Aetiology, Diagnosis and Treatment of Anterolateral Rotatory Laxity of the Knee

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MB BCh BAO MMedSc MD FRCS FRACS

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

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Summary

Anterior cruciate ligament (ACL) injuries are common, potentially disabling and often require reconstruction. As the incidence of ACL reconstruction has increased significantly, so too have the revision rates for this procedure. In 2013, the anterolateral ligament (ALL) was discovered and was heralded as the 'missing link' in the treatment of knee ligament injury. Given its location at the front and outside of the knee, it was thought to control anterolateral knee rotation that could not be achieved by the ACL alone. Within months of this discovery, surgical procedures were devised to reconstruct the ALL with a view to decrease the failure rates of ACL reconstruction. However, there was a lack of scientific research to substantiate these claims or support the use of this procedure in the setting of primary ACL reconstruction. This thesis investigated the ALL, the key structures that control anterolateral rotatory laxity, and how it can be diagnosed and treated effectively.

The findings confirmed that the ALL is a capsular structure within the anterolateral capsule of the knee and is merely one component of the anterolateral complex, which consists of the superficial and deep aspects of the ITB with its Kaplan fibre attachments on the distal femur. A loss of integrity of the anterolateral complex in the setting of ACL deficiency contributes to anterolateral rotatory laxity which can be diagnosed clinically with the pivot shift manoeuvre. MRI is not reliable in identifying injury to the ALL following ACL rupture but it can diagnose injury to the Kaplan fibres. However, the prevalence of injury to the Kaplan fibres is low (16.4% -23.37%) with acute ACL rupture. There is no association between the grade of pivot shift at the time of surgery and the radiological evidence of injury to the Kaplan fibres. With respect to the surgical management of anterolateral rotatory laxity, there is strong evidence that the addition of a lateral extra-articular tenodesis (LEAT) to an ACL reconstruction in chronic ACL-deficiency reduces lateral femoral translation. The best available evidence would suggest that the addition of a LEAT to an ACL reconstruction does not result in an increase rate of osteoarthritis. Finally, a distally based lateral extra-articular augmentation procedure (modified Ellison) can closely restore knee laxities to native values in an anterolateral capsule–sectioned knee and should be considered a good alternative to more proximally based LEAT procedures.

Statement of Authorship

I, Brian Meldan Devitt, declare that 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 this submitted for the award of any other degree or diploma.

I, Brian Meldan Devitt, declare that 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.

With regards to the extent of collaboration with another person or persons, although the publications involve joint authorship, I have made a significant and leading contribution to the work, equivalent to that expected for a traditional thesis. I am the primary author on six of the manuscripts, co-author on one, and lead investigator (last author) on two manuscripts presented in this thesis.

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All research procedures reported in this thesis were approved by the relevant Ethics Committee or Safety Committee or authorised officers (Ethics approval numbers: Epworth HREC study number 57012; Epworth HREC study number LR 183-14; Tissue Bank application number R15091-1A)

Signed:

Date: 30.06.2020

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Publications and Presentations Arising from this Thesis

Peer-reviewed Journal Articles

1. The Origin of the Knee Anterolateral Ligament Discovery: A Translation of Segond's Original Work With Commentary. Murgier J, Devitt BM, Sevre J, Feller JA, Cavaignac E. Arthroscopy. 2019 Feb;35(2):684-690.

2. MRI is not reliable in diagnosing of concomitant anterolateral ligament and anterior cruciate ligament injuries of the knee. Devitt BM, O'Sullivan R, Feller JA, Lash N, Porter TJ, Webster KE, Whitehead TS. Knee Surg Sports Traumatol Arthrosc. 2017 Apr;25(4):1345-1351.

3. The Kaplan Fibers of the Iliotibial Band Can Be Identified on Routine Knee Magnetic Resonance Imaging. Batty L, Murgier J, O'Sullivan R, Webster KE, Feller JA, Devitt BM. Am J Sports Med. 2019 Oct;47(12):2895-2903.

4. Radiological identification of injury to the Kaplan fibers of the iliotibial band in association with anterior cruciate ligament injury. Batty L, Murgier J, O'Sullivan R, Webster KE, Feller JA, Devitt BM. Am J Sports Med. (accepted for publication 16/4/2020) Manuscript: AMJSPORTS/2019/295311

5. Association between radiological evidence of Kaplan fiber injury, intraoperative findings and pivot shift grade in the setting of acute anterior cruciate ligament injury. Devitt, BM, Al'khafaji I, Blucher N, Batty L, Murgier J, O'Sullivan R, Webster KE, Feller JA. Am J Sports Med (Under Review).

6. Comparison of the Source and Quality of Information on the Internet Between Anterolateral Ligament Reconstruction and Anterior Cruciate Ligament Reconstruction: An Australian Experience. Devitt BM, Hartwig T, Klemm H, Cosic FT,

Green J, Webster KE, Feller JA, Baker JF. Orthop J Sports Med. 2017 Dec 7;5(12):2325967117741887.

7. The Role of Lateral Extra-articular Tenodesis in Primary Anterior Cruciate Ligament Reconstruction: A Systematic Review With Meta-analysis and Best-Evidence Synthesis. Devitt BM, Bell SW, Ardern CL, Hartwig T, Porter TJ, Feller JA, Webster KE. Orthop J Sports Med. 2017 Oct 24;5(10):2325967117731767.

8. Combined anterior cruciate ligament reconstruction and lateral extra-articular tenodesis does not result in an increased rate of osteoarthritis: a systematic review and best evidence synthesis. Devitt BM, Bouguennec N, Barfod KW, Porter T, Webster KE, Feller JA. Knee Surg Sports Traumatol Arthrosc. 2017 Apr;25(4):1149-1160.

9. Biomechanical Assessment of a Distally Fixed Lateral Extra-articular Augmentation Procedure in the Treatment of Anterolateral Rotational Laxity of the Knee. Devitt BM, Lord BR, Williams A, Amis AA, Feller JA. Am J Sports Med. 2019 Jul;47(9):2102-2109.

10. Al'khafaji I, Devitt BM. Editorial Commentary: Magnetic Resonance Imaging Evaluation of the Anterolateral Complex-Is Seeing Really Believing? Arthroscopy. 2020 Apr;36(4):1092-1094.

International Conference Presentations

1. Devitt B M, Batty L, Murgier J, O'Sullivan R, Webster KE, Feller JA, Devitt BM. No correlation with pivot shift grade and radiological evidence of Kaplan Fibre injury in the setting of acute anterior cruciate ligament rupture. Anterior Cruciate Ligament Study Group biennial meeting. January 2020, Kitzbühel, Austria.

2. Devitt B M, Lash N, O'Sullivan R, Porter T, Feller JA, Whitehead TS. MRI is not reliable in diagnosing of concomitant anterolateral ligament and anterior cruciate ligament injuries of the knee. International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine Biennial Meeting. June 2017, Shanghai, China.

3. Devitt BM, Bouguennec N, Barfod KW, Porter T, Webster KE, Feller JA. Combined anterior cruciate ligament reconstruction and lateral extra-articular tenodesis does not result in an increased rate of osteoarthritis: a systematic review and best evidence synthesis. International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine Biennial Meeting. June 2017, Shanghai, China.

4. Devitt BM, Lord BR, Williams A, Amis AA, Feller JA. Biomechanical Assessment of a Distally Fixed Lateral Extra-articular Augmentation Procedure in the Treatment of Anterolateral Rotational Laxity of the Knee. Anterior Cruciate Ligament Study Group. January 2018, Queensland, New Zealand.

5. Devitt BM. Comparison of Lateral Extra-articular Tenodesis Techniques: Which one should we choose? Asia-Pacific Knee, Arthroscopy and Sports Medicine Society (APKASS) meeting. June 2018, Sydney.

6. Devitt B M, Batty L, Murgier J, O'Sullivan R, Webster KE, Feller JA, Devitt BM. Radiological identification of injury to the Kaplan fibers of the iliotibial band in association with anterior cruciate ligament injury. International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine Biennial Meeting. May 2019, Cancun, Mexico.

National Conference Presentations

1. Devitt B M, Batty L, Murgier J, O'Sullivan R, Webster KE, Feller JA, Devitt BM. No association with radiological evidence of Kaplan Fibre injury and pivot shift grade in

the setting of acute anterior cruciate ligament rupture. Australian Knee Society Meeting. October 2018, Broom, Queensland.

2. Devitt B M, Lash N, O’Sullivan R, Porter T, Feller JA, Whitehead TS. MRI is not reliable in diagnosing of concomitant anterolateral ligament and anterior cruciate ligament injuries of the knee. Australian Knee Society Meeting. October 2017, Noosa, Queensland.

3. Devitt B M, Batty L, Murgier J, O'Sullivan R, Webster KE, Feller JA, Devitt BM. Radiological identification of injury to the Kaplan fibers of the iliotibial band in association with anterior cruciate ligament injury. Australian Knee Society Meeting. October 2017, Noosa, Queensland.

4. Devitt BM, Hartwig T, Klemm H, Cosic FT, Green J, Webster KE, Feller JA, Baker JF. Comparison of the Source and Quality of Information on the Internet Between Anterolateral Ligament Reconstruction and Anterior Cruciate Ligament Reconstruction: An Australian Experience. Australian Orthopaedic Association Meeting. October 2017, Brisbane, Queensland.

5. Devitt BM, Bell SW, Ardern CL, Hartwig T, Porter TJ, Feller JA, Webster KE. The Role of Lateral Extra-articular Tenodesis in Primary Anterior Cruciate Ligament Reconstruction: A Systematic Review With Meta-analysis and Best-Evidence Synthesis. Australian Knee Society Meeting. October 2017, Noosa, Queensland.

6. Devitt B M, Batty L, Murgier J, O'Sullivan R, Webster KE, Feller JA, Devitt BM. The Kaplan Fibers of the Iliotibial Band Can Be Identified on Routine Knee Magnetic Resonance Imaging. Australian Knee Society Meeting. October 2017, Noosa, Queensland.

7. Devitt B M. The anterolateral ligament of the knee: Fake news of the alternative fact. Australian Orthopaedic Association, Victoria Branch. February 2016, Lorne, Victoria.

8. Devitt B M. The anterolateral ligament: Fake news or alternative fact! Australian Knee Society Meeting. October 2018, Broom, Western Australia.

Chapter 1: Introduction, aims and objectives

The 'new' discovery

In November 2013, a young Belgian surgeon, Dr Stephen Claes, claimed to have discovered a new ligament which was integral to the stability of the knee(1). The ligament in question was named: '*The anterolateral ligament*'. Despite the study being published in the Journal of Anatomy, a publication with a relatively low impact factor and small readership, the discovery reached all the major mainstream media outlets within days of its scientific release(2, 3). This was largely due to the advent of social media and the rapid dissemination of information it afforded.

The anterolateral ligament (ALL) was heralded as the great panacea in the treatment of knee ligament injury and given its location at the front and outside of the knee was thought to control knee rotation knee that could not be achieved by the anterior cruciate ligament (ACL) alone which was located in the centre (1, 3). Claes et al, in their original manuscript submitted that '*given its structure and anatomic location, the ALL is hypothesized to control internal tibial rotation*' and *'…avulsion of the ALL could provide a clue to an important role for the ALL in rotatory knee instability patterns witnessed in many ACL-deficient knees.'*(1) It provided a plausible reason to explain why patients with ACL injuries, despite reconstruction, went on to further injury because they had also likely injured this ligament unbeknownst to themselves or the treating surgeons.

Although conceivable that this ligament was important, the simple explanation for persistent knee laxity caused by injury to one solitary structure seemed too good to be true. It provided the impetus for me to question the importance of the ALL and the role, if any, it has on controlling rotation of the knee. Indeed, this was the stimulus for me to go further and to explore the concept of anterolateral rotatory laxity of the knee and determine the following key factors:

1. Does the anterolateral ligament (ALL) really exist and, if so, what does it do?

2. What is the aetiology of anterolateral rotatory laxity of the knee?
3. How can anterolateral rotatory laxity of the knee be diagnosed?
4. And, what is the most effective method of treating anterolateral rotatory laxity of the knee through surgical reconstruction?

Ultimately, these questions formed the basis of my thesis.

Going backwards to move forwards

Using the discovery of the ALL as a point in time, a thorough review of historical anatomical studies was conducted to try to unearth whether this was a new anatomical finding, or merely a new label ascribed to an already existing structure. I was drawn to the first paragraph of the study by Claes et al in which they describe the '*Anatomy of the anterolateral ligament of the knee*.'(1) The authors make reference to the work of a French surgeon, Paul Segond, in which he describes as seemingly similar structure at the same anatomical location which was depicted as '*a pearly, resistant, fibrous band which invariably showed extreme amounts of tension during forced internal rotation..*'(4) The original description was published in his study, "*Les épanchements sanguins du genou par entorse*," which was a treatise on the origin of a traumatic haemathrosis of the following a so-called sprain. Furthermore, this seminal work was published in French in 1879 and has never been translated into English. Although this work has been widely cited, one must question whether many of the authors that have cited it have actually had the opportunity to read it. As such, I felt it was both relevant and important to provide a translation of this work and reveal what Segond actually described and how he discovered it.

Segond is most well-known for his description of an avulsion fracture on fracture on the anterolateral aspect of the proximal tibia which is eponymously named(4). A Segond fracture is a key radiographic finding that can be seen on plain radiographs and is pathognomonic for a rupture of the ACL(5). What is quite remarkable about this discovery is that it was made before Roentgen discovered X-rays. However nowadays, not only do we have radiographs to aid us in diagnosis of knee injuries but we also Magnetic Resonance

Imaging (MRI) which provides a detailed, highly sensitive and accurate tool to diagnose pathology and ligamentous injuries of the knee(6-8). One of the challenging aspects for surgeons in treating anterolateral rotatory laxity of the knee is that the patient's symptoms of instability do not always correlate with the clinical examination findings(9-11). The pivot shift test has long been regarded as the most sensitive test to diagnose both acute and chronic ACL injuries, but there is considerable variability in how it is conducted and even more subjectivity in how it is graded (11, 12). As such, a non-invasive, radiological method to diagnose injury to the anterolateral structures of the knee in the setting of ACL rupture could possibly aid in the identifying a cohort of patients that may be more prone to developing residual anterolateral laxity despite ACL reconstruction and, therefore, may warrant an additional lateral procedure to address the laxity. In order to evaluate this, a study was conducted to firstly identify the ability of MRI to detect the ALL in ACL-intact knees followed by a cohort of ACL-injured knees.

Complex by name and complex by nature

It appears that my doubts about the integral role of the ALL alone in controlling anterolateral rotatory laxity were shared by a number of researchers in the field(13). The controversy surrounding the ALL led to the formation of a consensus group in 2018. What emerged was that a complex of anterolateral structures exists which consists of the superficial and deep aspects of the iliotibial band (ITB) with its Kaplan fibre attachments on the distal femur, along with the ALL, which was defined as a capsular structure within the anterolateral capsule(14). Attention began to shift from the ALL to the ITB, and especially the Kaplan fibre attachments(15, 16). Biomechanical studies demonstrated that the ITB was an important restraint to anterior translation and internal rotation of the tibia(15, 17). Further studies postulated that the Kaplan fibre attachments by virtue of their location allow the distal ITB to function as a ligament and tighten during internal tibial rotation(18). Notably, in biomechanical studies trying to simulate anterolateral laxity of the knee, the Kaplan fibres have been sectioned to create a worst-case scenario of knee injury (15, 19, 20). A key question that remains, however, is whether the Kaplan fibres are injured in association with ACL rupture and, if so, whether this is a factor contributing to the spectrum of laxity after anterolateral complex injury. To answer this question, a three-part study was conducted: The first study aimed to assess whether routine MRI, using standard knee protocols could be used to identify the Kaplan fibres the ACL-intact knee. This was followed by a study to identify the prevalence of Kaplan fibre injury in the setting of both acute and chronic ACL injury using routine MRI. Finally, a further study was conducted which aim to correlate the radiological presence of Kaplan fibre and the grade of pivot shift at the time of ACL reconstruction.

Big Business

Knee surgery is big business nowadays. Within months of the discovery of the ALL, opportunistic orthopaedic surgeons, heavily backed by industry, released techniques to reconstruct the ligament(2, 3). Unfortunately, lost in the manic race for market share, the rigor of scientific proof was somewhat neglected(21). Coupled with this, the rapid dissemination of information regarding the ALL demonstrated the extraordinary capability of the internet and social media platforms(21). The result was the widespread promotion and uptake of the ALL reconstruction procedure across the orthopaedic community prior to even the publication of short-term, never mind long-term, results regarding its effectiveness(22). The lure of reducing recurrent instability by adding an ALL reconstruction to an ACL reconstruction was heralded by industry as the missing link in providing a patient with a stable knee and thereby reducing the risk of revision surgery(21). Not surprisingly, in an increasingly competitive industry, one is always fearful of unscrupulous surgeons passing on these theoretical claims to their patients on practice websites(23). The capability of the internet to disseminate diverse data across population presents unique opportunities but also poses significant challenges in terms of regulation of information, particularly in the healthcare industry(24, 25). In order to get an idea of what information our patient population is being exposed to, a study was conducted to evaluate the source and quality of information on the internet relation to ALL reconstruction compared with ACL reconstruction.

Lateral Extra-articular Tenodesis

Although the ALL has flattered to deceive as the root-cause of anterolateral rotatory laxity of the knee, what has re-emerged was a renewed awareness that an isolated ACL reconstruction in a primary ACL rupture is not always enough(26, 27). Surgeons have long recognized that a procedure on the anterolateral aspect of the knee offers a powerful tool to control rotation of the knee(28). The concept of combining a lateral extra-articular augmentation with an ACL reconstruction was developed with the objective of decreasing the failure rate of either technique carried out in isolation(29-31). The approach became popular in the 1980s and was adopted by a number of surgeons using a variety of extra-articular augmentation procedures(32, 33). Although most of these procedures diminished or obliterated the pivot shift, extra-articular augmentation fell out of favour when reports emerged about its unpredictability and unsatisfactory results(34-36). Biomechanical and clinical studies at the time suggested that intra-articular reconstruction alone would be sufficient in the treatment of knee laxity following isolated ACL tears and the addition of an extra-articular procedure added little to the overall functional outcome(37-41). However, as the incidence of ACL reconstruction has increased significantly over the past two decades, so too have the revision rates for this procedure, which now represent a significant surgical burden(42, 43). Therefore, there is a renewed interest in the use of Lateral Extra-articular Tenodesis (LET) procedures. Although, its utility has been highly promoted in the setting of revision ACL reconstruction, questions still remain as to its role in the setting of primary ACL reconstruction. A systematic review was conducted with the aim to determine whether the addition of a LET to a primary ACL reconstruction would result in improved rotational laxity and clinical outcomes compared with ACL reconstruction in isolation.

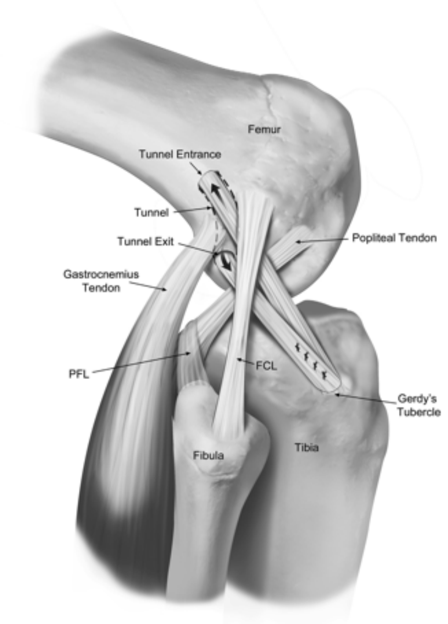
Primum non nocere

One of the key issues related to the downturn in usage of a LET in combination with an ACL reconstruction was the possibility of over-constraint of the lateral compartment of the knee(32, 44). The assertion was that a non-anatomic, non-isometric construct on the lateral aspect of the knee would alter the kinematics of the knee, exposed the lateral compartment to increase load, thereby increasing the risk of osteoarthritis(40, 44). It has been well established that patients who suffer an ACL rupture are at a greater risk of developing osteoarthritis in later life anyway(45, 46). Unfortunately, ACL reconstruction has not been shown to improve the prognosis for osteoarthritis(47). However, there are a number of confounding factors that need to be considered; the meniscal status of the knee, the presence of concomitant chondral damage, the activity level of the patient following reconstruction, and the time period from injury to reconstruction(47). A systematic review was conducted to analyse the long-term incidence of osteoarthritis in patients who had a LET performed in isolation or in combination with an intra-articular ACL reconstruction for the treatment of ACL deficiency.

Turning things upside-down

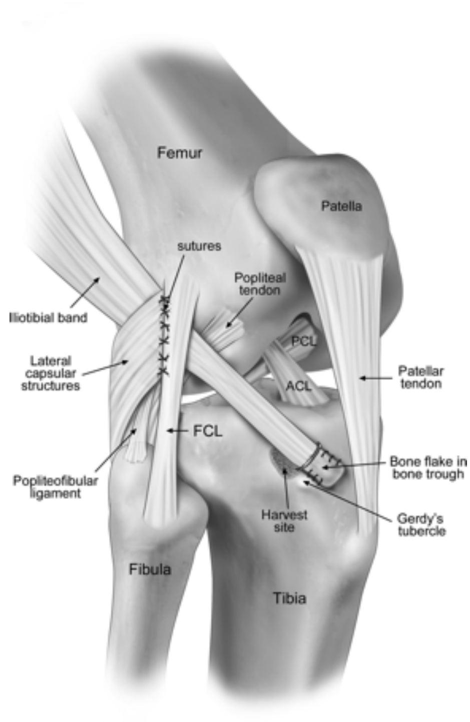
The majority of LET procedures are based on a proximally fixed construct, typically with a strip of ITB, which remains attached to its insertion at or near to Gerdy's tubercle(48). The free proximal end passes with deep or superficial to the fibular collateral ligament (FCL) and is typically fixed to the femur posterior and proximal to the lateral epicondyle (Figure 1.1).

Figure 1.1: *Lemaire technique(48) – Proximally based tenodesis (FCL, fibular collateral ligament; PFL, popliteofibular ligament).*



However, a distally fixed ITB transfer, originally described by Ellison, has also been used(33). This technique uses a strip of ITB, which is elevated from Gerdy's tubercle with a sliver of bone and reflected proximally and then passed deep to FCL and reattached to the region of Gerdy's tubercle from where it was taken (Figure 1.2).

Figure 1.2 : *Ellison technique(33, 48) – Distally based extra-articular tenodesis. (ACL, anterior cruciate ligament; FCL, fibular collateral ligament; PCL, posterior cruciate ligament.*



The proposed advantage of this technique was that it maintained an element of dynamic control of rotation by virtue of its continuity with the tensor fascia lata muscle at the hip joint(33). Therefore, by not fixing the strip of the ITB proximally but keeping it in continuity with the rest of the ITB and passing it under the fixed point of the femoral origin of the FCL, the construct would tend to tighten in extension, as it deviates from its natural alignment around the FCL, and slacken as the knee flexes(49). Theoretically, it is most effective at lower flexion angles where the pivot shift phenomenon occurs, with minimal or no effect with more flexed knee positions. Therefore, it should not interfere with natural rotatory laxities and should also avoid excessive tightness. In order to investigate the effectiveness of the Ellison procedure a biomechanical, robotic study was conducted. The aim of the study was to investigate the effect of a modified Ellison procedure in restoring native kinematics of the ACL-intact knee after complete section of the anterolateral capsule.

Objectives

The overall objectives of this thesis were as follows:

1. To further the understanding of the anatomy of the anterolateral complex of the knee and the aetiology of anterolateral rotatory laxity of the knee

2. To evaluate the efficacy of MRI as an imaging modality of the anterolateral complex and a diagnostic tool to identify injury

3. To analyse the role for lateral extra-articular augmentation procedures in the setting of primary anterior cruciate ligament reconstruction.

Section 1

Chapter 2: Anatomy of the anterolateral complex of the knee: Does the anterolateral ligament really exist?

- **Primary Aim:** To provide a detailed review of the currently available information in the literature on the anatomy of the anterolateral complex of the knee. I

- **Secondary Aim:** To investigated the etymology of the term ‘anterolateral ligament’ and reveal structure it truly depicts.

Chapter 3: Aetiology of anterolateral rotatory laxity of the knee and the pivot shift test

- **Primary Aim:** To provide a detailed review of the aetiology of anterolateral rotatory laxity of the knee.

- **Secondary Aim:** To discuss the role of the pivot shift test in diagnosis of anterolateral rotatory laxity.

Chapter 4: What did Segond really say?

Study 1: "The origin of the knee anterolateral ligament discovery: A translation of Segond's original work with commentary"

- **Primary Aim:** To translate the work of Paul Segond entitled, "*Les epanchements sanguin du genou par entorse*", which is a treatise of "*The origin of a traumatic haemarthrosis of the knee following a sprain*", from French into English. In doing so, a commentary is provided on key findings which are integral to the understanding of the anterolateral complex of the knee, some of which have been previously misrepresented.

Section 2

Chapter 5: An assessment of the ability of MRI to identify the anterolateral ligament in the anterior cruciate ligament-injured and -uninjured knee

Study 2: "MRI is not reliable in the diagnosis of concomitant anterolateral ligament and anterior cruciate ligament injuries of the knee"

- **Primary Aim:** To assess the ability of 3-Tesla MRI, using standard knee protocols to identify the ALL in ACL-injured patients compared to a matched control group of ACL-intact patients.

- **Secondary Aim:** To identify key qualitative MRI findings that might be associated with injury to the ALL.

Chapter 6: An assessment of the ability of MRI to identify the Kaplan fibres of the iliotibial band

Study 3: "The Kaplan fibres of the iliotibial band can be identified on routine knee magnetic resonance imaging"

- **Primary Aim**: To assess whether routine 3-Tesla MRI, using standard knee protocols, can be used to identify the Kaplan Fibres in the non-ACL-injured knee, thereby providing a baseline to facilitate future investigations into radiological signs of injury.

Chapter 7: Exploring the prevalence of radiological evidence of injury to the Kaplan fibres of the iliotibial band in association with anterior cruciate ligament injury

Study 4: "Radiological identification of injury to the Kaplan Fibres of the iliotibial band in association with anterior cruciate ligament injury"

- **Primary Aim:** To evaluate the prevalence of radiological Kaplan Fibre injury in a large cohort of ACL-injured knees, based on pre-defined diagnostic criteria.

- **Secondary Aim:** To determine whether the time from injury influenced the identification of Kaplan Fibre injury, and whether there was any association with radiological diagnosis of Kaplan Fibre injury and other radiological knee injuries.

Chapter 8: An assessment of association between radiological evidence of Kaplan fibre injury, intraoperative findings, and grade of pivot shift grade in the setting of acute anterior cruciate ligament injury

Study 5: "Association between radiological evidence of Kaplan fiber injury, intraoperative findings and pivot shift grade in the setting of acute anterior cruciate ligament injury"

- **Primary Aim**: To evaluate if there is an association between clinical assessment of pivot shift grade and radiological evidence of Kaplan Fibre injury at the time of anterior cruciate ligament reconstruction in acutely injured knees.

Section 3

Chapter 9: Anterolateral ligament reconstruction: What does Dr Google say?

Study 6: "Comparison of the source and quality of information on the internet between anterolateral ligament reconstruction and anterior cruciate ligament reconstruction: An Australian Experience"

- **Primary Aim**: To assess the source and quality of information on the internet related to ALL reconstruction compared to ACL reconstruction through the use of recognised scoring systems, identification of quality markers, and pathology-specific content scores.

Chapter 10: What is the role for lateral extra-articular augmentation procedures in the setting of primary anterior cruciate ligament reconstruction?

Study 7: "The role of the lateral extra-articular tenodesis in primary anterior cruciate ligament reconstruction: A systematic review with meta-analysis and best-evidence synthesis"

- **Primary Aim**: To systematically review the literature to determine whether the addition of LEAT to a primary ACLR would result in improved rotational stability and clinical outcomes compared with ACLR in isolation.

- **Secondary Aim**: To determine whether the time interval between injury and surgery influenced postoperative rotational stability.

Chapter 11: Does the combination of a lateral extra-articular tenodesis and an intra-articular anterior cruciate ligament reconstruction increase the risk of developing osteoarthritis?

Study 8: "Combined anterior cruciate ligament reconstruction and lateral extra-articular tenodesis does not result in an increased rate of osteoarthritis: a systematic review and best evidence synthesis"

- **Primary Aim**: To systematically review the literature to analyse the long-term incidence of osteoarthritis in patients who had a LEAT performed in isolation or in combination with intra-articular ACLR for the treatment of ACL deficiency.

Chapter 12: Biomechanical assessment of a distally fixed lateral extra-articular augmentation procedure in the treatment of anterolateral rotational laxity of the knee

Study 9: "Biomechanical assessment of a distally fixed lateral extra-articular augmentation procedure in the treatment of anterolateral rotational laxity of the knee"

- **Primary Aim**: To investigate the effect of a modified Ellison procedure in restoring native kinematics of the ACL-intact knee after complete sectioning of the anterolateral capsule.

- **Secondary Aim**: To assess the effect of closure of the ITB graft harvest site on knee kinematics.

Appendix IV: Editorial

Editorial commentary: *"Magnetic Resonance Imaging Evaluation of the Anterolateral Complex – Is Seeing Really Believing?"*

- **Primary Aim:** To provide commentary on a study submitted to the Journal of Arthroscopic and Related Surgery on a similar topic to those included in Section 2.

Thesis Outline

This thesis is comprised of a series of published works, which may be read independently. In keeping with the three overall objectives of this thesis, which aim to explore the aetiology, diagnosis, and the surgical treatment of anterolateral rotatory laxity of the knee in primary anterior cruciate ligament reconstruction, the thesis is comprised of three main sections:

- Section 1 – Anatomy of the anterolateral complex and aetiology of anterolateral rotatory laxity of the knee
- Section 2 – Radiological and clinical diagnosis of injury to the anterolateral complex of the knee
- Section 3 – The role for lateral extra-articular augmentation procedures in the setting of primary ACL reconstruction

The majority of chapters have been published in peer-reviewed journals, and are presented in the format in which it was published or accepted for publication. These chapters all employ the style specified by the relevant publishing scholarly journal. At the beginning of each chapter an introductory piece has been written to provide relevant background information to frame the published work. In addition, an epilogue, at the end of each chapter has also been written to provide further context and to link each subsequent study – these sections have not been submitted for publication, and are written in Australian English, and employ a citation and referencing format that is based on the Vancouver style.

Section 1

This section consists of three chapters, which includes one published work. Chapter 2 provides an in-depth review of the anatomy of the anterolateral complex of the knee, with particular reference to the origin of the term '*anterolateral ligament'* and the structure it reportedly describes. Chapter 3 focuses on the concept of anterolateral rotatory laxity and the diagnostic clinical manoeuvre, the pivot shift. Finally, Chapter 4 provides a translation of Paul Segond's treatise originally written in French in 1879. Because the writing style of the era was rather verbose, some of the passages were believed to be redundant and somewhat irrelevant and have, therefore, been omitted. A commentary has been added to provide some context to the findings and relate them to the current literature.

Section 2

This section consists of four published works focuses on the radiological and clinical diagnosis of injury to the anterolateral complex of the knee. A detailed evaluation of the role of routine, standard MRI is provided. Chapter 5 focuses on the ability of MRI to identify the ALL in the setting of an ACL-intact and ACL-injured knee. Chapters 6 and 7 concentrate on MRI imaging of the Kaplan fibres of the ITB and the prevalence of injury to this structure in the setting of primary ACL injury respectively. In Chapter 8, a clinical correlation is made between radiological evidence of Kaplan fibre injury in acute ACL rupture and the grade of pivot shift at the time of surgical reconstruction.

Section 3

This section contains four published works and centres on the role of lateral extra-articular augmentation procedure in the setting of primary ACL reconstruction. Chapter 9 delves into the surgical technique of ALL reconstruction and examines the source and quality of information available on the internet related to this procedure, making a comparison to ACL reconstruction. Chapter 10 concentrates on the role of lateral extra-articular augmentation procedures in the setting of primary ACL reconstruction by means of a systematic review, meta-analysis and best evidence synthesis. Chapter 11 aims to provide clarity on one of the big concerns regarding the long-term impact of lateral extra-articular augmentation procedures by evaluating the incidence of osteoarthritis through a systematic review and best evidence synthesis. Finally, Chapter 12 details a robotic, biomechanical study using a cadaveric model of anterolateral capsule deficiency to assess the ability of a distally based lateral extra-articular augmentation procedure to restore native knee kinematics.

Section 1

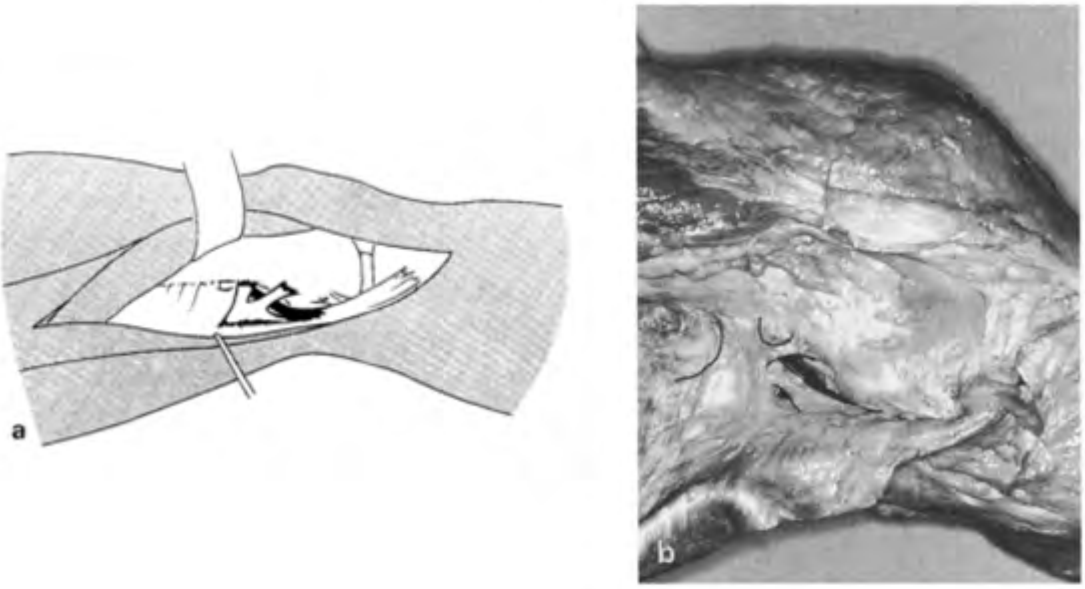
Anatomy of the anterolateral complex and aetiology of anterolateral rotatory laxity of the knee

Chapter 2: Anatomy of the anterolateral complex of the knee: Does the anterolateral ligament really exist?

Lessons from history

Numerous historical studies have been published exploring the anterolateral side of the knee(50, 51). In addition to Segond's original work, which has been translated in chapter 4, Kaplan, an anatomist and hand surgeon, made a significant contribution to understanding the anatomy of this region by describing the layers of the ITB attachment to the distal femur in his publication in 1958(50, 52). Following this, the lateral side of the knee was largely ignored in the literature for an extended period of time. It was considered by many a region akin to the "*dark side of the moon*", as described in John Feagin's seminal book "*Crucial Ligaments*", such was its mystery, obscurity and complexity(53). Terry et al finally shone some light on the area in their study in 1986, which meticulously detailed the two main component parts of the lateral fascia lata; the iliopatellar band and the iliotibial tract (ITT)(51). The authors used the term "*anterolateral ligament*" in this manuscript to refer to the deep, capsulo-osseous, and superficial layers of the ITT(51). Around the same period, Lobenhoffer et al further defined the contribution of the ITT by documenting the existence of "*the retrograde tract*" which provides a connection from the posterolateral aspect of the femur to Gerdy's tubercle on the anterolateral aspect of the tibia(54) (Figure 2.1 A and B); the authors describe this connection as *"an arc bridging the knee joint"* and make reference to a similar finding by Müller et al called the *"lig. femoro-tibiale laterale anterius*."(55)

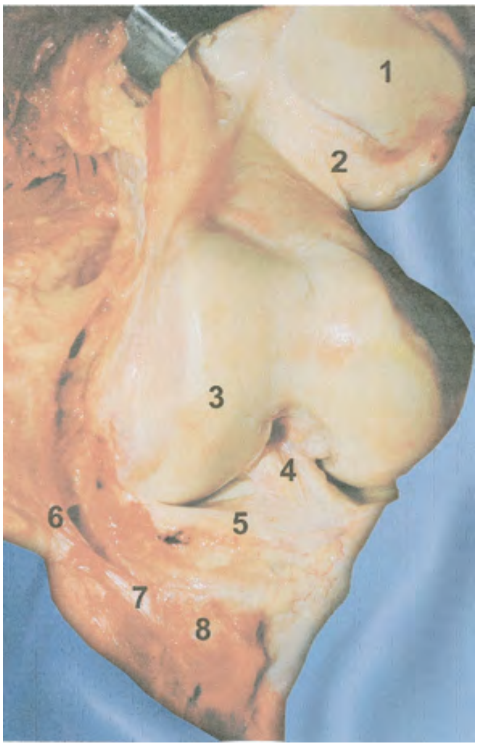
Figure 2.1 A and B: *Lobenhoffer et al(54) – "A. Retrograde fibre tracts. Note fibres running freely to insertion near to the septum, outline in black in B. "*



Chinese Whispers

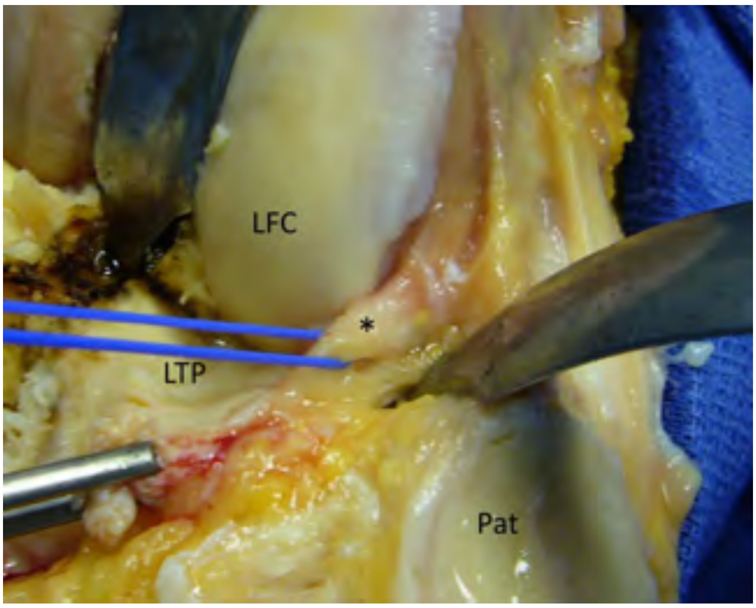
"*Chinese whispers"* refers to a children's game in which a sequence of repetitions of a story are told, each one differing slightly from the previous, so that the final telling bears only a scant resemblance to the original. This is a particularly apt description of how the confusion surrounding the nomenclature used to describe the complex anatomy of the anterolateral side of the knee was created(14). Vieira et al. are often credited with coining the phrase "*Anterolateral ligament"*, although they clearly make reference to the term originating from the study by Terry et al(56). But, the term actually goes back further and was indeed mentioned by Kaplan in his original work on the surgical approach to the lateral side of the knee which even preceded his anatomical treatise on the ITT(57); he makes the following statement: *"In extensive lateral approaches to the knee joint, it was noted that the iliotibial* *tract acted as an accessory anterolateral ligament of the knee preserving stability in which the lateral collateral ligament was lost.*" The structure which Vieira et al later described is a capsulo-osseous extension of the ITT which *"starts from the lateral supraepicondylar region, bordering the lateral edge of the lateral epicondyle and inserting laterally to the Gerdy's tubercle"(56)* (Figure 2.2).

