical plane. Kinematics measured in degrees. 'External' joint moment impulses presented. Sample size variation for impulse variables due to corrupt force plate data: n^a=46. Abbreviation: FAI = femoroacetabular impingement.

9.5.1 Relationship between PROM scores and running biomechanics

(i) Pelvis angles

Table 9.3 summarises the relationships between PROM scores and pelvis kinematics, and scatterplots are provided in the supplementary information (**Section 9.8.1**). One significant relationship was observed only, with lower (i.e., worse) HAGOS-Symptoms scores associated with smaller pelvic transverse plane excursion during the stance phase of running (unadjusted estimate 0.097 [95%CI 0.021, 0.174], pseudo R^2=0.122, P=0.014). The adjusted model estimate found that as HAGOS-Symptoms scored lowered by 10 points, pelvis transverse plane excursion values were 0.88°smaller.

Table 9.3. Unadjusted and adjusted relationships between PROM scores and pelvis angles during running.

	Sagittal plane excursion		Frontal plane excursion		Transverse plane excursion	
	Unadjusted	**Adjusted**	**Unadjusted**	**Adjusted**	**Unadjusted**	**Adjusted**
iHOT-Symptoms[a]						
Model	$R^2 = 0.004$	$R^2 = 0.008$ ($P = 0.951$)	$R^2 = 0.004$	$R^2 = 0.060$ ($P = 0.442$)	$R^2 = 0.002$	$R^2 = 0.061$ ($P = 0.437$)
b-value	0.007	0.008	-0.010	-0.005	0.008	0.010
95%CI	(-0.027, 0.042)	(-0.027, 0.044)	(-0.058, 0.037)	(-0.053, 0.043)	(-0.049, 0.064)	(-0.047, 0.067)
P value	$P = 0.664$	$P = 0.633$	$P = 0.659$	$P = 0.831$	$P = 0.787$	$P = 0.544$
iHOT-Sport[a]						
Model	$R^2 = 0.04$	$R^2 = 0.007$ ($P = 0.962$)	$R^2 = 0.010$	$R^2 = 0.069$ ($P = 0.377$)	$R^2 = 0.007$	$R^2 = 0.064$ ($P = 0.409$)
b-value	-0.006	-0.006	0.012	0.012	0.012	0.012
95%CI	(-0.032, 0.021)	(-0.033, 0.021)	(-0.024, 0.048)	(-0.024, 0.048)	(-0.032, 0.055)	(-0.031, 0.055)
P value	$P = 0.671$	$P = 0.678$	$P = 0.661$	$P = 0.507$	$P = 0.588$	$P = 0.586$
HAGOS-Symptoms						
Model	$R^2 < 0.001$	$R^2 = 0.003$ ($P = 0.989$)	$R^2 < 0.001$	$R^2 = 0.059$ ($P = 0.428$)	$R^2 = 0.122$	$R^2 = 0.159$ ($P = 0.049$)
b-value	<0.001	<0.001	0.003	<0.001	**0.097**	**0.088**
95%CI	(-0.046, 0.048)	(-0.048, 0.049)	(-0.061, 0.067)	(-0.065, 0.065)	**(0.021, 0.174)**	**(0.010, 0.166)**
P value	$P = 0\ 970$	$P = 0.983$	$P = 0.925$	$P = 0.991$	***P* = 0.014***	***P* = 0.028***
HAGOS-Sport						
Model	$R^2 < 0.001$	$R^2 = 0.003$ ($P = 0.988$)	$R^2 = 0.007$	$R^2 = 0.062$ ($P = 0.406$)	$R^2 = 0.023$	$R^2 = 0.079$ ($P = 0.290$)
b-value	0.002	0.002	0.013	0.008	0.029	0.025
95%CI	(-0.030, 0.035)	(-0.032, 0.035)	(-0.032, 0.057)	(-0.037, 0.052)	(-0.026, 0.085)	(-0.031, 0.081)
P value	$P = 0.886$	$P = 0.922$	$P = 0.571$	$P = 0.720$	$P = 0.294$	$P = 0.380$

Significant relationship ($P<0.05$) between PROM scores and running biomechanical variables indicated by **bold text***. R^2 indicates pseudo R^2 values. Excursion refers to total range of motion for the relevant anatomical plane. Sample size variation: n[a]=47. Abbreviations: HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT = International Hip Outcome Tool; PROM = patient-reported outcome measure; 95%CI = 95% confidence interval.

(ii) *Hip joint angles*

Patient-reported outcome measure scores were not associated with hip joint angles during the stance phase of running ($P>0.05$) (**Table 9.4** and scatterplots in **Section 9.8.2**).

(iii) Lower-limb joint moment impulses

Lower HAGOS-Sport scores were associated with smaller (external) hip external rotation moment impulses (unadjusted estimate ($x10^{-2}$) 0.026 [95%CI <0.001, 0.051], R^2=0.086, P=0.048) (**Table 9.5** and scatterplots in **Section 9.8.3**). Adjusted model estimates found that as HAGOS-Sport scores lowered by 10 points, hip external rotation moment impulses were 0.27 x 10^{-2} $N{\cdot}m{\cdot}s{\cdot}kg^{-1}$ smaller.

Table 9.4. Unadjusted and adjusted relationships between PROM scores and hip joint angles during running.

	Peak hip flexion		Peak hip extension		Sagittal plane excursion		Peak hip adduction		Frontal plane excursion		Transverse plane excursion	
	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted
iHOT-Symptoms[a]												
Model	$R^2 = 0.039$	$R^2 = 0.069$ ($P = 0.373$)	$R^2 < 0.001$	$R^2 = 0.284$ ($P = 0.002$)	$R^2 = 0.037$	$R^2 = 0.278$ ($P = 0.003$)	$R^2 = 0.007$	$R^2 = 0.076$ ($P = 0.332$)	$R^2 < 0.001$	$R^2 = 0.032$ ($P = 0.700$)	$R^2 = 0.003$	$R^2 = 0.103$ ($P = 0.194$)
b-value	-0.060	-0.053	-0.004	0.010	-0.064	-0.044	-0.017	-0.019	-0.003	<0.001	0.011	0.017
95%CI	(-0.149, 0.029)	(-0.144, 0.037)	(-0.085, 0.078)	(-0.062, 0.081)	(-0.161, 0.034)	(-0.131, 0.043)	(-0.076, 0.042)	(-0.077, 0.040)	(-0.070, 0.063)	(-0.068, 0.067)	(-0.052, 0.075)	(-0.046, 0.079)
P value	$P = 0.181$	$P = 0.242$	$P = 0.930$	$P = 0.675$	$P = 0\ 194$	$P = 0.316$	$P = 0.566$	$P = 0\ 527$	$P = 0.926$	$P = 0.985$	$P = 0.722$	$P = 0.589$
iHOT-Sport[a]												
Model	$R^2 = 0.008$	$R^2 = 0.047$ ($P = 0.553$)	$R^2 = 0.041$	$R^2 = 0.323$ ($P<0.001$)	$R^2 = 0.007$	$R^2 = 0.268$ ($P = 0.004$)	$R^2 = 0.004$	$R^2 = 0.071$ ($P = 0.364$)	$R^2 = 0.010$	$R^2 = 0.042$ ($P = 0.599$)	$R^2 = 0.050$	$R^2 = 0.147$ ($P = 0.076$)
b-value	0.021	0.021	-0.042	-0.042	-0.021	-0.021	-0.009	-0.009	0.017	0.017	-0.036	-0.036
95%CI	(-0.049, 0.090)	(-0.049, 0.091)	(-0.104, 0.019)	(-0.095, 0.011)	(-0.097, 0.055)	(-0.088, 0.046)	(-0.054, 0.036)	(-0.054,0.035)	(-0.034, 0.068)	(-0.034, 0.068)	(-0.084, 0.011)	(-0.082, 0.010)
P value	$P = 0.548$	$P = 0.547$	$P = 0.175$	$P = 0.116$	$P = 0\ 576$	$P = 0.527$	$P = 0.682$	$P = 0.677$	$P = 0.506$	$P = 0.509$	$P = 0.131$	$P = 0.120$
HAGOS-Symptoms												
Model	$R^2 = 0.015$	$R^2 = 0.053$ ($P = 0.478$)	$R^2 = 0.003$	$R^2 = 0.277$ ($P = 0.002$)	$R^2 = 0.005$	$R^2 = 0.268$ ($P = 0.003$)	$R^2 = 0.001$	$R^2 = 0.051$ ($P = 0.493$)	$R^2 < 0.001$	$R^2 = 0.030$ ($P = 0.$)	$R^2 < 0.001$	$R^2 = 0.111$ ($P = 0.147$)
b-value	-0.052	-0.048	0.020	-0.012	-0.032	-0.060	-0.010	-0.022	-0.009	-0.019	-0.009	-0.026
95%CI	(-0.176, 0.072)	(-0.174, 0.079)	(-0.091, 0.132)	(-0.111, 0.087)	(-0.166, 0.102)	(-0.180, 0.060)	(-0.092, 0.072)	(-0.105, 0.062)	(-0.100, 0.081)	(-0.112, 0.074)	(-0.095, 0.078)	(-0.111, 0.059)
P value	$P = 0.401$	$P = 0.452$	$P = 0.718$	$P = 0.805$	$P = 0.634$	$P = 0.321$	$P = 0.804$	$P = 0.605$	$P = 0.834$	$P = 0.683$	$P = 0.841$	$P = 0.546$
HAGOS-Sport												
Model	R^2=0.002	$R^2 = 0.045$ ($P = 0.556$)	$R^2 = 0.003$	$R^2 = 0.277$ ($P = 0.002$)	R^2<0.001	$R^2 = 0.256$ ($P = 0.004$)	$R^2 = 0.007$	$R^2 = 0.052$ ($P = 0.492$)	$R^2 = 0.012$	$R^2 = 0.035$ ($P = 0.658$)	$R^2 = 0.017$	$R^2 = 0.134$ ($P = 0.088$)
b-value	-0.013	-0.018	0.013	0.005	<0.001	-0.023	0.016	0.015	0.023	0.020	-0.027	-0.036
95%CI	(-0.099, 0.073)	(-0.105, 0.069)	(-0.064, 0.090)	(-0.063, 0.072)	(-0.093, 0.093)	(-0.105, 0.060)	(-0.040, 0.073)	(-0.042, 0.072)	(-0.039, 0.086)	(-0.044, 0.083)	(-0.086, 0.032)	(-0.093, 0.022)
P value	$P = 0.756$	$P = 0.681$	$P = 0.730$	$P = 0.891$	$P = 0\ 999$	$P = 0.586$	$P = 0.562$	$P = 0.600$	$P = 0.455$	$P = 0.537$	$P = 0.365$	$P = 0.217$

R^2 indicates pseudo R^2 values. Excursion refers to total range of motion for the relevant anatomical plane Sample size variation: n[a]=47. Abbreviations: HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT = International Hip Outcome Tool; PROM = patient-reported outcome measure; 95%CI = 95% confidence interval.

Table 9.5. Unadjusted and adjusted relationships between PROM scores and external hip joint moment impulses during running.

	Hip moment impulse								Knee moment impulse		Ankle moment impulse	
	Flexion		Extension		Adduction		External rotation		Flexion		Dorsiflexion	
	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Adjusted	Unadjusted	Unadjusted	Adjusted
iHOT-Symptoms[a]												
Model	$R^2 = 0.008$	$R^2 = 0.020$ ($P = 0.0842$)	$R^2 = 0.009$	$R^2 = 0.031$ ($P = 0.734$)	$R^2 = 0.001$	$R^2 = 0.019$ ($P = 0.860$)	$R^2 = 0.045$	$R^2 = 0.114$ ($P = 0.180$)	$R^2 = 0.003$	$R^2 = 0.065$ ($P = 0.439$)	$R^2 < 0.001$	$R^2 = 0\ 307$ ($P = 0.002$)
b-value	-0.028	-0.023	0.014	0.015	-0.008	-0.011	0.019	0.018	0.022	0.026	0.002	-0.022
95%CI	(-0.129, 0.073)	(-0.127, 0.081)	(-0.032, 0.060)	(-0.032, 0.063)	(-0.073, 0.057)	(-0.078, 0.055)	(-0.008, 0.045)	(-0.008, 0.045)	(-0.097, 0.142)	(-0.095, 0.146)	(-0.093, 0.097)	(-0.104, 0.060)
P value	$P = 0.574$	$P = 0.653$	$P = 0.544$	$P = 0.523$	$P = 0.804$	$P = 0.729$	$P = 0.168$	$P = 0.174$	$P = 0.708$	$P = 0.668$	$P = 0.964$	$P = 0.590$
iHOT-Sport[a]												
Model	$R^2 < 0.001$	$R^2 = 0.015$ ($P = 0.891$)	$R^2 < 0.001$	$R^2 = 0.021$ ($P = 0.833$)	$R^2 = 0.003$	$R^2 = 0.019$ ($P = 0.859$)	$R^2 = 0.027$	$R^2 = 0.096$ ($P = 0.250$)	$R^2 = 0.002$	$R^2 = 0.062$ ($P = 0.462$)	$R^2 < 0.001$	$R^2 = 0\ 302$ ($P = 0.002$)
b-value	-0.001	<0.001	0.001	0.001	-0.009	-0.009	0.012	0.011	0.012	0.011	0.006	0.005
95%CI	(-0.083, 0.080)	(-0.084, 0.082)	(-0.038, 0.036)	(-0.037, 0.039)	(-0.060, 0.043)	(-0.062, 0.044)	(-0.010, 0.033)	(-0.010, 0.033)	(-0.084, 0.108)	(-0.085, 0.107)	(-0.070, 0.083)	(-0.061, 0.070)
P value	$P = 0.974$	$P = 0.988$	$P = 0.957$	$P = 0.942$	$P = 0.738$	$P = 0.728$	$P = 0.288$	$P = 0.289$	$P = 0.802$	$P = 0.818$	$P = 0.866$	$P = 0.886$
HAGOS-Symptoms[b]												
Model	$R^2 < 0.001$	$R^2 = 0.014$ ($P = 0.896$)	$R^2 = 0.013$	$R^2 = 0.037$ ($P = 0.661$)	$R^2 = 0.010$	$R^2 = 0.027$ ($P = 0.767$)	$R^2 = 0.021$	$R^2 = 0.107$ ($P = 0.187$)	$R^2 = 0.006$	$R^2 = 0.067$ ($P = 0.399$)	$R^2 = 0.008$	$R^2 = 0\ 302$ ($P = 0.002$)
b-value	0.009	0.005	0.025	0.019	-0.030	-0.024	0.019	0.025	0.046	0.068	-0.039	-0.037
95%CI	(-0.132, 0 150)	(-0.141, 0.151)	(-0.040, 0.090)	(-0.048, 0.086)	(-0.121, 0.062)	(-0.119, 0.070)	(-0.020, 0.057)	(-0.013, 0.064)	(-0.128, 0.221)	(-0.108, 0.244)	(-0.171, 0.093)	(-0.152, 0.078)
P value	$P = 0.898$	$P = 0.946$	$P = 0.445$	$P = 0.566$	$P = 0\ 518$	$P = 0.607$	$P = 0.338$	$P = 0.194$	$P = 0.596$	$P = 0.438$	$P = 0.554$	$P = 0.520$
HAGOS-Sport[b]												
Model	$R^2 = 0.010$	$R^2 = 0.027$ ($P = 0.759$)	$R^2 = 0.033$	$R^2 = 0.059$ ($P = 0.461$)	$R^2 < 0.001$	$R^2 = 0.021$ ($P = 0.828$)	$R^2 = 0.086$	$R^2 = 0.165$ ($P = 0.053$)	$R^2 = 0.031$	$R^2 = 0.085$ ($P = 0.287$)	$R^2 = 0.008$	$R^2 = 0\ 295$ ($P = 0.002$)
b-value	-0.031	-0.037	0.027	0.026	<0.001	0.004	**0.026**	**0.027**	0.070	0.070	-0.026	-0.007
95%CI	(-0.127, 0.065)	(-0.135, 0.061)	(-0.017, 0.071)	(-0.019, 0.071)	(-0.062, 0.004)	(-0.060, 0.069)	**(<0.001, 0.051)**	**(0.002, 0.053)**	(-0.048, 0.187)	(-0.048, 0.188)	(-0.116, 0.064)	(-0.085, 0.072)
P value	$P = 0.513$	$P = 0.453$	$P = 0.230$	$P = 0.255$	$P = 0\ 977$	$P = 0.894$	**$P = 0.048$***	**$P = 0.034$***	$P = 0.239$	$P = 0.237$	$P = 0.562$	$P = 0.863$