Figure 2.2: *Vieira et al(56) – "Capsulo-osseous layer of the ITT with its origin at the supraepicondylar region of the femur, the arched direction of its fibres, and the insertion lateral to Gerdy's tubercle: (1) patella, (2) quadriceps tendon, (3) lateral femoral condyle, (4) anterior cruciate ligament, (5) lateral meniscus, (6) capsular-osseous layer, (7) capsular-osseous insertion of the ITT, and (8) Gerdy's tubercle."*



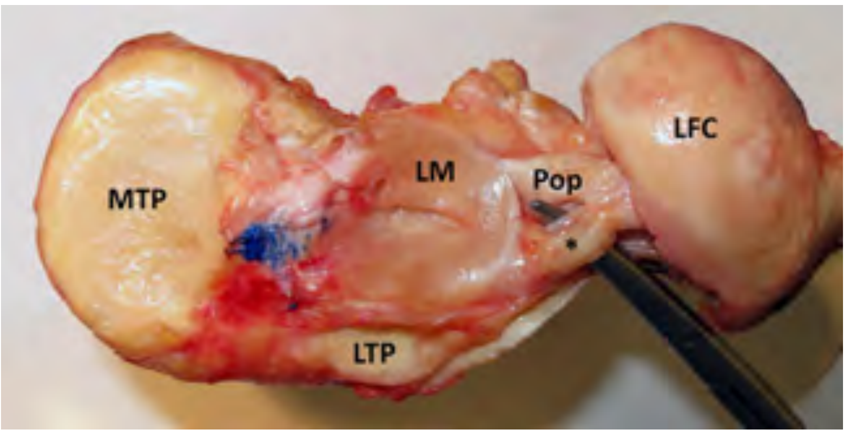
Vincent et al. in a dissection study of 30 patients undergoing total knee replacement described a consistent structure on the anterolateral aspect of the knee(58). The structure was identified from within the knee via a medial parapatellar approach with the patella everted and tibia translated anteriorly. In all cases a defined structure could be dissected free from the capsule (Figure 2.3). The authors referred to the structure as the 'anterolateral ligament' making specific reference to the study by Vieira et al and claimed they were describing the same structure(56). What is important to note is that the method of identification of this structure in live patients at the time of total knee replacement was from inside the knee and not from outside-in as had been reported by both Terry et al and Vieira et al(51, 56).

Figure 2.3: *Vincent et al(58) – "An intra-operative view of a left knee during a total knee arthroplasty demonstrating the anterolateral ligament (*) taking origin from the lateral femur. The lateral femoral condyle (LFC) femoral condyle, lateral tibial plateau (LTP), and everted patella (Pat) are labelled."*



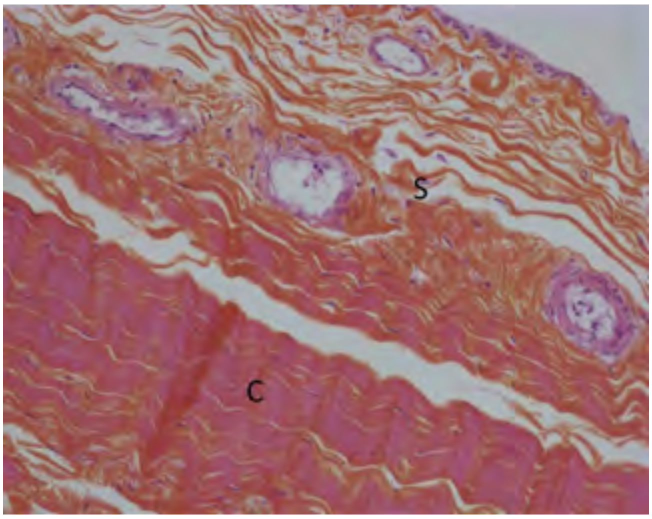
Notably, in the methodology, the authors describe the cadaveric dissection of 10 specimens to corroborate the findings of the in vivo dissection and explicitly detail the removal of the iliotibial band from its attachment to Gerdy's tubercle and the proximal fibula (Figure 2.4) to fully expose this structure. This, therefore, raises the question as to whether they were indeed describing the same structure at all. What the authors did describe was a structure with an origin on the lateral femoral condyle, closely associated with the popliteus tendon, which passed distally to insert on the proximal anterolateral tibia approximately 5 mm from the articular cartilage. Macroscopically, the structure was closely associated with the lateral meniscus near the junction of its anterior and middle thirds.

Figure 2.4 – *Vincent et al (58) - "A superior view of the tibial plateau of a left knee of a cadaveric specimen. The femur has been rotated laterally to provide visualization. The anterolateral ligament (*) can be seen taking origin on the lateral femoral condyle (LFC) just anterior to the popliteus tendon (Pop) and inserting onto the lateral meniscus (LM) and lateral tibial plateau (LTP). The medial tibial plateau (MTP) is also labelled."*



Vincent et al also carried histological analysis of the cadaveric specimens and reported the longitudinal sections demonstrated wavy collagenous fibres of the dense central core with a parallel orientation, suggestive of ligamentous or tendinous tissue (Figure 2.5). Indeed, they make the clear point that the structure is distinct from the lateral capsule despite describing how it was dissected free from the lateral capsule in the live specimens. So, is it a distinct structure or a capsular thickening?

Figure 2.5: *Vincent et al (58) –" A longitudinal section of the anterolateral ligament stained with hematoxylin and eosin and viewed at 9200 magnification demonstrates dense, well-organized connective tissue (C) bordered by synovial tissue (S)."*



Capsular thickening or distinct ligament?

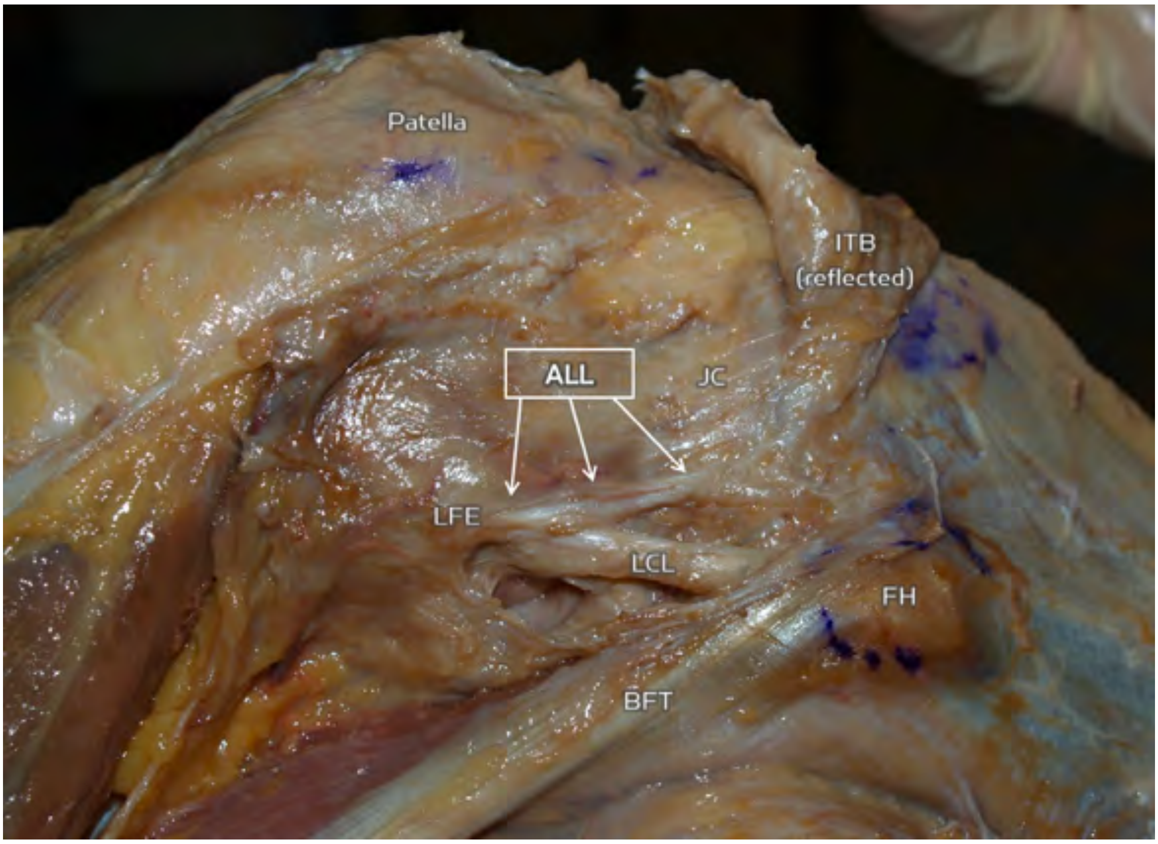
Hughston et al, in a study from 1976, had previously separated the lateral capsule of the knee into three portions: anterior, middle and posterior(59). The middle portion, the authors stated included the "*mid-third capsular ligament*", which they postulated played a major role in stability of the knee at about 30° of flexion. They further went on to describe the concept of anterolateral rotatory instability and maintained that this was caused by an injury to the mid-third capsular ligament in addition to a rupture of the ACL. The theory that the anterolateral ligament (ALL) and the mid-third capsular ligament were one and the same thing was proposed by Caterine et al in a cadaveric study of 19 fresh frozen cadavers(60). This study, in addition to others, performed histological analysis of the ALL structure and further substantiated the belief that it has ligamentous properties as a result of its well-organised collagen bundles(61). Indeed, it has been demonstrated that the ALL has significantly different biomechanical properties to the adjacent capsule; this is analogous the shoulder and the inferior glenohumeral ligament(62).

The rediscovery

It is clear that, despite reference to the ALL in a number of previous studies, it was the study by Claes et al., published in the Journal of Anatomy in 2013, that elevated the awareness of the ALL on a global scale(1). The disproportionate interest the study created, on what was at best a novel anatomical finding, was largely due to the widespread dissemination of this information through social and mainstream media(3). The inference through sensational publication was that this ligament, “*which no-one knew existed”* as was emblazoned across one headline, had an integral role in maintaining the rotational stability of the knee(63). Needless to say, the hype surrounding this “*new*” discovery, or “*re-discovery*” as it was termed, was like nothing ever previously witnessed in the field of orthopaedic sports medicine. The findings, although received with great interest generally, were the source of considerable controversy. Many of the specific anatomical details were contested and spawned a plethora of '*me-too*' studies, describing the differing quantitative and qualitative anatomy of the ALL. So, what did Claes et al find and how did they do it?

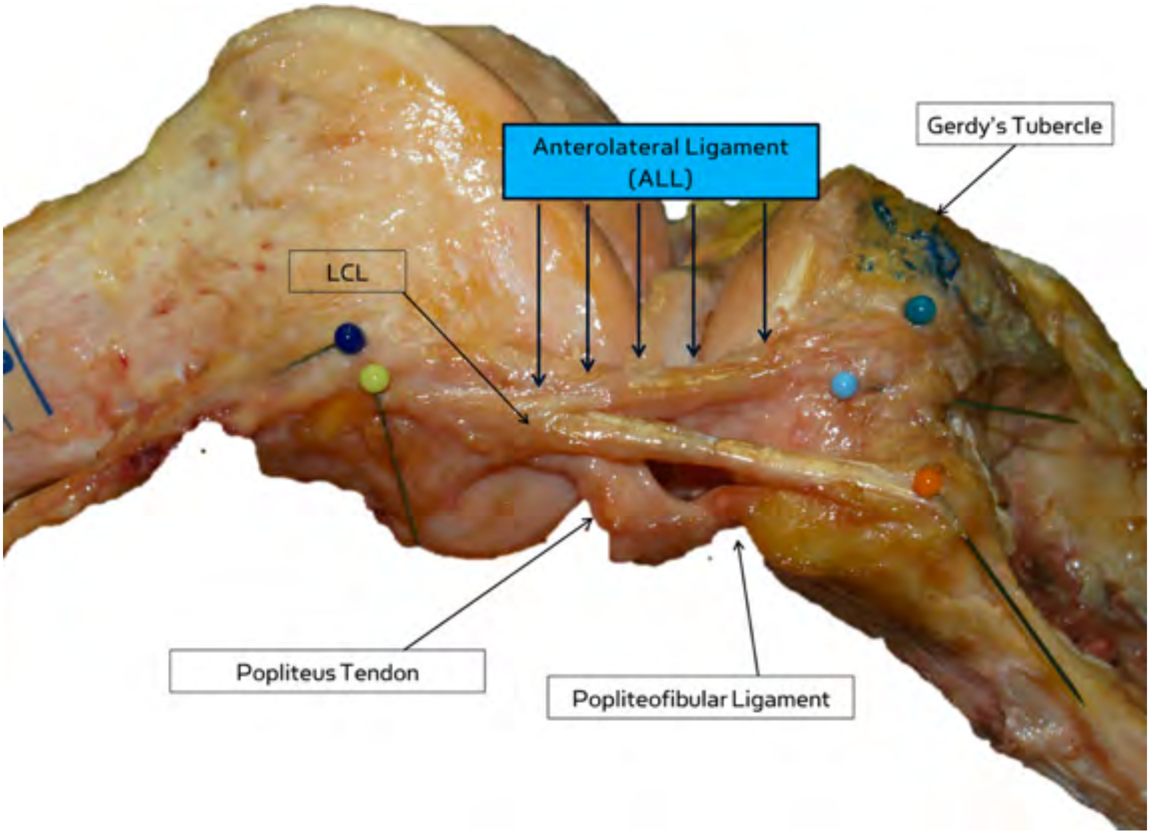
The authors carried out 41 cadaveric dissections on 41 unpaired, embalmed human cadaveric knees. Following the creation of a rectangular cutaneous flap over the lateral aspect of the knee, the Iliotibial band (ITB) was cut transversely at approximately 6 cm proximal to the lateral femoral condyle and then released from its tibial attachment on Gerdy's tubercle. The authors detail sharply cutting the deep ITB layer, which is also known as the Kaplan fibres, attached to the lateral aspect of the distal femur. With the ITB, reflected the superficial lamina of the capsule was incised posterior and parallel to the lateral collateral ligament (LCL) and an internal toque was applied to the knee which was flexed at 60°. The authors report that this manoeuvre exposed distinct fibres running from the region of the lateral femoral epicondyle to the proximal tibia posterior to Gerdy's tubercle, which were distinguishable from the loose capsule anterior to it (Figure 2.6). Following this, all macroscopically visible fibres of this ligamentous structure were carefully isolated at its insertional zone at the proximal tibia, posterior and proximal to Gerdy's tubercle, along its upwards course to the lateral femur. A qualitative and quantitative characterisation of the ALL was also performed.

Figure 2.6: *Claes et al(1) – "Lateral view of a typical right knee during dissection. With the ITB reflected, the ALL fibres are clearly distinguishable from the thin anterolateral joint capsule anterior to it. ALL, anterolateral ligament; LCL, lateral collateral ligament; LFE, lateral femoral epicondyle; BFT, biceps femoris tendon; FH, fibular head; JC, joint capsule."*



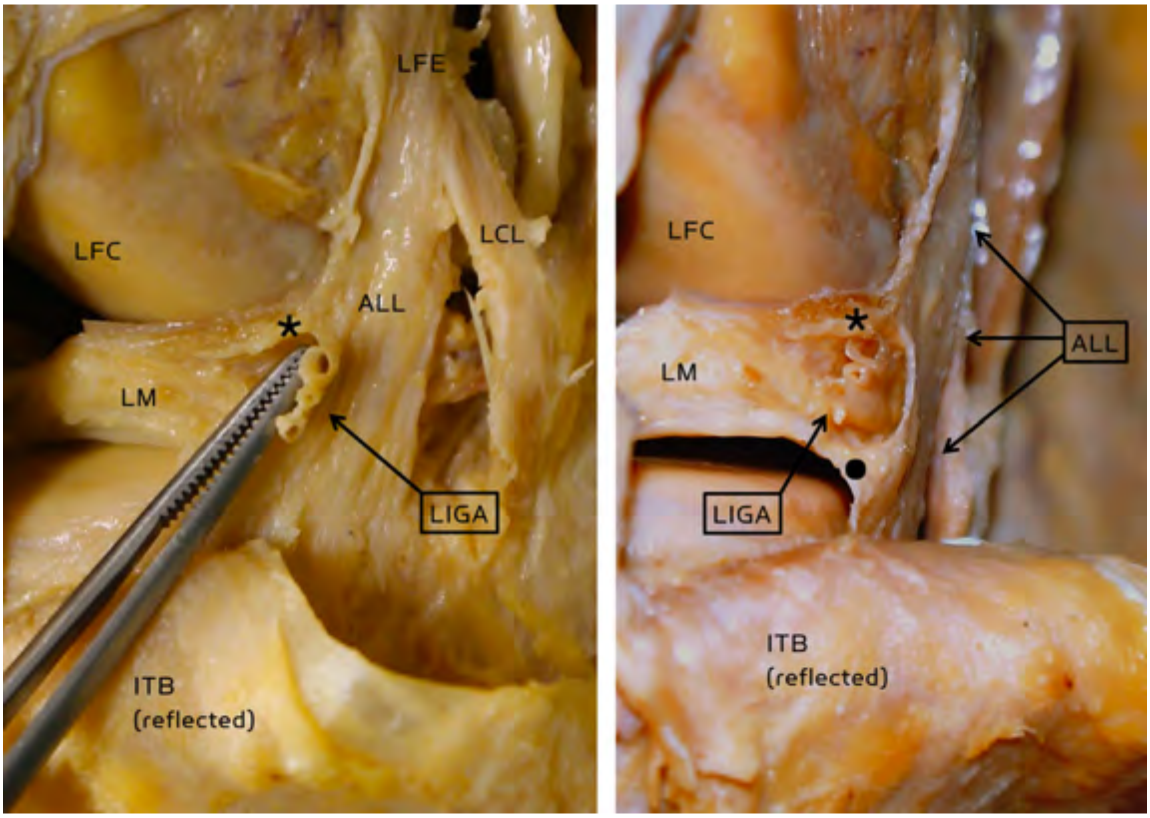
The authors reported that in all but one of the 41 dissected knees (97%) a distinct ligamentous structure was identified. In all cases, '*the major origin of the ALL was located on the prominence of the lateral femoral epicondyle, anterior to the socket from which the LCL originated, and proximal and posterior to the insertion of the popliteus tendon*' (Figure 2.7). The authors did detail that the most posterior fibres of the proximal ALL blended with the proximal part of the LCL in the majority of the dissected knees.

Figure 2.7: *Claes et al(1) – "Photograph of a typical right knee after complete dissection of the ALL, popliteus tendon, popliteofibular ligament and lateral collateral ligament."*



It is important to note that these findings were the source of most controversy and differed from subsequent studies, which possibly related to the technique of removing the superficial lamina of the capsule posterior and parallel to the LCL during the original exposure. From its femoral origin the body of the ALL ran an oblique course to insert on the proximal tibia, forming a strong connection with the periphery of the middle third of the lateral meniscus attached in meniscofemoral and meniscotibial portions (Figure 2.8). The lateral inferior geniculate artery and vein were found situated between the lateral meniscal rim and the ALL. Finally, the ALL was described as inserting into the proximal tibia as a thick capsular insertional fold, posterior to Gerdy's tubercle with no connecting fibres the ITB.

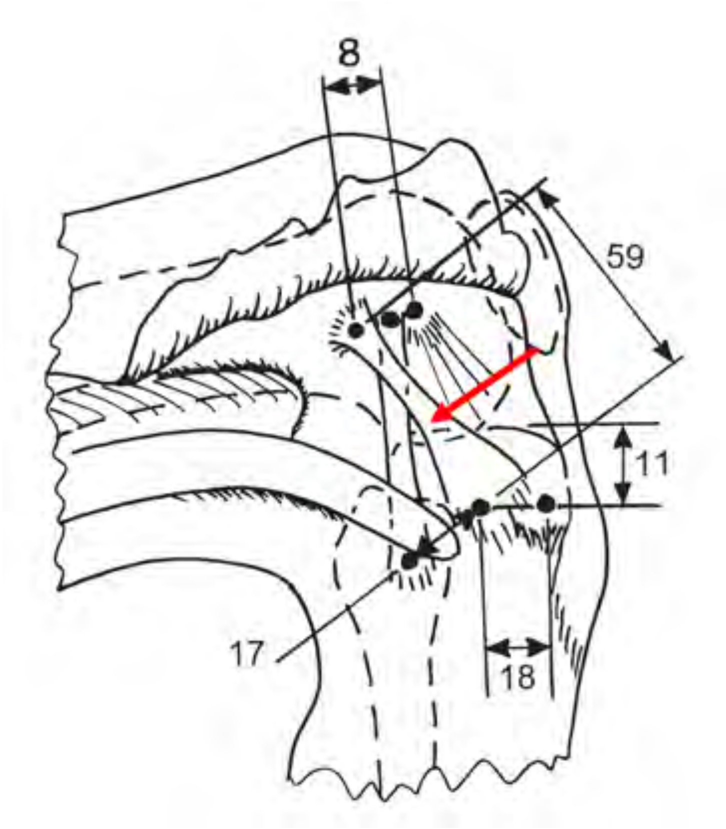
Figure 2.8: *Claes et al(1) – "Photograph of a left knee detailing the close relationship of the ALL with the lateral meniscus. ALL, anterolateral ligament; * - meniscofemoral portion of the ALL; • - meniscotibial portion of the ALL; ITB, iliotibial band; LCL, lateral collateral ligament; LIGA, lateral inferior geniculate artery and veins; LFC, lateral femoral condyle; LFE, lateral femoral epicondyle; LM, lateral meniscus."*



The devil is in the detail

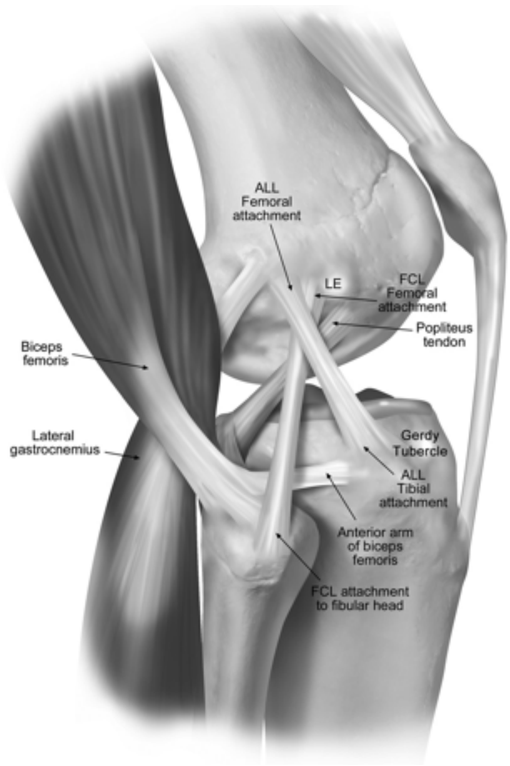
A number of anatomical studies were carried out closely following the publication of the study by Claes et al. A study by Dodds et al, published in March 2014, used 40 fresh-frozen cadavers as opposed to embalmed cadavers as was the case with the Claes et al study(64). The authors reported a consistent structure in only 33 knees (83%) which was superficial to the LCL and took its origin proximal and posterior to the LCL origin on the lateral epicondyle of the knee (Figure 2.9).

Figure 2.9: *Dodds et al(64) – "Schematic illustration to show the location of the anterolateral ligament on the lateral aspect of the knee (red arrow). The distances are means (mm) for all the specimens."*



A further study by Kennedy et al, using 15 nonpaired fresh-frozen cadavers, corroborated the location of the femoral origin of the ALL, confirming it was posterior and proximal to the LCL attachment(49) (Figure 2.10).

Figure 2.10: *Kennedy et al(49) – "The osseous landmarks and attachment sites of the main structures of the lateral knee (iliotibial band and non-ALL-related capsule removed) (lateral view, right knee). The ALL attached posterior and proximal to the FCL femoral attachment and coursed anterodistal to its anterolateral tibial attachment between the centre of Gerdy's tubercle and the anterior margin of the fibular head. The short head of the biceps femoris tendon had a direct arm that attached to the fibular head and an anterior arm that attached to the anterolateral tibia. ALL, anterolateral ligament; FCL, fibular collateral ligament; LE, lateral epicondyle."*

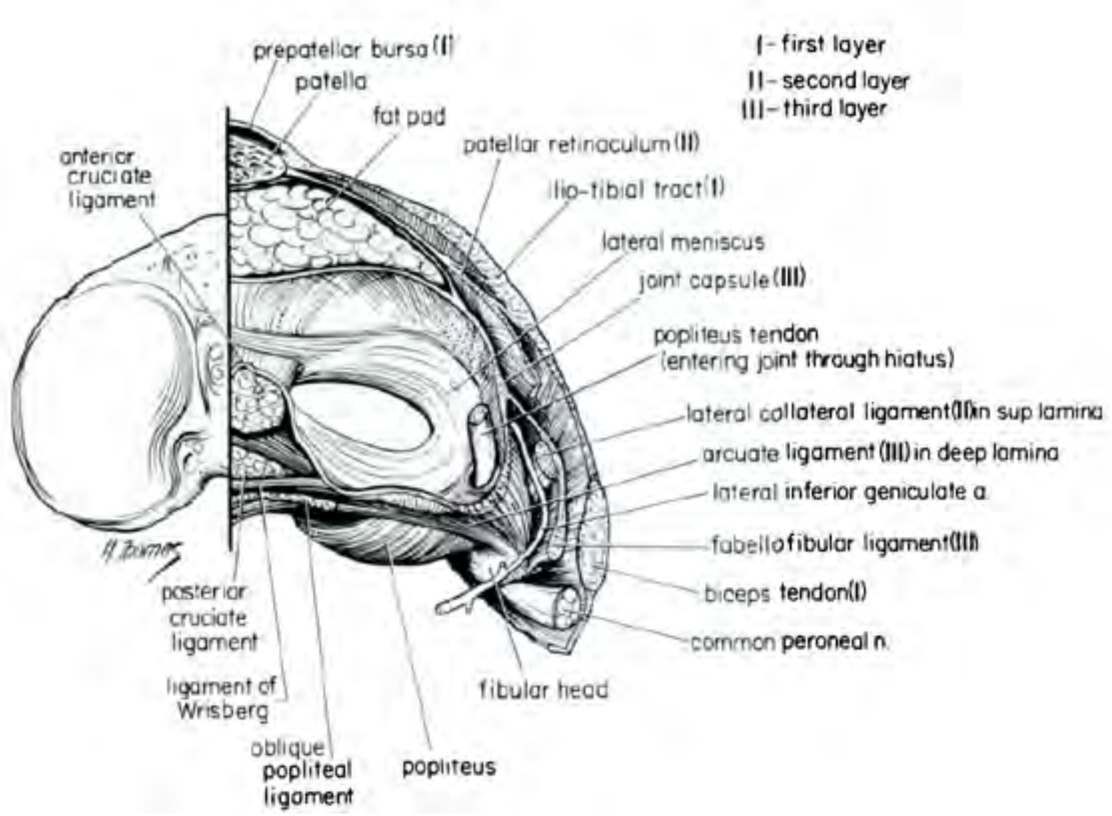


Unfortunately, these studies did little to quell the ever-increasing contention that arose surrounding the ALL, which was the source of a number of incendiary editorials and letters(65, 66). An attempt to develop consensus on the issue was made with the formation of the Anterolateral Complex Consensus Group which consisted of 36 international researchers and clinicians in the field(14). The group met in London, United Kingdom, in October 2017. The aims of the group were three:

1. Develop a consensus in terms of the anatomical terminology utilised for structures within the anterolateral capsule.
2. Produce position statements as to the kinematic role of key structures in the knee, pertaining specifically to anterolateral rotatory laxity and ACL deficiency.
3. Provide clinical guidance on when to utilise an anterolateral procedure in the ACL-deficient knee.

The group made specific reference to the layers of the lateral side of the knee and anterolateral complex. In particular, the anatomical work of Seebacher et al was heavily referenced, in which the lateral structure of the knee can be divided into three distinct layers(67) (Figure 2.11). The authors described Layer 3 of the anterolateral capsule as splitting into a superficial and deep lamina anterior to the LCL, and enveloping it posterolaterally. Accordingly, the consensus group concluded that the ALL is a structure within Layer 3 of the anterolateral capsule, and that the superficial lamina is the ALL with the deep lamina being the true capsule of the knee at this level.

Figure 2.11: *Seebacher et al(67) - A view of the right knee joint from above after removal of the right femur. Note the three layers of the lateral side and the division of the posterolateral part of the capsule (Layer III) into deep and superficial laminae which are separated by the lateral inferior genicular vessels.*



The group made the following statement regarding the anatomy of the anterolateral complex of the knee:

1. The ALL is a structure within the anterolateral complex
2. The structures of the anterolateral complex, from superficial to deep, are:
    a. Superficial IT band and iliopatellar band
    b. Deep IT band incorporating

            i. Kaplan fibre system
                1. Supracondylar attachments
                    a. Proxima
                    b. Dista
            ii. Retrograde (Condylar) attachment continuous with capsule-osseous layer of the IT band
    c. ALL and capsule
3. The ALL is a capsular structure within Seebacher Layer 3 of the anterolateral capsule of the knee(67).
4. The ALL has variable gross morphology between individuals in terms of size and thickness.
5. The ALL predominantly attaches posterior and proximal to the lateral femoral epicondyle and the origin of the LCL, runs superficial to the LCL and attaches on the tibia midway between the anterior border of the fibular head and the posterior border of Gerdy's Tubercle.
6. There is an attachment of the ALL to the lateral meniscus.

Based on this consensus, it is reasonable to conclude that the ALL does exist. It forms one part of the anterolateral complex of the knee, which as has been shown is complex by name and complex by nature.

Chapter 3: Aetiology of anterolateral rotatory laxity of the knee and the pivot-shift test

Anterolateral rotatory laxity

The anterolateral complex of the knee plays a critical role in normal knee kinematics(14). The anatomical details have been discussed extensively in *Chapter 2*. But, just as the anatomy has been controversial, so too has the function of each of the component parts biomechanically. The concept of "*anterolateral rotatory instability*" of the knee was introduced by Hughston et al in 1976(59). In their study, the authors described an injury pattern "*caused by a tear of the middle one-third of the lateral capsular ligament but it may be accentuated by other tears, principally a tear of the anterior cruciate.*" As this theory began to evolve, the pedants pointed out that "instability" is a subjective feeling experienced by the patient and what we, as physicians, can assess clinically is actually joint laxity. Therefore, the terminology has changed to reflect the correct scientific language: Anterolateral rotatory laxity.

There have been a number of important cadaveric biomechanical studies published which have investigated the role of the anterolateral structure particularly in the setting of ACL deficiency(68-70). Most of these have been sectioning studies examining the effect of sequential release of each of the component parts of the anterolateral complex in addition the ACL. In one such study, using a 6-degree-of-freedom robot, Rasmussen et al showed an increase in internal rotation of the knee following sectioning of the ALL(71). Most of the studies created a model of anterolateral laxity, as suggested by Hughston et al, by sectioning the ACL in combination with one or all of the structures of the anterolateral complex. Using navigation software, both Sonnery-Cottet et al and Monaco et al, demonstrated increased internal rotation laxity during a pivot shift test with combined ACL and ITB-deficiency and ACL and ALL deficiency respectively(72, 73). A further study by Kittl et al, using a 6-degree-of-freedom robot, examined the effect of ALL sectioning, as well as division of the superficial and deeper layers of the iliotibial tract(16). Notably, the ALL was found to have only a minor role in controlling internal rotation in the ACL-deficient knee. The iliotibial tract, in particular the deep and capsulo-osseous layers, were found to make a greater contribution to internal rotation control at larger flexion angles, with the ACL having its greatest contribution closer to extension. It should be noted that the ITB was not loaded during any of these studies, a point which is highly relevant to the findings of *Chapter 12* in this thesis.

The role of the anterolateral capsule, incorporating the anterolateral ligament (ALL) was also explored by means of optical tracking analysis and strain mapping(74). The authors observed that the anterolateral capsule behaved more like a fibrous sheet rather than a distinct ligamentous structure, disputing the existence of a discrete ALL. Further work by Thein et al, once again using serial sectioning, showed that the ALL only engaged in load sharing beyond the physiological limits of the ACL(75). As such, the authors concluded that the ALL was a secondary stabiliser to anterolateral translation only after deficiency of the ACL, rather than a co-stabiliser.

This conclusion was further corroborated through a study by Huser et al which examined the role of the anterolateral complex structures during a simulated pivot shift(76).
This was the first study to utilise a combination of anterior translation, valgus and internal rotation, as occurs in clinical examination of the pivot shift. The authors demonstrated that isolated ALL sectioning in the ACL intact knee resulted in no increase in anterior tibiofemoral compartment translation, concluding that the ALL does not function as a primary restraint to the pivot shift(76). The same group revealed in a further study that sectioning of the ALL and the ITB in ACL-deficient knees converted 71% of the specimens to a grade 3 pivot shift as measured by composite tibiofemoral translations and rotations(77). This finding was the premise for *Study 6* presented in *Chapter 8* in this thesis, which assessed the correlation between iliotibial band injury in the setting of acute ACL deficiency and the grade of pivot shift at the time of surgery. However, it is very important to remember that biomechanical studies, due to the limitations in the loads that can be subjected to the knee and the speeds at which the tests can be performed, are more likely to simulate knee examination in the

clinic through manual tests rather that the on-field loads that the knee withstands during sporting activity(78).

Finally, it is important to mention the role of the lateral meniscus in anterolateral rotatory laxity. Two studies have demonstrated increased lateral compartment anterior translation and internal rotation in the setting of lateral meniscus posterior root tears(79, 80). These findings and their relevance in the clinical setting have also been included and investigated in *Study 6, Chapter 8*.

Once again, the Anterolateral Complex Consensus Group weighed in as mediator and adjudicator on the biomechanical role of the anterolateral complex of the knee. The group concluded the following(14):

- The primary soft tissue stabiliser of coupled anterior translation and internal rotation near extension is the ACL. Secondary passive stabilisers include:

    - The ITB including the Kaplan fibre system
    - The lateral meniscus
    - The ALL and the anterolateral capsule

The pivot shift test

As has been illustrated above, the kinematics of the knee are complex even in its intact state. Following ligamentous injury and especially multi-ligamentous injury, this complexity can increase significantly. As such, clinical examination is not altogether straightforward either. Clinical examination of the knee involves examination of all six-degrees of freedom of the knee, through assessment of range of motion and a variety of specialty tests to designed to measure sagittal, coronal and rotatory laxity. With respect to ACL injury and assessment, the examination of the knee involves assessment of both anterior tibial translation with the Lachman or anterior drawer tests, and also anterolateral tibial translation with tests such as the pivot shift test. The Lachman test is a good test and has been shown to have sensitivity in the order of 85% with a high specificity for diagnosis of ACL rupture, in the order of 90-95%(81, 82). The pivot shift test, on the other hand, has poor sensitivity but an even higher specificity(81, 82). Assessment of the grade of pivot shift is important as it has been shown to correlate with patient outcomes following ACL reconstructive surgery, unlike measurements of anterior knee laxity, which do not(83). Indeed, the Anterolateral Complex Consensus Group have included a high grade pivot shift pre-operatively amongst their criteria for determining when an additional anterolateral procedure in the setting of primary ACL reconstruction is indicated(14).