R^2 indicates pseudo R^2 values. Values for external moment impulses, model estimates (b-value), and 95% confidence intervals (95%CI) multiplied by 10^2. Significant relationship ($P<0.05$) between PROM score and impulse variable indicated by **bold text***.Sample size variations: n^a=44; n^b=46. Abbreviations: HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT = International Hip Outcome Tool; PROM = patient-reported outcome measure; ROM = range of motion; 95%CI = 95% confidence interval.

9.5.2 Relationship between alpha angle and running biomechanics

Table 9.6 summarises the relationships between alpha angle and pelvis (A) and hip joint (B) kinematics, respectively. Scatterplots are provided in the supplementary information (**Section 9.8.4**). Larger alpha angles were associated with smaller peak pelvic rotation angles toward the stance leg (unadjusted estimate -0.059 [95%CI -0.166, -0.002], R^2=0.085, *P*=0.042) during the stance phase of running. Alpha angles were not related to hip joint kinematics in univariable models; however, larger alpha angles were associated with greater peak hip adduction angles in multivariable (adjusted) models that controlled for the effects of foot strike pattern and running speed (adjusted estimate 0.073 [95%CI 0.002, 0.145], *P*=0.045). Adjusted model estimates found that for every 10° increment in alpha angle above 60°, peak pelvic rotation angles toward the stance leg and peak hip adduction angles were lower by 0.64° and 0.73°, respectively.

Table 9.6. Unadjusted and adjusted relationships between alpha angle and pelvis (A) and hip joint (B) kinematics during running.

A) Pelvis angles

	Peak anterior tilt		**Peak pelvic drop**		**Peak pelvic hitch**		**Peak rotation toward stance leg**		**Peak rotation away from stance leg**	
	Unadjusted	**Adjusted**	**Unadjusted**	**Adjusted**	**Unadjusted**	**Adjusted**	**Unadjusted**	**Adjusted**	**Unadjusted**	**Adjusted**
Alpha angle Model	$R^2 = 0.005$	$R^2 = 0.036$ ($P = 0.643$)	$R^2 = 0.009$	$R^2 = 0.057$ ($P = 0.448$)	$R^2 = 0.072$	$R^2 = 0.119$ ($P = 0.123$)	$R^2 = 0.085$	$R^2 = 0.106$ ($P = 0.164$)	$R^2 = 0.004$	$R^2 = 0.119$ ($P = 0.124$)
b-value	-0.022	-0.029	0.017	0.024	-0.045	-0.048	**-0.059**	**-0.064**	-0.014	<0.001
95%CI	(-0.118, 0.074)	(-0.127, 0.069)	(-0.037, 0.071)	(-0.030, 0.079)	(-0.093, 0.002)	(-0.096, <0.001)	**(-0.166, -0.002)**	**(-0.122, -0.005)**	(-0.078, 0.050)	(-0.063, 0.062)
P value	$P = 0.646$	$P = 0.552$	$P = 0.526$	$P = 0$ 372	$P = 0.062$	$P = 0.052$	***P* = 0.042***	***P* = 0.034***	$P = 0.660$	$P = 0.983$

B) Hip joint angles

	Peak hip flexion		**Peak hip extension**		**Peak hip adduction**		**Peak hip abduction**		**Transverse plane excursion**	
	Unadjusted	**Adjusted**	**Unadjusted**	**Adjusted**	**Unadjusted**	**Adjusted**	**Unadjusted**	**Adjusted**	**Unadjusted**	**Adjusted**
Alpha angle Model	$R^2 = 0.006$	$R^2 = 0.047$ ($P = 0.532$)	$R^2 = 0.024$	$R^2 = 0.280$ ($P = 0.002$)	$R^2 = 0.065$	$R^2 = 0.128$ ($P = 0.101$)	$R^2 = 0.045$	$R^2 = 0.072$ ($P = 0.331$)	$R^2 = 0.074$	$R^2 = 0.152$ ($P = 0.058$)
b-value	-0.030	-0.030	-0.053	-0.022	0.064	**0.073**	-0.044	-0.045	-0.072	-0.059
95%CI	(-0.141, 0.082)	(-0.144, 0.083)	(-0.152, 0.046)	(-0.110, 0.066)	(-0.007, 0.135)	**(0.002, 0.145)**	(-0.104, 0.016)	(-0.106, 0.017)	(-0.147, 0.002)	(-0.133, 0.016)
P value	$P = 0.595$	$P = 0.592$	$P = 0.285$	$P = 0.616$	$P = 0.078$	***P* = 0.045***	$P = 0.142$	$P = 0$ 148	$P = 0.058$	$P = 0.118$

R^2 indicates pseudo R^2 values. Significant relationship ($P<0.05$) between alpha angle and running biomechanical variable indicated by **bold text***. Excursion refers to total range of motion for the relevant anatomical plane Abbreviation: 95%CI = 95% confidence interval.

9.6. Discussion

Relationships between running biomechanics and self-reported burden and cam morphology size were studied in active male football players with FAI syndrome. Overall, few significant relationships were observed. Self-reported hip/groin burden (as measured using the iHOT-Symptoms, iHOT-Sport, HAGOS-Symptoms, and HAGOS-Sport scores) was not associated with hip joint kinematics during running. Lower (i.e., worse) HAGOS-Symptoms and HAGOS-Sport scores were weakly associated with smaller transverse plane pelvis excursion and external hip external rotation moment impulse values, respectively. Cam morphology size was mostly unrelated to pelvis and hip joint kinematics in the football players with FAI syndrome. Two significant relationships were identified, with larger cam morphology associated with less pelvic rotation toward the stance leg during late stance phase and larger peak hip adduction angles at midstance. All observed relationships were weak, with less than 12% of the variance in biomechanical data explained by PROM scores or cam morphology size. In male football players with FAI syndrome who are participating in training and match play, running biomechanics appear mostly unrelated to symptom severity or cam morphology size.

Relationships between self-reported burden and lower-limb biomechanics during running were modest and limited to the transverse plane in our football players with FAI syndrome. Participants with worse HAGOS-Symptoms and HAGOS-Sport scores ran with less pelvis transverse plane excursion and smaller hip external rotation moment impulses, respectively, than those who were less symptomatic. Interestingly, a recent study of male FORCe participants found they walked with smaller transverse plane pelvis excursion and hip moment impulses when compared to asymptomatic players (196). In players with FAI syndrome, subtle reductions to pelvis ROM and transverse plane hip moment impulses in those with worse burden might suggest a strategy to avoid potentially painful hip joint loads during running. However, if biomechanics were a likely cause of hip/groin pain, we might have expected worse symptoms to be associated with higher hip joint loads (impulse), particularly in variables of greater magnitude (e.g., sagittal or frontal plane moment impulses). Overall, the clinical relevance of the observed relationships is uncertain given the weak relationships (pseudo R^2 values 0.086 to 0.097) and the absence of relationships between these biomechanical variables and other PROM scores.

Larger cam morphology was weakly associated with greater peak hip adduction and smaller peak pelvic axial rotation angles during running. When compared to controls, individuals with FAI syndrome have rarely displayed altered hip adduction ROM during activities of daily living (e.g., walking, squatting, stair ambulation) (126). During running, a larger peak hip adduction angle at midstance might increase a player's risk of bony impingement and pain. Whilst peak hip adduction angle was not associated with self-reported burden, strategies to reduce peak hip adduction during running might be useful for male football players with FAI syndrome, given the long-term implications of larger cam morphology are unknown. It should also be considered that the relationship, although significant, was not strong and that other factors not examined in this thesis, such as strength deficits (52) or other femoral bony morphologies (e.g., femoral antetorsion) (311), might explain more of the variance in peak hip adduction angles in our cohort. Larger cam morphology was also modestly associated with smaller peak pelvis axial rotation angles during late stance phase. This might represent a strategy to avoid potentially painful bony impingement during late stance phase, although other hip and pelvis angles were not associated with cam morphology size during this period. Overall, our findings indicate that cam morphology size was mostly unrelated to pelvis and hip joint kinematics during running at 3-3.5ms^{-1}; longitudinal studies can determine whether running biomechanics in those with larger cam morphology change over time.

There are limitations associated with this study that should be acknowledged. First, the Dunn 45° radiograph does not provide three-dimensional visualisation of the femoral head-neck junction, potentially affecting cam morphology measurements and thus relationships with pelvis and hip kinematics. However, radiographic evaluation of cam morphology size using the Dunn 45° radiograph has demonstrated adequate correlation with CT (266) and MRI (256, 265). We also did not investigate relationships between superior cam morphology (as measured using the anteroposterior pelvis radiograph) and pelvis and hip joint kinematics. We previously reported that superior cam morphology was unrelated to self-reported burden in people with FAI syndrome (**Chapter 6**) (312); however, we acknowledge that relationships might exist with biomechanics during running. Second, female football players were not included in this study. Given that we have reported sex-specific differences in lower-limb biomechanics between football players with and without hip/groin pain (196), it is likely that the relationships examined in this study may differ between men and women with FAI syndrome. Improved knowledge of lower limb biomechanics in women with FAI syndrome is needed (194). Third, we did not collect self-

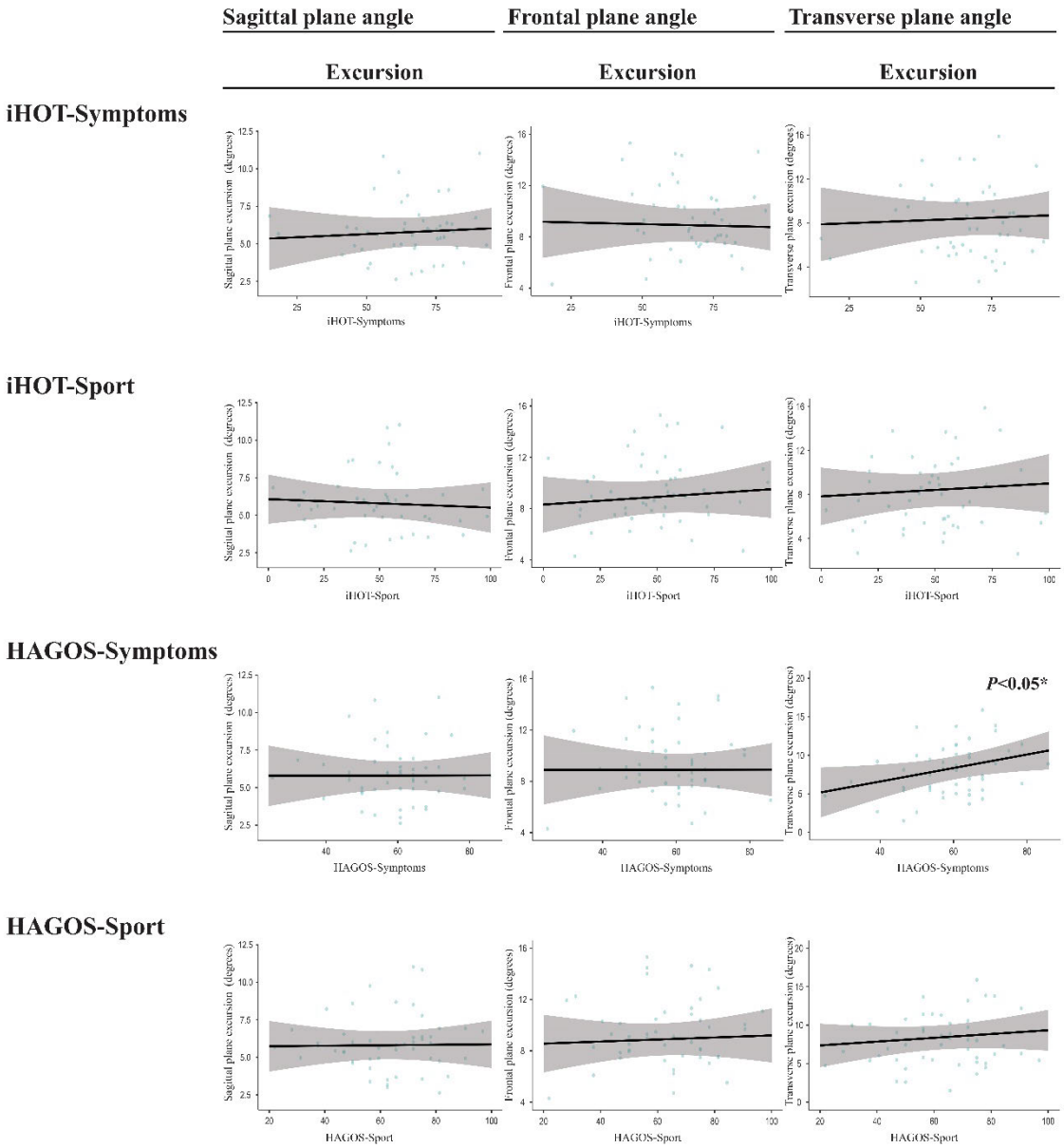
reported pain severity from participants whilst collecting running biomechanics data. We were therefore unable to determine how many players experienced pain during the running trials. Fourth, our global biomechanical measures do not provide information about site-specific loading within the hip joint (127). It is therefore possible that subtle biomechanical alterations were present in the hips of participants with worse symptoms or larger cam morphology, which were undetected by our global metrics. Fifth, it is possible that the moderate running speed investigated in this study did not require large enough hip ROM to elucidate relationships between hip joint biomechanics and self-reported burden or cam morphology size, if they existed. Finally, whilst PROM and biomechanical variables were selected *a priori* based on previous literature, the exploratory nature of our study and our decision to not adjust for multiple comparisons may have increased the chance of a type I error.