The pivot shift was initially described by Galway et al in 1980(84). The name of the test was derived from the "*pivot shift phenomenon*" which MacIntosh and Galway used to describe the subjective sequence of the "*knee going out*." The patient would describe an attempt to pivot laterally, during which something would shift or the knee would "go out". There had been many iterations of the manoeuvre described prior to this with varying names. Indeed, in the aforementioned study by Hughston et al, which described anterolateral rotatory instability, the authors refer to the diagnostic manoeuvre to assess for this as the Jerk test(59). Losee, in his study entitled, "*Concept of the pivot shift",* provides a very simple but eloquent summary description of the manoeuvre – to do it justice, I think it is important to consider it in full(85):

> *"The pivot shift is a symptom and sign of anterior cruciate ligament (ACL) and lateral and posterolateral capsular deficiency of the knee. Either a subluxation or reduction, or both in rapid succession, plus a simultaneous impingement of the lateral compartment of the knee causes a pivot shift. The knee must twist to sublux the lateral tibial plateau anteriorly and the lateral femoral condyle posteriorly, to cause a misfit of the joint; the knee must be partially flexed to sublux symptomatically; the lateral compartment of the misfitted joint must be compressed simultaneously during a twist into or out of subluxation to cause impingement. When the knee is subluxed while compressing the lateral compartment and then flexed to more than 40°, an intact iliotibial tract will cause reduction. However, an insufficient iliotibial tract will permit continued subluxation through further flexion."*

There are number of key points that should be highlighted; the manoeuvre to elicit a pivot shift must involve a '*twist*' or rotation of the tibia which is sufficient to cause subluxation of the anterolateral aspect of the joint anteriorly on the femur; compression of the two joint surfaces is key to cause 'impingement' of the tibia and the femur against each other in the subluxed position (misfitted joint); the ITB plays a critical role in guiding the reduction of the subluxed tibia when the knee is flexed to beyond 40°. Larson, in his description of "*Physical examination in the diagnosis of rotatory instability*" also emphasised the importance of the ITB which migrates as the knee is flexed past the centre point of the knee axis and pulls the tibia posteriorly into its reduced position(86).

Current descriptions of the pivot shift assess for dynamic ACL insufficiency by evaluating axial and sagittal stability of the knee as it is taken from extension to flexion with an internal rotation and valgus stress on the proximal tibia(87). Although other clinical classifications have been described(88), the pivot shift is typically graded according to the International Knee Documentation Committee grade from 0 to 3: 0 - no pivot, 1 - pivot glide, 2 - clunk, 3 - explosive/gross clunk)(89, 90). One of the problems is that not only is the grading of pivot shift subjective and dependent on the examiner's interpretation of what he/she feels, but there is also considerable variation in how the test is performed, both in terms of the technique, and also the magnitude of the applied loads and the speed at which the limb is moved. (3) However, the methodology for standardising the pivot shift has been described and shown to have improved accuracy(10). Musahl et al, in a study of 12 expert surgeons described, analysed and grouped surgeon-specific techniques of the pivot shift using a cadaveric model of anterolateral laxity of the knee(91). The study concluded that clinical grading, tibial translation, and acceleration vary between examiners performing the pivot shift test. It was determined that high forces and extremes of rotation are not necessary to produce a clinical detectable pivot shift. Ultimately, a standardized pivot shift test was proposed based on common key techniques utilised by the experts (Figure 3.8)(Table 3.1).

Figure 3.1: *Musahl et al(91) - Three-step standardised pivot shift test. Step 1: internal rotation of the tibia in extension; step 2: application of valgus; step 3: knee flexion and release of internal rotation—let tibia externally rotate*

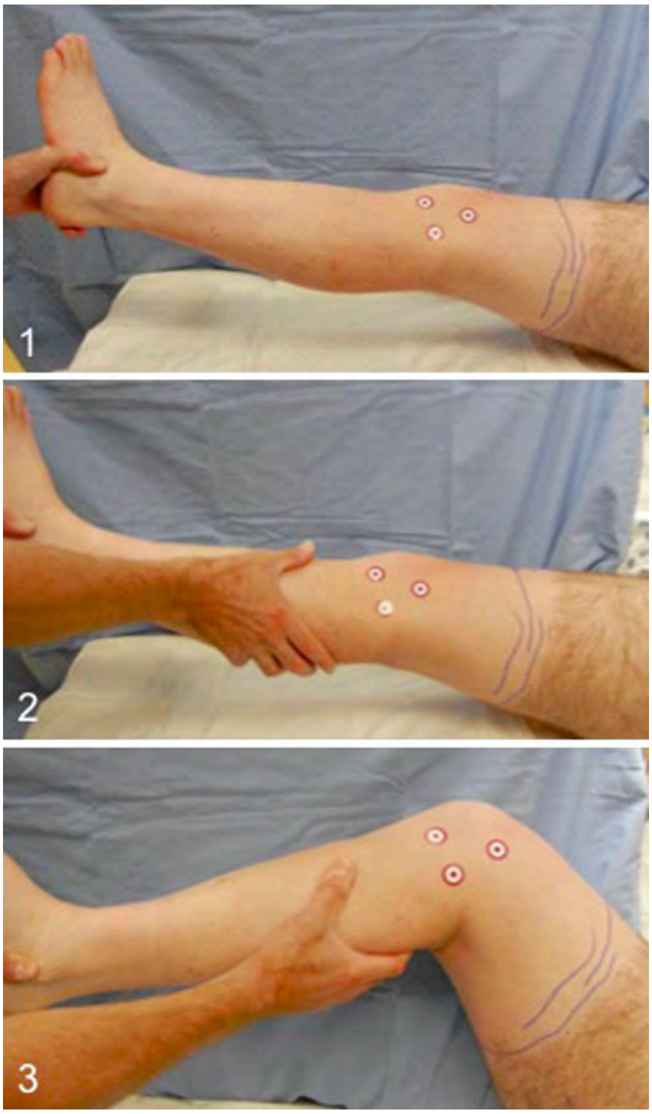


Table 3.1: Musahl et al(91) – Standardised Pivot Shift Test

Step 1
The examiner controls the patient's leg with the ipsilateral hand at the heel level. The examiner lifts the patient's leg off the table and slightly abducts the hip. The leg is internally rotated with the ipsilateral hand.
Step 2
To control the valgus stress, the examiner's contralateral hand is placed on the lateral side of the joint with the thumb up at just below the proximal tibia-fibula joint level. A gentle valgus stress is applied. The knee is naturally flexed with the combined stress of internal rotation and valgus stress. The examiner does not need to control this flexion and continues to the next step.
Step 3
Knee flexion is advanced with both the hands. Internal rotation and valgus stress are maintained until approximately 20° of knee flexion. At the point of shifting, the rotational stress of the ipsilateral hand is released, and the proximal tibia is guided into external rotation by the contralateral hand. In other words, at the time of shifting, the lateral side of the proximal tibia suddenly drops by gravity and the tension of the iliotibial band. The contralateral hand on the lateral side of the proximal tibia just gently supports this movement, which accentuates the reduction movement. The movement is felt at around 20–40° of knee flexion.

Numerous efforts have been made to address the inconsistencies and more consistently and reliably quantify the pivot shift with an array of various technologies that have been developed. Some use instrumented boots or footplates, and navigation systems, but the limitations of these devices are cost, size of the equipment, and in the case of navigation, the associated morbidity of pin-sites, making them impractical for daily clinical use(9, 92-94). Other approaches have included the use of accelerometers, electromagnetic sensors and image analysis of surface markers and all have shown promise(87, 93, 95). However, these devices are not without limitations, which is clearly seen by the lack of widespread adoption. Moreover, aside from small research cohorts, they have not been used as an objective tool to determine the requirement for the addition of a lateral augmentation procedure as initially hoped. Finally, It is important to note that investigations have also shown that the pivot shift phenomenon is multifactorial and that high-grade pivot shift is generally associated with a secondary injury to a variety of structures mentioned above in addition to the ACL(87). These factors clearly need to be considered in the analysis and interpretation of what significance can be given to the pivot shift grade. Further reference to the pivot-shift and its importance in the diagnosis of anterolateral rotatory laxity is included in a number of studies within this thesis.

Chapter 4: What did Segond really say?

Introduction

"Great is the power of steady misrepresentation - but the history of science shows how, fortunately, this power does not endure long."

- Charles Darwin

One of the great indulgences about writing a PhD thesis, is the dispensation to delve so deeply in one's chosen topic, that a normal person might consider this behaviour obsessive at best, or a wanton waste of time, if they were being kind. It is with this immoderation that instead of merely accepting the veracity of a citation, there is a sense of obligation to unearth said citation and read every last word, and not merely scan the abstract. Admittedly, this is not always possible. There are multiple barriers to journal access; forgetting one's password, the expense of paywalls on a meagre postgraduate subsistence, publication in a different language, and historical manuscripts so old that they predate the establishment of journals themselves. These excuses are usually sufficient to preserve the sense of self-righteousness of the PhD candidate and appease any guilt about adding an unverified citation. But, sometimes that horrible feeling of "*it would be nice just to read it myself"* just won't go away. Combine that with perseverance and a bit of serendipity, and it's amazing what manuscripts can be discovered.

And, so it was that the following manuscript, or treatise to give it its correct term, written by Paul Segond, a French surgeon, in 1879 was uncovered, translated and revealed to the English speaking world(96). The circumstances that enabled this to happen are largely due to the presence of another French surgeon, Jérôme Murgier, who was working as a knee fellow in our unit at the time. In our fortnightly research meeting, as we critiqued the anatomical paper by Claes et al, which described the "discovery" of the anterolateral ligament, the citation by Segond, contained in the first line of the introduction, was mentioned(1). Jérôme was asked to translate what the title of the citation really meant: '*Les épanchements sanguins du genou par entorse*'. He responded, "*the origin of a haemarthrosis following a knee sprain, or something like that. But, it's old French!.*" He was further questioned as to whether he had read the original, which he responded, "*of course not, it was written over one hundred and twenty years ago!*". It occurred to me that if a French surgeon with a specialist interest in knees, who indeed had even published on the anterolateral ligament (also including the citation in question), hadn't read this manuscript, there were probably few around who actually had. It was decided at this meeting that Jérôme would use his contacts in Toulouse, France, to source the original manuscript, translate it and find out what Segond actually said! I will not ruin the surprise just yet, but suffice to say the opening quote by Darwin for this introduction is particularly applicable in this setting, and we are glad to be able to correct any misrepresentations that may have been made in the past.

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Contribution

Mr Devitt, Mr Murgier and Professor Feller contributed to the conception and design of this manuscript. Mr Murgier and Mr Cavaignac sourced a professional translator to translate the original work into English. Mr Devitt, Mr Murgier, Ms Sevre, and Mr Cavaignac completed the collation and editing of the translated work. Mr Murgier and Mr Devitt wrote the manuscript. Ms Sevre, Professor Feller and Mr Cavaignac critically revised the manuscript for important intellectual content.

Conference presentations

Extracts from this work were present at a national conference:

Devitt B M. The anterolateral ligament: Fake news or alternative fact!
Australian Knee Society Meeting. October 2018, Broom, Western Australia.

Level V Evidence

The Origin of the Knee Anterolateral Ligament Discovery: A Translation of Segond's Original Work With Commentary

Jérôme Murgier, M.D., Brian M. Devitt, M.D., F.R.C.S., F.R.A.C.S., Julie Sevre, M.D., Julian A. Feller, F.R.A.C.S., and Etienne Cavaignac, M.D., Ph.D

Abstract: Paul Segond was a French surgeon who was in practice at the end of the 19th century. A prodigious anatomist, scientist, and surgeon in his day, he is best known for his treatise on the origin of traumatic hemarthrosis of the knee following injury. In this detailed description of the anatomy of the anterolateral aspect of the knee, he describes "a pearly, resistant, fibrous band that is placed under extreme tension when the knee is forcefully rotated internally," which has more recently been described as the anterolateral ligament or a capsular thickening contributing to the anterolateral complex of the knee. His work goes on to speculate about the role of this structure in controlling internal rotation of the knee. The original study was published in French in 1879. Although this work is widely cited, one must question whether many of the citing authors have actually had the opportunity to read it. As such, we sought to unlock this treasure by translating the original study into English and exposing this illuminating, forward-thinking and historical tour de force to the broader orthopaedic community.

The anterolateral ligament has been the source of much interest and debate since the publication of an anatomic study by Claes et al.[1] in 2013. Notwithstanding the importance of the anterolateral ligament, which itself has been the source of much controversy, what has emerged is that this structure is not a newly identified structure, but was in fact described more than a century earlier, in 1879. The original description was made by a French surgeon, Paul Segond, in his study entitled, "Les épanchements sanguins du genou par entorse,"[2] which was a treatise on the origin of a traumatic hemarthrosis of the knee following a so-called sprain. His seminal work was published in French and has never been translated into English. Although this work has been widely cited, one must question whether many of the authors that have cited it have actually had the opportunity to read it. As such, we felt it was both relevant and important to provide a translation of this work to show what Segond actually described and how he discovered it.

This article is a translation of relevant excerpts from the original text. Given the length of the entire work, which encompasses a vast array of details related to the etiology of hemarthrosis following a knee sprain, only the paragraphs that relate to the structures of the anterolateral aspect of the knee have been included.

It is important to put into context the era in which this work was conducted before reading this translation. The medical world at the end of the 19th century was primitive by today's standards, but much like today, there was a fascination with traumatic knee injuries, especially in France; Bonnet, Berger, Hennart, and other French authors published numerous studies on "knee sprains," dissecting cadavers, and simulating knee injuries. None of the sophisticated biomechanical equipment that exists today was available at the time, so the injuries were elicited through forceful manual manipulation. There was often disagreement and conjecture between these individuals, and their publications were often used as a means of rebuttal. A key

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example of 1 point of controversy was the role that rotation played in inducing knee injuries. Indeed, this issue appears to be critical to Segond's thinking, because he felt strongly that a rotational force caused injury to many knee structures, whereas others believed that it merely resulted in a lower limb fracture.

Opinion is 1 thing and proof is another. As such, Segond undertook a series of experiments. This fascinating work led to the description of what is now known as a "Segond fracture," for which he is probably best known. The description of his research is incredibly detailed and addressed the pathophysiology, anatomy, and epidemiology of knee ligament injuries. Segond described the subsequent eponymous injury as "specific damage behind Gerdy's tubercle"; this is particularly impressive considering that this was 16 years before x-rays were first described by Wilhelm Roentgen in 1895.

The following article provides an as literal as possible translation of part of Segond's treatise. Because the writing style of the era was rather verbose, we have omitted some of the passages we believe to be redundant or not containing relevant information. These passages are marked by (...). Some of the key points of Segond's work are every bit as relevant today as they were at the time of writing. Following the translation, a discussion of the clinical importance of this work, what it has led to in terms of our understanding of knee injuries, and remaining unanswered questions are provided.

Translated Excerpts From Manuscript by Segond

The anatomic lesions that can occur following forced movements of the [knee] joint have been studied since the work of Bonnet; however, the history of hemarthrosis following a sprain has been particularly neglected.[3]

On several occasions, surgeons have focused on the symptoms and treatment of this condition; however, the exact source of this profuse bloody effusion, which can fill the knee joint in no time at all, has not, until now, been the focus of specific research. (...)

The term *knee sprain* means "all the effects produced on this joint by forced movements resulting either from an external mechanical action or unusual and excessive muscle contractions, and often from both causes at once," said Panas. Preservation of the normal relationship between articular surfaces completes this definition of a sprain and clearly differentiates it from dislocation.

This classic definition clearly summarizes the various features of a sprain. At the same time, it shows us the importance of muscle action, whose role must not be forgotten when interpreting pathologic findings any more than when studying physiological phenomena. Every joint has very solid passive support elements—the ligaments. It also has genuine active ligaments—the muscles that surround it, protect it, and move it. The knee joint obeys this general rule. Thus, after a fall or a stumble, when the ligaments in the region are pulled, broken, or torn, the muscles in the region, due to their steady tonicity, play a constraining role that cadaver experiments cannot reproduce.

Nevertheless, these research methods remain important. If we focus solely on joint trauma, experiments on cadavers are the 1 and only way to study and truly know what clinical observation, when left to its own resources, only allows us to speculate.

Hence, this is the experimental method that we chose to use. Repeating the experiments of Bonnet, we were determined to produce anatomic lesions of a knee sprain, and to then, by performing meticulous dissection, look for a tear or any lesion that would be sufficient in its extent, nature and location to produce bleeding inside the joint.

By following this procedure and experimenting on more than 90 knees, we believe we have determined the typical pathogenic conditions for hemarthrosis caused by a knee sprain.

To reproduce as closely as possible the typical pathogenic conditions of a knee sprain, both in terms of the intensity of the trauma and the resistance the leg can produce against it, we employed, as an immobilization method, 1 or 2 assistants who firmly grasped the thigh while, from our side, we applied forced movements to the knee using the only traumatic force that we were capable of producing ourselves.

Clinical observation and experimentation show that forced rotational movements of the leg on the thigh are responsible for most knee sprains. It is therefore the lesions caused by this type of movement that especially cause us to wonder about the reason for the bloody effusions that we continue to study.

Experimental Study

To study the anatomic disturbances that occur in the knee under the influence of forced rotation of the leg, we were always careful to hold the leg solidly with the hands to forcibly rotate it. While we applied this movement, 1 or 2 assistants immobilized the femur.

Using this procedure, we nearly always produced lesions in the knee. We failed on a few occasions in subjects who were too young, too solidly built, or too old. On the former, our efforts produced no injury, while on the latter, fracture of the lower leg or distal femur terminated the experiment before any appreciable joint lesion occurred. However, this was not unexpected and helped to confirm the general laws formulated by Bonnet on bone and joint injuries.

Internal rotation of the lower leg relative to the thigh can occur under 3 different conditions: with the leg

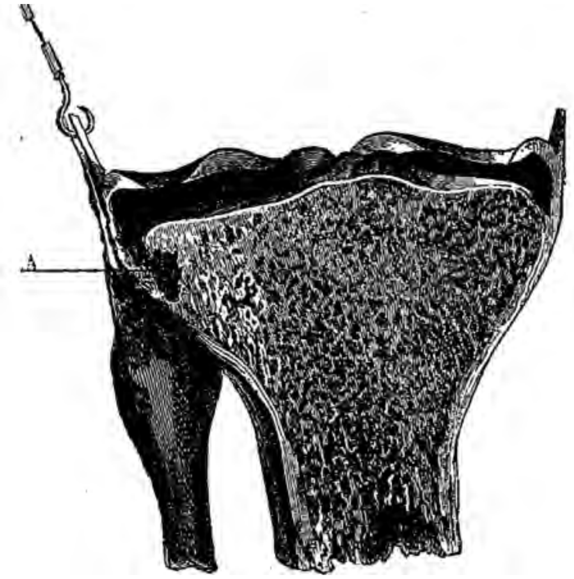

Fig 1. Transverse slice of the tibia passing through the middle of the lesion that we described above and behind Gerdy's tubercle. A, side view of this lesion.

extended, with the leg moderately flexed or even flexed at a right angle, and with the leg flexed at more than a right angle.

Extension

When the leg is extended, internal rotation is physiologically impossible. When trying to produce it on a cadaver, the only results that can be obtained are due to what we called the first stage of a forced adduction movement. Tearing of 1 of the insertions of the lateral collateral ligament will be the first consequence, and, almost immediately, an external rotation movement with the leg slightly flexed will, as we know, complicate the experiment. Moreover, this sprain-producing mechanism is very rare in clinical practice.

Moderate Flexion

If the leg is moderately flexed, at 35° for example, rotation becomes possible as a physiological movement. The proximal tibial epiphysis turns around the vertical axis passing through the center of the tibial tuberosity, which turns on itself. Torsion of the cruciate ligament becomes exaggerated and the collateral ligaments become taut. However, the point where the tension is the most intense is at the portion of the joint capsule mainly made up of solid attachments of the femoral aponeurosis posteriorly and on the tubercle of the lateral condyle of the tibia (Gerdy's tubercle).

This is easily seen when we examine a knee without its skin envelope. At this point on the fibrous tissue surrounding the knee, there exists a pearly, resistant, fibrous band that is placed under extreme tension when the knee is forcefully rotated internally. This physiological finding is of particular interest to us, as it can provide important data on the production of a specific lesion of Gerdy's tubercle which we have seen with some frequency following forced internal rotation movements. This lesion has never been described. We make this assertion after making many searches of the literature. We obtained this injury 17 times, either complete or incomplete, out of 40 experiments with internal knee torsion.

Figures 1, 2, and 3—which we owe to the kind assistance of our very good friend E. Brissaud—show various aspects of this injury. It is noteworthy because of the regularity of its location and is essentially made up of a tiny cavity hollowed out of the cancellous bone of the tibia. It connects to the inside of the joint through a small anteroposterior slot, the medial lip of which generally corresponds exactly to this blunt ridge where the superior and lateral aspects of the tibial plateau join.

This button hole or fissure, which is hidden by the external semilunar fibrocartilage [lateral meniscus], varies in width. While it can be very small, it never goes beyond the level of Gerdy's tubercle anteriorly, and the level of the tibiofibular joint posteriorly. The resulting wound in the cancellous bone is generally 5- to 10-mm deep. When the edges of this button hole are separated by turning the corresponding portion of the joint capsule inside-out (Fig 2), it has the shape of a small pigeon's nest. Thus, its main feature is an exclusive connection between the tibia's cancellous bone and the joint cavity.

Its usual location happens to be in complete harmony with its mechanism of injury. The pearly resistant fibers that make up the anterolateral portion of the fibrous tissue surrounding the knee, which we had mentioned

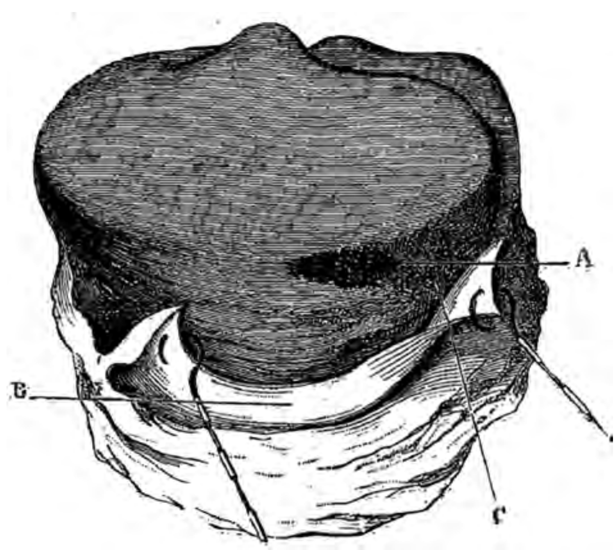

Fig 2. (A) Gerdy's tubercle. Same lesion as previous figure. The lesion is visible once the meniscus (B) is removed. The lesion creates a connection between the bone and the articulation.

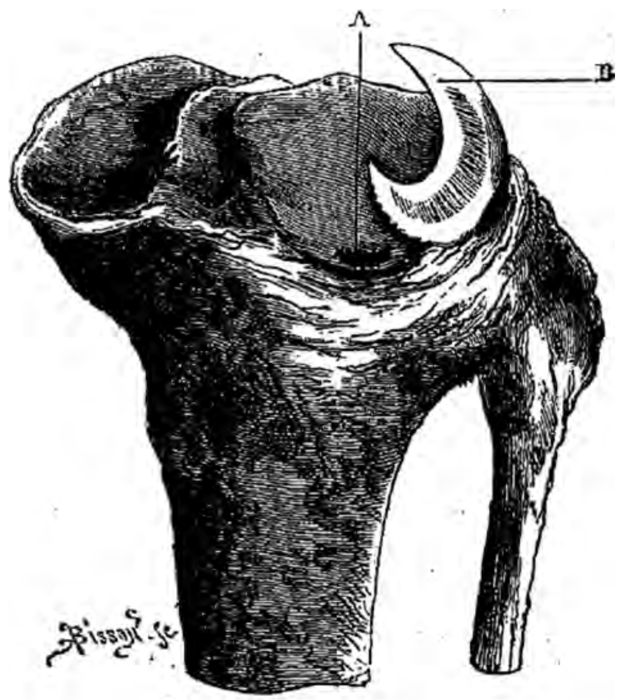

Fig 3. Same lesion (A). The typical extent of the bone fissure when it occurs in isolation, without any other joint damage.

previously, are placed under extreme tension when the leg is twisted internally, exert violent traction on their attachment point and pull it off. Gerdy's tubercle never fails, only a bone segment immediately behind it. Maybe this occurs because the bone tissue is weaker at this point; but no matter the explanation, this finding is consistent, which is the point to remember.

The injury we are describing can be either compete or incomplete. In other words, the bone wound may or may not be accompanied by rupture of the joint capsule. When it occurs without tearing the capsule and does not connect with the inside of the joint, we can label it as a first-degree lesion. It is sufficient to turn over the semilunar fibrocartilage [lateral meniscus] and gently tap an awl on the side of the tibial plateau, at the known point, to "fall" into the bone wound. However, the lesion is complete (14 of 17 times) in most instances. This is relevant to us because of the relationship with sprains due to stumbling. By this we mean a sprain due to leg rotation, while the leg is moderately flexed. We have induced this injury only in adults or older people. In some cases, as soon as the torsion is applied, even without much force, we can feel a small crack—the injury has been produced. In this case, it exists in isolation, without any other joint disturbance. Figure 3 is 1 example of this. In other cases, it can be complicated by tearing of the inferior attachment of the lateral collateral ligament or even a true sprain of the tibiofibular joint.

To conclude the work related to results obtained following forced internal rotation movements, with the leg minimally flexed, in very young subjects or subjects who were too heavy we can safely say that no lesions will occur. We have observed this in more than 20 knees (which we later subjected to other types of trauma).

When performing internal rotation with the leg flexed at a right angle, the results differ little from the previous ones, as the same ligaments tighten and provide resistance.

The fascia band inserting on Gerdy's tubercle is always placed under very high tension; however, the traction that it places on its tibial attachments is in a completely different direction. When the leg is minimally flexed, this traction is applied upward, externally, and forward, while it will be directly backward and perpendicular to the tibial axis when the leg is flexed at a right angle. This latter traction mode remains about the same when the leg is flexed even more. This observation is very easy to verify on a cadaver. When we use these experimental conditions, our injury is possible, but it becomes rarer.

Deep Flexion

Let us now look at the injuries caused by internal rotation when the leg is flexed at more than a right angle. This amount of flexion is a classic element of sprains due to a fall. In fact, nearly all patients will tell you that they fell and had their leg caught under them.

When the goal is to flex the leg and then to impart internal rotation to it, we can produce the movement in 2 manners, given the freedom of hip movements. In fact, the heel can be placed either outside or inside of the femoral axis and then the torsion applied. The resulting lesions differ in these 2 scenarios.

In the first case, the medial collateral ligament bears the brunt of the load. No matter which forced movement is performed—internal rotation or simply direct traction on the lower portion of the flexed leg—the resulting anatomic lesions are nearly always the same. Avulsion of the superior attachment of the anterior cruciate ligament, avulsion of the femoral attachment of the medial collateral ligament, tearing of Hoffa's fat pad, avulsion of the superior attachment of the posterior cruciate ligament, and detachment of the inferior attachment of the posterior cruciate ligament occurs alone or in combination in nearly all of our experiments. We produced tibial damage in 2 knees, but this did not occur in isolation. On a single occasion, it occurred without tearing of the collateral or cruciate ligaments; however, there was concurrent tearing of Hoffa's fat pad and, curiously, the anteromedial portion of the medial tibial condyle had a lesion that resembled—in all respects—the 1 on the opposite condyle. This finding occurred only once in our experiments.

If we now suppose that the leg flexion occurs with translation of the heel inside the femoral axis, the entire load, no matter the direction of the rotation, is no longer borne by the medial collateral ligament, but by the anterolateral portion of the joint capsule, the lateral collateral ligament and the cruciate ligaments, of which injuries remain extremely common. Avulsion of the insertions of the lateral collateral ligament, a specific lesion behind Gerdy's tubercle, tearing of the cruciate ligaments, tearing of Hoffa's fat pad, fracture of the proximal end of the fibula occurred in our experiments.

The extensive details provided above are necessary in our opinion, as they are the first-ever description of knee injuries that occur with forced rotation movements. We could not restrict ourselves to simply indicating our findings without looking into their mechanism or the reason they occur.

We now have to determine how, and to what extent, this experimental study can shed light on the pathogenesis of hemarthrosis in the knee following a sprain.

The lesions resulting from forced movements of the knee can be placed into 2 main groups, no matter the exact nature of the initial forced movement. One group relates to the peripheral ligaments around the joint, while the other is completely intra-articular. It is these that we think may cause the profuse, rapid and exclusively intra-articular bleeding. In fact, we do not believe that damage to the collateral ligaments are of great importance in this context.

Our tibial lesion also has all the conditions needed to contribute to the production of hemarthrosis because of the connection it establishes between the joint cavity and the cancellous bone in the proximal tibia, an area in which extensive vascularization was described by Professor Richet in the context of vascular tumors in bone. The proximal end of the tibia, according to Richet is, "not only the most vascularized in the tibia, but maybe even of all bones."

To summarize our opinion in view of these considerations, we believe that when faced with a knee sprain complicated by rapid intra-articular bloody effusion that is limited to the joint, the hemorrhage must be attributed to either damage to the cruciate ligaments, tearing of Hoffa's fat pad, or to the cancellous bone damage that we described in the tibia, behind Gerdy's tubercle.

We want to reiterate the vital importance of rotational movements of the lower leg relative to the thigh. In fact, we have shown how they complicate most of the forced movements that can be applied experimentally to a knee joint. Careful analysis of our [clinical] observations appears to confirm this experimental finding. We believe that forced rotational movements nearly always play a crucial role in the production of knee sprains and subsequent hemarthrosis.

Last, and to discuss only the simplest cases, clinical experience teaches us that while absolute healing occurs most of the time, the joint pain very often persists for a long time. If you see patients 2 or 3 months after their accident, many of them will tell you that they no longer walk like they did in the past. Their leg is weak, and their knee, which is larger than the opposite knee, easily becomes hot, red, and tender, even after a minimal amount of exercise.

These comments apply to all sprains but are particularly true when the knee sprain was accompanied by hemarthrosis. All of these possibilities must be fully considered in the prognosis of bloody effusion following knee sprains.

If we consider the lesions that appear to play the main role in producing knee hemarthrosis, we can see that they are not the type to produce clearly obvious symptoms. In fact, the specific avulsion that we described on the tibia will always show itself by the presence of a tender spot behind Gerdy's tubercle; however, there is no obvious sign that can show tearing of Hoffa's fat pad, while avulsion or tearing of the cruciate ligaments are generally not extensive enough to modify the integrity of normal joint movements to any extent. As is often the result, sources of bleeding can be diagnosed only by exclusion and is based only on experimental findings.

Conclusions

1. A knee sprain can be complicated by intra-articular effusion of pure blood.
2. This intra-articular hemorrhage is due to either a connection between the femoral or tibial cancellous bone and the inside of the joint cavity, or to tearing of the branches of the middle genicular artery and the small vessels inside Hoffa's fat pad.

These conditions occur when the cruciate ligaments are torn from their attachment points or rupture, when Hoffa's fat pad is torn, and when the bone fissure that we have described occurs behind and above Gerdy's tubercle. This latter injury pattern only occurs with sprains caused by forced internal rotation. The 2 others occur equally in nearly all forced movement of the knee joint.

3. It is not correct to say—as Bonnet did—that extreme knee rotation movements always leave the joint intact and inevitably cause both leg bones to fracture. On the contrary, extreme rotational movements cause very specific lesions on the side of the knee joint and figure in the etiology in the vast majority of knee joint sprains.
4. The profuse nature of the effusion, the speed of its production, and the often-excessive slowness of its resorption are the main clinical features of knee hemarthrosis.
5. When making the diagnosis of knee hemarthrosis, the considerations drawn from its abundance and the timing of its appearance are of considerable value, a

value that could even be called pathognomonic. The heavy or crackling nature of the fluctuation and early periarticular bruising are rare signs. Their absence does not change the diagnosis of hemarthrosis when there is profuse and rapid effusion following trauma. Methodical exploration of the joint and the search for point tenderness and abnormal movement can, in certain cases, provide precious information on the exact nature of the joint lesions. But it is important to remember that a hemorrhage can only be diagnosed by exclusion and is based only on experimental data.

6. In most cases, joint aspiration immediately followed by immobilization and methodical compression of the lower limb is the safest and best treatment for knee hemarthrosis due to a sprain.

Discussion

"The real voyage of discovery consists not in seeking new landscapes, but in having new eyes."Marcel Proust

Paul Segond was a general surgeon who was most interested in gynecology and urology. The translated work represents his sole contribution to the orthopaedic literature, and was based on experiments he conducted as a 27 year old.

The main finding of his study was an anterolateral structure of the knee with a bony insertion on the tibia between Gerdy's tubercle and fibula. This structure, which has recently been called the anterolateral ligament, was consistently present in the specimens. Segond noticed that in creating an anterior cruciate ligament (ACL) injury in moderate flexion, this structure was torn in almost 50% of cases. He described the tear as frequently involving a bony avulsion of the anterolateral capsule of the knee at its insertion on the anterolateral aspect of the proximal tibia. As mentioned previously, this fracture has subsequently been eponymously named after him; however, Segond was conscious that injury to this structure did not always involve an avulsion of bone, but could also be a solely soft-tissue lesion. He stated clearly that this structure acted as a restraint to internal rotation of the knee. To this end, he can be regarded as having introduced the concept of rotatory instability. Notably, in 2018, none of his findings have been rejected.

Critique and Context

Despite the extraordinary amount of work and quality of the manuscript, there are nonetheless some limitations of Segond's work. The main limit relates to the validity of the knee injury simulation protocol; the knees were injured manually with the aid of assistants. To induce a ligamentous injury by this mechanism requires a large force and this is likely to lead to a low level of reproducibility of the forces applied; moreover, there is limited information about the specimens and how they were preserved. This may have influenced the resistance of the soft tissues and therefore the results. This is particularly relevant in the context of bony avulsion injuries, which may have been more likely to occur in a cadaveric sample, particularly if the ligament was more rigid because of desiccation. Finally, cadaveric studies do not necessarily reproduce in vivo situations precisely; this should be taken into consideration when interpreting the results.

We should also see this study in its temporal context and acknowledge how forward-thinking Segond was at the time (1879). Around this period in France, the Third Republic had only just become established and the government was struggling to eradicate cholera and famine. People used steam cars and the "Marseillaise" had only recently become the French national anthem. The Eiffel Tower would be built 10 years later, although good red wine was already being produced all around the country. In the medical field, although ether and morphine were being used as anesthetics with variable success, surgeons were only just becoming aware of the importance of asepsis thanks to the work of Ernst Von Bergmann. Notably, roentgenograms had not yet been discovered, which makes the finding of a small avulsion fracture all the more remarkable.

What physicians lacked in technology, they made up for with inquisitiveness and intellect. They had a good knowledge of anatomy and were aware of the pathology of ACL tears; however, despite appreciating the pathology, they were unable to reconstruct or repair the ACL and could only rely on spontaneous healing to treat their patient. Seen in this context, the discovery of the "pearly, resistant, fibrous band" and its role is quite remarkable.

Despite the discovery of this band on the anterolateral aspect of the knee, Segond's work remained largely unknown or was forgotten for many decades. Indeed, when surgeons started to perform ACL reconstructions approximately 50 years later, the focus was primarily on restoring sagittal stability.[4] The description of rotational instability by Hughston et al.[5] made surgeons think differently about peripheral structures once again.

More recently, a plethora of studies have been published on this topic, providing new information about the anterolateral structures and their anatomy, histology, and biomechanical function.[6,7] Despite this, a considerable degree of controversy continues to exist. The debate has centered around whether a distinct anterolateral ligament exists and its potential role in the control of anterolateral rotatory laxity of the knee following ACL injury.[8] This ligament is part of an anterolateral complex of the knee and contributes, along with other structures (the iliotibial band, Kaplan fibers, and anterolateral capsule), to the control of anterolateral rotation of the knee[9,10] Interestingly, none of these studies have rejected Segond's work; in general, they have complemented or extended his findings.

A good story requires a beginning, middle, and end. Segond has provided a captivating beginning to the anterolateral instability saga, but a few chapters remain. Equipped with modern scientific tools and technological advances, the next steps must surely involve establishing a more accurate and reliable diagnostic approach to injury of the structures of the anterolateral complex. In this regard, there are promising studies emerging from the use of dynamic imaging such as ultrasound, but less convincing evidence for the reliability of magnetic resonance imaging.[11-14] The ideal conclusion of the tale would be the surgical means of restoring the native kinematics of the knee following injury to the anterolateral complex. New surgical techniques have been described to reconstruct or repair the anterolateral ligament in the setting of ACL deficiency and have produced promising preliminary results[15-18]; however, more studies are necessary to validate these surgical procedures. It is encouraging that this pursuit has been endorsed and supported by an international consensus group.[9,19-21]

Conclusions

Segond's seminal work has recently received increased attention, as shown by the rising number of citations, mostly in the English literature. It is likely that most authors have only listed the reference without reading or truly understanding Segond's work. With this in mind, we felt it was important to provide access to this paper to the non−French-speaking members of the orthopaedic community. We have learned from translating this study that Segond's contribution to the understanding of anterolateral instability should not be limited to merely a description of a bony avulsion. This man was not only a physician, but a scientist, anatomist, and biomechanist to boot!

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Epilogue

"The eyes only see what the mind is prepared to comprehend"

- Robertson Davies

The misrepresentations alluded to in the preamble to this study relate, in my opinion, to a misreading of the detail of the methodology employed by Segond and his assistants in his study(96). First of all, Segond was very aware of the importance of rotation as a mechanism of injury which occurs following a slip or a twist to cause a knee haemarthrosis and its corollary, ACL rupture. As he described, "*Clinical observation and experimentation show that forced rotational movements of the leg on the thigh are responsible for most knee sprains. It is therefore the lesions caused by this type of movement that especially cause us to wonder about the reason for the blood.*" In fact, the mechanism to induce these injuries is also worth mentioning and also attest to the understanding of anterolateral rotation of the knee as a cause of injury: "..*we employed, as an immobilization method, 1 or 2 assistants who firmly grasped the thigh while, from our side, we applied forced movements to the knee using the only traumatic force that we were capable of producing ourselves.*"

The next point to take from Segond's treatise is very simple but perhaps the most crucial of all. It relates to the method of dissection. The quotation that has been used ubiquitously to draw parallels with Segond's work and the findings of Claes et al, describes, "*a pearly, resistant, fibrous band that is placed under extreme tension when the knee is forcefully rotated internally.*" However, as any journalist will attest, quotes taken out of context can be interpreted very differently. What has failed to have been disclosed in manuscripts that use this phrase is the preceding sentence which provides the context and states: "*This can easily be seen when we examine a knee without its skin envelope*." It doesn't describe removing the ITB entirely as is the case in the study by Claes et al and many others(1, 58, 97, 98). What it is actually describing is the ITB itself. It is very obvious that Segond recognised the importance of the ITB, a fact that is supported by Kaplan and others that followed(50).

Therefore, to remove it as part of a dissection related to the lateral side of the knee, is like describing a banana having discarded its peel. And, we know what that can lead to!

Section 2

Radiological and clinical diagnosis of injury to the anterolateral complex of the knee

Chapter 5: The ability of MRI to identify the anterolateral ligament in the anterior cruciate ligament-injured and -uninjured knee

Introduction

Section 1 of this thesis detailed the anatomy of the anterolateral complex of the knee and discussed the aetiology of anterolateral rotatory laxity. It is clear that a number of structures play a role in controlling anterolateral rotation of the knee. Consequently, in the setting of ACL injury with combined anterolateral rotatory laxity, diagnosing injury to the specific structures contributing to this can be challenging. In the clinical evaluation of the ACL-deficient knee, increased anterolateral tibial translation can be assessed by the pivot shift test, as illustrated in Chapter 3. However, as discussed, this test is subjective and can be inconsistent and variable(91). As a result, there has been much interest in the use of radiological imaging to establish a diagnosis of injury to the structures of the anterolateral complex.

The appearance on plain radiographs of a '*Segond*' fracture, which has been described as an avulsion of an elliptic fragment of bone attached to the iliotibial band from the lateral aspect of the tibial plateau, has historically been considered pathognomonic for ACL injury(99). Yet, anterolateral laxity of the knee can also occur in the absence of bony injury. As such, Magnetic resonance imaging (MRI) has been used to investigate for the presence of damage to the structures of the anterolateral complex(100-103).

In keeping with the theme experienced to date with the anterolateral complex, where nothing appears straightforward, many of these studies have demonstrated inconsistent results with the use of MRI(60, 102, 104, 105); the visibility rates of the ALL have ranged from 51% to 100%(60, 104). Further, detection of the ALL in many of these studies was been performed on cadaveric specimens, or small series of either injured or uninjured knees. As a surgeon, I wanted to determine how useful a standard MRI, used in normal clinical practice, was in diagnosing injury to the anterolateral complex. In particular, could it assist us in determining those patients that may require additional surgery in addition to an ACL reconstruction following ACL injury. But, where to start considering the multitude of structures that comprise the anterolateral complex? The ALL, of course!

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Contribution

Mr Devitt, Associate Professor O'Sullivan, Mr Lash and Mr Whitehead contributed to the conception and design of this manuscript. Mr Devitt and Associate Professor O'Sullivan completed the reading of the MRIs. Mr Devitt, Professor Webster and Ms Porter and analysed the data. Mr Devitt wrote the manuscript. Mr Devitt, Associate Professor O'Sullivan, Professor Feller, Mr Lash, Ms Porter, Professor Webster, Mr Whitehead TS critically revised the manuscript for important intellectual content.

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KNEE

MRI is not reliable in diagnosing of concomitant anterolateral ligament and anterior cruciate ligament injuries of the knee

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Abstract
Purpose There has been a renewed interest in the anterolateral structures of the knee, including description of the anterolateral ligament (ALL) as a distinct structure. Recognizing injury to the ALL is challenging, particularly given the subjective nature of physical examination. Consequently, focus has turned to magnetic resonance imaging (MRI) to reach a preoperative diagnosis of this region. The aim of this study was to examine the ability of 3-Tesla (3T) MRI to identify the ALL in ACL-injured patients compared to a matched control group of ACL-intact patients. The hypothesis was that the ALL would be more difficult to identify in ACL-injured patients compared to ACL-intact patients.
Methods A prospective case control study was performed comparing 3T MRI scans of 63-patients with an ACL rupture with a control group of 64-patients without ACL injury. An experienced musculoskeletal radiologist and an orthopaedic surgeon evaluated the scans performed using standard knee protocols. The ALL was considered in three regions for analysis: femoral, meniscal, and tibial. The status of the ALL was determined as visualized or non-visualized, and the integrity was assessed as intact, attenuated, or focal discontinuity.
Results The detection rate of at least a portion of the ALL was 41/64 (64%) in the control group and 45/63 (72%) in the ACL-injured cohort, respectively. The entire length of the ALL could only be identified in 15/64 (23%) of the control group and 13/63 (21%) of the ACL-injured cases. In both groups, the visibility of the ALL was poorest at the femoral region and greatest at the tibial regions. The ALL, when visualized, was deemed to be intact in 55/63 (87%) of cases. Although the inter-observer reliability was excellent for detection of the ALL in the control group ($\kappa = 0.86$), this decreased to only moderate reliability in the ACL-injured group ($\kappa = 0.52$).
Conclusion This study demonstrates that MRI alone should not be relied upon to make a diagnosis of ALL injury in the setting of concomitant ACL injury due to the inability to accurately visualize this structure consistently in its entirety. To make a diagnosis of ALL injury or anterolateral instability of the knee and clinical correlation remains essential.
Level of evidence Case–control study, Level III.

Keywords Anterolateral ligament · Knee · Magnetic resonance imaging · Anterior cruciate ligament · Injury

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Introduction

It has long been recognized that rupture of the anterior cruciate ligament (ACL) causes anterolateral rotatory instability of the knee [11, 23, 31]. In 1976, Hughston et al. [16] postulated that anterolateral instability is caused by a tear of the middle one-third of the anterolateral capsule but may be accentuated by rupture of the ACL. More recently, it has been proposed that the anterolateral capsule is in fact a discrete ligament called the anterolateral ligament (ALL) [3, 6, 9, 28, 30]. This structure has been the focus of considerable debate regarding its potential role in knee kinematics, injury, and the need for repair or reconstruction in combination with ACL reconstruction [18, 19, 26].

Although the ALL has been described in numerous anatomical studies, considerable variability exists regarding its anatomical parameters [3, 6, 9, 12]. In particular, there is conflicting information regarding the ligaments femoral origin, its meniscal insertion, and the relationship to the joint capsule [14].

In the clinical evaluation of the ACL-deficient knee, anterolateral rotatory instability is assessed by manual tests such as the pivot-shift test, which is subjective and not quantitative [25]. As a result, there has been much interest in the use of radiological imaging to establish a diagnosis of injury to the ALL. The appearance on plain radiographs of a 'Segond' fracture, which has been described as an avulsion of an elliptic fragment of bone attached to the iliotibial band from the lateral aspect of the tibial plateau, has historically been considered pathognomonic for ACL injury [8]. Although this is true in the vast majority of cases, it has since been recognized that this fracture occurs at the described tibial attachment of the ALL [2, 5, 9, 18].

Anterolateral instability can occur in the absence of bony injury. Magnetic resonance imaging (MRI) has, therefore, been used to investigate for the presence of damage to the ALL. Previous studies have demonstrated inconsistent results with the use of MRI [3, 4, 7, 15, 24, 27, 29]; the visibility rates of the ALL have ranged from 51 to 100% [3, 29]. Further, detection of the ALL in many of these studies has been performed on cadaveric specimens, or small series of either injured or uninjured knees. To date, no study has used a control group to compare the findings in an ACL-injured and an ACL-intact group.

The aim of this study was to assess the ability of 3-Tesla (3T) MRI, using standard knee protocols to identify the ALL in ACL-injured patients compared to a matched control group of ACL-intact patients. A secondary aim was to identify key qualitative MRI findings that might be associated with injury to the ALL.

Methods

Human Research Ethics Committee approval was obtained for this study. From 2014 to 2015, 150 knee MRIs were prospectively identified for inclusion in the study. Two groups were established: 75 patients with MRI confirmation of ACL injury and 75 patients presenting medial joint line pain with MRI evidence of an intact ACL. Patients between the age of 16 and 60 years were included. The exclusion criteria included suboptimal MRI examination (characterized by motion artefact) or incomplete study (absence of coronal PD-weighted or axial PD-weighted fat-suppressed images), multiligamentous injury, significant osteoarthritis, previous ACL surgery, previous lateral meniscectomy, or the presence of hardware in the knee.

MRI imaging examinations of the knee were performed using the department protocol in the supine position with the leg extended using a Siemens (Erlangen, Germany) 3T MRI; the scans were performed using either a Magnetom Verio with an eight channel phased array coil or a Magnetom Skyra coil with an 15 channel phased array coil.

Three plane (sagittal, coronal, and axial) sequences using both proton-density- and fat-suppressed proton-density-weighted images were performed with TR between 3000 and 4000 ms, TE between 33 and 35 ms, matrix between 320 × 320 and 384 × 384 (phase × frequency), 3-mm slice thickness, and a field of vi w of 130 mm.

Following a detailed review of the available literature, a fellowship-trained musculoskeletal radiologist and a fellowship-trained orthopaedic surgeon performed a pilot evaluation of ten MRI scans together to establish a consensus on the qualitative features of the ALL. Given the discrepancy in anatomical description of the ALL from numerous studies, the details from one study by Dodds et al. [9] were used as the anatomical basis for the MRI assessment. The ALL was defined as separate to the capsule, lateral collateral ligament (LCL) and Iliotibial band, according to the findings of this study [9]. The ALL was assessed in all three imaging planes on a picture archiving and communications system. The ALL was divided

Fig. 1 Anterolateral ligament was divided into three sections for analysis (divisions marked with *white dotted-lines*): femoral, meniscal, and tibial

into three sections, and the visibility was assessed at each: femoral, meniscal, and tibial (Fig. 1). The ability to identify the ALL was determined as visualized or non-visualized. The integrity of the ALL at each section was evaluated as intact, focal discontinuity, or wavy. The presence or absence of a distinct attachment to the meniscus to the ALL was also noted. Bone bruising on lateral femoral condyle or lateral tibial plateau was also assessed. Finally, the presence of any further qualitative features suggestive of injury to the ALL was documented.

Statistical analysis

The results of the detection rates of the MRI are reported as the consensus of both raters. A statistical analysis of the ability of the raters to visualize the ALL at each defined portion was performed using Cohen *k* coefficients for categorical variables [17]. Agree/disagreement rates (percentage of all inter-observer comparisons with agreement/disagreement on a parameter) were also reported. *K* values were classified as described by Landis and Koch, with values of 0.81–1.00 indicating excellent agreement, 0.61–0.80 substantial agreement, 0.41–0.60 moderate agreement, 0.21–0.40 fair agreement, and 0–0.21 slight agreement [22].

Results

Of the 75 MRI, 12 MRIs were excluded from the ACL-injured group due to the presence of a multiligamentous injury in fi e cases, a suboptimal examination in six cases and a previous lateral meniscectomy in one case. Eleven MRIs were excluded in the ACL-intact group due to the suboptimal examinations in four studies, the presence of osteoarthritis in six studies and a previously undiagnosed chronic ACL injury in one study. Therefore, the study groups consisted of 63 MRI scans in the ACL-injured group and 64 MRI scans in the ACL-intact (control) group. These MRI scans were in 127 patients, with no bilateral MRI scans used.

The mean age in the ACL-injured group was 28 years (range 16–60 years). This compared to a mean age of 41 years in the control group (range 16–60 years). The left knee was scanned in 31/63 cases (49%) in the ACL-injured group and 32/64 cases (50%) of the control group. The ratio of male to female subjects was 3:1 (47 males, 16 females) in the ACL-study group and 2.5:1 (46 males, 18 females) in the control group.

The detection rate of at least some section of the ALL in the ACL-intact group was 41/64 (64%). The entire length of the ALL could be identified in only 15 of 64 (23%) cases. The ALL was identified at the femoral section in 22 of the 64 (35%) MRIs examined, in the meniscal section in 27 of 64 (42%), and the tibial section in 32 of 64 (50%) (Table 1). When visualized there was no evidence of injury to the ALL in any of the control cases. No bone oedema was identified in any case. At the meniscal section, a distinct capsular attachment could be detected in 25 of 27 (93%) cases when the ALL was clearly visualized.

The inter-observer agreement was excellent for the visualization of the ALL in each region with an overall κ value of 0.86 (95% CI 0.83–0.9). The inter-observer agreement rate was 93%. Data from both raters are shown in Table 1.

At least one section of the ALL in the ACL-injured group was detected in 45 of 63 (71%) cases. The entire length of the ALL could only be identified in 13 of 63 (21%) cases. The ALL was identified at the femoral section in 17 of 63 (27%) of the MRIs examined, at the meniscal portion in 33 of 63 (52%) and the tibial section in 40 of 63 (63%) (Fig. 2a–c; Table 1). Injury to the ALL was not observed at the femoral section and only in 4 of 63 (6%) MRIs at the meniscal section, and 9 of 63 (14%) cases at the tibial section. At the tibial section, focal discontinuity was noted in two cases and attenuation of the ALL in seven cases (Fig. 3). The inter-observer agreement was only moderate for the visualization of the ALL at each section in the ACL-injured group, with an overall κ value of 0.53. The inter-observer agreement rate was 76%. Data from both raters are shown in Table 2.

It was difficult to distinguish the femoral section of the ALL from adjacent structures, the lateral (fi ular) collateral

Table 1 Visualisation of the ALL in ACL-intact (control) patients

	Rater 1 (%)	Rater 2 (%)	Consensus (%)	Inter-observer κ value (95% CI)	Inter-observer agreement (%)
ALL visualization	64	64	64	0.86 (0.83–0.9)	93
Complete	20	25	23		
Partial	44	39	41		
Not visible	36	36	36		
Femur	36	34	35	0.83 (0.76–0.90)	92
Meniscus	44	41	42	0.87 (0.81–0.93)	94
Tibia	53	47	50	0.88 (0.82–0.94)	94

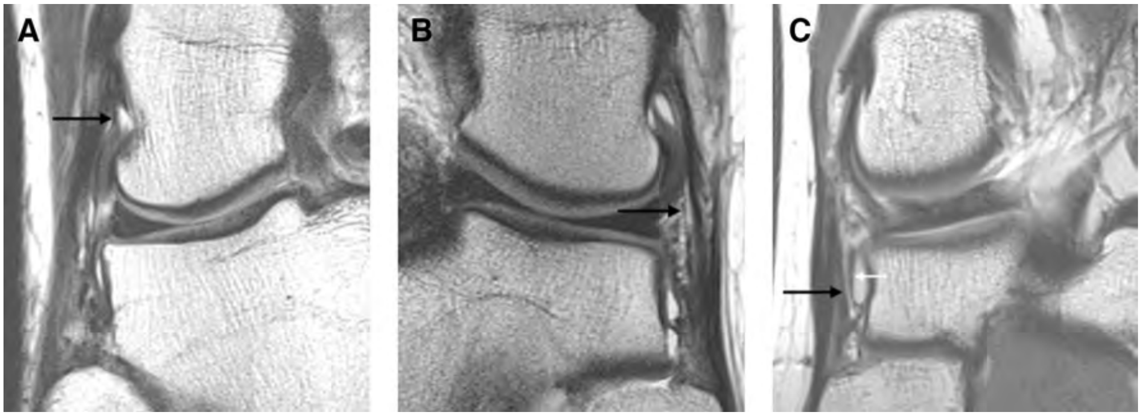

Fig. 2 **a**–**c** Three separate coronal proton-density MRI images of the knees depicting the appearance of the anterolateral ligament marked with a *black arrow*. **a** The femoral section in a right knee, **b** the meniscal section in a left knee, and **c** the tibial insertion of the right knee, which is visualized separate from the capsule (*white arrow*)

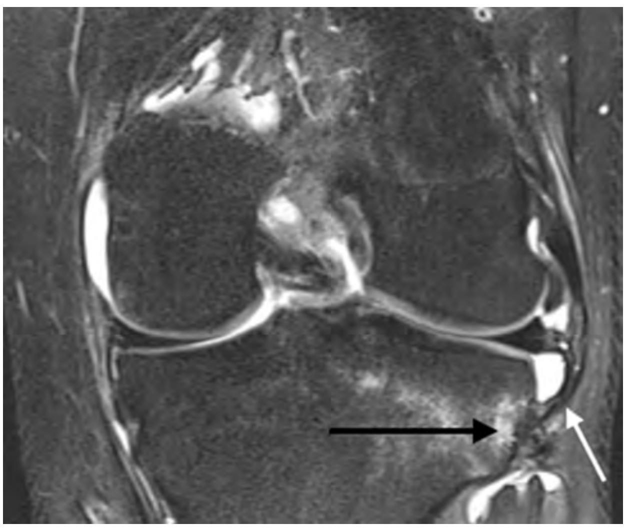

Fig. 3 Coronal T2 MRI of the left knee: the *black arrow* marks the bone-bruising pattern on the anterolateral aspect of the tibia, which was frequently seen. The *white arrow* marks the wavy appearance of the ALL suggestive of attenuation

ligament (LCL) and the popliteus tendon. The most commonly associated qualitative finding was bone oedema in the anterolateral aspect of the tibial plateau adjacent to Gerdy's tubercle, which was present in 32 of 63 (51%) cases (Fig. 3). On the lateral femoral condyle, bone oedema was only identified in two cases and was approximate to the proximal origin of the ALL. Lateral capsular oedema was a relatively frequent finding and was noted in nine cases (14%). Finally, the presence of a Segond fracture was identified in four cases (Fig. 4). However, due to the associated oedema in these cases it was difficult to differentiate the ALL from the anterolateral capsule.

Discussion

The main finding of this study was that the ALL could not be identified reliably using 3T MRI in either ACL-injured or ACL-intact patients. Specificall , in both groups, the visibility of the ALL was poorest at the femoral origin

Table 2 Visualisation of the ALL in ACL-injured patients

	Rater 1 (%)	Rater 2 (%)	Consensus (%)	Inter-observer κ value (95% CI)	Inter-observer agreement (%)
ALL visualization	62	79	71	0.52 (0.46–0.58)	76
Complete	17	24	21		
Partial	45	55	50		
Not visible	38	21	29		
Femur	25	29	27	0.44 (0.31–0.56)	78
Meniscus	54	51	52	0.43 (0.33–0.54)	71
Tibia	54	71	63	0.54 (0.44–0.64)	78

Fig. 4 Coronal T2 MRI of the left knee in a patient with an ACL rupture and a second fracture: the *white arrow* marks a Segond fracture with avulsion from the anterolateral aspect of the tibial plateau. The *small black arrow* depicts the anterolateral capsule, while the *large black arrow* demonstrates the iliotibial band

and greatest at the tibial insertion. Although the inter-observer reliability was excellent for detection of the ALL in the ACL-intact group ($\kappa = 0.86$), this decreased to only moderate reliability in the ACL-injured group ($\kappa = 0.52$). This study demonstrates that MRI alone should not be relied upon to make a diagnosis of ALL injury in the setting of concomitant ACL injury due to the inability to accurately and consistently visualize the structure. A clinical suspicion of injury combined with physical findings suggestive of anterolateral instability remains crucial in establishing a diagnosis of injury to the anterolateral structures of the knee.

The MRI identification of the ALL has been the topic of a number of studies since the 'rediscovery' of this structure in 2013 [3, 4, 15, 20, 29]. These studies can be broadly divided into three groups: cadaveric, uninjured knees, and injured knees. In their cadaveric study, Caterine et al. [3] were able to identify the ALL in all ten specimens. However, the images were acquired with a 3T MRI and a slice thickness of 0.4 mm was used, which is considerably thinner than the routine 3-mm slices used in the clinical setting.

In a series of 100 knees, using 1.5T MRI, Kosy et al. [20] detailed identification rates of at least a section of the ALL in 94% of cases; patients with ACL injury and lateral meniscal tear pathology were excluded. Helito et al. [15] also described high rates of detection with 1.5T MRI, demonstrating visibility of a portion of the ALL in 97.8% of 39 uninjured knees and full visualization in 72%. These detection rates differ considerably to an earlier study by the same authors in which all three portions of the ligament were identified in 33% of knees and some portion was visible in 82% of cases [13]. This highlights the inconsistency of detection of this structure. Porrino et al. [27], in 2015, reported 100% visibility of a lateral structure connecting the distal femur to the proximal tibia in 51 uninjured knees with a combination of 1.5 and 3T MRI. However, the authors concluded that what they identified was 'an ill-defined sheetlike structure' and made the recommendation to radiologists that 'it may be best to forgo an attempt to separate this structure into discrete divisions, such as the ALL, because these individual components are inseparable on routine MRI'.

In contrast, Taneja et al. [29], in a series of 70 MRIs (1.5 or 3T), could identify the ALL in 51% of knees, which was completely visible in 11% and partially visible in 40%; 13% of patients within this cohort had undergone previous knee surgery on the affected side. The demonstration of an anterolateral ligamentous structure in 64% of the ACL-intact cases in the current study lies somewhere between the existing studies in the literature. Importantly, a full delineation of the ligament in its entirety was only possible in 23% of the images. The current authors would also concur with the assertion of Porrino et al. that it is often very difficult to define a discrete structure of the ALL. One of the reasons to explain the discrepancy in detection rates of the ALL may be explained by the variation in anatomical studies. Dodds et al. [9] defined the ALL as separate to the capsule, LCL and Iliotibial band. However, others have suggested it is more of a capsular thickening at the anterolateral aspect of the knee [21]. Therefore, given the anterolateral capsule is clearly visible on most knee MRIs, it is likely that inconsistency in interpretation of what constitutes the ALL is responsible for the variation in identific - tion rates. More recently, Helito et al. [14] have even suggested that both superficial and deep component to the ALL exist, which perhaps further complicates the MRI interpretation. Considering that most routine MRI scans use 3-mm slice thickness, it is therefore not surprising that it is not clearly visualized in a number of cases.

Focusing on the visibility of the ALL in ACL-injured knees, Claes et al. [4] could identify the entire ligament in 76% of 271 knees. In addition, the authors reported a very high rate of injury, stating that 78.8% of knees demonstrated radiological abnormalities. Injury was defined as complete disruption of the ligament (all fibres discontinuous), marked irregularity of the contour of the ALL (e.g. 'bended out'), or the presence of intra- or peri-ligamentous oedema. No specific information was available about the type of MRI scans used in this study, which were taken from a variety of centres and reviewed by two orthopaedic surgeons. The authors did not subdivide of the ligament into sections, as described in the current and other studies

[13, 15, 27, 29]. The findings of the current study are not consistent with those of Claes et al. The entire length of the ALL was only visualized in 24% of cases, and, when visualized, the ALL was intact in the vast majority of cases at each portion. The result of the current study would be more in keeping with a recent study by Musahl et al. [24], exploring the correlation of MRI findings in ACL-injured patients and knee laxity. Of the 41 patients studied, 21 (51%) had an injury to the anterolateral capsule; the majority of which oedema within and surrounding the ligament (Grade 2) without complete disruption of the capsule (Grade 3), which only occurred in two cases [24].

A qualitative feature that was seen with reasonable regularity (10%) was the presence of oedema around the lateral capsule, at the lateral meniscal attachment. This was not regarded explicitly as an injury to the ALL as reported by Musahl et al. [24] because in the majority of cases the ligament could still be seen. However, even assuming that this oedema represented an injury to the ALL, the injury rates fall some way short of the level of 78.8% detailed by Claes et al. It is worth noting that the vast majority of MRI studies that have tried to define the ALL have excluded patients with signs of acute injury to lateral side of the knee [13, 15, 20, 27]. However, given that injury to the ALL is likely to be most relevant in the setting of an ACL rupture, which is also frequently associated with a lateral meniscal injury, the presence of oedema in this area may be significant, albeit not diagnostic of ALL injury in itself [10]. Likewise, the presence of bone bruising at the anterolateral cortex of the tibial plateau, which was present in 51% of cases, may point to a mechanism of traction of the anterolateral capsule at this location. The same pattern of oedema was seen with three of the four Segond fractures. However, once again, it is not diagnostic of ALL injury as a visible discontinuity of a ligamentous structure was not associated with this qualitative finding. Moreover, bone bruising is a very common finding in patients with ACL rupture, occurring in up to 78% of observed cases [1].

The authors acknowledge there are potential limitations of this study. In the ACL-injured cohort of patients, there is no information available on the timing between injuries and acquisition of the MRI. This may have an impact on the presence of a haemarthrosis or bone bruising in the acute setting compared to a more chronic situation. Also, no clinical examination findings assessing anterolateral instability were available for any of the patients. The mean age of ACL-injured group was younger (28 years) compared to the ACL-intact group (42 years), which was likely due to selection of a control group as those patients with medial joint line pain with MRI evidence of an intact ACL. A musculoskeletal radiologist and an orthopaedic surgeon undertook the assessment of the MRI scans. This differs from previous studies, which were performed exclusively by radiologists in most cases. However, the two observers developed a consensus on what represented the ALL prior to the commencement of the study based on the previous literature. In addition, the authors contend that the ability of an orthopaedic surgeon to detect this structure on MRI at an orthopaedic clinic is extremely relevant if MRI is to be considered a useful diagnostic tool.

Conclusion

Although it is possible to detect the ALL on MRI, the inconsistent identification of this structure throughout its course indicates that MRI is not a reliable tool to diagnose injury in the setting of concurrent ACL rupture. These results conclude that MRI alone should not be used to make a preoperative diagnosis of ALL injury or anterolateral instability of the knee and clinical correlation remains essential. Consequently, the decision to reconstruct the ALL should not be based on MRI findings alone

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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Epilogue

"Don't define your world in black and white because there is so much hiding amongst the greys."

The result of this study would suggest that while MRI has some utility in visualising at least a portion the ALL, as an accurate diagnostic tool it is well below par in the diagnosis of injury to this structure. But, why is this the case when MRI is so sensitive for the diagnosis of ACL injury(106)?

There are a number of potential reasons. The first and obvious one is that the ACL is a distinct, discernible and consistent structure situated within the notch of the knee, while the ALL is an indistinct, thin and inconstant structure, which is intimately associated with the anterolateral capsule of the knee(107). The deep and capsulo-osseous layers of the ITB are superficial to the ALL and together they form the anterolateral complex(13, 14). As was discovered in the current study, the close relationship of these structures renders specific identification of each individual component of the anterolateral complex particularly difficult, especially in the presence of voluminous intra-articular fluid which usually pools in the anterolateral gutter of the tibia, compressing the capsule and adjacent structures together against the more robust ITB.

In addition, the specific knee MRI protocols used are configured to best identify the ACL with most MRI scanners(108, 109). Indeed, one particularly important element of the current study was to try to identify the ALL using conventional MRI sequences that are typically employed in standard practice. Although, the MRI images were mostly high resolution (3 Tesla) with thin slices (3 mm) it is likely that the configuration of these slices was not optimal in detecting an obliquely oriented structure on the lateral side of the knee spanning from the posterior aspect of the femoral epicondyle to the anterolateral aspect of the tibia(64). Nonetheless, even when using specific protocols to localise the femoral attachment of the anterolateral ligament, Young et al reported the same deficiency of MRI in visualising the entire length of the ALL in the majority of cases(110). Indeed, because of the inadequacy of the scans to view the entirety of the ALL, Young et al, and other authors, have used less stringent criteria for the diagnosis of ALL pathology, which specify that it is only necessary to visualise at least one-third of the ligament (104, 110, 111). However, this would hardly be acceptable for ACL injury diagnosis and, therefore, a lesser degree of scrutinization should not be tolerated to make a diagnosis of ALL pathology, especially for an ill-defined structure.

When assessing an MRI there are a multitude of different sequences which can be used; the simplest way to think about them is to divide them according to the dominant influence on the appearance of tissues. Orthopaedic surgeons, by and large, like to keep things easy and the two sequences that are most frequently used in practice are T1 and T2(112). In basic terms, T1 is a fat sensitive sequence which is ideal for seeing anatomy and T2 is a fluid sensitive sequence which is useful for seeing pathology(113). On T2 sequences, fluid has a high signal intensity and appears white, muscle has an intermediate signal intensity and appears grey, and bone, ligament and meniscus have a low signal intensity and appear black. Following ACL injury, the intra-articular blood (haemarthrosis) will appear white, while a disrupted ACL will have a heterogenous, grey appearance lacking its usual definition and structural integrity(108). The radiological identification of injury to thinner, less well-defined structures, like the ALL, can be more difficult and, therefore, an assessor's eye would typically be drawn to the presence of fluid as a sign of injury, much like one would examine for a bruise on the skin clinically(114). As such, diagnosis of injury is less clear cut, or black and white if you will, and is open to interpretation based on varying shades of grey.

The interval of time between the injury and the MRI is likely to have a large bearing on the amount of fluid found in the knee, both intra-articularly and in the surrounding soft tissues(115). In terms of radiological diagnosis, this is both a help and a hindrance. The existence of fluid within the soft tissues, which is termed oedema, often signals the presence of injury but it can be quite extensive and widespread and, crucially, is not always confined to structure that has been damaged. Also, the appearance of oedema can alter with time and much like a bruise will dissipate, so too the presence of fluid on an MRI will diminish the longer the time from injury(116). Therefore, the timing of the MRI relative to the injury will likely have an impact on the diagnostic accuracy of the scan. This important issue has been considered in the design and methodology of further studies within this thesis

Chapter 6: An assessment of the ability of MRI to identify the Kaplan fibres of the iliotibial band

Introduction

Much like its anatomical neighbour, the anterolateral ligament, the Kaplan fibres have had somewhat of a renaissance in recent years as their importance in controlling anterolateral rotation has been realised(70). They represent a very significant structure in the anterolateral complex of the knee(14). Kaplan described these fibres, which attach the iliotibial tract to the supracondylar aspect of the lateral femur, and provided a comprehensive account of the relationship of the iliotibial tract to the knee joint(50). His study, which was published in 1958, entitled, *"The iliotibial tract; clinical and morphological significance"*, is a fascinating read and contains such detail as to put many modern accounts of anatomy to shame(50). The manuscript introduction contains an exhaustive historical account of early anatomical studies related to the iliotibial tract, stretching all the way back to the 16th century; included are findings from Andreas Vesalius (1514-1564), the legendary Flemish anatomist, and Jacques Maissiat (1805-1878), a French anatomist, after whom the iliotibial tract was named, Maissiat's band, until it was changed to iliotibial tract, or iliotibial band, in the last century(50).

Following this, a meticulous review of comparative anatomy, human cadaveric dissections – both foetal and adult, electrical stimulations studies of the tensor fascia lata and gluteus maximus, observations based on surgical procedures, and clinical observations was presented(50). These were all supplemented with wonderful photographs and line-drawing illustrations to provide clarity. To give an example of the thoroughness employed in this work, in the comparative anatomy part of the study, the following animals were dissected and studied: three Rhesus monkeys, one lemur, two gibbons, one alligator, one iguana, two bullfrogs, and several cats and dogs. One has to commend the dedication of the author, Emmanuel B, Kaplan (1894-1980), who in addition to his interest in anatomy was also a pioneering hand surgeon at the Hospital for Special Surgery, New York, United States(52).

He is credited with authoring over 100 publications, including four books, during his active professional career, which is some achievement at that time. Indeed, it is worth appreciating the quality of his published work and the rigorous scientific method that supports it, which perhaps is in contrast to some of the studies that are published nowadays, in an era of ubiquitous journal promotion and social media infiltration into everyday society. Perhaps, it also explains how Dr Kaplan got so much work done in his day, as he undoubtedly didn't have to endure the same level of distraction that modern day technology and constant news provides.

The following study revisits the ITB and assesses the ability of MRI to identify the Kaplan fibres; although the scans are confined only to humans on this occasion. In keeping with Kaplan's holistic approach to investigate the entire ITB and not simply the influence it has on the knee, a number of pilot MRI scans were first performed of the whole thigh to correlate the anatomical and radiological findings and to assess the adequacy of standard MRIs to view the entirety of the Kaplan fibre complex. It was determined that the field of view with standard MRI scans was satisfactory and indeed it provided a clear and elucidating medium to assess this important structure.

By the way, a gibbon is a rare, small, slender, long-armed, tree-dwelling ape, native to the forests of southeast Asia.

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Contribution

Mr Devitt, Associate Professor O'Sullivan, Professor Feller and Mr Batty contributed to the conception and design of this manuscript. Mr Devitt, Mr Batty, Mr Murgier, and Associate Professor O'Sullivan completed the reading of the MRIs. Mr Devitt, Professor Webster and Mr Batty and analysed the data. Mr Barry, Mr Murgier, and Mr Devitt wrote the manuscript.

Mr Devitt, Associate Professor O'Sullivan, Professor Feller, Mr Batty, Mr Murgier, and Professor Webster critically revised the manuscript for important intellectual content.

Conference presentations

This work was presented at a national conference:

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The Kaplan Fibers of the Iliotibial Band Can Be Identified on Routine Knee Magnetic Resonance Imaging

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Background: The Kaplan fibers (KFs) of the iliotibial band have been suggested to play a role in anterolateral rotational instability of the knee, particularly in the setting of an anterior cruciate ligament (ACL) rupture. Description of the normal magnetic resonance imaging (MRI) anatomy of the KFs may facilitate subsequent investigation into the MRI signs of injury.

Purpose: To assess if the KF complex can be identified on 3-T MRI using standard knee protocols.

Study Design: Cohort study (diagnosis); Level of evidence, 3.

Methods: 3-T MRI scans of 50 ACL-intact knees were reviewed independently by a musculoskeletal radiologist and 2 orthopaedic surgeons. Identification of the KFs was based on radiological diagnostic criteria developed a priori. Identification of the KFs in the sagittal, coronal, and axial planes was recorded. Interobserver reliability was assessed using the Kappa statistic. Detailed anatomy including distance to the joint line and relationship to adjacent structures was recorded.

Results: The mean patient age was 43 years (range, 15-81 years), 58% were male, and 50% were right knees. The KFs were identified by at least 2 reviewers on the sagittal images in 96% of cases, on the axial images in 76% of cases, and on the coronal images in 4% of cases. The mean distance from the KF distal femoral insertion to the lateral joint line was 50.1 mm (SD, 6.6 mm) and the mean distance to the lateral gastrocnemius tendon origin was 10.8 mm (SD, 8.6 mm). The KFs were consistently identified immediately anterior to the superior lateral geniculate artery on sagittal imaging. Interobserver reliability for identification was best in the sagittal plane (Kappa 0.5) and worst in the coronal plane (Kappa 0.1).

Conclusion: The KF complex can be identified on routine MRI sequences in the ACL-intact knee; however, there is low to moderate interobserver reliability. Imaging in the sagittal plane had the highest rate of identification and the coronal plane the lowest. There is a consistent relationship between the most distal KF femoral attachment and the lateral joint line, lateral gastrocnemius tendon, and superior lateral geniculate artery.

Keywords: Kaplan fibers; iliotibial band; anterior cruciate ligament; magnetic resonance imaging

There has been renewed interest in anterolateral structures of the knee and the role they play in anterolateral rotatory instability. Debate regarding the role of the anterolateral ligament as a secondary stabilizer is ongoing. However, as emphasized by the International Anterolateral Complex Consensus Group, the anterolateral ligament is only 1 component of the anterolateral complex (ALC).[5]

The iliotibial band (ITB) is another component of the ALC, and in recent biomechanical research it has been increasingly recognized as a restraint to anterior translation and internal rotation of the tibia.[4,11] However, in 1958 Kaplan[9] had already described the ITB as "a stabilizing ligament between the lateral femoral condyle and the tibia in continuity with the proximal part of the band. The stabilizing ligament is fixed to the upper portion of the lateral femoral condyle as a fixed point." These fibers that fix the ITB to the lateral femoral condyle have subsequently been referred to as the Kaplan fibers (KFs). Although not included in Kaplan's initial description,[9] 2 discrete bundles of fibers have since been described in anatomic dissections: the proximal KFs and the distal KFs (Figure 1).[6]

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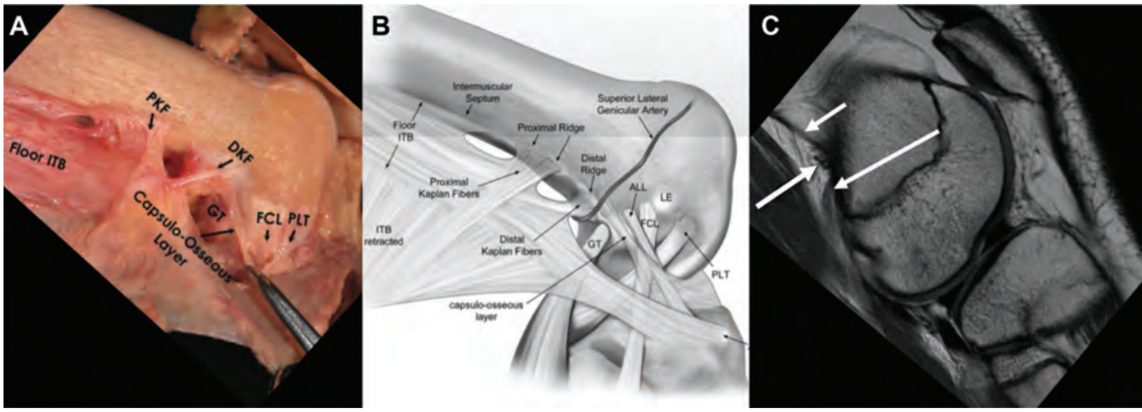

Figure 1. Composite image of (A) a cadaveric dissection, (B) illustration, and (C) proton density sagittal magnetic resonance image of a right knee viewed from the lateral aspect. (C) The short white arrow marks the Kaplan fiber complex, the medium white arrow marks the superior lateral geniculate artery, and the long white arrow marks the lateral gastrocnemius tendon. (A and B) (Images reproduced with permission from Godin JA, Chahla J, Moatshe G, et al. A comprehensive reanalysis of the distal iliotibial band: quantitative anatomy, radiographic markers, and biomechanical properties. *Am J Sports Med.* 2017;45(11):2595-2603.)