9.7. Conclusion

Running biomechanics in active football player with FAI syndrome were mostly unrelated to symptom severity or cam morphology size. Hip joint angles were not associated with self-reported burden (iHOT-Symptoms, iHOT-Sport, HAGOS-Symptoms, HAGOS-Sport scores). Lower (i.e., worse) HAGOS-Symptoms and HAGOS-Sport scores were weakly associated with smaller transverse plane pelvis excursion and (external) hip external rotation moment impulse values, respectively, but the clinical significance of these findings is uncertain. Larger cam morphology was modestly associated with larger peak hip adduction angles and smaller peak pelvis axial rotation angles during the stance phase of running. While considered a motion-related disorder, running biomechanics in football players with FAI were not largely influenced by symptoms or cam morphology size. Investigation of higher-impact tasks, or tasks that demand greater hip ROM, might identify other relationships with lower-limb biomechanics in people with FAI syndrome.

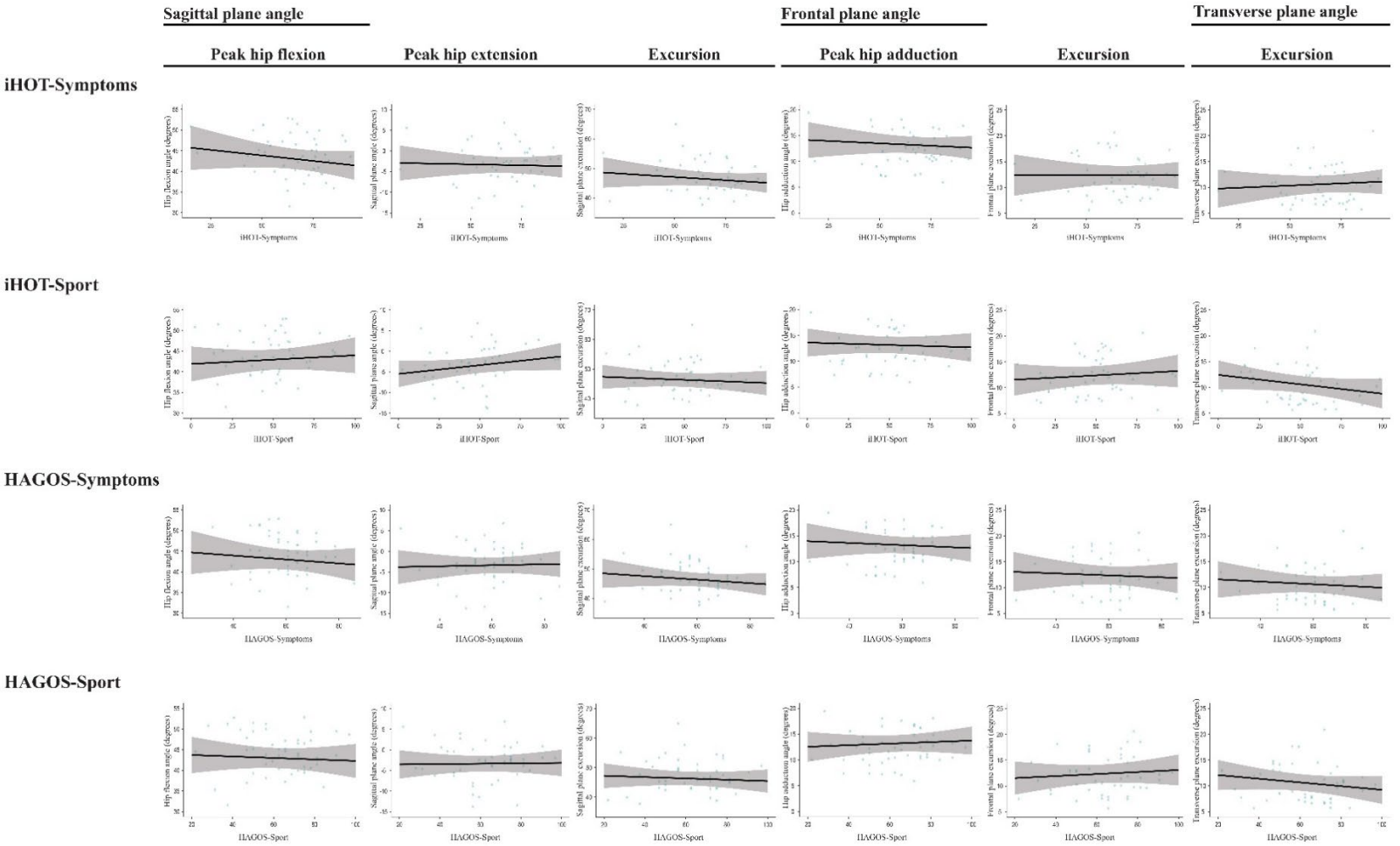
9.8. Supplementary information

9.8.1 Scatterplots of adjusted relationships between PROM scores and pelvis angles



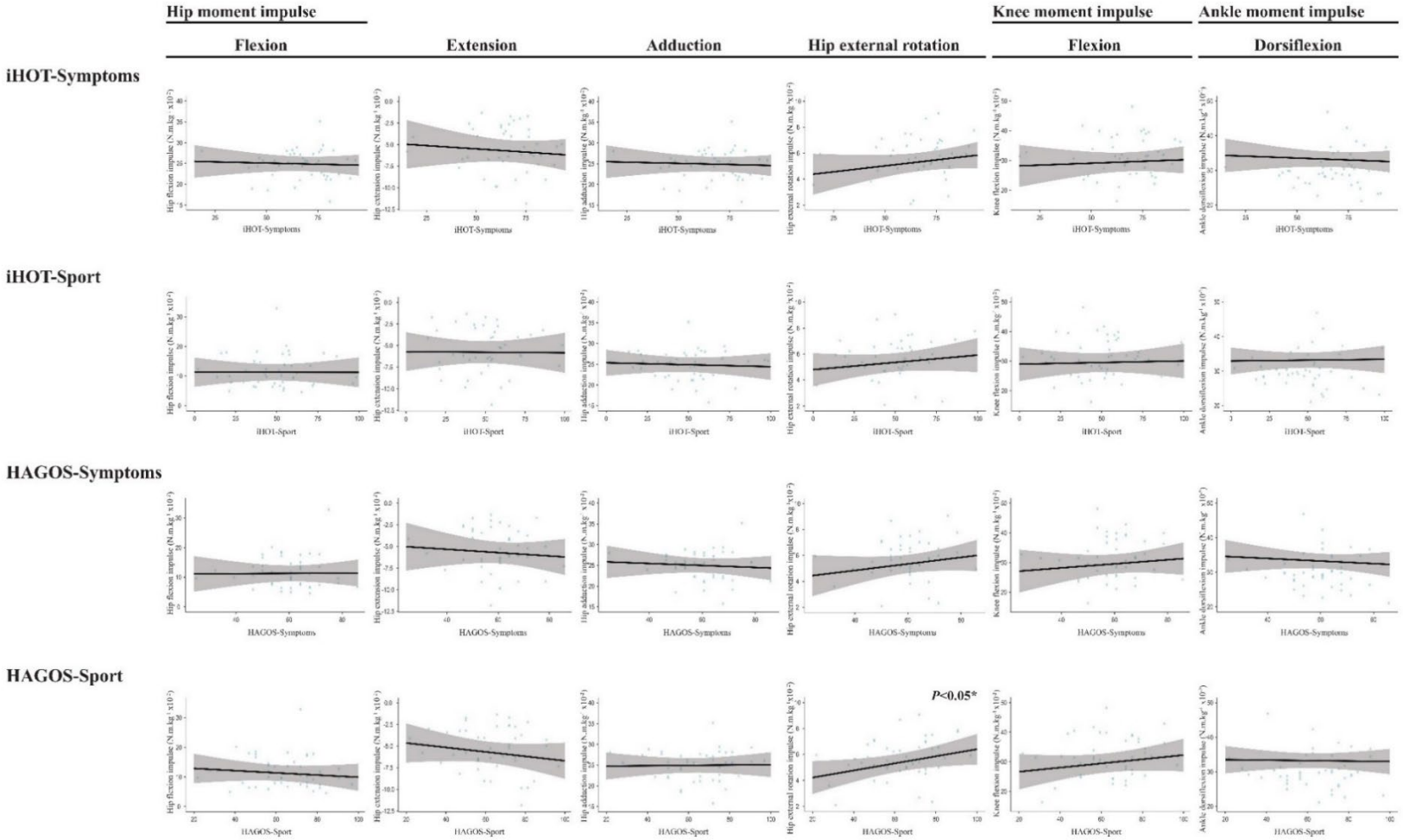
Relationships analysed unadjusted and adjusted for the covariates of foot strike pattern and running speed. Abbreviations: HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT = International Hip Outcome Tool; PROM = patient-reported outcome measure.

9.8.2 Scatterplots of adjusted relationships between PROM scores and hip joint angles



Relationships analysed unadjusted and adjusted for the covariates of foot strike pattern and running speed. Abbreviations: HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT = International Hip Outcome Tool; PROM = patient-reported outcome measure.

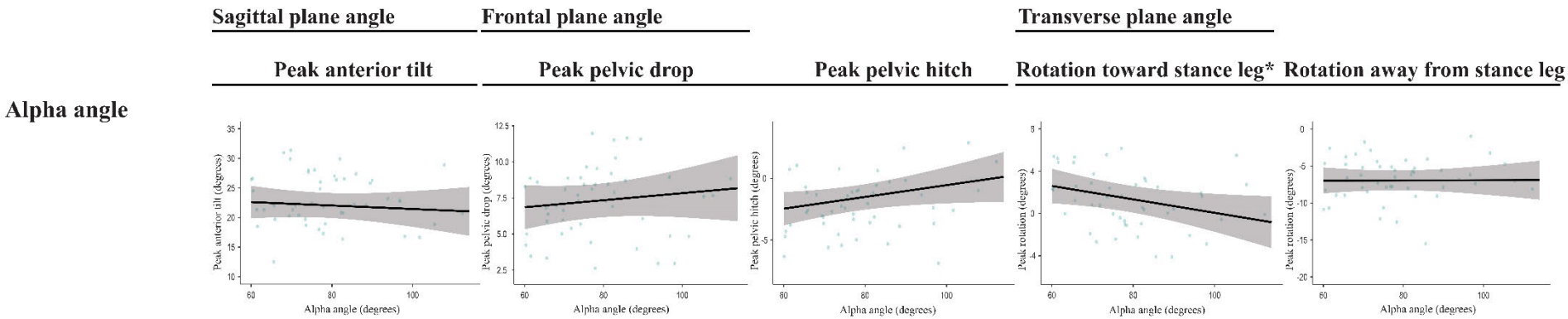
9.8.3 Scatterplots of adjusted relationships between PROM scores and external hip joint moment impulses



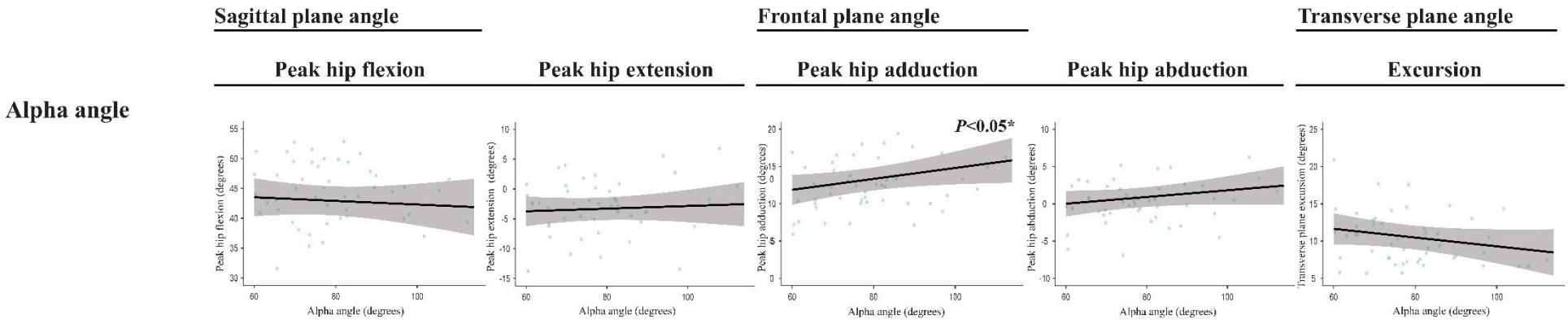
Relationships analysed unadjusted and adjusted for the covariates of foot strike pattern and running speed. Abbreviations: HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT = International Hip Outcome Tool; ROM = range of motion

9.8.4 Scatterplots of adjusted relationships between alpha angles and pelvic and hip kinematics

(i) Pelvis angles



(ii) Hip joint angles



Relationships analysed adjusted for the covariates of foot strike pattern and running speed. Abbreviations: HAGOS = Copenhagen Hip and Groin Outcome Score; iHOT = International Hip Outcome Tool; PROM = patient-reported outcome measure.

THESIS DISCUSSION AND CONCLUSIONS

Chapter 10. Thesis discussion and conclusions

Hip/groin pain is common in sub-elite football players (4). Many players continue to train and play despite longstanding hip/groin pain (5), but little is known about the burden experienced by players with current symptoms. Hip/groin pain can encompass intra- and extra-articular conditions (33, 38), with growing awareness of the potential for intra-articular conditions to generate symptoms (38). Diagnosis of some hip-related pain conditions requires imaging findings of altered bony morphology (e.g., FAI syndrome) and/or intra-articular soft tissue structures (e.g., cartilage defects, labral tears), together with symptoms and clinical signs suggestive of hip joint pain (38). Altered lower limb biomechanics might be evident in people with hip-related pain (126), but few studies have investigated sporting tasks in those still participating in sport (196, 200, 201). If alterations to hip joint structure (i.e., bony morphology and/or intra-articular conditions) and/or lower limb biomechanics are related to symptom severity in people with hip-related pain, treatments targeted to addressing these features might reduce the burden of hip/groin pain.

This thesis aimed to describe self-reported burden in football players with hip/groin pain and investigate the relationships between physical findings (i.e., hip joint structure and lower-limb biomechanics during running) and symptom severity. This final chapter summarises the thesis findings, strengths and limitations, directions for future research, clinical implications, and conclusions.

10.1. Summary of thesis findings

10.1.1 Measurement properties of the iHOT-33

Accurate measurement of self-reported burden requires PROM scores that are valid, reliable, and responsive for use in the target population. Whilst the iHOT-33 was recommended for use in active adults with hip-related pain, measurement properties of the iHOT-Total and all subscale scores were unknown in most people with hip/groin pain (i.e., non-surgical populations) (144). Study 1 (Part A, **Chapter 3**) evaluated the measurement properties of the iHOT-33 in adults with hip/groin pain who were not seeking surgery (n=278, 93 (33%) women), including football players from the FORCe study (n=164, 30 (18%) women). The iHOT-Total score and all subscale scores were found to be valid for use in non-surgical populations. Content validity was confirmed using semi-structured 1:1 interviews, with participants reporting the iHOT-33 items to be relevant, comprehensive, and comprehensible. Construct validity of all iHOT-33 scores was established using hypothesised relationships with relevant HAGOS scores. All iHOT-33 scores, except for the iHOT-Job, were reliable at the group-level, with SEM values ranging from 6.0 to 9.5 points. None of the iHOT-33 scores were reliable at the individual level, hence large MDC values were reported for monitoring change in individuals (range 16.6 to 26.2 points) when compared to groups (2.3 to 3.7 points). This disparity in MDC values is consistent with in other recommended PROMs such as the HAGOS (148). All iHOT-33 scores were responsive to change over a period of six months, except for the iHOT-Job in individuals not undertaking treatment. In summary, the iHOT-Total and subscale scores had adequate measurement properties to evaluate self-reported hip/groin burden in those not seeking surgery.

10.1.2 Self-reported burden in football players with hip/groin pain

Part B of this thesis investigated the burden of hip/groin pain in active football players and explored associations with hip joint bony morphology and intra-articular soft tissue conditions. In Study 2 (**Chapter 4**), scores for the iHOT-33 and the HAGOS were compared between football players with (n=184, 38 (21%) women) and without (n=55, 14 (25%) women) hip/groin pain. Overall, symptomatic football players reported substantial hip/groin burden despite being capable of training and match play. Symptomatic players

reported lower (i.e., worse) median scores for all iHOT-33 and HAGOS subscales than asymptomatic players. The iHOT-Sport and HAGOS-QOL subscales recorded the lowest group median scores (45 [IQR 29] and 60 [20], respectively), with asymptomatic players recording scores of 99 [4] and 100 [0] for these subscales. The lowest scoring question for the iHOT-33 was item 19 (median score = 32 [39]), *"How concerned are you that the pain in your hip will increase if you participate in sports or recreational activities?"* Symptomatic football players appeared to report worse physical burden during high-impact sporting activities (HAGOS-Sport = 66 [22], pseudo $R^2 = 0.75$) than activities of daily living (HAGOS-ADL = 80 [25], pseudo $R^2 = 0.50$). Self-reported burden was similar for men and women, with female sex associated with worse HAGOS-Pain scores only; although, the 4-point difference in median scores was within the measurement error of the instrument and has unknown clinical relevance. Subtle sex-specific differences in individual item scores suggested that female football players reported worse hip/groin pain after activity and with sustained postures (e.g., sitting) than men, possibly indicating variations in disease presentations. It is also possible that different diagnostic entities might have existed between, and within, symptomatic male and female football players. As players with FAI syndrome may be more likely to undergo surgery when compared to players with other hip/groin conditions (251), discerning whether self-reported burden differs between those with and without FAI syndrome might aid diagnosis and treatment planning.

Femoroacetabular impingement syndrome is a common cause of longstanding hip/groin pain in athletes, but it was unknown whether self-reported burden differed between those with FAI syndrome and athletes with other causes of hip groin pain. Study 3 (**Chapter 5**) examined this relationship in football players with hip/groin pain and a positive FADIR test (n=165, 35 (21%) women), finding that those with cam (alpha angle ≥60°) and/or pincer (LCEA ≥40°) morphology (i.e., FAI syndrome) did not report worse burden than those with other causes of hip/groin pain (unadjusted estimates ranged from -4.69 to 0.34 [95%CI -12.62, 7.59], $P>0.05$). Mediation analyses in Study 3 found that the presence of cartilage defects and/or labral tears, thought to be the sequalae of FAI syndrome (38, 47), did not explain the effect of FAI syndrome on self-reported burden, primarily due to cartilage and labral findings being unrelated to PROM scores (indirect effect estimates ranged from -0.17 to 0.83 [95%CI -1.18, 2.55], $P>0.05$). Dichotomising the continuous alpha angle enabled us to compare people with and without FAI syndrome, but the potential effect of cam morphology size on self-reported burden warranted further investigation.

Study 4 (**Chapter 6**) investigated whether cam morphology size and location were associated with self-reported burden in football players with FAI syndrome (alpha angle ≥60°; n=118, 12 (10%) women). Symptomatic football players with larger anterosuperior cam morphology (measured using the Dunn 45° radiograph) reported lower (i.e., worse) iHOT-Total, iHOT-Symptoms, iHOT-Job, and iHOT-Social scores than those with smaller cam morphology (unadjusted estimate range -0.553 to -0.319 [95%CI -0.900, -0.037], P<0.05). Adjusted model estimates found that for every 10° alpha angle increment above 60°, iHOT-33 scores were 3.7 points (iHOT-Total), 3.5 points (iHOT-Symptoms), 4.9 points (iHOT-Job), and 5.8 points (iHOT-Social) lower. Anterosuperior cam morphology size was not associated with iHOT-Sport score nor any HAGOS scores. Superior cam morphology size was not related to any iHOT-33 or HAGOS scores. The modest strength of relationships between anterosuperior cam morphology size and iHOT-33 scores (pseudo R^2=0.046 to 0.087) suggest that other factors, potentially including biomechanical movement patterns, might explain more of the variance in self-reported hip/groin burden in symptomatic football players.

10.1.3 Running biomechanics in football players with hip/groin pain

Knowledge of whether biomechanical patterns differ between athletes with and without hip/groin pain during sporting tasks is limited (196, 200, 201). Part C of this thesis compared running biomechanics between symptomatic and asymptomatic football players (Study 5, **Chapter 8**) and explored whether biomechanical patterns in those with FAI syndrome were associated with self-reported burden or cam morphology size (Study 6, **Chapter 9**). Findings from Study 5 (**Chapter 8**) indicated that symptomatic football players (n=78, 16 (21%) women) did not display different pelvis angles or lower-limb joint angles, moments, or moment impulses during the stance phase of running (3-3.5m.s^{-1}), when compared to asymptomatic players of the same sex (n=38, 13 (34%) women). The presence of various hip/groin pain diagnostic entities may have contributed to data variability in our symptomatic players, thus Study 6 (**Chapter 9**) investigated those with FAI syndrome only. As few female FORCe participants with running biomechanical data had FAI syndrome (n=4), 49 male football players only were investigated. Overall, lower-limb biomechanics during the stance phase of running were mostly unrelated to self-reported burden (iHOT-Symptoms, iHOT-Sport, HAGOS-Symptoms, and HAGOS-Sport

scores) and cam morphology size (alpha angle measured using the Dunn 45° radiograph). Football players with FAI syndrome and worse self-reported burden did not display largely different hip joint angles compared to those who were less symptomatic; however, lower (i.e., worse) HAGOS-Symptoms and HAGOS-Sport scores were weakly associated with smaller transverse plane pelvis excursion (unadjusted estimate 0.097 [95%CI 0.021, 0.174], pseudo R^2=0.122, *P*=0.014) and external hip external rotation moment impulse (unadjusted estimate ($x10^2$) 0.026 [95%CI <0.001, 0.051], pseudo R^2=0.086, *P*=0.048) values, respectively. For cam morphology size, players with larger alpha angles demonstrated smaller peak pelvic rotation angles at terminal stance, when compared to those with smaller cam morphology (unadjusted estimate -0.059 [95%CI -0.166, -0.002], pseudo R^2=0.085, *P*=0.042). Larger cam morphology was also associated with greater peak hip adduction angles at midstance, although this was only observed in models that controlled for foot strike and running speed (adjusted estimate 0.073 [95%CI 0.002 to 0.145], *P*=0.045).

10.2. Strengths and limitations of this thesis

Whilst study-specific strengths and limitations are discussed in each chapter, the following sections provides an overview of the strengths and limitations of the thesis.

10.2.1 Measurement of self-reported burden

The mixed methods approach to determine the measurement properties of the iHOT-33 is a strength of this thesis and adds depth to the data presented. Content validity of the iHOT-33 was established using 1:1 semi-quantitative interviews, garnering unrestricted information from the unique perspective of patients with hip/groin pain. Qualitative research can importantly expand understanding of quantitative research findings, providing complementary knowledge to aid clinical reasoning (313). Qualitative findings regarding the content of the iHOT-33 supported our decision to interrogate various domains of hip/groin burden beyond pain and symptoms. Considering this, the absence of a qualitative study exploring of the concept of burden in active football players with hip/groin pain is a limitation of this thesis and warrants future investigation. Furthermore, the definition of burden used throughout this thesis was limited to the items and constructs of the iHOT-33 and HAGOS; however, other features of the hip/groin pain experience (e.g., socio-economic impacts and alterations to general and psychological health) might also be considered in future studies.

The absence of standardised PROMs that assess participants' psychological state is a limitation of this thesis. Whilst domains of the iHOT-33 and HAGOS explore the psychosocial impacts of hip/groin pain, measures such as the Hospital Anxiety and Depression Scale (250) are useful tools that can screen for the presence of anxiety disorders or depression in patients with musculoskeletal conditions (314). Anxiety and lowered mood may be common in injured athletes, are associated with rehabilitation outcomes, and may not resolve with improved physical function (244). Improved understanding of the relationship between the severity of self-reported burden and non-physical factors (e.g., emotions, cognitions, behaviours) is needed in athletes with hip/groin pain. Screening symptomatic football players' psychological state (using new tools such as the HIP-Return to Sport After Injury (HIP-RSI) score (315)) may identify football players who may benefit from targeted interventions and may provide some insights into the mechanisms of current rehabilitation programmes.

10.2.2 Imaging techniques and assessment

Using recommended radiographic views to assess bony hip morphology (63, 316) and differentiating between the AP and Dunn 45° radiographs when investigating relationships with self-reported burden are strengths of this thesis. Furthermore, cam and pincer morphology were defined by an alpha angle ≥60° and LCEA ≥40°, respectively, consistent with contemporary recommendations (38, 63, 64). Assessing chondrolabral conditions in Study 3 (**Chapter 5**) using high-resolution, unenhanced 3.0T MRI minimised participant risk (100) whilst likely providing comparable accuracy to contrast-enhanced MRI (102-104).

However, there are limitations associated with the imaging techniques and assessment methods used in this thesis. Whilst radiographs are recommended as the first line imaging technique in the clinical setting (38, 63, 316), MRI or CT may more accurately assess femoral and acetabular bony morphology size and orientation (63, 316). When compared to radiographs. the use of MRI and CT may be limited by high costs and additional radiation exposure, respectively, as well as complex image reformatting that may not be routinely available (266). To mitigate the limitations of radiography, bony morphology was assessed using semi-quantitative methods, which are more reliable than other measurement techniques (317) and are consistent with large epidemiological studies (74-76, 121, 210). Although reliable, using a single radiographic view only to measure global acetabular

coverage and identify pincer morphology and acetabular dysplasia (Study 3 (**Chapter 5**) and Study 4 (**Chapter 6**)) may have led to misclassification bias. Other radiographic measures of acetabular depth and orientation might have identified additional pincer morphologies (e.g., global or focal retroversion), but these subjective measures have poor reliability (318, 319) and uncertain accuracy when compared to CT measures (63, 318, 320). Scoring of cartilage defects and labral tears in Study 3 (**Chapter 5**) of this thesis was completed by a single trained musculoskeletal radiologist and inter-observer reliability was not established. Whilst good inter-observer reliability has been demonstrated for assessing chondrolabral pathology with the SHOMRI in people with FAI syndrome (103), it is possible that cartilage defects and labral tears were over- or under-reported (misclassification bias), potentially affecting reported relationships with self-reported burden.

10.2.3 Biomechanical research

The use of a customised biomechanical model in Study 5 (**Chapter 8**) and Study 6 (**Chapter 9**) is a strength of this thesis. The model incorporated a dynamic optimisation procedure to estimate the knee joint flexion-extension axis, which provides superior alignment of this axis when compared to other methods (e.g., knee alignment device, trans-epicondylar axis method) (278). Accurate alignment of the knee joint flexion-extension axis using this method is associated with greater reliability of joint angle data (including hip axial rotation) and less knee joint crosstalk (i.e., the relationship between flexion-extension and varus-valgus kinematic profiles) than other methods (278); which is likely important for tasks such as running that require larger knee joint ROM than walking.