More recent cadaveric and biomechanical investigations have sought to further define the anatomy of the KFs and investigate the role they play in knee stability.[4,6,8] Lutz et al[13] have postulated that the KFs hold the ITB against the lateral epicondyle, which allows the distal ITB to function as a ligament and tighten during internal tibial rotation. As such, the KFs have been ascribed a potentially important role in maintaining rotatory stability of the knee. Notably, in biomechanical studies trying to simulate anterolateral instability of the knee, the KFs have been sectioned to create a worst-case scenario of knee injury.[4]

A key question that remains is whether the KFs are injured in association with an anterior cruciate ligament (ACL) rupture and, if so, whether this is a factor contributing to the spectrum of instability seen after ACL injury. Magnetic resonance imaging (MRI) is routinely used to image the ACL-injured knee, but its role in identifying the structures of the ALC is controversial.[1-3,7,14-16] The aim of this study was to assess whether routine 3-T MRI, using standard knee protocols, can be used to identify the KFs in the non–ACL-injured knee, thereby providing a baseline to facilitate future investigations into radiological signs of injury.

METHODS

Human research ethics committee approval was obtained for this study as part of a larger study focusing on the ALC of the knee. After review of recent anatomic descriptions and clinical photography,[4-6,8,9,11,13] along with a cadaveric dissection by one of the authors, an experienced fellowship-trained musculoskeletal radiologist (R.O.) and 2 fellowship-trained orthopaedic surgeons (L.B., J.M.) performed a pilot evaluation of 10 MRI scans to establish a consensus about the qualitative MRI features of the KFs. This was done by correlating the anatomic images and descriptive anatomy of the fibers[6,8,9,13] and by using their described relationship to the lateral joint line, the superior lateral geniculate artery, and the lateral head of gastrocnemius. The relationship of the most distal attachment of the KFs to the superior lateral geniculate artery was highlighted in Kaplan's original study[9] and was more recently confirmed in an anatomic study by Godin et al,[6] who also detailed distances to the lateral joint line. Radiological criteria were developed to identify the KFs (Table 1).

TABLE 1
Diagnostic Criteria for MRI Identification of the KFs[a]

- Extra-articular, linear, posterolateral structure[4-6,9,11]
- Seen on at least 2 consecutive slices
- Connecting the ITB to the femur (or the trajectory consistent with this if inadequate field of view)
- Continuing distally from the intermuscular septum[5]
- Low signal on PD/T2 sequences
- Possible tubercle/ridge on the posterolateral femur[6]
- Approximately 68 mm above the lateral joint line for the proximal KFs and 48 mm for the distal KFs[6]

[a]ITB, iliotibial band; KF, Kaplan fiber; MRI, magnetic resonance imaging; PD, proton density.

A cohort of 50 patients with knee MRI performed between December 2013 and February 2015 were identified. All included patients had medial joint line pain for investigation and had MRI evidence of an intact ACL. The exclusion criteria were suboptimal MRI examination (motion artifact), incomplete study (imaging not available in all 3 planes), knee ligamentous injury, significant osteoarthritis, previous ACL or other knee surgery, or the presence of hardware in the knee. MRI examinations were performed using the department protocol with the patient in the supine position and the knee extended using a Siemens 3-T MRI; the scans were performed using either a Magnetom Verio with an 8-channel phased array coil or a Magnetom Skyra coil with a 15-channel phased array coil. Three plane (sagittal, coronal, and axial) sequences using both proton density– and fat-suppressed proton density–weighted images were performed with repetition time (TR) between 3000 and 4000 ms, echo time (TE) between 33 and 35 ms, matrix between 320 × 320 and 384 × 384 (phase × frequency) with 3-mm slice thickness, and a total field of view of 130 mm. The mean field of view above the lateral joint line was 77, 75, and 72 mm with SDs of 6, 5, and 7 mm for the sagittal, coronal, and axial planes, respectively.

A data collection sheet was developed and included patient characteristic data (age, sex, knee side), the identification of the KFs in each plane (sagittal, coronal, axial), and the presence of an associated bony ridge at the femoral insertion as recently described by Godin et al.[6] Despite the pilot assessment, it was recognized that reviewers may identify unanticipated findings, patterns, or appearances not included in the data collection sheet, and therefore a comments section was included to allow contemporaneous recording of these. If the KFs were identified in 1 plane, the 3-dimensional cursor tool was used to identify the same position on other planes to see if they could be visualized in those planes. There was no prescribed identification procedure for the reviewers. However, after the pilot the sagittal images were generally assessed first, with the lateral gastrocnemius origin used as a readily identifiable landmark to localize the region. When the KFs were identified, the distance (in millimeters) from the distal femoral attachment of the KFs to the lateral joint line was measured with a line parallel to the longitudinal axis of the tibia as demonstrated in Figure 2. Using the sagittal slices, the distance from the middle of the KF femoral insertion to the midpoint of the lateral head of the gastrocnemius origin was measured (Figure 2). The relationship of the KFs to the superior lateral geniculate artery was recorded as anterior or posterior on the sagittal imaging.

Although the aim of this study was to be pragmatic and assess the utility of routine MRI scans available in the clinical environment, it became evident that the most proximal extent of the KF complex was not always visible in its entirety within the MRI field of view. Therefore, 6 subsequent MRIs were performed with an extended proximal field of view to allow characterization of the most proximal aspect of the KF complex and to establish if proximal and distal bundles could be identified individually. Three reviewers (L.B., R.O., B.M.D.) assessed these 6 scans in collaboration and reported findings as a consensus. The 50 MRI initial scans were subsequently re-reviewed to develop consensus as to whether discrete proximal and distal bundles could be identified.

Data Analysis

The number of scans in which the KFs could be identified in each plane was recorded for each reviewer. The frequency with which 1, 2, or 3 reviewers could identify the structure was calculated separately for each plane. Cohen Kappa coefficients were also calculated.[10] The Kappa values were classified as described by Landis and Koch,[12] with values of 0.81 to 1.00 indicating excellent agreement, 0.61 to 0.80 substantial agreement, 0.41 to 0.60 moderate agreement, 0.21 to 0.40 fair agreement, and 0 to 0.20 slight agreement.

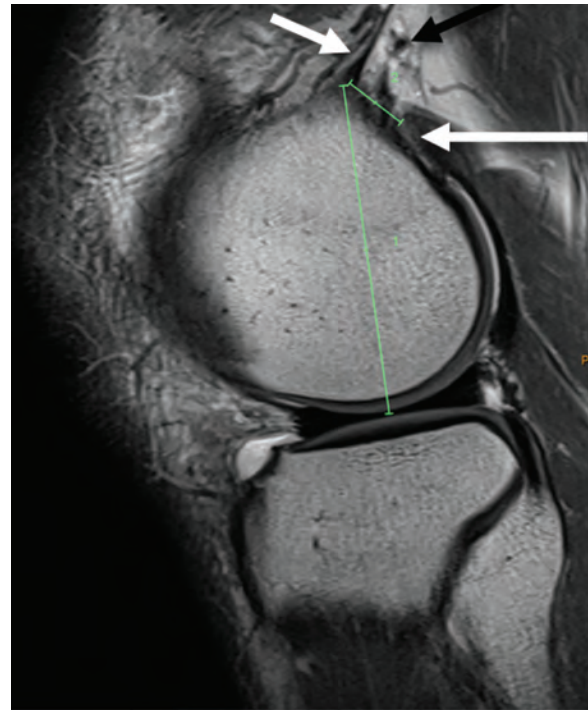

Figure 2. Sagittal plane proton density magnetic resonance image of the left knee. The short white arrow depicts the Kaplan fibers' most distal femoral attachment, the black arrow marks the superior lateral geniculate artery, and the long white arrow marks the lateral gastrocnemius tendon. Lines 1 and 2 demonstrate the technique of measurement between the Kaplan fibers to the lateral joint line and lateral gastrocnemius origin, respectively.

RESULTS

The mean patient age was 43 years (range, 15-81 years), 29 patients (58%) were male, and 25 (50%) were right knees. The reviewers identified the KF complex most often in the sagittal plane and least often in the coronal plane (Table 2). The KF complex was identified by at least 2 reviewers in 96% of cases for the sagittal images, 76% for the axial images, and 4% for the coronal images. When only 1 reviewer was required to have identified the KFs, the rates of identification were notably increased for the coronal and axial images (Table 3). Interobserver reliability assessment for identification of the KFs indicated moderate agreement for sagittal images, with a Kappa value of 0.5, and slight agreement for the coronal and axial images, with Kappa values of 0.1 and 0.2, respectively. Case examples are shown in Figures 3 to 6.

Of the visualized KFs, the mean distance from the distal-most attachment of the KF femoral insertion to the lateral joint line on the sagittal images was 50.1 mm (SD, 6.6 mm)

TABLE 2
Identification of the KF Complex and Associated Tubercle[a]

	Reviewer 1	Reviewer 2	Reviewer 3
KFs sagittal	47/50 (94)	46/50 (92)	44/50 (88)
KFs coronal	5/50 (10)	10/50 (20)	15/50 (30)
KFs axial	43/50 (86)	26/50 (52)	35/50 (70)
Tubercle sagittal	0/50 (0)	4/50 (8)	0/50 (0)
Tubercle coronal	4/50 (8)	2/50 (4)	0/50 (0)
Tubercle axial	27/50 (54)	31/50 (64)	0/50 (0)

[a]Data are presented as n/N (%). KF, Kaplan fiber.

TABLE 3
Number of Reviewers Identifying Kaplan Fiber Complex[a]

No. of Reviewers	Sagittal Plane	Coronal Plane	Axial Plane
3 reviewers	82 (41/50)	2 (1/50)	38 (19/50)
2 reviewers	96 (48/50)	4 (2/50)	76 (38/50)
1 reviewer	96 (48/50)	48 (24/50)	94 (47/50)

[a]Data are presented as % (n/N).

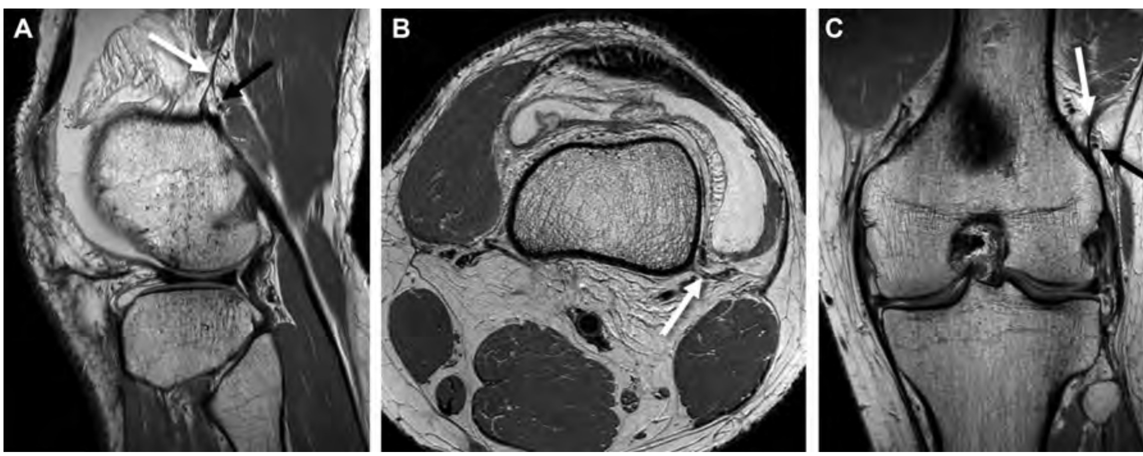

Figure 3. (A) Sagittal, (B) axial, and (C) coronal proton density magnetic resonance imaging sections of a left knee depicting the Kaplan fiber complex with the white arrow and the superior lateral geniculate vessels with the black arrow. The Kaplan fibers are seen as an extra-articular, linear, posterolateral structure of low signal intensity.

(52.7, 46.3, and 51.3 mm for each reviewer). The mean distance to the lateral gastrocnemius tendon origin was 10.8 mm (SD, 8.6 mm) (16.4, 5.3, and 10.7 mm for each reviewer). In the sagittal images, the KFs were identified by all 3 reviewers as being anterior to the superior lateral geniculate artery in all cases. Identification of a bony ridge at the site of the KF femoral attachment was most frequent in the axial plane with an average detection rate of 39% (64%, 54%, and 0% for individual reviewers) and lowest in the sagittal plane with a rate of 3% (8%, 0%, and 0% for individual reviewers).

A number of qualitative observations were made by the reviewers. With reduced muscle bulk in the vastus lateralis and increased fat in this region, there was enhanced visualization of the KFs (Figure 7B), although the structure could still be visualized clearly in the presence of large muscle volume (Figure 7A).

Best appreciated in the axial plane, the KFs could be seen as a distinct structure arising from the ITB and forming a confluence with the lateral intermuscular septum (Figure 8). All 3 reviewers thought the best identification technique for the KFs was to look first at the sagittal images and identify the lateral gastrocnemius tendon and then superior lateral geniculate artery. Identification of the superior lateral geniculate artery was typically easier on T2 sequences (Figure 4B) and often seen as part of a leash of 3 vessels (vena comitantes) on coronal and sagittal imaging (Figures 1C, 5C, and 6C). Once identified, further assessment using proton density sequences was preferable where the KFs were visualized with greater clarity. The morphology of the femoral insertion varied, ranging from a single thick linear insertion (Figure 1) to the appearance of division into multiple smaller strands inserting individually from the posterolateral femur to the epicondylar region (Figure 6A). In the axial plane, the reformatted images were often not proximal enough to visualize the fibers in continuity with the ITB laterally. They could, however, be seen traversing from the lateral femur in that trajectory (Figures 3, 5, 6, and 8).

The 6 MRI scans with an extended field of view had a mean field of view 138, 139, and 135 mm above the lateral joint line for the axial, sagittal, and coronal planes, respectively (Figures 9 and 10). The minimum distance above the lateral joint line in any plane was 125 mm. By consensus, the KFs were identified in the sagittal plane in all 6 (100%) cases, the axial plane in all 6 cases (100%), and the coronal plane in 4 cases (67%). These scans allowed visualization of the KFs in continuity with the ITB laterally, especially on the axial view (Figure 9B), although otherwise they were thought to provide little additional

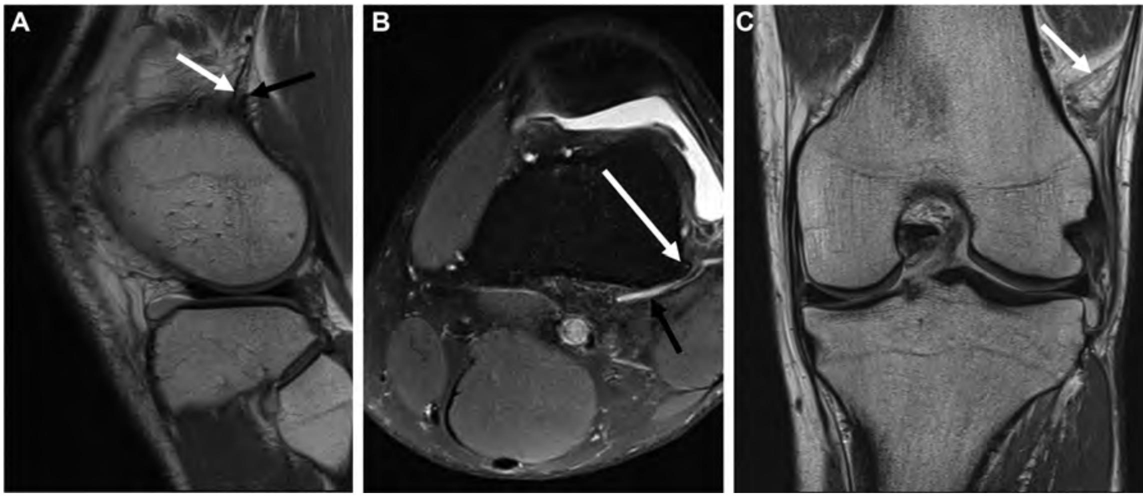

Figure 4. (A) Sagittal proton density, (B) axial fat saturated T2 and (C) coronal proton density magnetic resonance imaging sections of a left knee depicting the Kaplan fibers marked with the short white arrow and the superior lateral geniculate vessels marked with the black arrow. (B) The long white arrow marks a tubercle associated with the Kaplan fibers femoral attachment. The axial reformats were not proximal enough in this series to visualize the entire Kaplan fiber complex in the axial plane. All images have been correlated with the use of a 3D cursor tool.

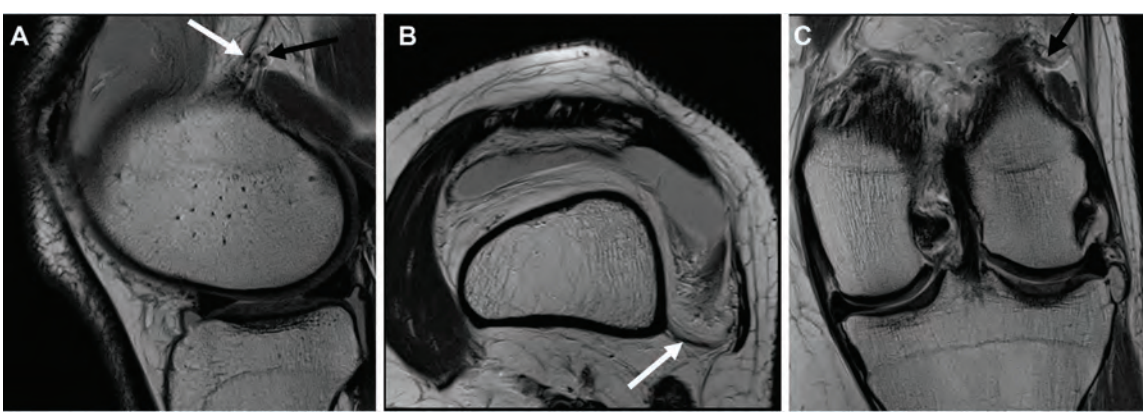

Figure 5. (A) Sagittal, (B) axial, and (C) coronal proton density magnetic resonance imaging sections of a left knee depicting the Kaplan fibers with the white arrow and the superior lateral geniculate vessels with the black arrow. The Kaplan fiber complex could not be visualized on the coronal images despite the superior lateral geniculate vessel being identifiable (black arrow).

information about the complex compared with the routine images. The more proximal extension was predominantly filled with the vastus lateralis and posterior compartment musculature as shown in Figures 9 and 10. By consensus, discrete proximal and distal KFs were identified in 1 (17%) of the 6 extended scans and in 4 (8%) of the 50 routine scans.

DISCUSSION

The main finding of this study is that the KF complex of the ITB can be identified on routine knee MRI in the ACL-intact knee. This finding is based on the high identification rates among the independent reviewers and the close correlations of the MRI findings to recent anatomic descriptions of the KFs.[5,6] The structure identified as the KFs fulfilled diagnostic criteria established a priori and had consistent relationships to adjacent structures, namely the lateral gastrocnemius tendon, the superior lateral geniculate artery, and the lateral joint line. Both the ITB and the KFs have been proposed as important secondary stabilizers in the ACL-deficient knee.[4,5,11,13,14] With ongoing efforts to define the factors affecting the spectrum of instability, the radiological identification and description of the KFs on routine MRI scans in the nonpathological state may be important. This study provides a baseline to facilitate radiological identification of KF injury with the ultimate goal of investigating their role in anterolateral rotatory instability. This investigation supports MRI as a potential modality for diagnosis of KF injury.

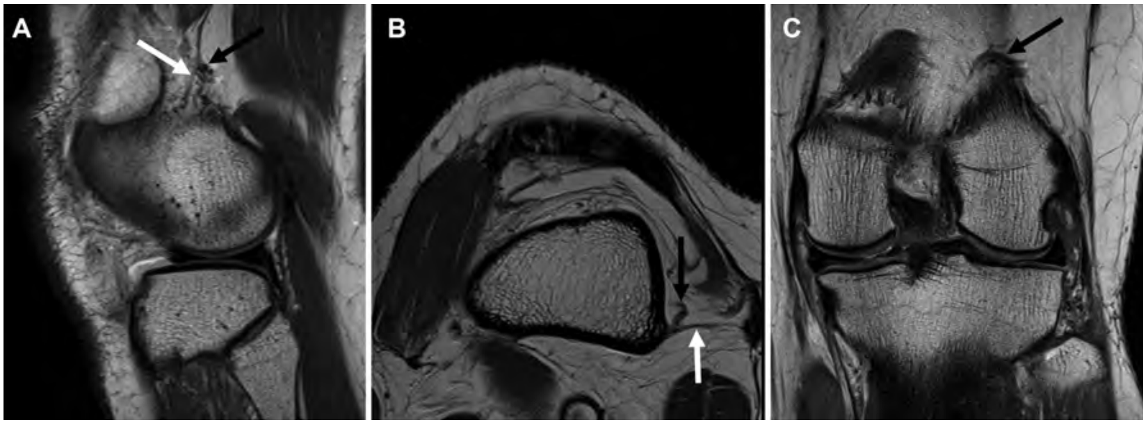

Figure 6. (A) Sagittal, (B) axial, and (C) coronal proton density magnetic resonance imaging sections of a left knee depicting the Kaplan fiber complex with the white arrow and the superior lateral geniculate vessels with the black arrow. The Kaplan fiber complex could not be visualized on the coronal images despite the superior lateral geniculate vessel being identifiable (black arrow).

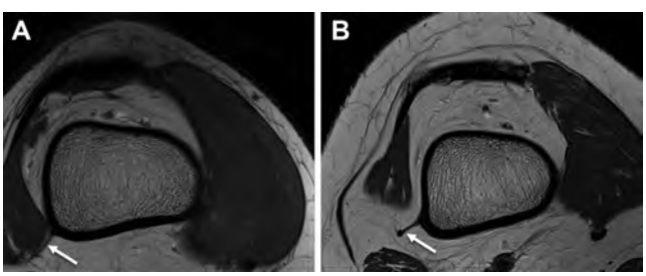

Figure 7. Axial proton density magnetic resonance imaging slices of the right knee in 2 different patients. (A and B) There is enhanced visualization of the Kaplan fibers (arrow) associated with reduced vastus lateralis muscle bulk and increased fat in the region (B); however, the Kaplan fibers (arrow) can still be identified in image A.

The average distance between the distal-most femoral attachment of the KF complex and the lateral joint line was 50.1 mm (SD, 6.6), similar to the distance of 47.9 mm (SD, 8 mm) for the distal KF bundle described in the cadaveric anatomic and radiographic study by Godin et al.[6] The average distance to the lateral gastrocnemius tendon was 10.8 mm (SD, 8.6 mm) compared with 18 mm (SD, 7.8 mm) on lateral radiographs by Godin et al. Three new bony landmarks on the lateral femur were identified by Godin et al: the proximal ridge, distal ridge, and lateral gastrocnemius tubercle. The proximal ridge and the distal ridge are where the proximal and distal KF bundles attach to the posterolateral femur. Detection rates for an osseous ridge seen in association with the femoral KF attachment were highly variable in the current study. They ranged between 0% and 64% for individual reviewers and between 3% and 39% on average between all reviewers (Table 2). Notably, the 2 orthopaedic surgeons (L.B., J.M.) had much closer correlations with each other than with the radiologist (R.O.). This may reflect different thresholds as to when focal cortical thickening is termed “a ridge.” Computed tomography may also be a more reliable way to identify the associated bony ridges radiologically.

The identification of the KFs forming a confluence with the distal intermuscular septum in the axial plane correlates with the cadaveric description provided by the ALC Consensus Group[5] describing the KF system as “continuing distally from the intermuscular septum.” Godin et al,[6] however, described the intermuscular septum as terminating proximal to the proximal KFs. In an anatomic dissection study of 20 cadavers, Herbst et al[8] noted that the KFs were thicker and had a different trajectory compared with the intermuscular septum, characterized by their transverse course from lateral to medial. This correlates well with axial sections toward the proximal aspect of the complex in this study (Figures 5B, 7, 8, and 9B). The low identification rates in the coronal plane may be due to the oblique orientation of the KFs. Reformatting the coronal images with the knee in more internal and external rotation may be of benefit in identifying and characterizing the KFs in this plane but would have limited clinical value given that it is not a standard reformatting.

In the current study, it was difficult to differentiate between the proximal and distal KFs radiologically. This is in keeping with Kaplan’s original anatomic description in which he did not identify discrete proximal and distal bundles.[6,9] The difference in the radiological and anatomic appearance of the KF complex may be explained by the fact that a discrete proximal and distal KF attachment may appear more obvious once fat, muscle, and connective tissue have been removed by dissection; these images of 2 distinct proximal and distal attachments of the ITB are clearly depicted in some anatomic photographs (Figure 1),[6] but there is likely to be variation of the in vivo appearances. Herbst et al[8] found the metaphyseal (proximal) KFs in 100% of dissections, and the epicondylar (or distal) KFs were seen in 80% (16/20) of specimens. The recent publication from the

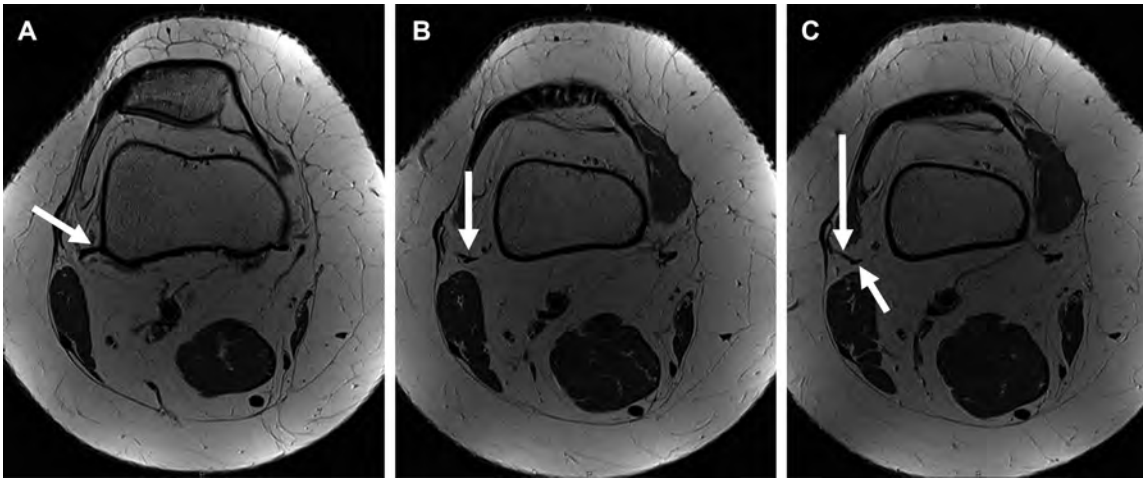

Figure 8. Sequential axial proton density magnetic resonance imaging slices of a right knee. (A) The white arrow marks the insertion of the Kaplan fiber complex onto the posterolateral femur with associated tubercle. (B) Confluence of the lateral intermuscular septum and the Kaplan fibers. (C) Kaplan fibers continuing laterally to the iliotibial tract (long white arrow) from the confluence (short white arrow).

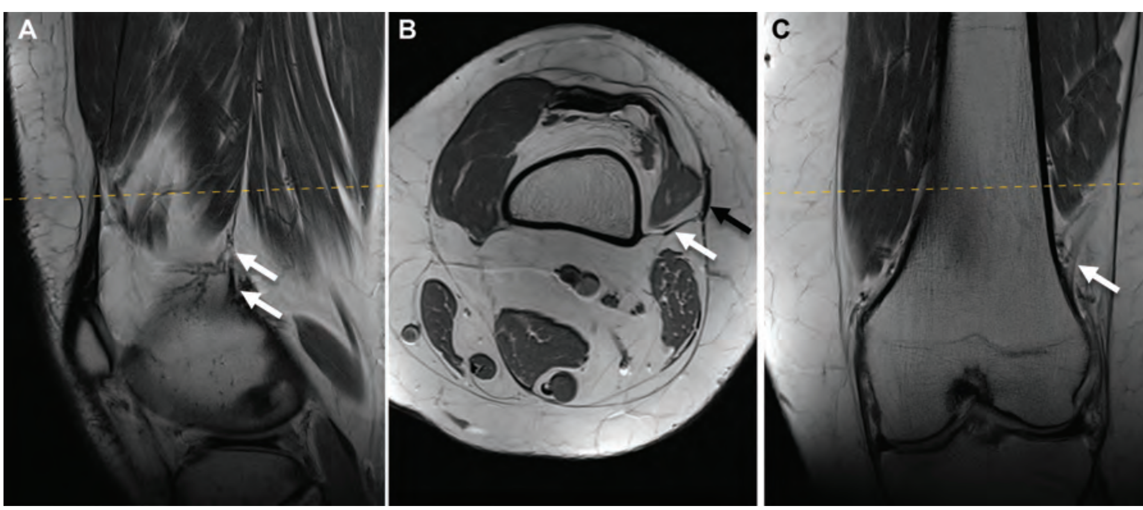

Figure 9. Proton density magnetic resonance imaging sequences with proximal coil placement. The dashed lines in the (A) sagittal and (C) coronal images are set at 77 and 75 mm above the joint line, respectively (the mean proximal field of view in the standard magnetic resonance images). The majority of the extended scan above the line is of the vastus lateralis and posterior compartment muscle bodies. (B) The Kaplan fibers are marked with white arrows and the iliotibial band is marked with a black arrow.

International Anterolateral Complex Consensus Group[5] illustrates an almost continuous attachment of the proximal and distal KF bundles to the lateral aspect of the distal femur, which is different from the appearance in the study by Godin et al.[6] Furthermore, radiologically and with 3-mm MRI slices and the knee oriented to best visualize the ACL, differentiation of 2 discrete attachment points may be difficult, as has been shown in the current study.

The authors acknowledge that there are limitations with this study. The field of view in routine MRI scans did not always allow visualization of the most proximal aspect of the KF complex in its entirety; the deficiency was typically visualizing the KFs arising from the ITB, as seen in Figures 5B, 8C, and 9B. In the quantitative anatomic study of 10 cadavers by Godin et al,[6] the proximal KFs insert onto the femur at a mean of 68 mm (SD, 9.4 mm) above the lateral joint line. In the current study, the mean field of view was above this level in all planes (77 mm sagittal, 75 mm coronal, and 72 mm axial). This reflects what can be seen on routine MRI that would be available in the typical clinical environment. Requesting an extended field of view in MRI scans may be 1 approach to ensure visualization of the most proximal part of the KF complex. However, apart from visualizing the connection of

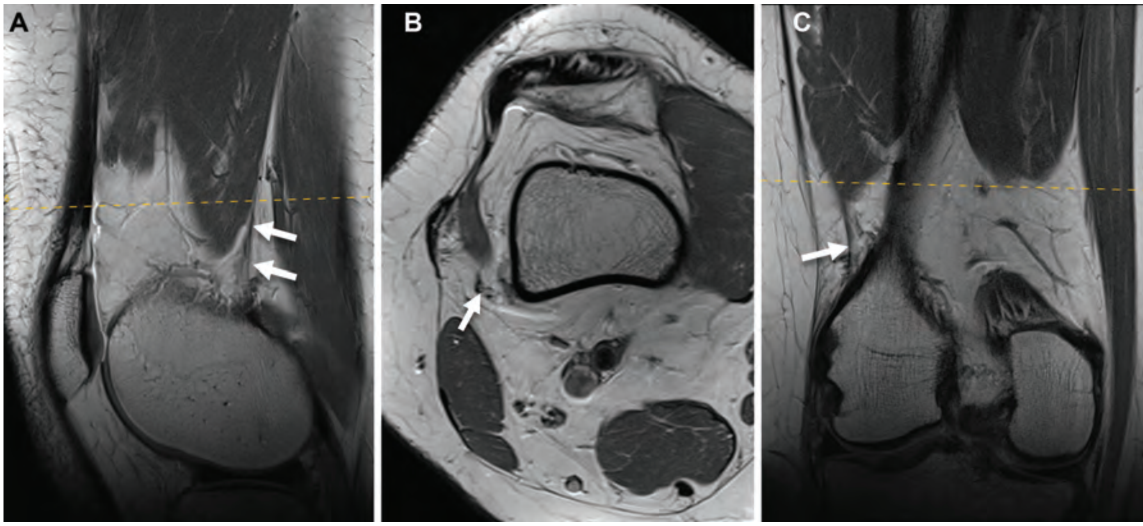

Figure 10. Proton density magnetic resonance imaging sequences with proximal coil placement. The dashed lines in the (A) sagittal and (C) coronal images are set at 77 and 75 mm above the joint line, respectively (the mean proximal field of view in the standard magnetic resonance images). The majority of the extended scan above the line is of the vastus lateralis and posterior compartment muscle bodies. The Kaplan fiber complex is marked with white arrows in A, B, and C.

the KFs to the ITB, in the additional 6 extended-view MRI scans in this study there was minimal gain with the more proximal field of view (Figures 9 and 10).

Despite the consensus of the reviewers in identifying the KF complex, there was only modest interobserver reliability in the assessment as measured by Kappa statistics. The best interobserver correlation was seen for the sagittal images, reflecting the reviewers' anecdotal findings that this was the most reliable plane in which to identify the KFs. The explanation for the low interobserver reliability scores is likely multifactorial. There is undoubtedly variability in the interpretation of the MRI anatomy of this area, and we believe there is also a learning curve in the identification of these fibers that may have affected this initial series. When using a binary outcome (seen or not seen), the Kappa assessment takes chance into account as there is a 50% chance of agreement if guessing only. Because of this, very high levels of correlation are required to obtain high Kappa values in this setting. However, when considering variation between reviewers with respect to the measured distance from the most distal femoral attachment of the KFs to the lateral joint line and the lateral gastrocnemius tendon, there was only small variation in reported distances, supporting the argument that the reviewers were independently identifying the same structure.

CONCLUSION

MRI is a useful tool for radiological identification of the KF complex, which can be seen on routine sequences in the ACL-intact knee. There are high rates of identification, with the sagittal plane being the best plane in which to identify the KFs and the coronal plane being the worst. There is variability in the interpretation of the MRI anatomy of this area as reflected by modest interobserver reliability. Radiologically, it is difficult to distinguish discrete proximal and distal bundles, but there is a consistent and identifiable relationship between the most distal attachment of the KF complex to the superolateral geniculate artery, lateral gastrocnemius origin, and lateral joint line that correlates well with recent cadaveric descriptions.

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Epilogue

"Give me six hours to chop down a tree and I will spend the first four sharpening the axe." -

- Abraham Lincoln

In many ways, Kaplan's influence on this study goes further than simply the eponymous name given to the fibres attaching the ITB to the distal femur that he described(50). The painstaking manner in which he conducted his original study provided inspiration in more ways than one, and prompted us to adopt a similarly meticulous assessment of the radiological features of the Kaplan fibres. In the first instance, a thorough review of the anatomical literature was conducted to provide an accurate template upon which to correlate the radiological features of the Kaplan fibre complex.

However, it was not all plain sailing. One of the difficulties in using anatomical studies and the typically beautiful images of dissections and clear illustrations they contain as a guide is they often remove some of the imperfections to make things look that bit more pretty. I suppose its analogous to a perfect Facebook moment being truly reflective of a person's everyday existence; of course, it's not realistic. Initially, we really struggled to identify a proximal and distal attachment of the Kaplan fibre complex radiologically as described anatomically and very clearly illustrated(70). This frustration led us to expanding the field of view of the scans, in case we weren't proximal enough on the femur. But, alas we kept on coming back to the same radiological image of a confluence of fibres with no discernible separation between a proximal and distal attachment. Interestingly, on reviewing a number of different anatomical photographs from a different study at varying stages of dissection, we discovered that the division between a proximal and distal attachment was either not obvious or not there at all(14). Finally, we returned to Kaplan's original description from 1958 and realised that our findings were in keeping with these findings in which he did not identify discrete proximal and distal bundles(50). The difference in the radiological and anatomic appearance of the Kaplan fibre complex may be explained by the fact that a discrete proximal and distal Kaplan fibre attachment may appear more obvious once fat, muscle, and connective tissue have been removed by dissection. It is quite amazing what can be fashioned with a sharp object – just ask Abraham Lincoln.

Thankfully, it was possible to draw on the results of quantitative anatomical studies to be able to provide reliable radiological coordinates from anatomical landmarks to aid in the identification of the Kaplan fibre complex(70). A consistent and identifiable relationship was found between the most distal attachment of the Kaplan fibre complex and the superolateral geniculate artery, lateral gastrocnemius origin, and lateral joint line. Indeed, these findings have proved very useful in the identification of the Kaplan fibres in the setting of ACL injury, and have not only provided a roadmap for where to look but also revealed subtle clues about the presence or absence of injury based on the extent of disruption to the superolateral geniculate artery which is intimately related to the Kaplan fibre attachment. The results of this study certainly sharpened not only our eyes to detect the Kaplan fibres but also our minds to consider the collateral damage that may occur in the event of injury.

Chapter 7: Radiological identification of injury to the Kaplan fibres of the iliotibial band in association with anterior cruciate ligament injury

Introduction

"Blind faith, no matter how passionately expressed, will not suffice. Science for its part will test relentlessly every assumption about the human condition."