The large sample sizes investigated in Study 5 (**Chapter 8**) and Study 6 (**Chapter 9**) (n=78 and n=49, respectively) are strengths of the biomechanical studies in this thesis. Studies of biomechanics typically recruit low participant numbers, and the relatively large samples investigated in this thesis improves the generalisability of the calculated group mean values and minimises the effect of random error on statistical tests (222), increasing confidence in the results.

Inherent challenges exist in biomechanical studies that can impact the interpretation of findings. The customised biomechanical model used in this thesis required reliable placement of markers on pre-defined anatomical locations to calculate participants

anthropometric properties and lower-limb joint centres (310). Inaccurate or inconsistent marker placement, which is more common in inexperienced testers (321), may have resulted in random measurement error within the calculated biomechanical variables of interest. To minimise the potential for such error, markers were applied to participants' bodies according to a standardised protocol (130). Furthermore, as lower-limb marker placement will affect lower-limb outputs from the musculoskeletal model, these markers were placed by one of two post-doctoral research fellows only (Dr Matthew King and Dr Benjamin Mentiplay) who were highly experienced in biomechanical data collection and analysis. The trunk and upper limb markers were applied by either Dr Joshua Heerey or Mr Mark Scholes according to the same standardised protocol (130).

Estimating the hip joint centre using the Harrington regression equations (277) can contribute to variability in hip joint angle data, regardless of correct marker placement. Although the Harrington equations (277) may be more accurate than functional methods (e.g., geometric sphere fit method) when hip joint ROM is constrained in clinical populations (e.g., cerebral palsy) (322), symptomatic football players did not display large hip joint ROM impairments during running when compared to asymptomatic players (**Chapter 8**). Whilst functional measures may have provided marginally superior estimation of the hip joint centre (322), the Harrington regression equations are largely unaffected by sex and age (323) and are equally reliable as functional methods when assessing lower-limb kinematics during running tasks (324). Overall, error in lower limb joint angles due to mis-location of the hip joint centre was unlikely to be substantial.

Soft tissue artefact associated with the use of skin markers likely contributed to error in the kinematic data. Markers placed on the thigh may be particularly susceptible to soft tissue artefact, thus two strategies were implemented to minimise this effect: 1) segment tracking markers were placed on the distal third of the thigh (an area known to be associated with less soft tissue artefact (325)); and 2) pelvic markers and shank markers were used to calculate the hip and knee joint centres, respectively. Thigh markers, therefore, were only used with the calculated hip and knee joint centres to define the femoral anatomical reference frame (278).

As sub-maximal running was investigated in this thesis, a target running speed (3-3.5m.s^{-1}) was selected to minimise the effect of varying running speeds on biomechanical variables (295). The selected running speed, however, might not reflect a typical running speed for

some football players, limiting generalisability of the results. Future studies might consider investigating maximal sprinting and cutting, which are relevant tasks for competitive football players. Maximal sprint speed might be negatively related to hip/groin pain severity; thus, future studies should carefully consider the appropriateness of statistically controlling for running speed in this situation (326).

10.2.4 Study population and design

The recruitment of a cohort who were still participating in sport is a strength of this thesis, enhancing the generalisability of the results to most football players with hip/groin pain and, over time, improving understanding of the temporal relationship between hip/groin pain, hip joint structure, and biomechanics. Football players were recruited from sub-elite competitions in Melbourne and Brisbane, Australia, using various methods, including online or print advertising and information sessions conducted at football clubs. Nonetheless, selection bias may have affected participant recruitment, where included football players may not represent all football players with and without hip/groin pain.

Relatively large sample sizes are a strength of the studies of this thesis. Studies 4 and 6 investigated the largest samples individuals not seeking surgery for FAI syndrome (n=118 and 49, respectively) and Study 5 examined biomechanics in the second largest reported sample of athletes with and without hip/groin pain (n=116). Although large samples were investigated, an *a priori* power analysis was not undertaken for the studies of this thesis. Studies 2 to 6 used baseline data from the prospective FORCe study, where the sample size for symptomatic participants was powered to evaluate change in hip joint structure using MRI over a 2-year period (130). For Studies 2 and 5, the control participant sample size was determined by personnel and budgetary constraints. Cross-sectional studies of the FORCe cohort are the first to report imaging (59, 131, 183) and biomechanical findings (196, 297) in female football players; however, the relatively small number of women compared to men in this thesis means we were likely underpowered to detect whether the relationship between hip joint structure and self-reported burden differed by sex (Studies 3 and 4) or whether small differences in running biomechanics existed between symptomatic and asymptomatic women (Study 5). Further large-scale studies of women are needed to confirm the findings from this thesis.

Different intra- and extra-articular conditions may have contributed to hip/groin pain in our symptomatic football players (33, 34, 327) and affected relationships between self-reported burden and hip joint structure and biomechanics. Diagnostic entities such as adductor-, iliopsoas-, pubic-, and inguinal-related groin pain are known to be present in football players (30) but were not assessed in this thesis. All symptomatic football players had a positive FADIR pain provocation test. The FADIR is a recommended clinical test for FAI syndrome and other causes of hip-related pain (38, 45, 327), but its limited specificity means that some symptomatic football players might have had hip/groin pain that did not emanate from an intra-articular condition. Reduced internal rotation ROM in a neutral hip position might aid the diagnosis of FAI syndrome (55), but further work is needed to confirm this finding and determine the ROM deficit needed for diagnosis.

The cross-sectional study designs in this thesis are unable to determine causal relationships between self-reported burden and hip joint imaging findings or biomechanics, and thus are a limitation of this thesis.

10.3. Research implications and future directions

This thesis found that symptomatic football players reported substantial hip/groin burden, despite continuing to train and play. When findings from this thesis are combined with earlier FORCe studies (131, 183, 196), an unclear relationship exists between hip joint imaging findings (including cam morphology and chondrolabral conditions) and the presence (131, 183) and severity of hip/groin pain. Furthermore, few biomechanical impairments were evident in symptomatic FORCe participants when compared to asymptomatic players, with no clinically meaningful differences observed during running or the single leg drop jump (196).

Studies of FORCe participants in this thesis and others (109, 191) used cross-sectional data from the baseline assessment and thus were unable to determine causation. Longitudinal studies can help to understand the natural history of a condition and identify factors associated with worsening disease (328). Despite their importance, longitudinal studies can be expensive, inefficient (e.g., few participants experience the outcome of interest), and time consuming (328) (requiring more time than is available to a PhD candidate). These issues may be particularly pertinent in studies of degenerative joint disease in younger, active individuals who are earlier on the disease pathway. The longitudinal arm of the

FORCe study (yet to be completed) will improve understanding of whether hip joint morphology is associated with worsening self-reported burden or joint structure over time, as well as the role hip joint biomechanics has with respect to these disease features. A summary of the cross-sectional findings from the FORCe cohort and the prospective research questions is provided in **Figure 10.1**.

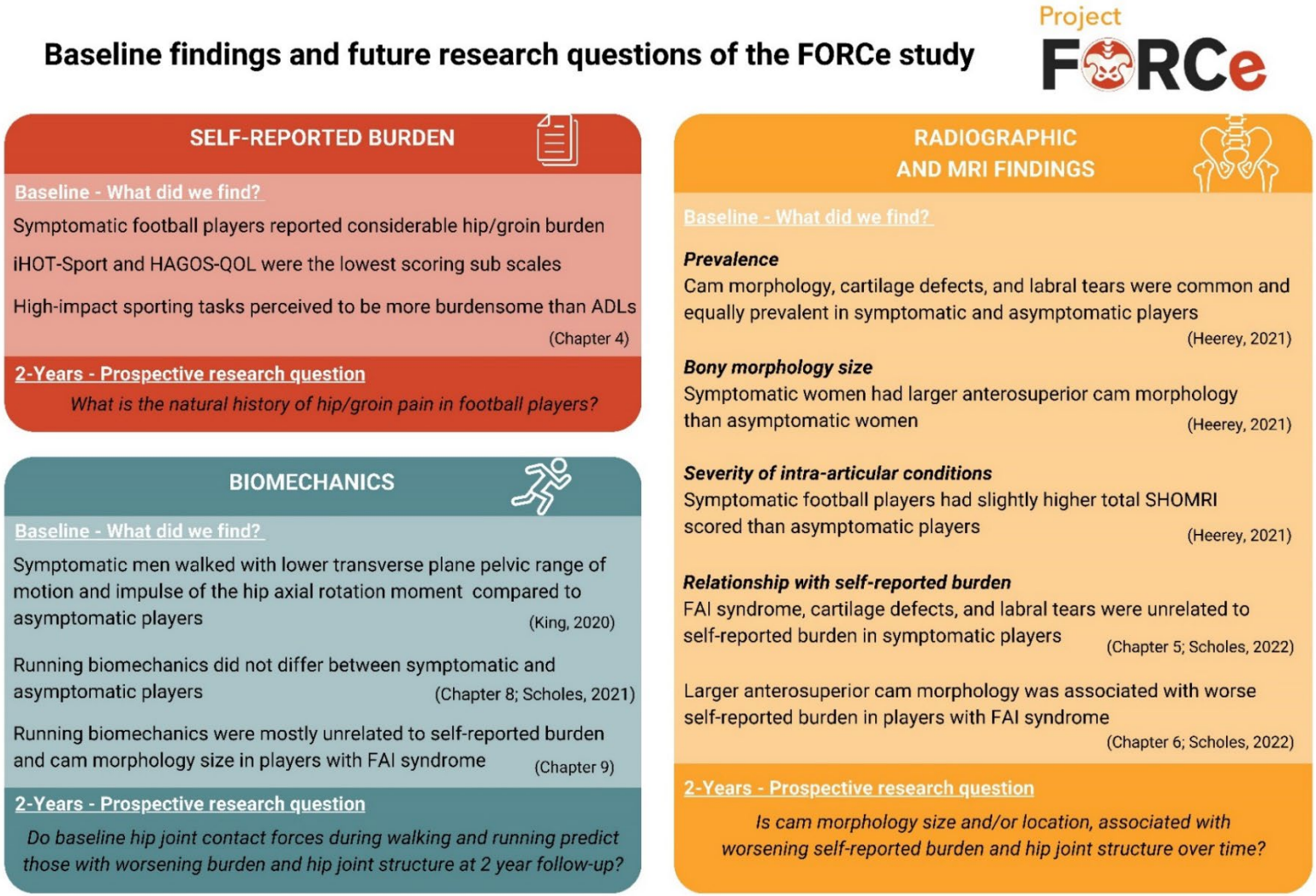


Figure 10.1. Summary of findings from cross-sectional studies of FORCe participants and proposed prospective research questions.
Abbreviations: FAI = femoroacetabular impingement; FORCe = femoroacetabular impingement and hip osteoarthritis cohort; HAGOS – Copenhagen Hip and Groin Outcome Score; iHOT = International Hip Outcome Tool; SHOMRI = Scoring Hip Osteoarthritis with Magnetic Resonance Imaging; QOL = Quality of life. References: Heerey (2020) (109), King (2020) (191), Scholes et al. (2021) (305), **Chapter 5**, Scholes et al (2022) (269), **Chapter 6**, Scholes et al (2022) (312).

Future prospective FORCe studies will target structural and biomechanical predictors of worsening hip joint structural disease, but other longitudinal investigations are needed in individuals at risk of developing hip/groin pain. Identifying factors predicting the development of cam morphology and hip/groin pain, including the potential role of cam morphology in initiating symptoms, will aid the development of primary prevention strategies, potentially reducing the incidence and burden of hip/groin pain in young adults. For those undergoing interventions for hip/groin pain, improved knowledge of expected surgical and non-surgical treatment effects and factors associated with prognosis are needed. Future findings from the PhysioFIRST study (**Section 2.3**) (208) and a placebo-controlled hip arthroscopy RCT (329) may provide insights into mechanisms of non-surgical and surgical treatments, respectively, as well as prognostic factors for these treatments. Until then, knowledge from this thesis can inform future investigations of people with, and at risk of, hip/groin pain, with the specific research implications discussed below.

10.3.1 The PROMIS of an exciting future

Collecting PROM data in the research setting can be burdensome for participants, with many hip/groin PROMs sharing common items (275), leading to excessive or redundant questions, questionnaire burnout, and potentially inaccurate data with limited research value (330). The Patient-Reported Outcomes Measurement Information System (PROMIS) amalgamates items from common hip/groin-related PROMs and uses Item Response Theory and Computer Adaptive Testing to create a single generalisable PROM for a given domain (e.g., pain, physical function) (331). The PROMIS has potential to provide accurate estimates of health status with the completion of fewer questions, with early studies suggesting greater efficiency (330) and very good correlation with iHOT-12 scores (332) in people undergoing hip arthroscopy for FAI syndrome. This thesis found the subscale scores of the iHOT-33 to be valid and reliable, allowing future studies to examine the measurement properties of a PROMIS domain against a relevant iHOT-33 subscale score. Knowledge of the measurement properties of the PROMIS is very limited in those seeking surgery and unknown non-surgical populations. Whilst the content validity of PROMIS items may be mostly established, future studies of more than 100 participants (214) are needed to establish other measurement properties (e.g., construct validity, reliability, and responsiveness) in people seeking non-surgical and surgical treatments. Findings from 1:1 interviews in Study 1 (**Chapter 3**) suggest the PROMIS might be aided by future qualitative

studies of active athletes with hip/groin pain to generate items relating to sports function and performance. In the meantime, findings from this thesis indicate the iHOT-33 subscales are an excellent option to assess hip/groin burden in non-arthritic populations. Future intervention studies should consider using the iHOT-33 subscales scores, affording easier interpretation of the relative treatment effects across surgical and non-surgical populations.

Future qualitative and quantitative studies may provide insights into the psychosocial burden of hip/groin pain identified in this thesis. The iHOT-33 and HAGOS may not adequately capture the full extent of the psychosocial burden of hip/groin pain in active athletes, and additional items and/or PROMs may be needed to assess its full impact. Measures such as the Hospital Anxiety and Depression Scale (250) may augment the iHOT-33 and HAGOS and identify athletes with concomitant psychological conditions, but its usefulness in athletes with hip/groin pain warrants investigation. The Hip-Return to Sport After Injury (HIP-RSI) score is a valid and reliable measure of psychological readiness to return to sport after hip arthroscopy (315). Future studies may assess the measurement properties of the HIP-RSI in those undertaking exercise-based rehabilitation and examine its ability to detect altered psychological status in symptomatic athletes still participating in sport.