- Edward O Wilson – American biologist, naturalist, and writer

One of the issues that sits uneasily with me is the model used for biomechanical simulation of anterolateral rotatory laxity. In this model, a worst-case scenario of anterolateral injury is created with sectioning of the Kaplan fibres, anterolateral lateral ligament, and anterolateral capsule(15, 19). However, it is not common to see significant disruption of the ITB in the context of ACL-injury; discontinuity or considerable damage to the ITB is typically as a consequence of a very high energy displacement force, such as occurs in a motor vehicle accidents, resulting in a multi-ligamentous knee injury(117). What is more, from a personal experience of exposing the lateral aspect of the distal femur to carry out a distal femoral osteotomy, release of the Kaplan fibre attachment is quite a rigorous ordeal, often necessitating robust, sharp dissection and frequently a change of blade!

Whilst a number of authors have described visualising haemorrhage in the region of the Kaplan fibres during surgical exploration, these experiences are either anecdotal or with relatively small numbers of patients and do not explicitly detail disruption to the continuity of the Kaplan fibre complex (66, 118, 119). It has been postulated that injury to the superior lateral genicular vessels is responsible for this haemorrhage due to its proximity to the Kaplan fibres(66, 70). But, are these authors assuming that the presence of haemorrhage heralds serious structural damage to the lateral side of the knee? Or could it be '*just a* *bruise*', representing nothing more than a minor injury below? The aim of the following study was to answer this question and determine the true prevalence of injury to the Kaplan fibres in the setting of ACL injury.

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Contribution

Mr Devitt, Associate Professor O'Sullivan, Professor Feller and Mr Batty contributed to the conception and design of this manuscript. Mr Devitt, Mr Batty, Mr Murgier, and Associate Professor O'Sullivan completed the reading of the MRIs. Mr Devitt, Professor Webster and Mr Batty and analysed the data. Mr Batty, Mr Murgier, and Mr Devitt wrote the manuscript. Mr Devitt, Associate Professor O'Sullivan, Professor Feller, Mr Batty, Mr Murgier, and Professor Webster critically revised the manuscript for important intellectual content.

Conference presentations

This work was presented at a national and international conference:

Devitt B M, Batty L, Murgier J, O'Sullivan R, Webster KE, Feller JA, Devitt BM. Radiological identification of injury to the Kaplan fibers of the iliotibial band in association with anterior cruciate ligament injury. Australian Knee Society Meeting. October 2017, Noosa, Queensland.

Devitt B M, Batty L, Murgier J, O'Sullivan R, Webster KE, Feller JA, Devitt BM. Radiological identification of injury to the Kaplan fibers of the iliotibial band in association with anterior cruciate ligament injury. International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine Biennial Meeting. May 2019, Cancun, Mexico.

Radiological Identification of Injury to the Kaplan Fibers of the Iliotibial Band in Association With Anterior Cruciate Ligament Injury

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Background: Recent biomechanical studies have demonstrated that the Kaplan fibers (KFs) of the iliotibial band play a role in the control of anterolateral rotation of the knee. However, controversy exists regarding whether the KFs are injured in conjunction with anterior cruciate ligament (ACL) injury.

Purpose: To establish the prevalence of radiological injury to the KFs in the ACL-injured knee; to evaluate the effect of the time interval between injury and magnetic resonance imaging (MRI) on diagnosis of KF injury; and to assess for any association between KF injury and other qualitative radiological findings.

Study Design: Cohort study (diagnosis); Level of evidence, 3.

Methods: Preoperative MRI scans were reviewed for 161 patients with ACL injury. Specific diagnostic criteria were developed and applied to identify KF injury. Chi-square testing was performed to look for associations among KF injury, the time from injury to MRI, and associated radiological knee injuries.

Results: Radiological evidence of KF injury was identified in 30 (18.6%) patients. The diagnosis of KF injury was higher in patients who had MRI scans performed within 90 days of injury as compared with ≥90 days after injury (23.7 vs 6.4%; P = .010). Patients with an MRI diagnosis of KF injury had significantly higher rates of lateral meniscal injury (40% vs 18%; P = .007), posteromedial tibial bone marrow edema (73% vs 44%; P = .003), and injury to the lateral collateral ligament (13% vs 3%; P = .019) or medial collateral ligament (23% vs 8%; P = .019).

Conclusion: The prevalence of injury to the KF in patients with ACL injury as diagnosed by MRI was relatively low (18.6% of patients). However, the time interval from injury to MRI was relevant to diagnosis, with significantly higher rates of injury identification in patients with early (within 90 days) versus delayed (≥90 days) MRI. KF injury was associated with higher rates of injury to the lateral meniscal and collateral ligaments, as well as posteromedial tibial bone bruising.

Keywords: ACL; Kaplan fiber; MRI

In the anterior cruciate ligament (ACL)–deficient knee, the coupled motion of anterior tibial translation and internal tibial rotation can lead to the clinical entity of anterolateral rotatory laxity.[6,16] This phenomenon has a spectrum of severity that is multifactorial in etiology.[20,23,28,34] The clinical assessment of anterolateral rotatory laxity in ACL-deficient knees is typically performed with the pivot-shift test, which can yield vastly different results, ranging from a subtle glide to an "explosive" pivot and audible clunk.[13] This suggests that more than just injury to the ACL is at play. As such, there has been a resurgence in interest in the role of the anterolateral structures of the knee.[10]

The attachments of the iliotibial band (ITB) to the distal femur, the Kaplan fiber (KF) complex, were described by Kaplan[17] in 1958 and, with the ITB, have been recognized as a potentially important "secondary passive stabilizer" in

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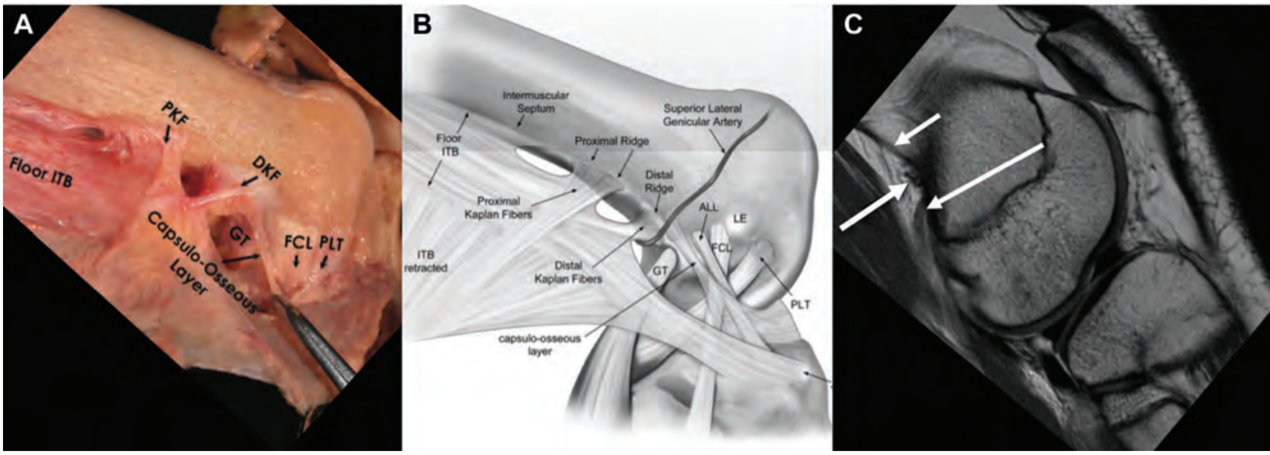

Figure 1. (A) Composite image of a cadaveric dissection, (B) illustration, and (C) proton density sagittal magnetic resonance image of a right knee viewed from the lateral aspect. The short white arrow marks the Kaplan fiber complex; the medium white arrow, the superior lateral geniculate artery; and the long white arrow, the lateral gastrocnemius tendon. (A, B) Images reproduced with permission from Godin JA, Chahla J, Moatshe G, et al. A comprehensive reanalysis of the distal iliotibial band: quantitative anatomy, radiographic markers, and biomechanical properties. *Am J Sports Med*. 2017;45(11):2595-2603. ALL, anterolateral ligament; DKF, distal Kaplan fiber; FCL, fibula collateral ligament; GT, gastrocnemius tendon; ITB, iliotibial band; LE, lateral epicondyle; PKF, proximal Kaplan fiber; PLT, popliteus.

the ACL-deficient knee.[8,9,12,15,21,22] Recent anatomic investigations have described 2 separate KF bundles inserting onto the distal femur 53 mm and 31 mm proximal to the lateral epicondyle (Figure 1).[11] Biomechanical studies have highlighted the role of the ITB in controlling internal tibial rotation, especially at higher degrees of knee flexion.[19] Indeed, sectioning studies of the anterolateral complex have proposed that the KFs may play an even greater role than the anterolateral ligament (ALL) in controlling internal tibial rotation in the ACL-deficient knee.[8,9] This has led to qualitative and quantitative anatomic studies that have enhanced the understanding of the KFs and provided the basis for radiological identification with magnetic resonance imaging (MRI).[10,11,15] Recent radiological studies have shown that the KF complex can be identified on standard knee MRI in the ACL-intact knee,[1] and there is emerging evidence that radiological evidence of KF injury can be seen in the setting of ACL injury.[18,36] Concomitant anterolateral injury at the time of ACL injury has also been highlighted in surgical dissection studies.[7,24]

Although it is possible to identify injury to the KF complex on MRI, there is a paucity of information on specific diagnostic criteria in the current literature, with variable prevalence rates of injury and small patient numbers.[18,36] It also remains unclear if the time interval from injury to MRI affects diagnosis of KF injury. Therefore, the aim of this study was to evaluate the prevalence of radiological KF injury in a cohort of ACL-injured knees based on predefined diagnostic criteria. We also aimed to determine whether the time from injury influenced the identification of KF injury and whether there was any association between radiological diagnosis of KF injury and other radiological knee injuries.

METHODS

Ethics Approval

Human research ethics committee approval was obtained for this study as part of a longitudinal study investigating a cohort of patients with ACL injuries.

Patient Population and Study Setting

A radiological study was conducted on 161 patients undergoing primary ACL reconstruction at a private orthopaedic clinic in Melbourne, Australia. All patients were part of a longitudinal study, with data recorded in a prospective database. Inclusion criteria were all patients aged between 15 and 50 years undergoing a primary ACL reconstruction. Exclusion criteria were suboptimal MRI examination (motion artifact) or incomplete MRI study (absence of sagittal, coronal, and axial proton density–weighted or fat-suppressed/proton density–weighted images). This cohort was stratified into 2 groups based on the time from injury to acquisition of the MRI scan: group 1, MRI within 90 days of injury; group 2, MRI $\geq$90 days after injury. A consecutive series of patients for each group were used for analysis. Group 1 patients were included from January 2014 to June 2015, while group 2 patients were included from February 2014 to December 2017. There were 114 eligible patients in group 1 and 47 in group 2. Data recorded included demographic details, date of injury, date of MRI, and diagnosis of other radiological injuries.

TABLE 1
Diagnostic Criteria for Signs of KF Injury[a]

Signs of Injury	Criteria
Direct	Discontinuity of the KFs
	Femoral avulsion of the KFs
Indirect	Thickening and/or intrasubstance signal change of the KFs
	Focal bone marrow edema at KF insertion site to the femur
	Soft tissue edema in region of KF
	Wavy appearance to the KFs

[a]KF, Kaplan fiber.

MRI Protocols and Analysis

The MRI evaluation was conducted by 3 fellowship-trained orthopaedic knee surgeons. Two reviewers (L.B., J.M.) independently reviewed all scans, and differences were resolved by a third reviewer (B.D.), who independently reviewed all cases of disagreement. Radiological investigation of the MRI scans was carried out in accordance with methodology reported by Batty et al.[1] The included MRI examinations were performed at various radiology clinics. They were typically on 3-T machines and performed with a mixture of T1, proton density, fat-suppressed proton density, and fat-suppressed T2 sequences with a dedicated knee coil. Variation in MRI scan sequencing and formatting reflects the current clinical environment in Australia. Before establishment of consensus with the third reviewer, percentage agreement between the initial 2 reviewers for KF injury criteria (Table 1) was as follows: discontinuity of the KF, 89%; femoral avulsion of the KF, 93%; thickening ± intrasubstance signal change of the KF, 95%; focal bone marrow edema at the KF insertion site to the femur, 99%; soft tissue edema in the region of the KF, 75%; wavy appearance to the KF, 84%.

KF Injury Diagnostic Criteria

Identification of injury to the KFs was based on diagnostic criteria developed in conjunction with an experienced musculoskeletal radiologist (R.O.S.) reflecting the principles applied to diagnosis of other ligamentous and soft tissue injuries. This was done after a pilot review of MRI scans of ACL-injured knees. Direct and indirect signs of KF injury were established (Table 1). For this study, the diagnosis required at least 1 direct sign of injury or 2 indirect signs in any plane.

Definitions and Diagnostic Criteria for Other MRI Findings

Meniscal injury was considered present if there was a linear high-intensity signal in the body of the meniscus communicating with the joint line[33] or if there was a tear of the peripheral attachment of the posterior horn of the medial meniscus at the meniscocapsular junction (ramp lesion).[5]

Bone edema was defined as abnormality in the medullary signal intensity, with decreased signal intensity on T1-weighted images and increased signal intensity on T2-weighted images.[3]

Figure 2. A left knee with an acute injury. There is (D) a pivot-shift marrow edema pattern and (C) soft tissue edema in the region of the Kaplan fibers. This edema is not localized to the Kaplan fiber region, and (A) diffuse posterior edema can be seen on the axial image. The Kaplan fiber complex is radiologically intact on (B) a sagittal proton density–weighted image (white arrow) and (A, D) axial and sagittal fat-suppressed T2-weighted images (white arrows).

Pivot-shift bone marrow edema was defined as a focal area of juxtacortical bone edema at the posterolateral tibial plateau in conjunction with bone edema on the anterolateral femoral condyle (Figures 2D and 3A). Posteromedial bone marrow edema was defined as bone marrow edema in the juxtacortical bone of the posteromedial tibial plateau. A Segond fracture was defined as a tibial rim avulsion fracture approximately halfway between the fibular head and the Gerdy tubercle.[26] ALL tibial insertion edema was defined as focal bone marrow edema halfway between the fibular head and the Gerdy tubercle (Figure 2C). Lateral collateral ligament (LCL) injury was considered present if there was a grade 2 or 3 injury. Grade 1 LCL injury was defined as periligamentous edema. Grade 2 injury was defined as a partial tear with evidence of intrasubstance signal intensity and indistinctness of the fibers, with grade 3 injuries being defined as a complete tear or avulsion.[30]

Medial collateral ligament (MCL) injury was considered present if there was a grade 2 or 3 injury. Grade 1 injury was defined radiologically by high signal medial to the MCL in the soft tissues, grade 2 as high signal medial to the MCL with partial disruption, and grade 3 as complete ligamentous disruption.[32]

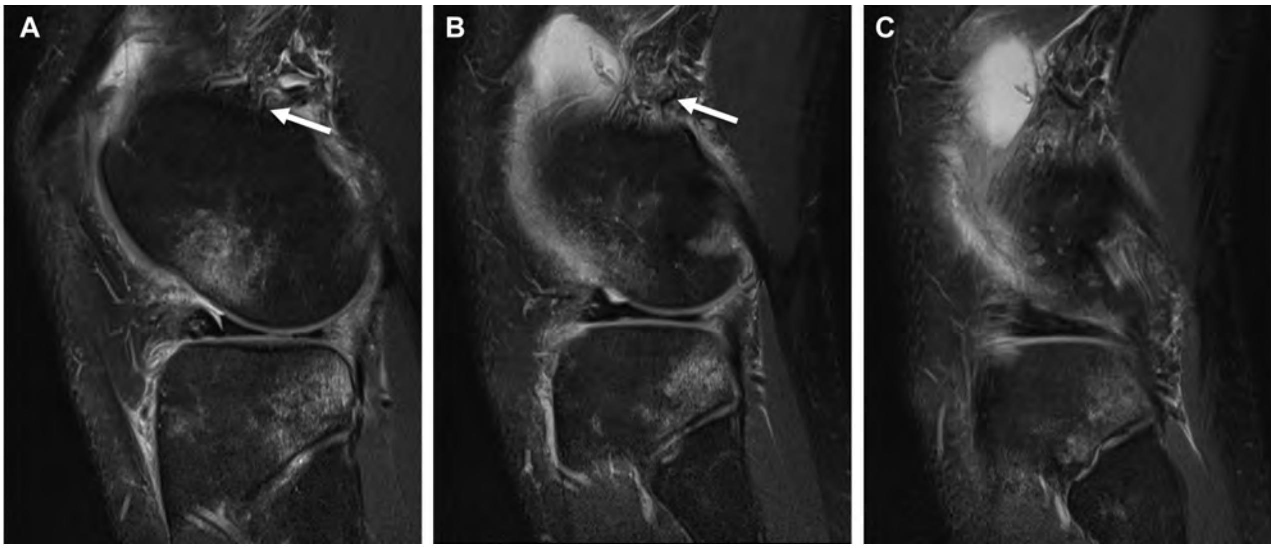

Figure 3. (A-C) Sequential fat-suppressed T2 sagittal magnetic resonance images of a left knee with an acute anterior cruciate ligament injury. The Kaplan fiber complex has a wavy appearance (arrow), and there is discontinuity of the Kaplan fiber complex.

Statistical Analysis

Continuous variables were described with means, standard deviations, and ranges. Median values and interquartile ranges were calculated where appropriate. The Student *t* test was used for comparison of means between groups for numerical data, and chi-square analysis (or Fisher Exact test where cell counts were below 5) was performed to assess distribution of categorical data. All analyses were done with SPSS Statistics (v 25.0.0.0; IBM) and Microsoft Excel (Microsoft Corporation). A P value $\leq .05$ was considered statistically significant.

RESULTS

Patient Characteristics

Of the 161 included patients, the mean age was 26 years (SD, 7.81; range, 15-47); 109 (67.7%) were male; and 85 (52.8%) had injury to the right knee. The mean time from injury to MRI was 204.6 days (SD, 603.4; range, 0-5843) with a median time of 16 days (interquartile range, 4-109). A total of 114 scans were performed within 90 days of injury, and 47 scans were performed $\geq$90 days after injury.

Identification of the KFs

For the population as a whole, the KFs—uninjured (Figure 2) or injured (Figures 3-6)—were identified in the coronal plane in 101 cases (63%), in the sagittal plane in 158 cases (98%), and in the axial plane in 150 cases (93%). For the 114 scans completed within 90 days of injury, the KFs were identified in the coronal, sagittal, and axial planes in 68 (60%), 111 (97%), and 106 (93%) cases, respectively. For the 47 scans completed $\geq$90 days after injury, the KFs were identified in 33 (70%), 47 (100%), and 44 (94%) cases for the coronal, sagittal, and axial planes.

KF Injury Rates and Diagnosis

KF injury was diagnosed in 30 (18.6%) of the 161 patients (Figures 3-6). The characteristics of patients with diagnosed KF injury as compared with those without are summarized in Table 2.

For the 30 patients with KF injury, the diagnosis was made on the basis of direct criteria in 21 patients. Indirect criteria were met by 29 of the 30 patients. In total, 20 patients met direct and indirect injury criteria.

For the MRI scans performed within 90 days of injury, the diagnosis of injury was made in 27 (23.7%) of the 114 cases. For the MRI scans performed $\geq$90 days after injury, the diagnosis of KF injury was made in 3 (6.4%) of the 47 scans. This difference was statistically significant (χ^2 = 6.570; P = .010).

Radiological Features Associated With KF Injury

Five additional radiological diagnoses had a significantly higher prevalence in the KF-injured group as compared with the KF-intact group (Table 1). These factors were edema in the region of the KFs, lateral meniscal injury, posteromedial tibial bone marrow edema, and injury to the LCL or MCL (Table 2).

There was no association between KF injury and the presence of a medial meniscal injury or the presence of pivot-shift bone marrow edema (Table 2). No patient in this series had MRI evidence of a Segond fracture; however, 36 (22.4%) had evidence of focal marrow edema in the region of the ALL insertion. The rate of anterolateral tibial focal marrow edema was lower in the KF-injured

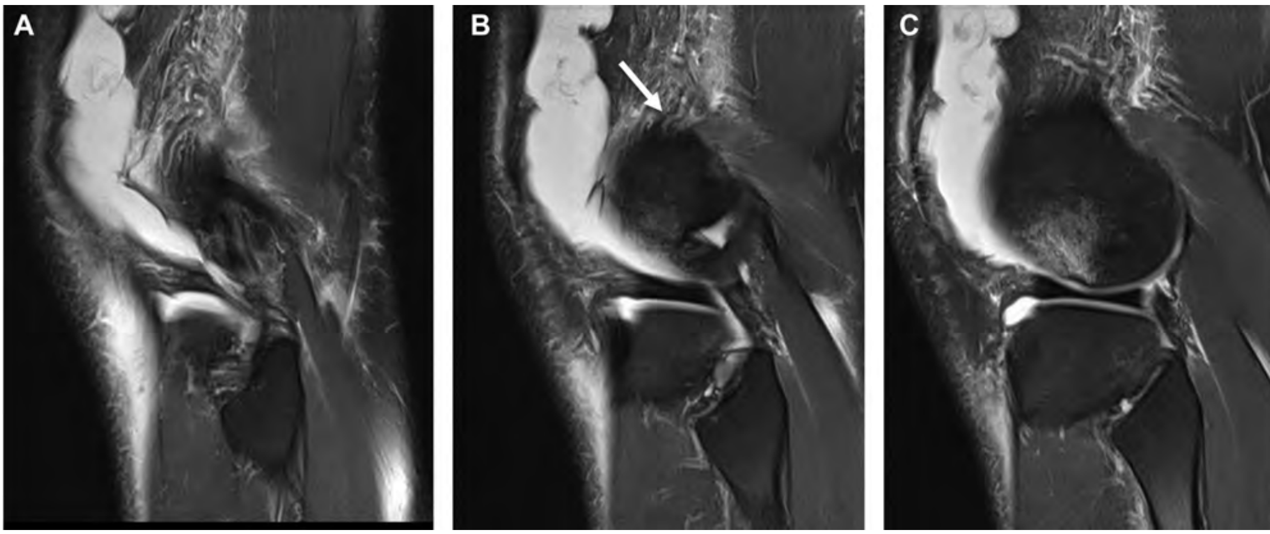

Figure 4. (A-C) Sequential fat-suppressed T2 sagittal slices of a left knee with an acute anterior cruciate ligament injury. The Kaplan fiber complex (white arrow) has a wavy appearance with discontinuity representing intrasubstance tearing.

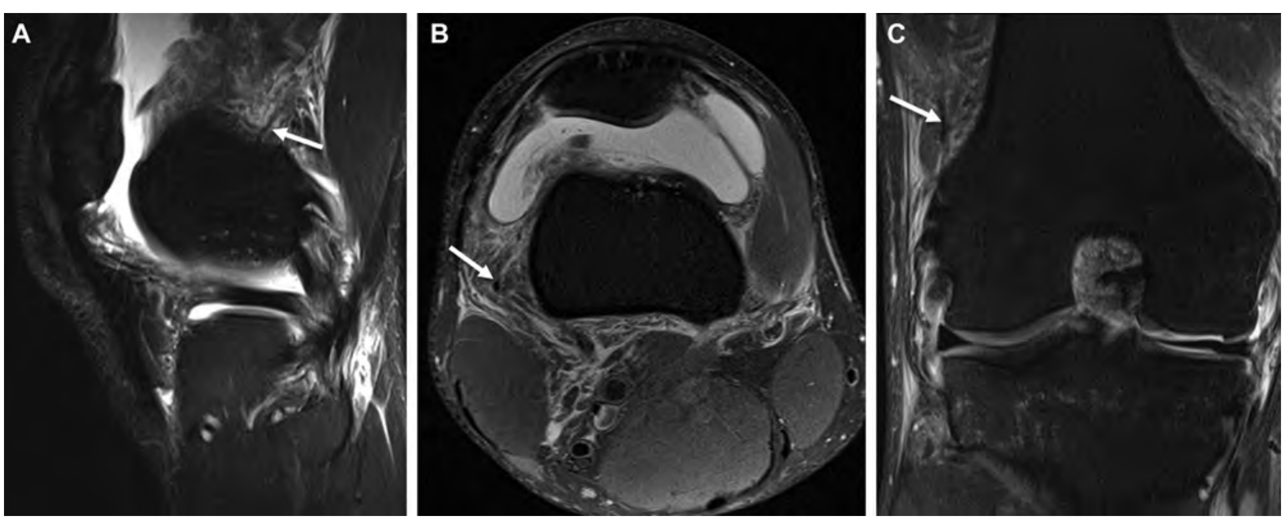

Figure 5. (A) Fat-suppressed sagittal, (B) axial, and (C) coronal T2 images of a right knee with an acute anterior cruciate ligament injury. There is diffuse edema around the Kaplan fiber complex (white arrow) and posterior knee. There is altered signal intensity of the Kaplan fiber complex.

group at 13% as compared with 24% in the KF-intact group; however, this difference was not statistically significant (P = .188). There were no cases of focal bone marrow edema in the region of the KF femoral attachment.

DISCUSSION

The main finding of this study was that it was possible to identify injury to the KFs with MRI in the ACL-injured knee (Figures 3-6). A radiological diagnosis of KF injury, based on specific diagnostic criteria, was made in 18.6% of patients. Importantly, a significantly higher rate of KF injury was seen on MRI scans performed within 90 days of injury (23.7%) as compared with ≥90 days (6.4%). Furthermore, radiological diagnosis of KF injury was associated with concomitant MRI-diagnosed knee injuries—namely, lateral meniscal injury, posteromedial tibial bone marrow edema, and injury to the lateral and medial collateral ligaments. This may suggest a higher-energy injury or that a differing injury mechanism is required to cause disruption of the KF complex. Injury to the KFs as diagnosed on MRI may have important clinical ramifications in the management of ACL injury given that biomechanical studies have suggested that the KFs play an important role in controlling anterolateral rotatory laxity.[8,9] Despite being able to identify

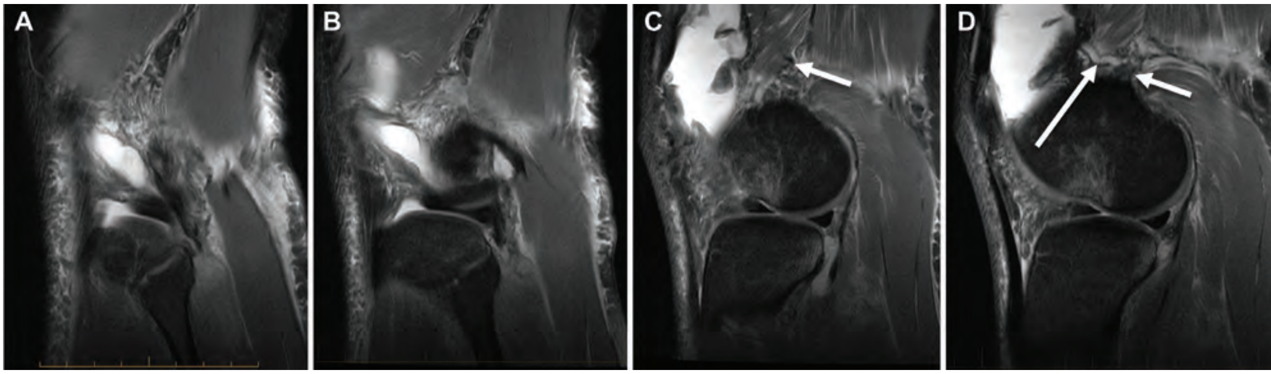

Figure 6. (A-D) Sequential fat-suppressed T2 sagittal images of a left knee in a patient with an acute anterior cruciate ligament injury. (C, D) There is a pivot-shift marrow edema pattern and a femoral impaction injury. The Kaplan fiber complex has avulsed off the femur, best appreciated on panel C (arrow). The superior lateral geniculate artery is seen in panel D (long arrow), as is the residual femoral attachment of the Kaplan fiber (short arrow).

TABLE 2
Comparison of Patients With and Without Radiological KF Injury[a]

	Radiological KF Injury, No. (%)		
	No (n = 131)	Yes (n = 30)	*P* Value
Patient demographics			
Age, y[b]	26.2 (7.7, 15-47)	26.9 (8.3, 15-46)	.691
Male	90 (68.7)	19 (63.3)	.571
Right knee	74 (56.5)	11 (33.3)	.079
MRI <90 d after injury	87 (66.4)	27 (90)	.008
MRI ≥90 d after injury	44 (33.6)	3 (10)	
Kaplan fiber identification			
Coronal	83 (63.4)	18 (60)	.731
Sagittal	129 (98.5)	29 (96.7)	.509
Axial	121 (92.4)	29 (96.7)	.400
Associated MRI findings			
Focal bone marrow edema at KF insertion site to the femur	0 (0)	0 (0)	—
Soft tissue edema in region of KF	55 (42)	29 (97)	<.001
Lateral meniscal injury	23 (18)	12 (40)	.007
Medial meniscal injury	57 (44)	11 (37)	.494
Posteromedial tibial edema	57 (44)	22 (73)	.003
LCL injury	4 (3)	4 (13)	.04
MCL injury	11 (8)	7 (23)	.019
Segond fracture	0 (0)	0 (0)	—
Focal edema at ALL tibial insertion	32 (24)	4 (13)	.23
Pivot shift marrow edema	83 (63)	22 (73)	.301

[a]Dashes denote not applicable. ALL, anterolateral ligament; KF, Kaplan fiber; LCL, lateral collateral ligament; MCL, medial collateral ligament; MRI, magnetic resonance imaging.
[b]Mean (SD, range).

KF injury on MRI based on the proposed diagnostic criteria, it is still unknown how this correlates with anterolateral rotatory laxity in the clinical environment.

A number of studies have been carried out to describe the MRI appearances of the structures of the anterolateral complex in normal and ACL-injured knees.[1,2,4,14,25,27,35] Importantly, many of these previous studies largely focused on the ALL and anterolateral capsule and did not consider KFs. However, 2 recent MRI studies concentrated on the proximal aspect of the anterolateral complex, including the KFs. Van Dyck et al,[36] in a study of 69 patients who had MRI within 6 weeks of sustaining an ACL injury, determined that the KFs were injured in some capacity in 33% of cases; the diagnosis of injury was based on the findings of periligamentous edema in 21 cases and partial tearing in 2 cases. Khanna et al,[18] in a series of 20 patients with ACL injury with a pivot-shift pattern of bone marrow edema, determined that the femoral attachment of the ITB, which correlates with the KFs, could be visualized in 17 cases and that injury was evident in 14 cases (82%). The determination of injury was based on the presence of any altered signal within the ligament, periligamentous edema, and disruption of the fibers.

The results of the current study indicate a lesser rate of KF injury (18.6%) than the 2 aforementioned studies.[18,36] This is likely due to the radiological diagnostic criteria used to define injury. Van Dyck et al[36] and Khanna et al[18] included the presence of periligamentous edema as being diagnostic of injury. In the current study, the presence of soft tissue edema was only 1 factor in the diagnosis of injury, and it had to be associated with at least 1 other direct or indirect sign of injury, such as a wavy appearance, thickening, intrasubstance signal change, or localized bony edema at the KF femoral attachment. Interestingly, the appearance of edema around the KF region was quite common, as found in 52% of cases in the current study. However, the presence of widespread edema is a frequent finding in acutely injured knees, particularly in the posterior aspect of the knee, and can be associated with posterior capsular injury, meniscal injury, or posterolateral corner injury.[29,31,37] In many cases, when the KFs were viewed in the coronal and sagittal planes, the edema appeared directly proximate to the KFs, but on further analysis in the axial plane, the edema was diffuse and likely associated with a posterior capsular injury (see Figures 2 and 5).

The challenge in establishing diagnostic criteria to define a clinically significant KF injury is the lack of a gold standard against which to compare. In this regard, surgical exploration and MRI correlation were used by Monaco et al[24] in a study of 26 patients with acutely injured knees. They determined that MRI has low sensitivity, specificity, and accuracy for the diagnosis of ITB injury, and there was only a fair agreement with surgical findings and MRI. This highlights the difficulties in the radiological assessment of injury.

The time interval between injury and MRI was very relevant and had an effect on the diagnosis of injury to the KF complex; in patients who had MRI within 90 days of ACL injury, the rate of KF injury was significantly higher than in MRI scans performed after this time point (23.7% vs 6.4%). Explanations for this observation could include potential healing of this extra-articular structure or possibly that it is just more difficult to diagnose injury in the subacute setting. Soft tissue edema was an indirect diagnostic criterion, which would have resolved significantly by the 90-day mark. It is possible that this finding is partly reflective of our proposed diagnostic criteria.

The current study also revealed a significant association between KF injury and 5 other radiological findings: lateral meniscal injury, soft tissue edema in the region of the KF, posteromedial tibial bone marrow edema, and injury to the lateral and medial collateral ligaments. This suggests that injury to the KF complex may be associated with higher-energy ACL injuries that involve additional damage to the collateral ligaments and capsular injury. This finding correlates with the study by Helito et al,[14] who performed a similar radiological investigation into the anterolateral complex. Looking specifically at the ALL, the authors examined 252 patients with ACL injuries and diagnosed ALL injuries in 40% of patients. ALL injury was associated with concomitant injury to the LCL, MCL, popliteus, anterolateral capsule, ITB, and tibial plateau bone contusions. In contrast to the current study, however, there was no association with ALL injury and meniscal injury.

Limitations

There are limitations in this study. First, the KF tears were diagnosed on unvalidated diagnostic criteria and not confirmed by other means (ie, surgical exploration). However, the diagnostic criteria were developed in conjunction with a musculoskeletal radiologist and reflect the principles applied to diagnosing other ligamentous and soft tissue injuries. Further work correlating MRI findings with clinical and surgical data will allow diagnostic criteria to be refined. There is undoubtedly variability and an element of subjectivity in evaluating the anterolateral structures on MRI. The use of a third reviewer to develop consensus in case of disagreement and the diagnostic criteria were both aimed at addressing this. The KFs are not routinely visible in every plane in the ACL-intact knee,[1] which was also the case in this investigation. In this analysis, if the KFs were not seen, they were considered to be intact. This may falsely lower the reported injury rate. However, overall, the detection rate of the KFs was high (98.5% in at least 1 plane), thus minimizing this possibility. The MRI scans included in this study were from various sources with differing protocols. The most proximal extent of the KF complex may have been outside the field of view, as previously reported.[1] Differing magnet strengths may also affect the diagnostic capabilities in the clinical environment. However, we believe that these challenges reflect the current realities of evaluating routine MRI scans in clinical practice. Ideally, equal numbers of MRI scans before and after 90 days from injury would have been available to investigate the effect of time to MRI upon KF injury diagnosis. The lower number of MRI scans performed $\geq$90 days after ACL injury reflects the ease of access to MRI after knee injury and current clinical practice in Australia. Finally, patients undergoing nonoperative management of their ACL injury were not included in this study, as they were not recorded in the database.

CONCLUSION

The prevalence of injury to the KF complex in patients with ACL injury as diagnosed by MRI was relatively low (18.6% of patients). However, the time interval from injury to MRI was relevant to diagnosis, with significantly higher rates of injury identification in patients with early (within 90 days) versus delayed ($\geq$90 days) imaging. KF injury was associated with higher rates of injury to the collateral ligaments and lateral meniscus and with posteromedial tibial bone bruising.

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Epilogue

"I have often heard it said from me father and me mother
That the going to a weddin' is the making of another"

Old maid in a Garret – Donal O'Shaughnessy

One of the satisfying aspects of completing a study is the feeling that you have truly fulfilled your aims and comprehensively answered the question you set out with. However, in the time it takes for your brain to send an impulse to your levator anguli oris muscle to smile, you are accosted with that enduring question that haunts each and every academic surgeon: "*But, are these results really clinically relevant?*"

So, much in the same way as the lyrics of the above song advise that, "*going to a wedding is a making of another*", the completion of one research study often only really serves to provide the stimulus and impetus for the next one. That is not to demean the conclusions of the current study, which have clearly shown the prevalence of injury the Kaplan fibres is relatively low (18.6% of patients) and is more readily diagnosed in patients with acute ACL injury. Not to mention that injury to the Kaplan fibres was associated with higher rates of pathology of the lateral meniscus and collateral ligaments, as well as posteromedial tibial bone bruising. Although these finding are helpful in understanding the pathology which contributes to anterolateral rotatory laxity of the knee, to truly harness the potential that MRI offers as a diagnostic tool in this setting it is crucial to correlate these findings with the clinical assessment of rotatory laxity.

Hence, just as the old maid in the song sadly came to realise that there are finite windows of opportunity in life, the ensuing study in *Chapter 8* seeks to take advantage of an exclusive episode of time shortly after injury. The optimal period when the MRI findings and clinical examination of knee laxity truly reflect any Kaplan fibre injury sustained following an ACL rupture has been chosen. Perhaps then, I will be able to smile again!

Chapter 8: Assessment of the association between radiological evidence of Kaplan fibre injury, intraoperative findings, and grade of pivot shift grade in the setting of acute anterior cruciate ligament injury

Introduction

"Because radiographs have a lot to contribute, the whole of diagnosis is often put upon their shoulders, and the large (often unique) contribution of clinical examination is overlooked."

- Professor Alan Graham Apley

It is important not to lose sight of the fact that radiologic investigations have a tertiary role in the diagnosis of knee injuries, a distance behind a thorough history and physical examination(120). The above quote was written by Professor Apley, one of the great orthopaedic educators, in an editorial entitled, "*Intelligent Kneemanship*", published in 1964(121). Although we have made many advances in orthopaedic sports surgery in the over half a century since this was written, we need only substitute the word 'radiographs' with 'MRI scans' and take the same salutary lesson today. It is with this sentiment in mind that the following study was devised.