Strategies to improve the usability of standardised PROMs such as the iHOT-33 in the clinical setting are needed. Reported large MDC values, the potential for irrelevant items, and the time-burden for therapists to calculate scores are barriers to regular use of PROMs in the clinic. Whilst the PROMIS may afford efficient capture of patient-reported data in the future, measures such as the Patient-Specific Functional Scale (333) may be an alternative to condition specific PROMs like the iHOT-33 in the clinical setting, especially in high functioning patients for whom ceiling effects may exist with standardised PROMs. Future studies might investigate the measurement properties of the Patient-Specific Functional Scale against relevant iHOT-33 subscale scores in active athletes with hip/groin pain.

10.3.2 Cam morphology may be one piece in the hip/groin pain puzzle

Femoroacetabular impingement syndrome is a motion-related condition (45), where bony features other than cam morphology (e.g., acetabular or femoral version, femoral neck-

shaft angle) might influence the dynamic interaction between the femoral head-neck junction and the acetabulum (63, 268). This thesis mostly examined cam morphology in isolation, but future studies might investigate whether a metric that combines femoral and acetabular anatomy (268) explains more variance in self-reported burden in those with FAI syndrome. Future studies investigating this relationship could characterise acetabular and femoral bony anatomy using CT or MRI, which can provide 3D assessment that is not afforded by radiographs. Recent advances in artificial intelligence and statistical shape modelling of radiographs have identified hip shape variants that might lead to hip OA (334). Further studies are needed to investigate whether hip shape variants relate to self-reported burden (and change in burden over time) in active young-adults, including examining the potential effects of sex and activity level (i.e., sport) on these relationships.

Knowledge of the relationship between bony morphology and hip joint biomechanics is very limited, with previous studies investigating cam morphology size during low load tasks (e.g., walking, squatting) in surgical populations only (284, 335). Future studies might examine the relationships between movement patterns and other femoral and acetabular morphological features and, in the absence of prospective data, investigate cohorts across the spectrum of FAI syndrome. High-impact, multiplanar tasks that demand greater hip ROM than running (e.g., cutting, kicking) might elucidate relationships between hip joint biomechanics and bony morphology (including cam morphology size) if they exist.

Groin pain entities (33), which were not evaluated in our symptomatic football players, can co-exist with hip-related pain conditions (6, 38) and contribute to hip/groin pain, potentially altering relationships that were investigated in this thesis. Future studies might assess relationships between the presence of hip-related and groin pain entities. Hip adductor muscle weakness and reduced hip joint axial ROM are evident in those with groin pain (288), potentially altering hip joint forces over time. Longitudinal studies are needed to investigate the interaction between hip-related and groin pain entities on the development and progression of structural hip joint disease over time.

10.3.3 Greater knowledge of biomechanics during sports specific tasks is needed

Knowledge of biomechanical impairments during sporting tasks in athletes with hip/groin pain is limited, with previous studies mostly investigating hopping/landing tasks in

exclusively male (200, 201) or male-dominated (196) cohorts. Future studies of sport-specific multiplanar tasks (e.g., cutting, kicking) might elucidate differences between those with and without hip/groin pain, potentially informing exercise-based treatments. More studies of female football players are needed.

Future studies might use electromyography and models of muscle dynamics (from 3D motion capture and GRF data) to investigate neuromuscular activity during running and other high-impact sports-specific tasks (e.g., cutting), providing insights for joint specific loading in people with hip-related pain. Running, like walking, is a continuous and cyclical task optimised for efficiency in the individual, where subtle variations in muscle activity, with or without obvious kinematic or kinetic impairment, might alter hip joint contact forces and thus hip pain (206, 304). Future prospective studies of FORCe participants will investigate if the resultant hip joint contact force predicts worsening hip/groin burden and structural disease over time. Other longitudinal studies might investigate if such a metric could identify those who will develop hip/groin pain in the first place, or if certain biomechanical patterns are associated with prognosis in those undergoing treatment.

Improving the accuracy of biomechanical models will advance our understanding of movement patterns and internal forces in people with hip/groin pain. Errors in hip joint centre estimations will impact the accuracy of lower-limb joint angle and moment data more than other sources of error (e.g., marker placement, soft tissue artifact, body segment parameters) (336, 337). Magnetic resonance imaging is the gold standard for estimating the hip joint centre (322), but is costly and requires multidisciplinary expertise and time for post-processing (337). Future studies may determine the accuracy of Harrington regression equations for estimating the hip joint centre in young adults with FAI syndrome when compared to MRI. Improving estimations of muscle dynamics in biomechanical models may increase the accuracy of calculated internal forces, such as hip joint contact forces. Electromyography informed models have been used at the knee and ankle, but reliably collecting data from the deep hip muscles is difficult, potentially limiting its use (338). Magnetic resonance imaging might be used to tailor models to variations in condition-specific bone or muscle morphology (338), with more studies needed to assess the feasibility of such models. Finite element analyses can be used to model hip joint contact stresses in those with hip-related pain, with recent findings suggesting that cam morphology may be associated with increased hip joint stresses (272). Finite element models may be informed by bony (e.g., cam morphology, acetabular or femoral version) and soft tissue

(e.g., non-uniform cartilage thickness, labrum, muscle) morphology obtained from MRI and hip joint contact forces estimated from motion capture data (272). With advancing knowledge of hip shape variants associated with hip/groin pain and improved biomechanical modelling, future studies might identify adverse hip joint loading conditions in those with, or at risk of, hip-related pain.

Inertial Measurement Units (IMUs) offer a convenient, valid, and reliable alternative to three-dimensional motion capture to derive some spatiotemporal features of running and estimate GRF variables in the clinical setting (339). These units afford researchers the opportunity to investigate large samples of athletes with and without hip/groin pain in real-world settings, including across various surfaces, shoe types, fatigue states, and environmental conditions (340). Future studies might investigate if IMU-derived variables can delineate symptomatic and asymptomatic football players during sport specific tasks (e.g., sprinting, cutting, kicking) or identify those at risk of developing hip/groin pain. Further work is needed to establish the validity and reliability IMU data during such tasks in people with hip/groin pain. Early research suggests that estimating lower-limb joint kinematics and kinetics using IMUs is possible (341), opening the door to estimate internal forces in the future.

10.4. Clinical implications of thesis findings

The findings of this thesis suggest that whilst hip/groin pain is burdensome in football players still capable of training and match play, it is unclear what role, if any, hip joint structure and running biomechanics play with respect to symptom severity. Prospective studies investigating the role of hip joint structure and biomechanics on hip joint disease in young adults are lacking, but future longitudinal findings from the FORCe cohort will partially fill this knowledge gap. Although this thesis consisted of cross-sectional data only, findings can inform assessment and treatment planning in football players with hip/groin pain. The following sections will discuss the specific clinical implications of this thesis and place these findings in the context of the existing literature, where appropriate.

10.4.1 The iHOT-33 can now be used to measure hip/groin burden in non-surgical populations

Accurately quantifying patients' perceived hip/groin burden is essential to determine the severity of their condition and success of treatments. Whilst the iHOT-33 had been recommended to assess active adults with hip/groin pain (144), findings from this thesis mean that it can now be confidently used in those not seeking surgery. The subscale scores had acceptable measurement properties, and clinicians may now choose to assess constructs that might be more relevant to individual patients (e.g., iHOT-Sport score in symptomatic athletes). Using the individual iHOT-33 subscale scores also overcomes previously reported concerns about the structural validity of the cumulative iHOT-Total score (144). Clinicians should be aware of the MDC values for iHOT-33 scores (16.6 to 26.2 points) when monitoring individual patients in the clinic, as these values indicate the minimum change required to exceed the measurement error of the instrument. Whilst these values are higher than those at the group level, they are comparable to MDC values for the HAGOS scores and do not preclude the use of the iHOT-33 in the clinical setting. The iHOT-33 was recently found to contain the greatest number of unique items when compared to other commonly used PROMs for hip/groin pain (275), suggesting that it may be a valuable tool to quantify hip/groin burden when used in isolation or when combined with other measures.

10.4.2 Pain and symptom measures alone may not capture hip/groin burden in symptomatic football players

Athletes with hip/groin pain often seek treatment to improve their ability to participate in sport or enhance sports performance (146, 173, 342). **Figure 10.2** compares HAGOS scores for the symptomatic football players included in the studies in this thesis and athletes seeking nonsurgical (175) and surgical treatment (172) for hip/groin pain. Active football players appear to perceive higher HAGOS-Sport, HAGOS-PA, and HAGOS-QOL scores than athletes undertaking treatment, suggesting these subscales are likely to be important to assess hip/groin burden in symptomatic athletes.

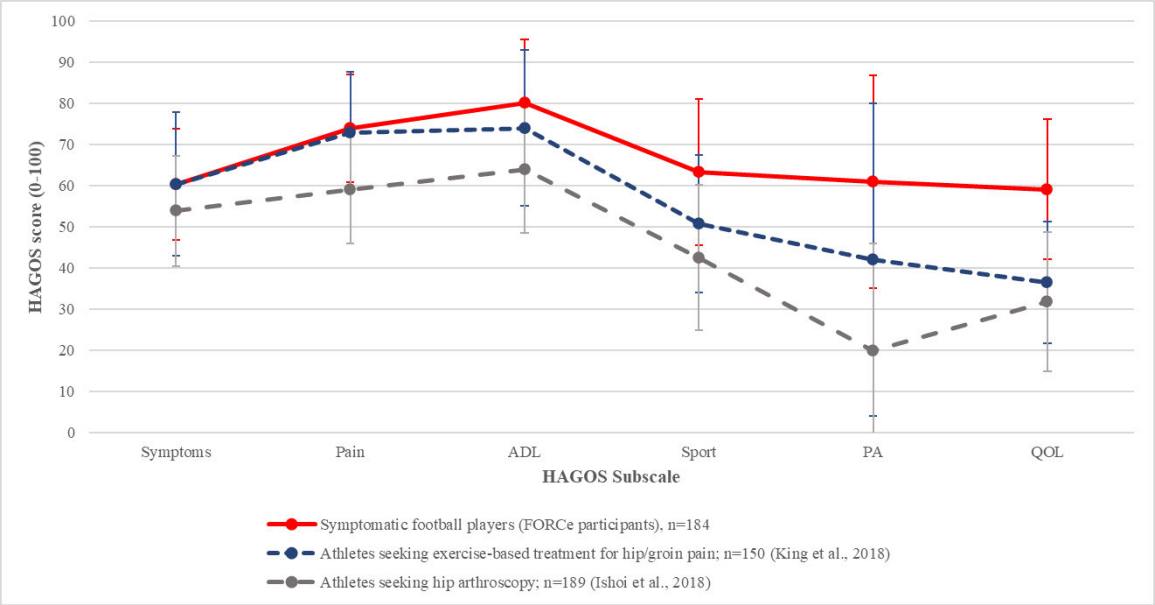


Figure 10.2. Comparison of Copenhagen Hip and Groin Outcome Scores (HAGOS) for symptomatic football players and athletes seeking treatment.
Group mean HAGOS scores reported (error bars indicate standard deviations) for symptomatic football players, King et al. (2018) (175) and Ishoi et al. (2018) (172). Abbreviations: ADL = physical function during activities of daily living; PA = participation in physical activities; QOL = hip-related quality of life.

The psychosocial burden of longstanding hip/groin pain, which is unlikely to be captured by self-reported measures of pain and symptoms, may importantly impact an athlete's perception of the severity of their condition and their decision to seek treatment. Football may be an integral part of a player's identity and social life; thus, injury or prolonged hip/groin pain may have consequences far beyond pain and symptoms. For example, the iHOT-Sport and HAGOS-QOL, which measure injury-related cognitions and emotions, were the lowest scoring subscales in symptomatic football players and hence may be valuable tools to monitor treatment outcomes in this population. Anxiety about worsening hip/groin pain with continued sports participation was the lowest scoring item in the iHOT-33 in symptomatic players, suggesting that screening of psychosocial factors (e.g., pain beliefs, depression, social engagement) may add to traditional physical assessments of hip/groin pain (343). Self-efficacy and QOL may be enhanced with interventions that aim to improve pain and physical function, but strategies to address aberrant pain behaviours and beliefs may add benefit (343). Individuals with longstanding hip/groin pain often perceive their condition through a biomedical lens (343). Whilst it is beyond the scope of this thesis, clinicians may consider discussing the multidimensional nature of longstanding hip/groin pain, including the relative importance of modifiable physical (e.g., strength, training load, movement patterns) and non-physical (e.g., pain beliefs) factors in hip/groin pain (343). Further work is needed to develop and test education strategies in athletes with longstanding hip/groin pain.

10.4.3 Hip joint structure has an uncertain relationship with self-reported burden in symptomatic football players

Findings from this thesis indicate that football players with FAI syndrome and/or chondrolabral pathology do not report worse hip/groin burden than players without these conditions. Given this, and the high prevalence of cam morphology and chondrolabral findings in asymptomatic players (131, 183), it is unclear if FAI syndrome (defined by a positive FADIR test and an alpha angle ≥60°) is a relevant diagnostic entity in symptomatic football players. Whilst dichotomising the continuous alpha angle measurement at 60° assists in identify homogenous cohorts for research studies (64), simply defining the presence of FAI syndrome in this way appears unhelpful for treatment planning in the clinical setting. Findings from this thesis indicate that larger anterosuperior cam morphology (visualised on the Dunn 45° radiograph) may play a small role in the self-reported burden of football players with FAI syndrome, but this should be interpreted in the context of other physical and non-physical factors that might impact self-reported burden. The long-term effects of FAI syndrome (including those with larger cam morphology) and other hip-related pain conditions (e.g., cartilage defects and labral tears) are unknown in young adults. Prospective studies, such as the FORCe study, will help to determine whether these conditions lead to persistent or worsening hip/groin pain and structural joint disease, assisting with treatment planning for symptomatic football players.