One of the limitations of the study presented in *Chapter 7* was the variation in time between injury to the ACL and the acquisition of the MRI. Nevertheless, it transpired that the time interval between injury and MRI was particularly relevant and had an impact on the diagnosis of injury to the Kaplan fibre complex; in patients who had an MRI within 90 days of ACL injury the rate of Kaplan fibre injury significantly higher than in MRI scans performed after this time point (23.7% vs 6.4%). Explanations for this observation could include potential healing or possibly that it is just more difficult to diagnose injury in the sub-acute setting. Soft tissue oedema was an indirect diagnostic criterion which would have resolved significantly by the 90-day mark.

But, a further variable also needs to be considered; in order to be able to make a correlation between the MRI findings of damage to the Kaplan fibres and clinical assessment of injury, the interval between the MRI and the clinical examination is another crucial factor. In order to mitigate these issues, as part of the inclusion criteria for the following study, in a group of primary ACL-injured patients an interval of no more than 60 days between injury, MRI and ACL reconstruction was used. In the concluding paragraph of his editorial, Apley offers one final sage piece of advice which is equally applicable to designing a study as to preparing for an operation: "*But the surgeon who explores without first carefully reviewing the possibilities, is, like his Polar equivalent. A mere adventurer – a surgical buccaneer."* Let's hope the following study passes muster.

The manuscript is under review for publication in the American Journal of Sports Medicine as:

Devitt, BM, Al'khafaji I, Blucher N, Batty L, Webster KE, Feller JA. Association between radiological evidence of Kaplan fiber injury, intraoperative findings and pivot shift grade in the setting of acute anterior cruciate ligament injury (Submitted for review – June 2020)

Contribution

Mr Devitt, Associate Professor O'Sullivan, Professor Feller and Mr Batty contributed to the conception and design of this manuscript. Mr Devitt, Mr Al'khafaji, and Ms Blucher completed the reading of the MRIs and radiographs. Mr Devitt, Professor Webster and Mr Al'khafaji analysed the data. Mr Devitt, Mr Al'khafaji and Mr Batty wrote the manuscript. Mr Devitt, Mr Alkhafaji, Ms Blucher, Associate Professor O'Sullivan, Professor Feller, Mr Batty, Mr Murgier, and Professor Webster critically revised the manuscript for important intellectual content.

Conference presentations

This work was presented at a national and international conference:

Devitt B M, Batty L, Murgier J, O'Sullivan R, Webster KE, Feller JA, Devitt BM. No association with radiological evidence of Kaplan Fibre injury and pivot shift grade in the setting of acute anterior cruciate ligament rupture. Australian Knee Society Meeting. October 2018, Broom, Queensland.

Devitt B M, Batty L, Murgier J, O'Sullivan R, Webster KE, Feller JA, Devitt BM. No correlation with pivot shift grade and radiological evidence of Kaplan Fibre injury in the setting of acute anterior cruciate ligament rupture. Anterior Cruciate Ligament Study Group biennial meeting. January 2020, Kitzbühel, Austria.

Title:

Association between radiological evidence of Kaplan fiber injury, intraoperative findings and pivot shift grade in the setting of acute anterior cruciate ligament injury

Running title: Kaplan fiber injury in the ACL injured knee

Abstract

Background: Biomechanical studies have suggested the Kaplan fibers (KF) of the iliotibial band (ITB) play a role in controlling anterolateral rotation of the knee. There is a paucity of clinical information on whether injury to the KF in the setting of anterior cruciate ligament (ACL) rupture contributes to increased rotatory laxity of the knee.

Hypothesis/Purpose: To evaluate the association between radiological evidence of KF injury, intraoperative arthroscopic findings and grade of pivot shift at the time of ACL reconstruction (ACLR). It was hypothesized that Kaplan fiber injury would be associated with increased injury to the lateral compartment of the knee and a higher grade of pivot shift.

Study design: Case control study – Level III.

Methods: A retrospective MRI analysis was conducted on 267 patients with ACL-injured knees who underwent primary ACLR. Patients who had MRI and surgery within 60 days of injury were included. MRI was performed using standard knee protocols and diagnostic criteria were applied to identify KF injury. Associations were made between the MRI findings, intraoperative findings and grade of the pivot shift with the patient examined under anaesthesia at the time of ACLR.

Results: The prevalence of KF injury was 17.6% (47/267 patients). Arthroscopic evidence of lateral meniscal injury was associated the KF injury (p=0.010). The majority of patients in both the intact- and injured-KF groups had a grade 2 pivot shift (75% and 70% respectively). A small minority had Grade 3 pivot shift; 5% in the intact- versus 6.4% in the injured-KF groups. There was no association between radiological evidence of KF injury and pivot shift grade (p=0.6).

Conclusion: In acute ACL injury, KF injuries were not very common (17.6%) and the rate of grade 3 pivot shift was low (5.4%). When present, KF injuries were not associated with a higher grade pivot shift. However, there was an association between KF injury and lateral meniscal tears identified at the time of ACLR. The role of the KF in controlling anterolateral rotatory laxity in acute ACL injury in the clinical setting may be less evident compared to the biomechanical setting.

Key terms: Anterior Cruciate Ligament, Kaplan Fiber, Anterolateral Rotatory Laxity, Pivot Shift, MRI

What is known about the subject: Recent biomechanical sectioning studies have highlighted the importance of the iliotibial band (ITB) in controlling internal rotation in the ACL deficient knee, especially at higher flexion angles. The KFs are believed to be an important component of the anterolateral complex and anchor the distal ITB against the femur to aid in controlling antero-lateral tibial translation and rotation. The KFs can be identified on MRI and KF injury can be diagnosed concomitantly with

ACL injury. It is unclear if radiological injury of the KFs is associated with the degree of anterolateral rotatory laxity as measured by the pivot shift.

What this study adds to existing knowledge: This is the first study of which we are aware of that has examined the association between radiological evidence of KF injury and both the intraoperative arthroscopic findings and clinical assessment of anterolateral rotatory laxity.

Introduction

Eliminating anterolateral rotatory laxity of the knee is one of the key objectives of anterior cruciate ligament (ACL) reconstruction (ACLR)[22]. Injury to the anterolateral complex of the knee in addition to the ACL has been established as a significant contributing factor in the aetiology of anterolateral rotatory laxity[14]. Of the structures that comprise the anterolateral complex, the iliotibial band (ITB) has been shown to play an integral role in providing rotational control of the knee[11, 27]. In a study to determine the contribution of each anterolateral structure and the ACL in restraining simulated clinical laxity in both the intact and ACL-deficient knee, Kittl et al showed the ITB was the primary restraint at 30° to 90° degrees of flexion[27]. A further robotic biomechanical study by Geeslin et al revealed that sectioning of the KF attachment of the ITB to the distal femur led to greater tibial internal rotation at higher flexion angles (30° to 90°) as compared with sectioning of the anterolateral ligament (ALL)[10]. Additionally, it was shown that both the ALL and KF contribute to restraint of the pivot shift and anterior tibial translation in the ACL-deficient knee.

In clinical assessment of the ACL deficient knee, the pivot shift manoeuvre is a highly specific and important test to evaluate anterolateral tibial translation and rotational laxity[21, 29]. Indeed, the grade of pivot shift following ACLR has been found to correlate with patient outcome[29]. A number of clinical studies have demonstrated that ACLR alone is not sufficient to eliminate rotatory laxity, especially in cases of chronic ACL injury or with a high-grade pivot shift prior to the procedure[8, 20, 38]. Noyes et al identified that the structures of anterolateral aspect of the knee play an important role as secondary stabilisers and deficiency to these may result in a higher grade of pivot shift[36]. Song et al have also revealed that abnormal lateral posterior tibial slope (PTS) is a predictor of grade 3 pivot shift[39]. It is important to note that in cadaveric, biomechanical simulation models of anterolateral rotatory laxity an extensive release of not only the anterolateral capsule and ALL, but also of the KF attachment of the ITB, is carried out in order to create a worst-case scenario of injury[11, 23, 24]. However, there is limited information, aside from anecdotal reports and small studies, about how often the ITB and KF are compromised in association with an ACL injury[9, 43, 46].

Recent radiological studies have shown that the KF can be identified on standard knee MRI in the ACL-intact knee[1] and there is emerging evidence that radiological evidence of KF injury can be seen in the setting of ACL injury[26, 44]. However, it remains to be determined if and when KF injuries are clinically significant in terms of arthroscopic findings and assessment of rotatory laxity. Therefore, the aim this study was to evaluate the association between radiological evidence of KF injury, intraoperative arthroscopic findings and grade of pivot shift in a large cohort of patients undergoing ACLR following acute ACL injury. It was hypothesized that KF injury would be associated with increased injury to the lateral compartment of the knee and give rise to a higher grade of pivot shift at the time of ACLR.

Material and methods

Ethics approval

Human Research Ethics Committee approval was obtained for this study as part of a longitudinal study investigating a cohort of patients with ACL injuries.

Patient population and study setting

A radiological and clinical study was conducted on 267 consecutive patients undergoing ACL reconstruction at a private orthopaedic clinic in Melbourne, Australia. All patients were part of a longitudinal study with data recorded in a prospective database over a 5-year period between January 2014 and June 2018. Inclusion criteria for the longitudinal study were as follows: age between 15- 40 years, no previous surgery to either knee, no associated collateral ligament damage in the affected knee that required surgery or a modification of rehabilitation, no associated posterior cruciate ligament injury in the affected knee, and no previous cruciate or collateral ligament injury with residual laxity in the opposite knee. From this larger cohort, only patients with acutely injured and treated ACLs were included in this study. This was defined as patients who had both their MRIs and ACLR within 60 days from the date of injury. This period was selected because the interval between injury and MRI has been shown to be important in diagnosing KF injury radiologically[2]. Further, it was felt that the short interval between injury and clinical examination would more truly reflect the degree of laxity sustained as a result of the index injury[34]. The exclusion criteria were suboptimal MRI examination (motion artefact), or an incomplete study (absence of one or more of plain knee radiographs, sagittal, coronal and axial PD-weighted or PD-weighted fat-suppressed MR images).

Patient demographics

Demographic data included age, sex, laterality of injury, and sports activity at time of injury. These sport activities were categorized into pivoting and non-pivoting sports according to the classification by Hefti et all.[15] Pivoting sports are defined as activities requiring frequent change of direction (e.g., Australia rules football, soccer, netball, basketball, volleyball, alpine skiing, field hockey, and tennis). All sports that do not fit this classification were considered non-pivoting sports (e.g., running, walking, martial arts, weight lifting, and cricket). In addition, the patient's mechanism of injury was classified as contact or non-contact. Contact injuries were defined as ACL tears that occurred from a direct force placed on the affected lower limb. Injury mechanisms that were outside this definition were considered non-contact.

MRI protocols and analysis

The MRI scans included were from various providers with differences in sequencing and reformatting, but they were typically performed using 3 Tesla magnets and a dedicated knee coil. The sequences included either T1 or proton density sequences, and fat-suppressed proton density or fat-suppressed T2 sequences. This reflects current clinical practice in Australia. The MRI evaluation was conducted by three fellowship trained orthopaedic knee surgeons. Two reviewers (XX and XX) independently reviewed all scans. Differences were resolved by a third reviewer (XX) who independently reviewed all cases of disagreement.

KF injury diagnostic criteria

Identification of injury to the KFs was based on diagnostic criteria as described by Batty et al (Table 1)(Figure 1)[11]. The diagnosis of injury to the KF required at least one direct sign of injury or at least 2 indirect signs in any plane.

Table 1: Diagnostic criteria for signs of injury to the KFs

Direct signs of injury
Discontinuity of the KFs
Femoral Avulsion of the KFs
Indirect signs of injury
Thickening of the KFs
Bone marrow oedema at distal KF insertion site (posterolateral femur)
Localised soft tissue oedema in region of KFs
Wavy appearance to the KFs

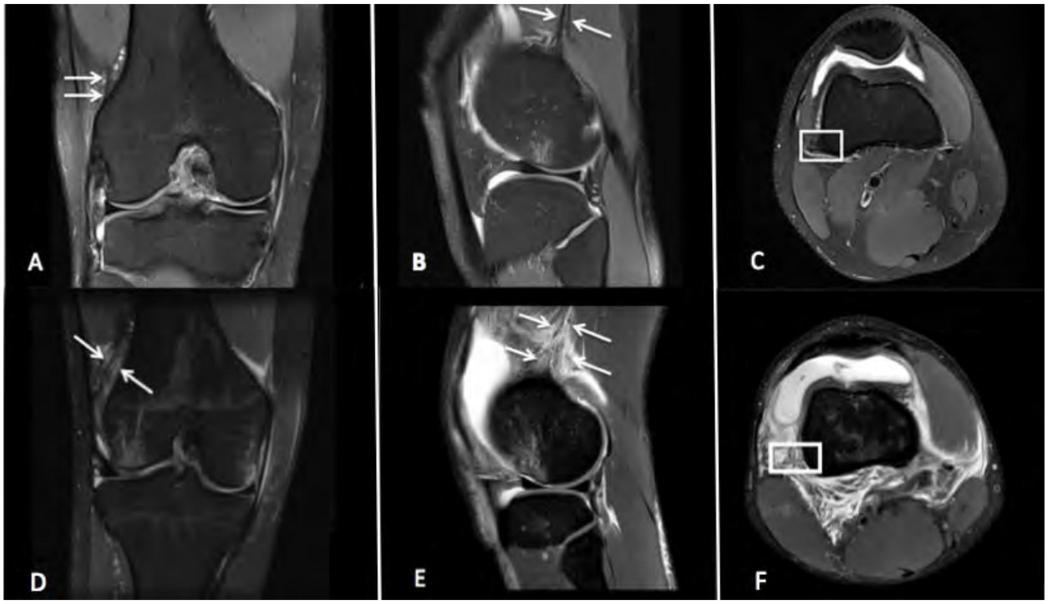

Figure 1- T2 Fat supressed images of the knee. A/B: White arrows identifying the intact KF complex on coronal and sagittal views respectively. C: Axial image identify the non-injured KF complex (white box). D: Coronal imaging displaying wavy appearance of injured KF (white arrows). E: Sagittal image with white arrows identify intra-substance tear of the KF. F: Axial image of injured KF with associated oedema and wavy fibers (white box).

Assessment of medial and lateral tibial slope

The influence of tibial slope was also examined, as this has been reported to be a predictor of pivot shift grade in acute ACL injury[39]. A single fellowship-trained orthopaedic surgeon reviewed each radiograph according to a previously described method which was shown to have excellent intra- and inter-observer agreement[35]. Analysis was performed using InteleViewer software (Intelerad Medical Systems). The medial and lateral posterior radiographic tibial slopes were defined as 90° minus the angle between the proximal tibial anatomic axis and a tangential line drawn along each plateau. The anatomic axis of the tibia was determined using 2 circles positioned at 5 and 15 cm distal to the tibial joint surface to the level of the outer cortex, as described in previous studies[35]. A line passing through the center of these 2 circles represented the tibial anatomic axis (Figure 2). The proximal tibial anatomic axis was chosen as the reference, as it has been shown to accurately represent the mechanical axis of the tibia on short lateral knee radiographs[35].

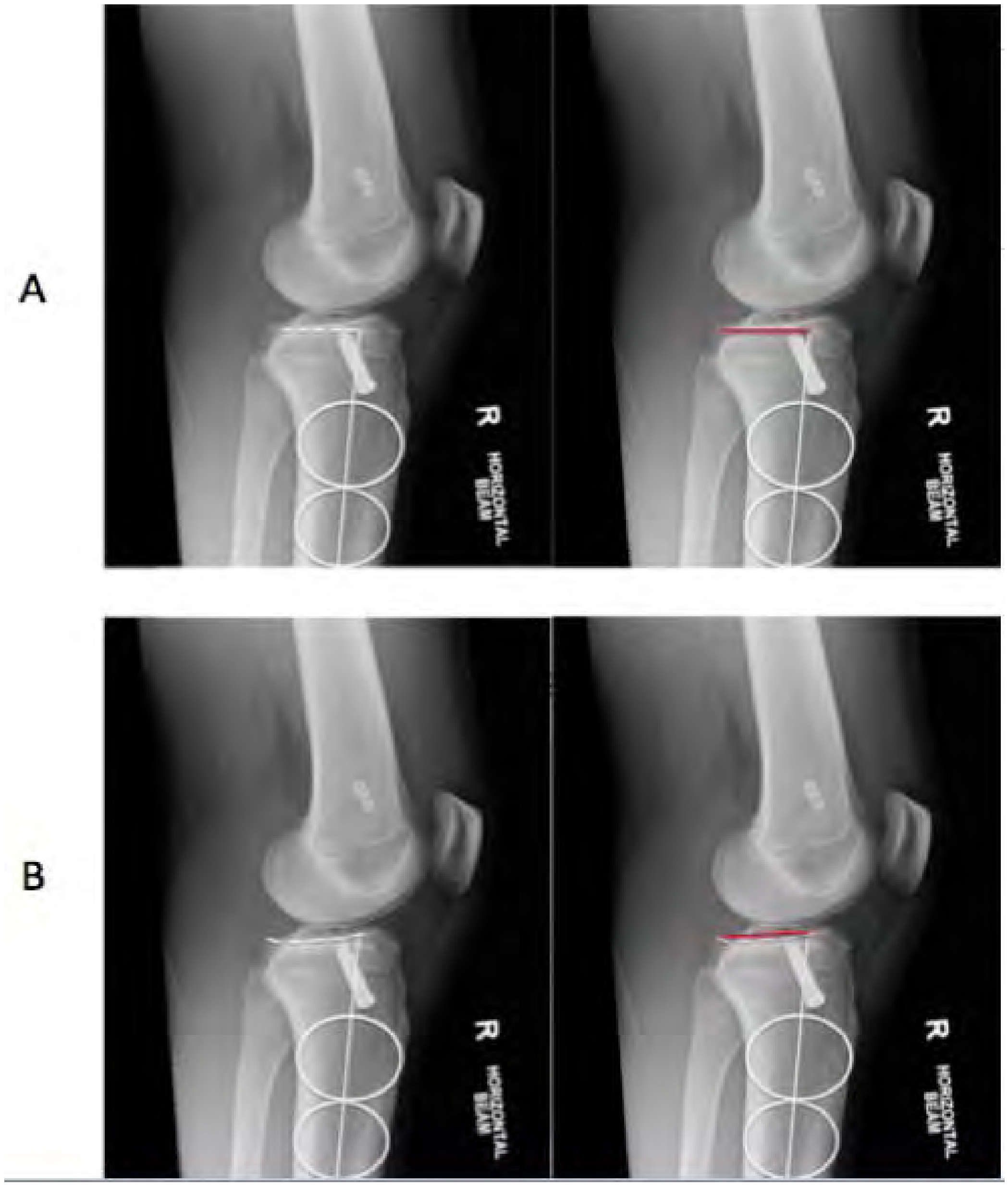

Figure 2- Posterior tibial slope was measured on the lateral radiograph relative to the central axis of the tibia, which was identified by applying 2 circles to the proximal tibia at 5 and 15 cm distal to the joint surface and drawing a line connecting their centers. (A) The surface of the lateral tibial plateau was identified and a tangential line (red) drawn. The angle between the tangential line and the central axis of the

tibia was measured. (B) The medial posterior tibial slope was identified and measured in a similar manner.

Pivot shift evaluation and grading

The clinical examination was performed by one of three knee surgeons contributing patients to the longitudinal study and was done by the treating surgeon before the operation, with the patient anaesthetised. The pivot shift was also graded according to the IKDC grading system[17] and scored as negative (grade 0), glide (grade 1), clunk (grade 2) or gross (grade 3).

Arthroscopic assessment of meniscal and chondral injury

An initial arthroscopy was performed as part of the ACL reconstruction. A thorough assessment of the menisci and articular surfaces was made and the findings, including the location and pattern of any meniscal tears, was recorded. The location of the meniscal tears was recorded in four zones: anterior, middle, and posterior thirds, and a separate zone for the posterior root. The integrity of the posterior root was assessed and recorded if deficient. The ICRS classification was used to categorise articular surface injury[3].

Statistical analysis

Continuous variables were described using means, standard deviations (SD) and ranges. The Student's t test was used for comparison of means between groups (injured KF vs. intact KF) for numerical data and chi-square analysis (or Fisher's Exact test where cell counts were below 5) was performed to assess distribution of categorical data. Chondral injury was categorized dichotomously as no injury (ICRS 0) or injury (ICRS 1-4) due to the low reported rates within each grade. Analysis of anterolateral rotational laxity using pivot shift grade was categorized as low grade (IKDC grade 1) and high grade (IKDC grade 2 and 3) due to the low reported rates of grade 3 pivot shift. All analyses were done using IBM SPSS Statistics V25.0.0.0. A p value of ≤ 0.05 was considered statistically significant.

Results

Patient demographics

The mean age of the 267 included patients was 23.6 years (SD 6.7, range 14-43), and 158 (59.2%) were male. There were 142 (53.2%) right knees. The mean time from injury to MRI scanning was 4.92 days (SD 5.9, range 0-38). The mean time from injury to surgery was 33.9 days (SD 14.7, range 8-60).

Prevalence of KF injury

The KFs could be identified in 100% of MRIs in at least one plane. Visualisation of the KFs was best in the sagittal plane where it was identified in 254 (95.1%) patients, compared to 251 (94%) patients in axial planes, and 143 (53.6%) patients in the coronal plane. Agreement on the presence of KF injury between the two reviewers was reached in 231 (86.5%) of cases. KF injury was diagnosed in 47 (17.6%) patients. The characteristics of patients diagnosed with KF injury compared to those without are summarised in Table 2. There was no significant difference in patient demographics between patients with intact and injured KFs in terms of age (p=0.627) or sex (p=0.151).

As regards the mechanism of injury, 102 (38.2%) patients stated their injury resulted from a contact mechanism, while non-contact injuries occurred in 165 (61.8%); there was no significant difference between contact or non-contact mechanism of injury and the presence of KF injury (p=0.518). In addition, there was no significant association between KF injury and the participation in a pivoting or non-pivoting activity at the time of ACL injury (p=0.301).

Posterior tibial slope and KF injury

No association was found with either medial or lateral posterior tibial slope and radiological evidence of KF injury. The mean lateral posterior tibial slope for knees with intact and injured-KFs was 10.22° (SD 2.94, range: 0.98-17.77) and 10.79° (SD 3.06, range: 4.8-20.36) respectively (p=0.650). The mean medial posterior tibial slope was 9.04° (SD 3.0, range 1.9-19.22) and 9.41° (SD 2.94, range: 3.31-16.76) for knees with intact and injured KF respectively (p=0.963). .

Arthroscopic findings associated with KF injury

The presence of lateral meniscal injury was significantly associated with KF injury (p=0.010) (Table 2). At arthroscopy, lateral meniscal tears were identified in 55% (26 patients) of cases with KF injury compared to 31% (68 patients) of cases without. In the KF injured group, the location of the tears within the lateral meniscus was variable; 42% (11/26) were in the posterior third, 35 % (9/26) were in the posterior root, and 23 % (6/26) were in the middle third. There were no posterior root avulsion injuries. In terms of treatment, 14 tears required partial debridement, 7 tears were partial thickness or stable and did not require treatment, and 5 tears required meniscal repair. No significant associated was found between medial meniscal tears and KF injury. There was no association between chondral injury at any site in the knee and KF injury (Table 2).

Association between radiological evidence of KF injury and clinical examination of knee laxity

Regarding pivot shift grade, the majority of patients in both the intact and injured-KF groups had a grade 2 pivot shift with rates of 75% (165 patients) and 70% (33 patients) respectively. Only 5.2 % (14 patients) of the entire cohort had a grade 3 pivot shift, which was comprised of 5% (11 patients) in the intact- versus 6.4% (3 patients) in the injured-KF group. No statistically significant association was found between the clinical examination grade of pivot shift under anaesthesia and the radiological evidence of KF injury (p=0.600) (Table 2).

Table 2 Comparison of patients with and without radiological Kaplan fiber injury

	No radiological Kaplan fiber injury (n=220)	Radiological Kaplan fiber injury (n=47)	p
Patient demographics			
Mean age (SD, Range)	23.31 (6.54, 13.7-43.2)	24.84 (7.20, 14.9-42.9)	0.627
Sex (M:F)	129:91 (59%:41%)	29:18 (62%:38%)	0.151
Non-Contact:Contact	134:86 (61%:39%)	31:16 (66%:34%)	0.518
Pivoting sport: Non-pivoting sport	206:14 (94%:6%)	42:5 (89%:11%)	0.301

Associated Meniscal injury (Arthroscopic diagnosis)			
Lateral meniscal injury	68 (31%)	26 (55%)	0.010
Medial meniscus injury	51 (23%)	10 (21%)	0.778
Associated Chondral injury (Arthroscopic diagnosis)			
Lateral femoral condyle injury	15 (7%)	5 (11%)	0.366
Lateral tibial plateau injury	10 (5%)	1 (2%)	0.695
Medial femoral condyle injury	25 (11%)	6 (13%)	0.785
Medial tibial plateau injury	4 (2%)	1 (2%)	1.000
Patella injury	21 (10%)	6 (13%)	0.506
Trochlear groove injury	2 (1%)	1 (2%)	0.442
Associated Posterior Tibial Slope			
Lateral Tibial Slope (SD, Range)	10.22 (2.94: 0.98-17.77)	10.79 (3.06: 4.8-20.36)	0.963
Medial Tibial Slope (SD, Range)	9.04 (3.0, 1.9-19.22)	9.41 (2.94, 3.31-16.76)	0.650
Clinical examination findings			
Pivot Shift			
0	0 (0%)	0 (0%)	0.600*
1	44 (20%)	11 (24%)	
2	165 (75%)	33 (70%)	
3	11 (5%)	3 (6%)	

SD-standard deviation, *- Pearson Chi-Square evaluation of low grade pivot shift and Lachman test (IKDC grade 1) and high grade pivot shift and Lachman test (IKDC grade 2 and 3)

Discussion

This study revealed that the prevalence of KF injury (17.6%) and rate of grade 3 pivot shift clinical examination findings (5.2%) at the time of ACLR were low in the setting of acute ACL injury (<60 days from injury to surgery). When present, KF injury was not associated with a higher grade pivot shift. However, there was an association between KF injury and lateral meniscal tears identified arthroscopically at the time of ACLR (p=0.010). The mechanism of ACL injury, contact or non-contact, was not found to be a significant factor in the rate of KF injury (P=0.518), nor was the lateral or medial posterior tibial slope as measured on plain radiographs (P=0.963 and P=0.650, respectively).

The anterolateral complex of the knee has been studied extensively in recent times as its importance in controlling anterolateral rotation has been realised, particularly in the setting of the ACL-deficient knee[10, 12, 14, 28]. A number of studies have been carried out to describe the MRI appearances of the structures of the anterolateral complex in both normal and ACL injured knees[1, 4, 6, 19, 31, 33, 37, 42]. However, correlation of radiological evidence of anterolateral complex injury with clinical examination of rotatory laxity is limited. Miyaji et al, in a study of 82 patients, compared the pivot shift grade in patients with ACL injury with and without anterolateral capsule injury detected with MRI[31]. Their study revealed that anterolateral capsule injury was not consistently detected on MRI and did not affect rotatory knee laxity as assessed by the pivot shift. On the other hand, Musahl et al, in a similar study of 41 patients with acute ACL injury, found that MRI evidence of a concomitant injury to the anterolateral capsule, medial meniscus, or lateral meniscus was associated with increased knee rotatory laxity in patients with an ACL injury[34]. The results of the current study found no association with pivot shift grade and MRI evidence of KF injury, which would concur with the findings of Miyaji et al but conflict with those of Musahl et al. It is perhaps somewhat surprising that injury to the KFs did not result in a higher grade of pivot shift considering that biomechanical sectioning studies have shown that the KFs assume a greater role in controlling internal rotation of the knee compared to the anterolateral capsule[10].

The pivot shift test is the most specific clinical assessment of pathological knee joint rational laxity after ACL rupture when performed under anaesthesia[30, 45]. The test evaluates the combined tibiofemoral internal rotation and anterior tibial translation that occurs with ACL deficiency and the pathological motion that is produced [18, 25]. A grade 3 pivot shift, which is determined by an explosive clunk on reduction of the tibia during the manoeuvre, has been shown to correlate with poorer clinical outcomes and recently has been suggested as a possible indication for an additional anterolateral procedure in the setting of ACL reconstruction[14 40, 41]. Only a small percentage of patients had a grade 3 pivot shift in either group; 5% (11 patients) in the intact versus 6.4% (3 patients) in the injured-KF group. Miyaji et al had similarly low numbers of patients with a grade 3 pivot shift in both the anterolateral capsule-injured and intact groups[31]. Unfortunately, direct comparison cannot be made with the study by Musahl et al, as their quantitative assessment of anterior translation of the lateral tibial compartment was carried out in this study using an iPad system[34].

The time from injury to surgery is an important consideration when correlating radiological and clinical findings. Chang et al, in a clinical and radiological study of 154 knees with ACL tears, determined that MRI may have some usefulness for predicting the grade of knee laxity in patients with symptomatic ACL injury, but its value is limited, especially in patients with a longer time interval between injury and the performance of MRI.[5] Explanations for the discrepancy in radiological and clinical findings could include potential healing of the soft tissue structures in the interval between the MRI and physical examination. In the study by Miyaji et al, the '*waiting period*' between ACL injury and ACL reconstruction ranged from between 238 and 294 days[31]. This contrasts with the study by Musahl et al in which the average time interval between the injury and MRI was 7 ± 11 days and the average time interval between MRI and the quantitative pivot-shift test was 43 ± 36 days[34]; this represents an acutely injured group and is similar to the cohort in the current study, in which mean time from injury to MRI was 4.92 days (SD 5.9, range 0-38) and the mean time from injury to surgery was 33.9 days (SD 14.7, range 8-60). Therefore, given this short time interval, one would expect that the assessment of laxity at surgery is more truly reflective of the structural damage sustained at the index injury.

It is important to consider the reason for such a low rate of grade 3 pivot shift in the current study and especially in those patients with KF injury. It is possible that the explanation for this relates to the selection criteria of the study, which included only patients with a primary, acute ACL injury, the majority of which were due to non-contact injury whilst playing pivoting sports. As such, patients with more chronic ACL deficiency were excluded. It has been postulated that patients with chronic ACL deficiency are more likely to have undergone multiple pivot shift events, thereby attenuating the secondary stabilisers on the anterolateral aspect of the knee with the resultant effect of increasing rotational laxity[7, 36]. A review by Tanaka et al, which assessed what it takes to have a high-grade pivot shift, suggested that disruption of the secondary restraints to anterior translation of the lateral compartment, including the lateral meniscus, anterolateral capsule, and ITB contributes to a high-grade pivot shift in the ACL-deficient knee. However, on the basis of the current findings, which showed no association with acute KF injury and a high grade of pivot shift, it would appear that it may take more than a single insult or injury to cause increased laxity of these secondary stabilisers[10, 27]. Interestingly, there was an association between

KF injury and arthroscopic evidence of lateral meniscal injury, which may represent an early finding of a spectrum of injury to the anterolateral complex which potentially evolves as a result of repeated pivot shift events[36].

Song et al, in a retrospective study compared 30 patients (30 knees) with grade 3 pivot shift with 30 patients (30 knees) with grade 1 and 30 patients (30 knees) with grade 2 pivot shift to determine what factors contribute to a grade 3 pivot shift[39]. They found the best set of predictors of grade 3 pivot shift were playing a pivoting sport at the time of injury, abnormal lateral posterior tibial slope, anterolateral capsular ligament disruptions, and lateral meniscal lesions. The pivot shift test was performed with the patient under anaesthesia and carried out ≤3 weeks from the date of injury. An increased posterior tibial slope was defined as ≥10.6° for lateral tibial plateau and ≥9.4° for the medial tibial plateau. Although injury to the KFs was not assessed or included in the criteria by Song et al, it is interesting that no association could be found between any of the aforementioned risk factors and KF injury in the current study. Perhaps this reflects the small numbers of patients with grade 3 pivot shift within the intact and injured-KF groups. Moreover, in the current study the overwhelming majority of patients had a grade 2 pivot shift in both the intact and injured-KF groups. It is interesting to note that grade 2 pivot shift or higher was one of the inclusion criteria in a recent randomised control trial by Getgood et al, which compared the 2-year outcomes of a large cohort of patients considered to be at high risk of re-injury following ACL reconstruction[15, 16]. The study cohort included patients between the 14 and 25 years with ACL deficiency who were treated with either autologous hamstring ACL reconstruction in isolation or combined with a LET. The presence of 2 or more of the following factors constituted a high risk of re-injury: participation in competitive pivoting sport, grade 2 pivot shift or greater, generalized ligamentous laxity, and genu recurvatum (>10°). Based on these criteria, regardless of KF injury status, the vast majority of the patients included in the current study would be considered high risk of re-injury.

The sensitivity, specificity and accuracy of MRI in making a diagnosis of injury to structures of the anterolateral complex is also highly relevant to the findings of the current study. Monaco et al, in a study of 26 with acutely injured knees evaluated the correlation between MRI and surgical exploration[32]. They determined that MRI has low sensitivity, specificity, and accuracy for the diagnosis of ITB injury and there was only a fair agreement with surgical findings and MRI. Getgood, in an editorial on the subject, stated that it is often 'challenging' to determine which component of the anterolateral complex is injured as '*high signal is often seen on T2-weighted images of acute ACL injury*'[13]. However, the same concerns also apply in the surgical setting. A number of authors have described visualising haemorrhage in the region of the KF during surgical exploration[9, 43, 46]. It has been postulated that injury to the superior lateral genicular vessels is responsible for this haemorrhage due to its proximity to the KF[10, 46]. But details from these studies do not explicitly describe disruption to the continuity of the KF complex, nor have they correlated injury with rotatory laxity [9, 43, 46]. Therefore, it is important not to assume that the presence of haemorrhage or oedema alone on MRI heralds serious structural damage to the lateral side of the knee. In the current study, the presence of soft tissue oedema was only one factor in the diagnosis of injury and it had to be associated with at least one other direct or indirect sign of injury such as a wavy appearance, thickening, intra-substance signal change or localised bony oedema at the KF femoral attachment. These rigorous diagnostic criteria perhaps explain the lower rate of injury diagnosis in the current study.

Limitations

There are limitations to this study. The MRI evaluation of the anterolateral structure is subject to variability and an element of subjectivity. However, the MRIs were read by two reviewers independently who were blinded to the clinical examination findings. The use of a third reviewer to develop consensus in cases of disagreement and the selected diagnostic criteria were both aimed at addressing this subjectivity. The MRI scans included in this study were from various sources with differing protocols. We believe this scenario does reflect the current realities for an orthopaedic surgeon evaluating MRI scans in their day to day practice. The pivot shift tests were performed by different surgeons preoperatively under general anaesthesia and inter- and intra-observer reliability was not assessed. Nevertheless, all 3 surgeons were experienced sub-specialist knee surgeons with a particular interest in the ACL reconstruction. The statistical analysis of the association between the specific IKDC grade of pivot shift and KF injury was not possible due to the spread among categories; in particular, the small numbers of patients with a grade 3 pivot shift prevented analysis across all three categories. Combining the grade 2 and 3 pivot shift groups provided sufficient power to detect a small to medium effect size between the intact and injured-KF groups, however no effect was present.

Conclusion

This study demonstrated that in acute ACL injury, KF injury was not very common (17.6%) and that the rate of grade 3 pivot shift at the time of ACLR was low (5.4%). When present, KF injuries were not associated with a higher grade pivot shift. However, there was an association between KF injury and lateral meniscal tears identified at the time of ACLR. Based on these findings, the role of the KF in controlling anterolateral rotatory laxity in acute ACL injury in the clinical setting may be less evident compared to the biomechanical setting.

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Epilogue

"Not all those who wander are lost."
— J.R.R. Tolkien, The Fellowship of the Ring

All trilogies must come to an end. And, so it is that the triumvirate of radiological studies exploring the Kaplan fibre attachment of the ITB has concluded not with a cliff hanger or a happy ending but with the realisation that there is more to the story of anterolateral rotatory laxity than simply the Kaplan fibres. The circuitous journey through the radiological anatomy of the lateral side of the knee has revealed that while it is possible to identify the Kaplan fibre complex, the prevalence of injury in the setting of ACL rupture is relatively low (17.6%). Furthermore, although there are certain qualitative MRI signs associated with Kaplan fibre injury, no association was found between any of these and an increased grade of pivot shift. What has become apparent throughout *Section 2*, is the inconvenient truth that anterolateral rotatory laxity is not caused by injury to one isolated structure on the lateral aspect of the knee in the setting of ACL injury.

It is equally important not to lose sight of the more subtle, hidden message that the final study reveals; in acute primary ACL injury the prevalence of clinical evidence of high grade (IKDC grade 3 pivot shift) anterolateral rotatory laxity is very low (5-6%), irrespective of radiological evidence of Kaplan fibre injury. Considering that the Anterolateral Complex Consensus Group has recently included grade 3 pivot shift as a possible indication for lateral extra-articular tenodesis, the requirement for its use in acute primary ACL reconstruction should, therefore, also be very low.

However, with recent studies suggesting a reduced rate of ACL graft failure with the addition of a lateral extra-articular tenodesis in young active patients, it is likely that the interest in this procedure will increase further in the not too distant future(122). Considering that the timing of ACL reconstruction is typically more acute nowadays, as reflected by the cohort in the current study, there is also a distinct risk that LET will be used unnecessarily. Therefore, before wandering blindly down this path surely it would be prudent to take some direction from the experiences with this procedure from the past, particularly in the context of primary ACL reconstruction. In Section 3, the role of extra-articular augmentation procedures in primary ACL reconstruction is explored and discussed.

Section 3

The role for lateral extra-articular augmentation procedures in the setting of primary ACL reconstruction

Chapter 9: Anterolateral ligament reconstruction: What does Dr Google say?