Surgical and non-surgical treatment options exist for those with FAI syndrome. Femoral head-neck osteochondroplasty can significantly reduce alpha angles (176) and improve reported pain and function in patients with FAI syndrome (166, 344), but its ability to alter patients' risk of hip OA is unknown. Interestingly, PROM scores after hip surgery are rarely associated with post-operative alpha angles or the magnitude of bony resection (176), suggesting that other patient factors may importantly affect treatment outcomes. Many demographic (e.g., elevated BMI, female sex, older age) and radiographic or intraoperative findings (e.g., cartilage defects) are associated with negative outcomes from surgery (345, 346), and these should be considered when planning treatment. Exercise-based treatments, which do not alter cam morphology size, can be associated with reduced pain and improved function in people with FAI syndrome (155). Rehabilitation programmes that target known physical impairments in FAI syndrome (e.g., strength (52) or biomechanical (126) impairments) may be most effective (155); however, the optimum treatment strategy is

unknown, and evidence of long-term outcomes is lacking (155). It is possible that exercise-based treatments might be less effective in those with larger cam morphology (241), but full-scale studies are needed confirm this potential relationship. With reported physiotherapist-led programmes lacking high-quality return to sport elements (155) and as few as one in five athletes returning to optimal sports performance after hip arthroscopy (172), better understanding of the mechanism of non-surgical and surgical treatments is needed to improve treatment selection and outcomes in football players with FAI syndrome.

10.4.4 Gross impairments to running biomechanics are not evident in symptomatic football players

Symptomatic football players did not display obvious biomechanical impairments when compared to asymptomatic players, suggesting that running biomechanics assessment is unlikely to aid diagnosis or guide interventions in football players still capable of training and match play. When findings from this thesis are interpreted with the current literature, it appears that biomechanical differences between athletes with and without hip/groin pain are task- (196, 200-202) and sex-specific (196); however, the small magnitude of the differences means that they are unlikely to be detectable with the naked eye or two-dimensional video analysis in the clinical setting. Symptomatic football players may be more likely to perceive impairment to physical function during high-impact, multiplanar tasks (e.g., cutting, kicking) than low-load uniplanar tasks (e.g., walking); thus, investigation of these tasks may elucidate more pronounced biomechanical impairments that could guide exercise-based interventions.

Obvious biomechanical impairments during running are unlikely in active football players with FAI syndrome when compared to asymptomatic players, irrespective of their symptom severity or cam morphology size. When considering previous reports of gross biomechanical impairments during walking in people undergoing surgery for FAI syndrome (284-287), findings from this thesis suggest that more pronounced alterations to running biomechanics might be evident in those with worse symptoms who have modified their lifestyle due to persistent hip/groin pain. Whilst individuals may alter their movement patterns in response to more severe pain, other factors such as deconditioning due to cessation of sport or fear of movement may be more strongly associated with biomechanical impairments in surgical populations than in active football players. Further studies are

needed to explore relationships between these factors and running biomechanics across the spectrum of hip/groin pain patients, including in those seeking non-surgical treatment who may or may not have ceased sport. It is also unknown if the relationship between cam morphology size and running biomechanics differs over time or in patients seeking different treatments for FAI syndrome, warranting further investigation.

10.5. Final summary and thesis conclusions

Hip/groin pain is common in sub-elite players, with many continuing to train and play despite longstanding symptoms. Prior to this thesis, the self-reported burden of hip/groin pain was unknown in active football players with current symptoms.

This thesis established the measurement properties of the iHOT-33 subscale scores, allowing subsequent studies to examine reported burden in football players across an array of domains. Symptomatic football players reported substantial psychosocial burden (iHOT-Sport and HAGOS-QOL subscales), indicating that these domains may be important when quantifying the severity of hip/groin conditions and treatment outcomes in this population.

Hip joint imaging findings (i.e., cam morphology, cartilage defects, labral tears) in symptomatic football players were mostly unrelated to self-reported burden. Football players with FAI syndrome did not report worse burden than players with other hip/groin pain conditions. Cartilage defects and labral tears were unrelated to self-reported burden and did not mediate the relationship between FAI syndrome and symptom severity. Larger anterosuperior cam morphology, visualised on the Dunn 45° radiograph, was associated with worse self-reported burden in football players with FAI syndrome, but the weak relationships suggests that other factors explained most of the variance in affected iHOT-33 scores.

Running biomechanics did not differ between active football players with and without hip/groin pain, when men and women were investigated separately. In male football players with FAI syndrome, running biomechanics were mostly unrelated to self-reported burden and cam morphology size. Longitudinal studies will enhance understanding of the relationships between cam morphology, chondrolabral conditions, and lower-limb biomechanics on self-reported burden and hip joint structural disease over time.

In conclusion, the findings of this thesis suggest that whilst hip/groin pain is burdensome in football players still capable of training and match play, it is unclear what role, if any, hip joint structure and running biomechanics play with respect to symptom severity.

Appendices

Appendix A: 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 B: 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 C: Ethics approval letter for football players with hip/groin pain (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 D: Ethics approval letter for football players without hip/groin pain (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 E: Patient information statement used for football players with hip/groin pain (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
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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 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 5 minutes 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 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 your 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 your 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?

1) 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).

2) 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.

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.

SCHOLES, M.

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 chooses 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 F: Patient information statement used for football players without hip/groin pain (La Trobe University).

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 HyltonMenz, 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, Dr Adam Culvenor, 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 a private radiology clinic. 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

SCHOLES, M.

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). HEC reference number HEC16-045

Thank you

Prof Kay Crossley

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

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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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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

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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.

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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 H: Patient information statement used for football players without hip/groin pain (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 in 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)

SCHOLES, M.

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 I: Informed consent for football players with hip/groin pain (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:

Appendix J: Informed consent for football players without hip/groin pain (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 HyltonMenz, 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, Dr Adam Culenor, Matthew King, Joshua Heerey, Peter Lawrenson, Kate Croft, Jade Tan, Denise Jones and Brooke Howells

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.	Yes ☐	No ☐

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:
Subject Signature:	Date:

Appendix K: Informed consent for football players with hip/groin pain (University of Queensland).

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

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:

	Yes	No
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	☐	☐

Subject Signature:	Date:

Appendix L: Informed consent for football players without hip/groin pain (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: 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 and Brooke Howells

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.

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 consent for the information obtained from my involvement in the study be used in future research.	Yes ☐	No ☐

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:
Subject Signature:	Date:

Appendix M: The International Hip Outcome Tool-33 (iHOT-33).

From Mohtadi et al. (2012) (147)

iHOT33

INTERNATIONAL HIP OUTCOME TOOL

NAME

DATE OF BIRTH

TODAY'S DATE

WHICH HIP IS THIS SURVEY ABOUT?

If we've asked you to tell us about one hip in particular, tick that. Otherwise, tick the one which causes most trouble.

Left

Right

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

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 N: The Copenhagen Hip and Groin Outcome Score (HAGOS).

From Thorborg et al. (2011) (148)

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
☐	☐	☐	☐	☐

1

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.

Appendix O: Ethics approval for the Physiotherapist-led treatment for femoroacetabular impingement syndrome (PhysioFIRST) study.

HEC17-080 (Pending - UHEC) - Application finalised as Approved

ResearchMasterEthics@latrobe.edu.au

Thu 21/09/2017 10:02 AM

To: Joanne Kemp <J.Kemp@latrobe.edu.au>;

Cc: Denise Jones <D.Jones@latrobe.edu.au>; Anthony Schache <A.Schache@latrobe.edu.au>; Kay Crossley <K.Crossley@latrobe.edu.au>; Sally Coburn <S.Coburn@latrobe.edu.au>; ResearchMasterEthics <ResearchMasterEthics@latrobe.edu.au>;

** This is an automatically generated email, please do not reply. Contact details are listed below.**

Dear Joanne Kemp,

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: HEC17-080
Application Status/Committee: University Human Ethics Committee

Project Title: The physiotherapy for Femoroacetabular Impingement Rehabilitation STudy (PhysioFIRST): A participant and assessor-blinded randomised controlled trial of physiotherapy for hip impingement.

Chief Investigator: Joanne Kemp

Other Investigators: Kay Crossley, Sally Coburn, Denise Jones, Anthony Schache, Dr Steven McPhail

Date of Approval: 21/09/2017
Date of Ethics Approval Expiry: 31/08/2021

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 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 ResearchMaster (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 P: Patient information statement for participants in the Physiotherapist-led treatment for femoroacetabular impingement syndrome (PhysioFIRST) study.

La Trobe Sports and Exercise Medicine Research Centre

LTU ethics approval number HEC17-080

The physiotherapy for Femoroacetabular Impingement Rehabilitation STudy (PhysioFIRST): A participant and assessor-blinded randomised controlled trial of physiotherapy for hip impingement.

Investigators: Dr Joanne Kemp, Sally Coburn, Denise Jones, Dr Anthony Schache, Dr Benjamin Mentiplay, Matthew King Associate Professor Dr Steven McPhail, Professor Kay Crossley

Participant Information Statement

We invite you to participate in our project: "The physiotherapy for Femoroacetabular Impingement Rehabilitation STudy (PhysioFIRST): A participant and assessor-blinded randomised controlled trial of physiotherapy to reduce pain and improve function for hip impingement."

We would like to give you some background information to explain why we think this project is important and describe what we would like you to do if you decide to join us in this research.

What is the purpose of this study?

Femoroacetabular (hip) impingement is a painful condition that commonly affects healthy active younger adults. It can limit their ability to continue playing sport and perform normal daily activities. It can be related to extra bone formation at the hip joint known as a cam deformity. Physiotherapy is one treatment people may use to reduce their symptoms and improve their function. We would like to compare the benefits of two different physiotherapy treatments to find the best way to manage this condition. Funding for this project has been provided by La Trobe Sports and Exercise Medicine Research Centre at La Trobe University, an Arthritis Australia State/Territory Affiliate grant and a National Health and Medical Research Council Early Career Fellowship grant to Dr Kemp.

Who can participate in this study?

- People aged 18 to 50 years
- People with hip or groin pain aggravated by activity some of the time for more than 6 weeks
- People with signs of hip impingement when the hip is tested by a physiotherapist
- People with x-rays showing you have a 'cam deformity'

You are not eligible to participate in this study if:

- You cannot understand written or spoken English
- You have had physiotherapy in the past three months
- You have had hip surgery before
- You are not able to commit to a
  - **12-week physiotherapy program**
  - **a subsequent 12-week gym program, where you attend three times per week**
  - **baseline** (beginning) physical assessment
  - **follow-up** (24 weeks - after all treatments) physical assessment
- You are unable to have an x-ray of your pelvis (both hips at once) eg. You are pregnant or breastfeeding/unwilling

What does the project involve?

1. *Screening assessment (10 mins)*

You will be asked some questions about your hip over the phone to ensure you are eligible for the study. You will be asked to provide details of where any previous x-rays of your sore hip were taken for assessment of the digital copy to see if you have a 'cam deformity'. If you don't have x-rays we will organise a free hip (pelvic) x-ray for you at an x-ray clinic convenient to you (Imaging at Olympic Park, 60 Olympic Blvd, Melbourne or at Lake Imaging, Howitt St, Ballarat) if you are willing and able. The x-ray assessment will take about 30 minutes.

2. *Physical testing of your hip and questionnaires – Baseline (45 mins)*

If your movement tests and x-rays indicate you are eligible, we will ask you to attend an appointment at a mutually convenient time at La Trobe University, Bundoora, in Melbourne, or at Lake Health Group, Ballarat, to undergo baseline measurement of your hip movements and strength. These baseline tests will take about half an hour.

Following the assessment we will ask you to complete several questionnaires online, and will be provided with instructions for access to the website. If you prefer you may complete a paper version of the questionnaires instead. The questionnaires will ask you questions about your hip/groin pain, other hip-related symptoms and your levels of physical activity and take about 15 minutes to complete.

3. *A free MRI of your hip (45 mins)*

If you are willing to participate in this portion of the research, we will investigate your hip joint structure in detail via a magnetic resonance imaging (MRI) scan at Imaging at Olympic Park, 60 Olympic Blvd, Melbourne. Parking is free and parking instructions are on the referral. The MRI will take place prior to the intervention period as well as 12 months after to examine any changes in your hip joint. You may not be able to participate in this section of the testing if you have a pacemaker, metal implants, or claustrophobia. Participation in this section of the research is optional.

4. *Physiotherapy treatment (12 weeks)*

After the first assessment and completion of the questionnaires, you will be randomly allocated to one of the physiotherapy treatment groups. Both treatments are used regularly by physiotherapists. You will then be asked to attend one of three physiotherapy clinics in Melbourne (or at Lake Health Group in Ballarat). Your treatment will comprise two phases which is provided free of charge and includes physiotherapy treatments and a 3 month gym membership.

In Phase 1, you will receive 6 free physiotherapy treatments over a period of twelve weeks. Each fortnightly treatment will last 30 minutes and will be performed by an experienced and project-trained physiotherapist. You will also be asked to perform a gym-based exercise program once per week in the gym at the same clinic. There are also exercises to complete at home twice per week. All treatments and any use of gym equipment will be provided at no cost to you.

5. *Gym membership (12 weeks)*

In Phase 2, you will receive a free 3-month gym membership and continue the exercise program you received in Phase 1 three times per week. You will receive a further three free physiotherapist reviews to continue to monitor your progress.

6. *Physical testing of your hip and questionnaires – Follow-up (45 mins)*

You will then return to La Trobe University, Bundoora (or Lake Health Group, Ballarat) for a final physical assessment. This will take approximately the same amount of time as the first assessment (about 45 minutes). The examiner physiotherapist will not know which treatment you have received. We ask you not to discuss your treatment with the examiner. We will also provide the same follow-up questionnaires for you to complete again (15 minutes), on paper, or online, and will ask you some questions about your experience of the project.

You will not receive any payment for your participation; however you will have free x-ray (and MRI if applicable) and assessment of your hip problem and free comprehensive physiotherapy if you are eligible and choose to participate.

We will also give you a $100 gift voucher for attending the final 6-month assessment of your hip at La Trobe University, as your assessment provides data critical to the success of our study. You may also ask for a copy of your assessment results.

We also ask that if you are considering another treatment for your hip or another musculoskeletal condition, you discuss the impact this might have on the study with the project leader, Dr Joanne Kemp.

Are there any potential side-effects?

The impingement and movement tests represent usual examination by a physiotherapist. You may experience a small amount of discomfort in the joints or tiredness in the muscles during the movement and strength testing and interventions. Please report any undue discomfort or pain experienced during the testing. If the pain or discomfort is deemed to be excessive by yourself or the examiner, testing or treatment will cease.

If you have not already had a hip xray and require one to determine if you may participate, you will be exposed to a very small amount of radiation. 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 this study is about 0.32 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. If you decide to participate in the MRI scans, there is no further exposure to radiation with MRI.

If required, emergency procedures will be used to deal with any medical event that arises during testing or physiotherapy treatments. La Trobe University and participating physiotherapy clinics and gymnasiums have documented procedures for emergencies. This includes annual first aid and CPR training and appropriate management of fire for all staff.

What if I have any concerns during the study?

This study is funded La Trobe Sports and Exercise Medicine Research Centre at La Trobe University, Bundoora, Arthritis Australia and National Health and Medical Research Council fellowship grant to Dr Kemp. This study adheres to the La Trobe University Human Ethics Guidelines and National Statement on Ethical Conduct in Human Research. Whilst you are free to discuss your initial participation in this study with the project coordinator (Sally Coburn ph: 0408 761 237), you may want to talk an officer of the University not involved with the study. If so, you may contact the Ethics Manager, Heidi Gaulke on ph: (03) 9479 1443. If you choose to participate, you are free to call the project chief investigator with any queries following the baseline assessment of your hip (Dr Joanne Kemp ph: 0484 776 536)

Can I withdraw from the study if I wish?

Your participation in the study is voluntary. If you do not wish to take part you are under no obligation to do so. If you decide to take part and later change your mind, you are free to withdraw from the study at any stage. You may also withdraw any unprocessed data previously supplied by you.

If you are a student of La Trobe University, your decision whether to take part or not to take part, or to withdraw, will not affect your affiliation with the university in any way.

If you are a patient of any of the investigators or project physiotherapists, your decision whether to take part or not to take part, or to withdraw, will not affect your relationship with the physiotherapy clinic or your future physiotherapy management in any way.

Will my details be kept confidential?

Our procedures require allocation of a code number to identify you and any data associated with your participation. This assures your anonymity as your name will not be used. You will be videoed performing a single leg squat but will be de-identified for analysis. No findings that identify you will be published and access to individual results is restricted to the investigators. Coded data will be stored for at least 5 years. All data and results will be handled in a strictly confidential manner, under guidelines set out by the National Health and Medical Research Council. The chief investigator is responsible for maintaining this confidentiality. This project is subject to the requirements of the La Trobe University Human Ethics Guidelines. However, you must be aware that there are legal limitations to data confidentiality.

What will happen to the results of the study?

Summaries of the study results will be sent to participants, if requested on the consent form. It is possible that results from this study will be presented at a local, national or international conference, or published in a peer reviewed journal. Results may also be used for teaching purposes and web-based translational material. All results are **de-identified**.

How do I get more information?

You should ask for any information you want. If you would like more information about the study, or if there is any matter that concerns you, either now or in the future, do not hesitate to ask one of the investigators or project coordinator. Before deciding whether or not you should take part you may wish to discuss the matter with a relative or friend or with your local doctor. You should feel free to do this. A newsletter will be sent to update you during the project. A project summary will be available, on request via email/post at the conclusion of the study and will include no identifiable information.

About the investigators:

Prof Kay Crossley is a sports physiotherapist and professor at La Trobe Sports and Exercise Medicine Research Centre at La Trobe University, Bundoora.

Dr Joanne Kemp is a sports physiotherapist and post-doctoral researcher at La Trobe Sports and Exercise Medicine Research Centre at La Trobe University, Bundoora.

Sally Coburn is a physiotherapist and research assistant at La Trobe Sports and Exercise Medicine Research Centre at La Trobe University, Bundoora.

Denise Jones is a physiotherapist and research assistant at La Trobe Sports and Exercise Medicine Research Centre at La Trobe University, Bundoora.

Dr Anthony Schache is a physiotherapist and senior research fellow at La Trobe Sports and Exercise Medicine Research Centre at La Trobe University, Bundoora.

Dr Benjamin Mentiplay is an exercise scientist and researcher at La Trobe Sports and Exercise Medicine Research Centre at La Trobe University, Bundoora.

Matthew King is a physiotherapist and PhD candidate at La Trobe Sports and Exercise Medicine Research Centre at La Trobe University, Bundoora.

A/Prof Steven McPhail is a health economist at University of Queensland

Contacts:

Enquiries and eligibility:
Richard Johnston
Mob: 0484 761 237
Email: r.johnston@latrobe.edu.au.

If you have commenced participation:
Dr Joanne Kemp
Email: j.kemp@latrobe.edu.au
Mob: 0484 776 536

Appendix Q: Informed consent for participants in the Physiotherapist-led treatment for femoroacetabular impingement syndrome (PhysioFIRST) study.

LA TROBE UNIVERSITY Participant Code: PF ___ ___ ___ physioFIRST STUDY

La Trobe Sports and Exercise Medicine Research Centre

Consent form for persons participating in research projects

LTU ethics approval number HEC17-080

The physiotherapy for Femoroacetabular Impingement Rehabilitation STudy (PhysioFIRST): A participant and assessor-blinded randomised controlled trial of physiotherapy for hip impingement.

Investigators: Dr Joanne Kemp, Sally Coburn, Denise Jones, Dr Anthony Schache, Dr Benjamin Mentiplay, Matthew King, Associate Professor Dr Steven McPhail, Professor Kay Crossley

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.

I consent to my data being included in other research projects. I acknowledge that my data will be coded, but can be potentially identified.	Yes ☐	No ☐
I consent to my single leg squat test being videoed. I acknowledge that any video data will be de-identified.	Yes ☐	No ☐
I understand my participation will not affect my current or future staff/student affiliation/physiotherapy management with:	Yes ☐	No ☐

_____

I consent to be involved in the additional testing of physical activity using the Fitbit device	Yes ☐	No ☐
I consent to be involved in the additional testing of my movement patterns through biomechanical assessment	Yes ☐	No ☐
I consent to be involved in the additional testing of hip joint structure via Magnetic Resonance Imaging (MRI) scans	Yes ☐	No ☐
I wish to have a have a summary report sent to me at the conclusion of my participation in this project.	Yes ☐	No ☐

LA TROBE UNIVERSITY

Participant Code: PF ___ ___ ___

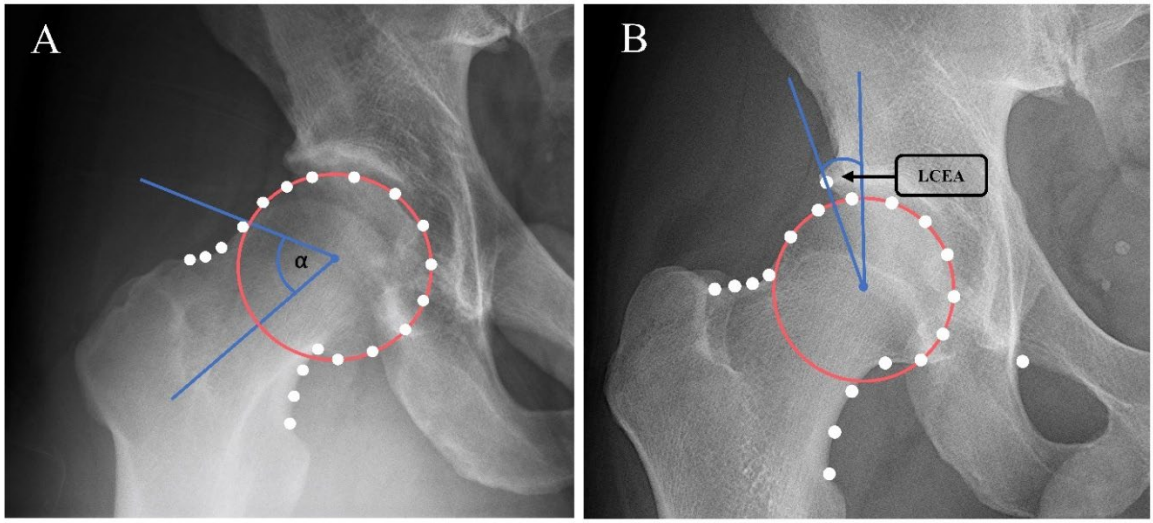
physiFIRST STUDY

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:

Appendix R: Quantitative measures of bony hip morphology for Studies 3 and 6.



The white points on the image are representative of the manual point set that was placed on pre-determined locations on the surface of the femur and acetabulum. Abbreviations: α = alpha angle; LCEA = lateral centre-edge angle.

Alpha angle

Cam morphology was determined by measuring the alpha angle on the Dunn 45° radiograph (Image A). The points placed on the femoral head and neck determined the circle of best fit around the femoral head and centre of 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.

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 weightbearing portion of the acetabular sulcus (Figure B). 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.

Appendix S: List of surface marker names.

Marker Code	Location/Definition
Head, arms, and trunk	
C7	C7 Spinous process
LSH and RSH	Left and right shoulder
LELB and RELB	Left and right elbow
LWR and RWR	Left and right wrist
Pelvis	
LASI and RASI	Left and right anterior superior iliac spine
SACR	Sacral marker – mid-point between the left and right posterior superior iliac spines
P1	Sacral plate marker 1 – Left
P2	Sacral plate marker 2 – Right
P3	Sacral plate marker 3 – Inferior
Thigh and patella	
LTHAP and RTHAP	Left and right thigh anterior proximal
LTHAD and RTHAD	Left and right thigh anterior distal
LTHLP and RTHLP	Left and right thigh lateral proximal
LTHLD and RTHLD	Left and right thigh lateral distal
LLEPI and RLEPI	Left and right lateral epicondyle
LMEPI and RMEPI	Left and right medial epicondyle
LPAT and RPAT	Left and right patella
Shank	
LTIAP and RTIAP	Left and right tibia anterior proximal
LTIAD and RTIAD	Left and right tibia anterior distal
LTILAT and RTILAT	Left and right tibia lateral
LLMAL and RLMAL	Left and right lateral malleoli
LMMAL and RMMAL	Left and right medial malleoli
Foot	
LHEEL and RHEEL	Left and right heel
LMFS and RMFS	Left and right midfoot superior
LMFL and RMFL	Left and right midfoot lateral
LP1MT and RP1MT	Left and right proximal (base) 1st metatarsal
LP5MT and RP5MT	Left and right proximal (base) 5th metatarsal
LTOE and RTOE	Left and right toe

Appendix T: Confirmation of authorship.

Study 1 (Chapter 3)

Statement from the authors confirming the authorship contribution of the PhD candidate.

As the co-authors of the publication:

Scholes MJ, King MG, Crossley KM, Jones DM, Semciw AI, Mentiplay BF, Heerey JJ, Lawrenson PR, Coburn SL, Johnston RTR, Bell EC, Girdwood M, Kemp JL. The International Hip Outcome Tool 33 (iHOT-33) is valid, reliable, and responsive in patients with hip and groin pain treated without surgery. *American Journal of Sports Medicine.* 2021;49(10):2677-88.

We certify that Mark James Scholes made the following contributions:

- Study administration
- Developed concept and design of the study
- Developed testing protocol used within the study
- Recruitment
- Data collection, processing, and curation
- Statistical analyses and data visualization
- Writing of the manuscript and response to reviewers' comments

Dr Matthew King	[redacted]	Date: 19/01/2022
Prof. Kay Crossley		Date: 19/01/2022
Dr Denise Jones		Date: 19/01/2022
A/Prof Adam Semciw		Date: 19/01/2022
Dr Benjamin Mentiplay		Date: 19/01/2022
Dr Joshua Heerey		Date: 19/01/2022
Dr Peter Lawrenson		Date: 19/01/2022
Ms Sally Coburn		Date: 19/01/2022
Dr Richard RTR Johnston		Date: 19/01/2022
Ms Emily Bell		Date: 19/01/2022
Mr Michael Girdwood		Date: 19/01/2022
A/Prof Joanne Kemp		Date: 19/01/2022

Study 3 (Chapter 5)

Statement from the authors confirming the authorship contribution of the PhD candidate.

As the co-authors of the publication:

Scholes MJ, Kemp JL, Mentiplay BF, Heerey JJ, Agricola R, Semciw AI, Souza R, Link T, Majumdar S, King MG, Lawrenson PR, Crossley, KM. Does femoroacetabular impingement syndrome affect self-reported burden in football players with hip and groin pain? A cross-sectional study of 165 symptomatic sub-elite players. *Sports Health*. 2022. Accepted.

We certify that Mark James Scholes made the following contributions:

- Study administration
- Developed concept and design of the study
- Developed testing protocol used within the study
- Recruitment
- Data collection, processing, and curation
- Statistical analyses and data visualization
- Writing of the manuscript and response to reviewers' comments

A/Prof Joanne Kemp	[redacted]	Date: 19/01/2022
Dr Benjamin Mentiplay		Date: 19/01/2022
Dr Joshua Heerey		Date: 19/01/2022
Dr Rintje Agricola		Date: 19/01/2022
A/Prof Adam Semciw		Date: 19/01/2022
Prof Richard Souza		Date: 19/01/2022
Prof Thomas Link		Date: 19/01/2022
Prof Shamila Majumdar		Date: 19/01/2022
Dr Matthew King		Date: 19/01/2022
Dr Peter Lawrenson		Date: 19/01/2022
Prof Kay Crossley		Date: 19/01/2022

Study 4 (Chapter 6)

Statement from the authors confirming the authorship contribution of the PhD candidate.

As the co-authors of the publication:

Scholes MJ, Kemp JL, Mentiplay BF, Heerey JJ, Agricola R, King MG, Semciw AI, Lawrenson PR, Crossley KM. Are cam morphology size and location associated with self-reported burden in football players with FAI syndrome? *Scandinavian Journal of Medicine & Science in Sports*. 2022. In press.

We certify that Mark James Scholes made the following contributions:

- Study administration
- Developed concept and design of the study
- Developed testing protocol used within the study
- Recruitment
- Data collection, processing, and curation
- Statistical analyses and data visualization
- Writing of the manuscript and response to reviewers' comments

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Study 5 (Chapter 8)

Statement from the authors confirming the authorship contribution of the PhD candidate.

As the co-authors of the publication:

Scholes MJ, Crossley KM, King MG, Schache AG, Kemp JL, Semciw AI, Sritharan P, Heerey JJ, Mentiplay BF. Running biomechanics in football players with and without hip and groin pain. A cross-sectional analysis of 116 sub-elite players. *Physical Therapy in Sport*. 2021;52:312-21.

We certify that Mark James Scholes made the following contributions:

- Study administration
- Developed concept and design of the study
- Developed testing protocol used within the study
- Recruitment
- Data collection, processing, and curation
- Statistical analyses and data visualization
- Writing of the manuscript and response to reviewers' comments

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