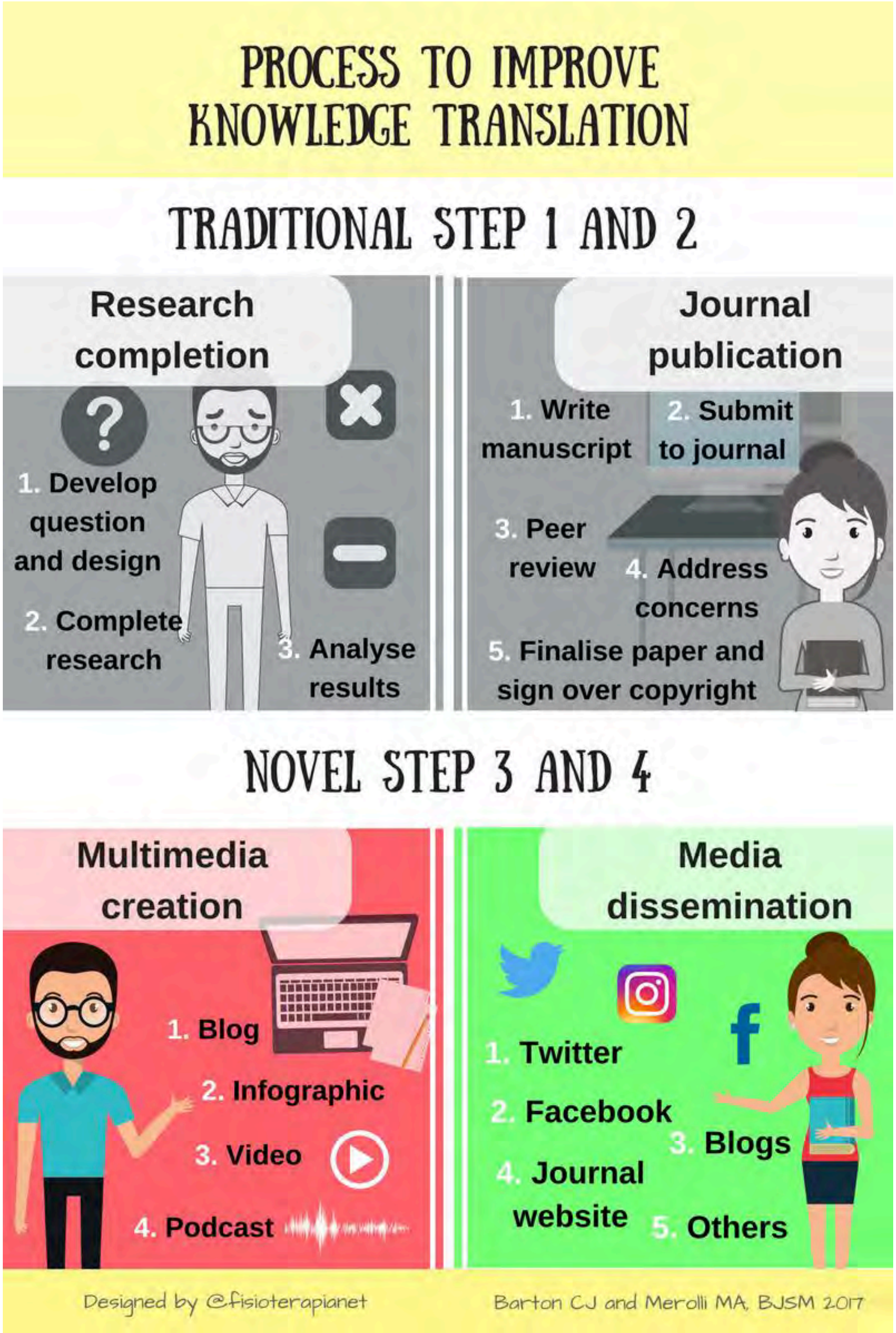
Introduction

“Today’s news is tomorrow’s fish and chip paper”

The idiom above is often used to convey the fleeting nature of news and how quickly it can become redundant and obsolete. Indeed, the phrase itself is now somewhat outdated as it originally referred to the printed newspapers, which have largely been superseded by internet news. As for its secondary function to absorb grease from fish and chips, that too has ceased on grounds of hygiene. In our ever-changing world, the flow of information is rapid and increasingly succinct. Long gone are rambling diatribes of monotonous news. Nowadays people crave bulletins, or brief synopses, ideally in 140 characters or less(123).

The same is true in the scientific literature, where infographics, which detail (often with cartoons) the salient findings of a particular study, are positively encouraged to enhance knowledge translation (Figure 1)(124). However, a big concern exists as to whether the messages being promulgated in these infographics are indeed accurate and supported by fact. Or are they just clickbait designed to attract the attention of the reader and provide them with one key message and as a result oversimplifying a complex conclusion? The phrase “*get visible or vanish*” has been used to replace the “*publish or perish*” aphorism, which describes the much-criticised pressure to publish academic work in order to succeed in an academic career(124, 125).

Figure 1: *Barton, CJ and Merolli, MA. BJSM 2017 - An infographic used to promote the process to improve knowledge translation*



One of the fundamental principles of scientific writing is that statements should be supported by citation from the scientific literature(126). A key part of the format of writing a scientific manuscript is not simply presenting the results or conclusion of the study but providing an introduction, methodology and, most importantly, a discussion(127-131). In the latter section, the main findings of the study can be compared to previous studies and the limitations of the study, which are present in almost every case, can be outlined. These vital issues are frequently completely missed in infographic material (Figure 2)(132). As such, the use of abridged information has the potential to be misleading and publicise a message or conclusion that is not completely supported by rigorous scientific study(133).

Figure 2: *Smellie, A (Daily Mail newspaper article)(132) - The infographic that was displayed alongside an article entitled, "Revolutionary new operation to repair joint uses ligament nobody knew existed until six months ago." The infographic displays the steps for an ALL reconstruction with proprietary devices from an implant company.*

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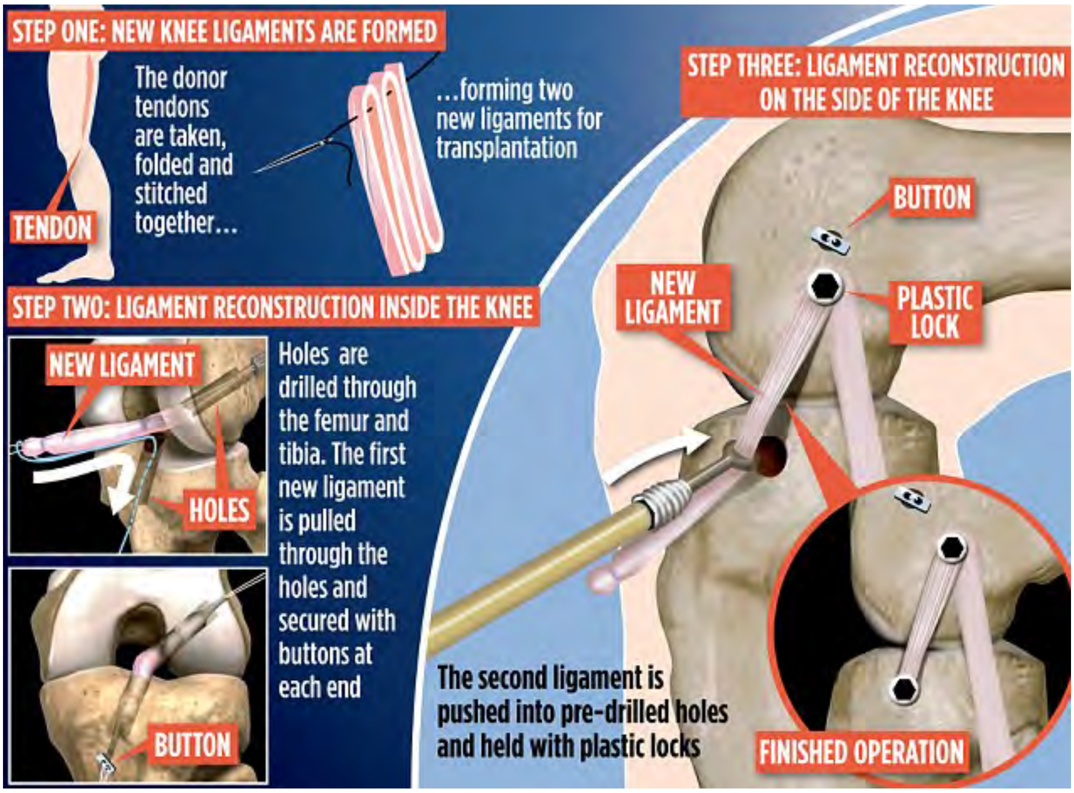

As the first chapter of *Section 3*, which focuses on the role of lateral extra-articular augmentation in the setting of primary ACL reconstruction, the following study discusses ALL reconstruction, the newest variety of lateral extra-articular tenodesis. This procedure was devised within months of the study by Claes et al, reporting the "rediscovery" of the

ALL(132). The promotion of this lateral extra-articular augmentation technique was enhanced in the context of the widespread exposure it received throughout the internet(21). The study employs a novel methodology which was used to assess the source of information on the internet related ALL reconstruction that was available to patients in Australia and the quality of information provided. In doing so, a comparison is made with the source and available information on the internet related to ACL reconstruction, one of the more common procedures carried out in orthopaedic sports medicine.

The manuscript is published in the Orthopaedic Journal of Sports Medicine as:

Devitt BM, Hartwig T, Klemm H, Cosic FT, Green J, Webster KE, Feller JA, Baker JF. Comparison of the Source and Quality of Information on the Internet Between Anterolateral Ligament Reconstruction and Anterior Cruciate Ligament Reconstruction: An Australian Experience. Orthop J Sports Med. 2017 Dec 7;5(12):2325967117741887.

Contribution

Mr Devitt and Mr Baker contributed to the conception and design of this manuscript. Mr Devitt, Mr Hartwig, Dr Cosic, and Mr Klemm carried out the internet systematic review and evaluation of the data. Mr Devitt, Dr Green, Professor Webster and Mr Baker analysed the data. Mr Devitt, Mr Baker and Dr Cosic wrote the manuscript. Mr Devitt, Mr Hartwig, Mr Klemm, Dr Cosic, Dr Green, Professor Webster, Professor Feller and Mr Baker critically revised the manuscript for important intellectual content.

Conference presentations

This work was presented at a national conference:

Devitt BM, Hartwig T, Klemm H, Cosic FT, Green J, Webster KE, Feller JA, Baker JF. Comparison of the Source and Quality of Information on the Internet Between Anterolateral Ligament Reconstruction and Anterior Cruciate Ligament Reconstruction: An Australian Experience. Australian Orthopaedic Association Meeting. October 2017, Brisbane, Queensland

Comparison of the Source and Quality of Information on the Internet Between Anterolateral Ligament Reconstruction and Anterior Cruciate Ligament Reconstruction

An Australian Experience

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Investigation performed at OrthoSport Victoria, Epworth Healthcare, Melbourne, Australia, and the School of Allied Health, La Trobe University, Melbourne, Australia

Background: The internet is a valuable tool, but concerns exist regarding the quality and accuracy of medical information available online.

Purpose: To evaluate the source and quality of information on the internet relating to anterolateral ligament reconstruction (ALLR) compared with anterior cruciate ligament reconstruction (ACLR).

Study Design: Cross-sectional study.

Methods: A questionnaire was administered to 50 ACLR patients in Australia to determine their use of the internet to research their operation and their familiarity with the anterolateral ligament (ALL) of the knee. The most common search terms were determined, and the first 70 websites returned by the 5 most popular search engines were used to assess the quality of information about ACLR and ALLR. Each site was categorized by type and was assessed for quality and validity using the DISCERN score, the *Journal of the American Medical Association* (JAMA) benchmark criteria, and a novel specific content score for each procedure. The presence of the Health on the Net Code (HONcode) seal was also recorded.

Results: The majority (84%) of ACLR patients used the internet to research their operation. The quality of information available for ALLR was significantly inferior to that for ACLR according to the DISCERN score (37.3 ± 3.4 vs 54.4 ± 4.6; $P < .0001$) and specific content score (5.3 ± 1.3 vs 11.0 ± 1.5; $P < .0001$). ACLR websites were predominantly physician produced, while the majority of ALLR websites were academic. In contrast to ACLR websites, the majority of ALLR websites did not provide information on the indication for treatment or potential complications. ALLR websites scored better on the JAMA benchmark criteria due to the predominance of academic websites. A greater proportion of ACLR websites (14.6%) versus ALLR websites (2.5%) provided an HONcode seal. Correlation was demonstrated between the DISCERN score and specific content scores for both ACLR and ALLR but not with JAMA benchmark criteria. The specific content score had high reliability for both ACLR and ALLR.

Conclusion: The majority of patients undergoing ACLR in Australia used the internet to research the procedure. The quality of information on the internet relating to ALLR was significantly inferior to information about ACLR. Most ALLR websites failed to include crucial information about the indication or options for treatment, prognosis, and potential complications. Surgeons should be aware of the information to which their patients are exposed through the internet and should be proactive in directing patients to appropriate websites.

Keywords: internet; ACL reconstruction; ALL reconstruction; quality of information

The internet is an extraordinarily valuable tool that has transformed many aspects of modern life. The capability of the internet to disseminate diverse data across populations and nations presents unique opportunities but also poses

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significant challenges in terms of regulation of information, particularly in the health care industry. Traditionally, health care professionals were the primary source of information for health care consumers, but in recent times the internet, social media, and print journalism have assumed an increasingly greater role.[1,8,14] Although it is important for health care consumers to be informed, a number of studies have demonstrated that many health care websites contain inaccurate or misleading information.[4,10,16,21,24] Another concern relates to regulation, as the pharmaceutical and medical devices industries are increasingly using the internet to market their products, not just to health care professionals but also directly to the general public.[19]

In the setting of knee surgery, anterior cruciate ligament (ACL) injury is one of the most commonly treated conditions.[13] Previous studies have demonstrated that the internet is an important source for patients seeking information about ACL reconstruction (ACLR), although the quality of information has been reported to be variable and often commercially driven.[4,5,11] The increasing pervasiveness of the internet in the field of orthopaedics is probably best illustrated by the case example of the anterolateral ligament (ALL). Following the publication of an anatomic study by Claes et al,[7] who reported the presence of a distinct ligamentous structure on the anterolateral aspect of the knee, there was widespread interest beyond the traditional scientific publications. The findings of the study were reported on website blogs[18] and taken up by mainstream print media within weeks of release of the scientific publication.[9] Surgical techniques quickly emerged to perform ALL reconstruction (ALLR) in combination with ACLR.[22,23] The proposed benefit of performing ALLR in combination with ACLR is to provide greater rotational control of the knee than provided by ACLR alone, which theoretically has the potential to reduce graft failure.[23] Ironically, recent criticism has emerged—through the same print media that heralded the "discovery" of the ALL—that the development of ALLR has been too rapid and that proven evidence of the efficacy of surgery is lacking; the cynicism of the *New York Times* article is illustrated by the title: "Surgery Fixes a Ligament (If It Exists): Does It Fix the Knee?"[15]

The aim of this study was to assess the source and quality of information on the internet related to ALLR compared with ACLR through use of recognized scoring systems, identification of quality markers, and pathology-specific content scores. The hypothesis was that the quality of information available would be inferior for ALLR in contrast to ACLR. A secondary aim was to survey a cohort of patients who had undergone ACLR to determine the prevalence of internet use preoperatively to research the surgery and to assess the patients' awareness of the ALL.

TABLE 1
Patient Questionnaire

Demographics
Patient name
Age
Occupation
Questions
1. Did you use the internet to research your operation?
2. What search engine(s) did you use?
3. What terms did you search for?
4. Did you find the information helpful? Yes/No
5. Have you heard of the anterolateral ligament of the knee?
6. If yes, where did you hear about it?

METHODS

Prior to the commencement of a web search, a questionnaire was administered to 50 consecutive postoperative ACLR patients in Australia (Table 1). The patient cohort consisted of 33 men and 17 women with a mean age of 25 years (range, 13-51 years). The questionnaire was designed to determine whether the patients had used the internet preoperatively to research their operation, which search terms and which search engines the patients had used, and whether they were familiar with the ALL of the knee.

From the questionnaire it was established that the term *ACL reconstruction* was the most commonly used search term for ACLR. This search term was then used to carry out an internet search. Only a minority of patients were familiar with the ALL or any relevant abbreviations. Therefore, the full term *anterolateral ligament reconstruction* was used for the internet search.

Consistent with previous studies,[4] the 5 most popular search engines—as determined by total market share—were used by patients: Google (65%), Bing (16%), Yahoo! (8%), Lycos (<1%), and AOL (<1%).[17] To reflect the disproportionate use of the various available search engines, and in keeping with our questionnaire findings, an analysis was performed on the first 30 of approximately of 530,000 websites returned by Google (www.google.com) and 10 each from AOL (www.aol.com), Bing (www.bing.com), Lycos (www.lycos.com), and Yahoo! (yahoo.com). Duplicate websites and those that were inaccessible were excluded from the review (Table 2). Searches were performed on January 25, 2016, and were carried out in Australia.

The first part of the analysis involved separating the websites into the following categories: academic, physician, nonphysician (allied health professionals such as physical therapists, occupational therapists, and alternative medicine providers), media, commercial, social media, and advertisement. These classifications were based on those

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||Waikato Hospital, Hamilton, New Zealand.
The authors declared that they have no conflicts of interest in the authorship and publication of this contribution.
Ethical approval was not sought for the present study.

TABLE 2
List of Websites Returned for Anterior Cruciate Ligament and Anterolateral Ligament Reconstruction as Sorted by Search Engine

Search Engine	Anterior Cruciate Ligament	Anterolateral Ligament
Google	www.precisionhealth.com.au/services/orthopaedic-surgery/conditions-treated/cruciate-ligament-injuries? gclid=CIfH6rzMqsoCFVYGvAodGpQPPA www.melbourneorthopaedics.net.au/? gclid=CKajp5rRqsoCFQolvQoda1sD4w en.wikipedia.org/wiki/Anterior_cruciate_ligament_reconstruction www.sydneyknee.com.au/acl-reconstruction/ www.knee-surgeon.com.au/ligament-reconstruction.html www.youtube.com/watch? v=q96M0jRqn7k www.orthosports.com.au/content_common/pg-acl-reconstruction.seo orthoinfo.aaos.org/topic.cfm? topic=a00297 www.perthortho.com.au/resources/keith-holt/ACL-Rehab.pdf www.nlm.nih.gov/medlineplus/ency/article/007208.htm www.webmd.com/a-to-z-guides/anterior-cruciate-ligament-acl-surgery www.orthosa.com.au/anterior-cruciate-ligament-acl-reconstruction/ www.osv.com.au/info-sheets/knee/anterior-cruciate-ligament-acl-reconstruction www.osv.com.au/info-sheets/knee/rehabilitation-following-anterior-cruciate-ligament-reconstruction www.arthrohealth.com.au/acl-reconstruction/ www.latrobe.edu.au/news/podcasts/transcript/? mode=results&queries_id_query=256371 www.mayoclinic.org/tests-procedures/acl-reconstruction/home/ovc-20166733 www.brettfritsch.com.au/ligament-reconstruction.html www.leopinczewski.com.au/? page=Rehabilitation-Protocols www.knee-surgeon.net.au/acl-reconstruction/ www.mog.com.au/uploads/doctor_pdfs/Rehabilitation+protocol+of+ACL+Reconstruction.pdf www.jointreconstruction.com/knees/acl-reconstruction/ www.sydneyhipandknee.com.au/knee-sydney-hip.html www.myorthopod.com.au/acl-reconstruction-rehabilitation.html www.anteriorhip.net.au/patient-info/anterior-cruciate-ligament-reconstruction/ www.hipandknee.com.au/reconstuction.html www.melbournehipandknee.com.au/knee-procedures/acl-reconstruction.aspx www.hipandkneesurgery.com.au/patient-info/acl-reconstruction-with-allografts-and-lars-ligaments/ drchrisdougherty.com/dr-chris-dougherty/ www.betterhealth.vic.gov.au/health/surgicalbrochures/acl-reconstruction	www.dailymail.co.uk/health/article-2613883/Surgeons-finally-win-Battle-Wounded-Knee-Revolutionary-new-operation-repair-joint-uses-ligament-knew-existed-six-months-ago.html www.arthrex.com/resources/video/JOVv2r2KoE-v7gFCU0pqVw/anterolateral-ligament-reconstruction-using-swivelock jbjs.org/content/64/3/352.abstract www.arthrex.com/knee/anterolateral-ligament-reconstruction ajs.sagepub.com/content/28/2/144.short arch.neicon.ru/xmlui/handle/123456789/3007140 https://www.youtube.com/watch? v=2ZGxInokLz8 www.ncbi.nlm.nih.gov/pubmed/25740835 www.ncbi.nlm.nih.gov/pmc/articles/PMC4508556/ drrobertlaprademd.com/what-is-the-anterolateral-ligament-of-the-knee/ ojs.sagepub.com/content/1/7/2325967113513546.full www.slideshare.net/hiraharamd/anterolateral-ligament-all www.sydneyknee.com.au/the-anterolateral-ligament-of-the-knee-and-its-evolution-in-acl-reconstruction/ www.coastalorthopaedics.com.au/pdf/anterolateral-ligament-of-the-knee-information.pdf icjr.net/report_114_all_anatomy.htm#.VqWyOvl95pg www.sofarthro.com/medias/telechargements/mastercourse2015/04_tenodese/sonnery.pdf medicalxpress.com/news/2013-11-orthopaedic-surgeon-anterolateral-ligament-acl.html https://en.wikipedia.org/wiki/Anterolateral_ligament onlinelibrary.wiley.com/doi/10.1111/sms.12524/abstract link.springer.com/article/10.1007%2Fs00167-015-3783-5 nerdyfacts.com/reviews/anterolateral-ligament.com? gclid=CK_N6vSdxMoCFQqAvQodwagCnw www.mrjameslewis.co.uk/anteriorcruciateligamentreconstruction.html www.hindawi.com/journals/crior/2013/648908/ www.sciencedirect.com/science/article/pii/S2255497113000840 www.moiramccarthy.com/anterolateral-ligament-reconstruction/ www.pagepress.org/journals/index.php/or/article/view/5773 www.aaos.org/CustomTemplates/VideoGallery.aspx? id=28377&nav=552&ssopc=1 www.calvinjohnsonmd.com/anterolateral-ligament-reconstruction/ www.researchgate.net/post/What_is_your_opinion_on_the_relevance_of_the_Anterolateral_Ligament-ALL_and_its_relevance_for_rotational_stability_of_the_knee2 www.actaorthopaedica.be/acta/download/2014-1/08-Claes%20et%20al.pdf
Lycos	www.nhs.uk/Conditions/repairtotendon/Pages/Introduction.aspx orthoinfo.aaos.org/topic.cfm? topic=A00549 www.bupa.co.uk/health-information/directory/a/acl	www.ncbi.nlm.nih.gov/pmc/articles/PMC4523866/ www.bioportfolio.com/resources/pmarticle/498510/Anatomy-of-the-anterolateral-ligament-of-the-knee.html clinicaltrials.gov/ct2/show/NCT02680821 www.kneesurgeryacl.com/new-knee-ligament/ www.hampshireknee.co.uk/all-anterolateral-ligament-reconstruction
AOL	www.emoryhealthcare.org/acl-program/surgical-recovery/acl-rehab-expectations.html orthopedics.about.com/cs/aclrepain/a/acldecision.htm	www.sydneyknee.com.au/wp-content/themes/ypo-theme/pdf/anterolateral-ligament-knee-evolution-acl-reconstruction.pdf

(continued)

TABLE 2 (continued)

Search Engine	Anterior Cruciate Ligament	Anterolateral Ligament
	ehealthmd.com/acl-tears/recovery-after-acl-reconstruction#axzz3xHN7NI00 www.webmd.com/a-to-z-guides/anterior-cruciate-ligament-acl-injuries-surgery health.ucsd.edu/specialties/surgery/ortho/areas-expertise/sports-medicine/conditions/knee/Pages/acl-tear.aspx www.healthline.com/health/acl-reconstruction	
Yahoo	www.sydneyhipandknee.com.au/knee-acl-reconstruction-surgery-sydney-hip.html	
Bing	index.about.com/index? am=broad&q=acl+reconstruction&an=msn_s&askid=7ae7051c-b3bb-4e47-8e73-43cdc54b8ceb-0-ab_msb&dqi=&qsrc=999&ad=semD&o=28795&l=sem	www.ncbi.nlm.nih.gov/pmc/articles/PMC2989041/ en.wikipedia.org/wiki/Anterior_cruciate_ligament www.cartilagerestoration.org/blog/anterior-lateral-ligament en.wikipedia.org/wiki/Anterior_cruciate_ligament_reconstruction

described in previous work.[4] Academic websites were defined as those with an affiliation to a university or medical society. Physician websites included professional sites for individual physicians or group practices not affiliated with an academic institution. Media websites were nonmedical news-oriented sites. Websites were considered commercial if they included products for sale. Social media included websites such as YouTube, Facebook, and Twitter. Finally, advertisement was any website that displayed advertisements.

Websites were assessed for quality and validity by use of the DISCERN score,[6] and a pathology-specific content score was used for both ACLR and ALLR to assess the quality of information in each search. In addition, the *Journal of the American Medical Association* (JAMA) benchmark criteria[21] and the presence or absence of a Health on the Net code (HONcode) certification were noted.[3]

The DISCERN tool was designed to allow consumers and information providers to determine the quality of health information for treatment choices.[6] The tool has 16 questions; the first 8 questions relate to the reliability of the publication, and 7 questions address specific details of the information about treatment choices. The final question assesses the overall quality of the website. Scores of 60 or higher represent websites that are useful and appropriate sources of information, while scores of 30 or lower are indicative of websites with serious shortcomings that are not appropriate sources of information.

To ascertain the information value of each website specifically related to the surgical procedure in question, a pathology-specific content score was developed for both ACLR and ALLR. The ACLR-specific content score was modified from a similar tool developed and published by Bruce-Brand et al[4] (Table 3). A similar tool using the same format was designed to assess the value of information for ALLR (Table 4). One point is allocated for the presence of predefined terms that relate to general characteristics of the condition, the prognosis, options for treatment, and complications, resulting in a score between 0 and 20. This was done in consultation with a fellowship-trained orthopaedic sports surgeon (B.M.D.) and by referencing peer-reviewed literature. A higher score indicates a more informative website.

TABLE 3
Scoring for Web Content Specific to ACL Reconstruction[a]

General	Management	Complications
Anatomy	Nonoperative	Infection
Mechanism of injury	Physical therapy	Graft failure
Function of ACL	Autograft reconstruction	Knee pain
Requirement for surgery	Allograft reconstruction	Degenerative knee
Associated injuries (eg, meniscus, lateral and medial collateral ligaments)	Synthetic reconstruction	
Timing of surgery	Anatomic reconstruction	
Rehabilitation	Revision reconstruction	
Return to sport/work	Meniscal repair	

[a]One point was allocated for each item mentioned on the website, for a total of 20 points. ACL, anterior cruciate ligament.

The JAMA benchmark criteria, originally published by Silberg et al,[21] consist of 4 categories to determine whether a source of information is credible: authorship, attribution, disclosure, and currency. Authorship requires the authors and contributors to provide their affiliations and credentials. Attribution relates to the listing of references and sources as well as all relevant copyright information. Disclosure is assessed on whether website “ownership” is fully disclosed as well as any sponsorship, advertising, commercial funding, or conflicts of interest. Currency requires that the website provide the dates when the content was posted and updated. One point is allocated for each of the criteria that are met, with a maximum score of 4; a score of 4

TABLE 4
Scoring for Web Content Specific to ALL Reconstruction[a]

General	Management	Complications
Anatomy of ALL	Indication for surgery	Infection
Function of ALL	Direct repair	Graft failure
Segond fracture	Extra-articular reconstruction	Knee pain
Mechanism of injury	Anatomic reconstruction	Degenerative osteoarthritis
Requirement for treatment	Synthetic graft	
Revision surgery	Allograft	
Return to sport/work	Autograft	
Evidence for treatment	Revision anterior cruciate ligament reconstruction	

[a]One point was allocated for each item mentioned on the website, for a total of 20 points. ALL, Anterolateral ligament.

indicates a credible source, while a score of zero indicates that the source of information is questionable.

The HONcode seal is used as a mark of accreditation for websites that comply with listed standards and publish transparent health-related information.[3] The presence or absence of this seal was assessed for each website.

Independent *t* tests were used to compare means between ACLR and ALLR. The Pearson correlation coefficient was used to assess convergent validity between scales, and the intraclass correlation coefficient (ICC) was used to measure interrater reliability for the new pathology-specific content scores. Statistical analysis was performed by use of R 3.3.2/RStudio 1.0.136. The level of significance was set at 5%.

RESULTS

Patient Questionnaire

Overall, 84% of the patients (42/50) used the internet to research their procedure preoperatively. Of these, 40 (95%) used Google as the primary search engine (Figure 1). Thirty-two percent of patients (16/50) had prior knowledge of the ALL. The knowledge was from variable sources, most frequently from online information (7/16; 44%). The other sources were word of mouth (4/16), medical professionals (2/16), and academic studies (3/16).

Website Analysis

A total of 41 unique websites were analyzed for ACLR, and 40 unique websites were analyzed for ALLR (see Table 2). Figure 2 shows the breakdown according to website type. The majority of ACLR websites were physician produced (n = 23; 56%). In contrast, the majority of ALLR websites were academic (n = 18; 45%), but physician-produced websites were also numerous (n = 11; 27.5%). Figure 3 illustrates the origin of the websites from each of the searches. The

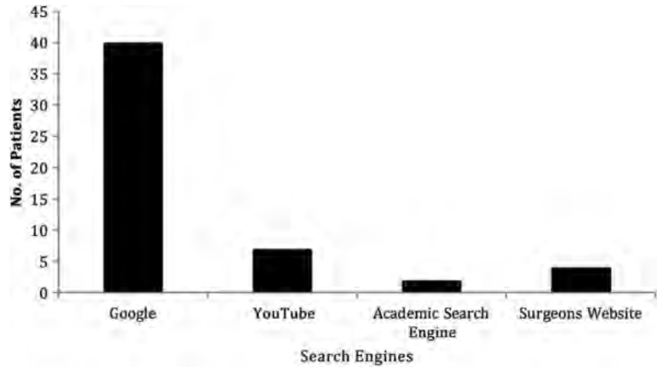

Figure 1. Frequency of websites used for anterior cruciate ligament reconstruction searches.

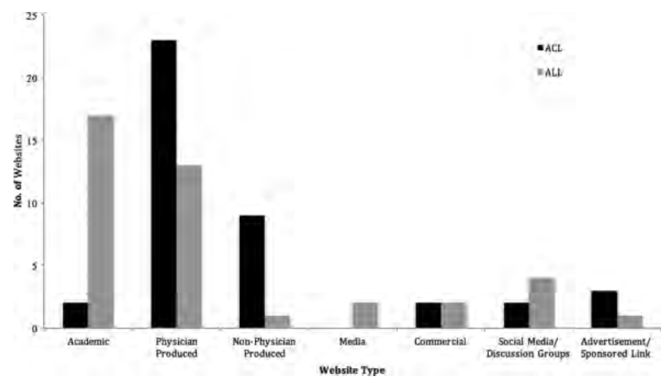

Figure 2. Frequency of website type returned for anterior cruciate ligament (ACL) and anterolateral ligament (ALL) reconstruction searches.

majority of websites returned for ACLR were Australian (n = 23; 56%), whereas the majority of websites analyzed for ALLR were international sites (n = 37; 92.5%).

DISCERN Scores

The mean DISCERN score for ACLR websites was 54.37 ± 4.6, whereas the score for ALLR websites was 37.3 ± 3.4 ($P < .0001$). Eighteen ACLR websites scored 60 or higher on the DISCERN tool, representing websites that are useful and appropriate sources of information. Only 2 ALLR websites scored 60 or higher. Four ACLR websites scored 30 or lower on the DISCERN tool, representing websites with serious shortcomings that are not appropriate sources of information, compared with 8 ALLR websites. Figure 4 demonstrates DISCERN scores by website type.

Pathology-Specific Content Score

Figure 5 demonstrates the distribution of specific content scores according to website type for ACLR and ALLR. The highest score for an ACLR website was 18 of 20, which was recorded in both academic and physician-produced sites. The highest score for an ALLR website was 17 of 20, which was for a commercially produced website.

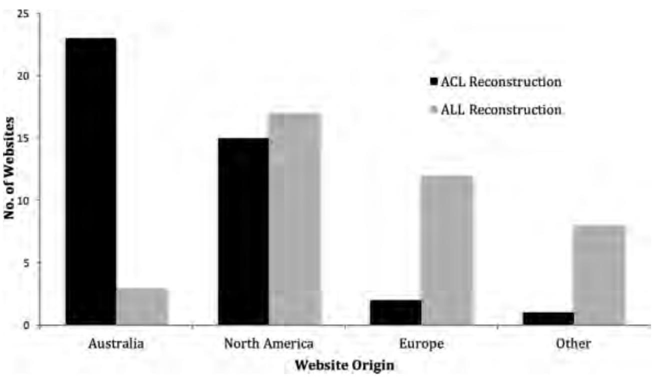

Figure 3. Origin of websites returned for anterior cruciate ligament (ACL) and anterolateral ligament (ALL) reconstruction searches.

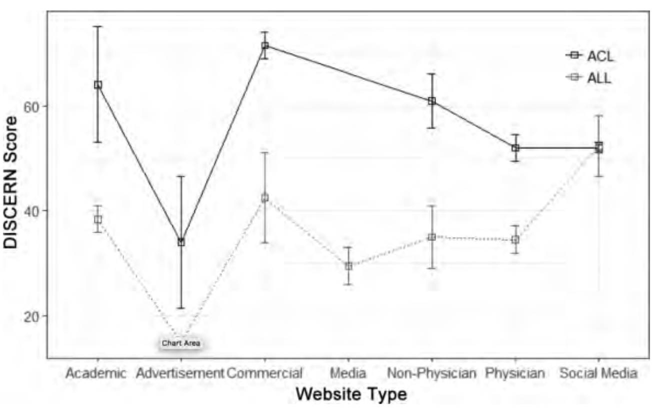

Figure 4. DISCERN scores by website type returned for anterior cruciate ligament (ACL) and anterolateral ligament (ALL) reconstruction searches.

Regarding ACLR websites, the greatest deficiency in terms of content was information on complications, specifically the potential to develop osteoarthritis, which was mentioned on only 4 websites. ALLR websites demonstrated a more widespread deficiency in content; only 9 websites discussed the mechanism of injury, 13 websites mentioned the requirement for treatment, and 8 websites listed a complication of any type related to the surgery.

Regarding pathology-specific content scores, ACLR websites had a mean score of 11.05 ± 1.5 (out of 20), which was significantly higher than the mean score for ALLR websites—5.3 ± 1.3 (P < .0001). Figure 6 shows the frequency distributions for pathology-specific content scores among website types. A notable difference was found in the distribution of specific content scores. For ACLR websites, 14 was the most frequent score, while for the ALLR websites the most frequent score was zero.

JAMA Benchmark Criteria

The mean JAMA benchmark criteria score for ACLR websites was 1.9 ± 0.4, and that for ALLR websites was 2.8 ± 0.4

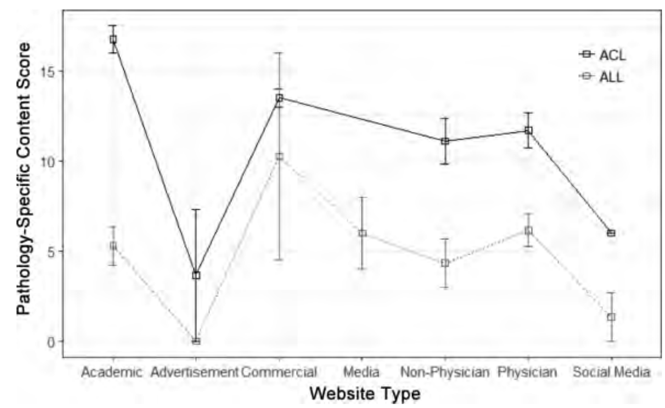

Figure 5. Pathology-specific content score by website type returned for anterior cruciate ligament (ACL) and anterolateral ligament (ALL) reconstruction searches.

(P = .007) (Figure 7). Four ACLR sites had maximal scores compared with 13 ALLR sites.

Convergent Validity and Reliability

The ACLR-specific content scores demonstrated close correlation with the DISCERN scores (ICC, 0.58; 95% CI, –0.33 to 0.75; P < .0001) but no correlation with the JAMA benchmark criteria (ICC, 0.13; 95% CI, –0.19 to 0.42; P = .43). The ACLR-specific content scores demonstrated high intraclass correlation, reflecting excellent internal consistency of the new tool (ICC, 0.997; 95% CI, 0.994-0.998; P < .0001).

The ALLR-specific content score demonstrated correlation with the DISCERN scores (ICC, 0.49; 95% CI, 0.21-0.70; P = .0013) but no correlation with the JAMA benchmark criteria (ICC, 0.26; 95% CI, –0.06 to 0.53; P = .1085). We found 2 outliers between the DISCERN score and the ALLR-specific content score, scoring highly on the DISCERN score and poorly on the ALLR-specific content score. If these outliers are excluded, the intraclass correlation is 0.72 (95% CI, 0.52-0.85; P < .0001). The ALLR-specific content score demonstrated a high intraclass correlation of 0.877 (95% CI, 0.780-0.933; P < .001).

HONcode Certification

Six (14.6%) of the ACLR websites were HONcode certified compared with 1 (2.5%) of the ALLR websites. ACLR websites with HONcode certification demonstrated a mean DISCERN score of 72.50 (95% CI, 69.87-75.13), whereas websites without HONcode certification had a mean score of 51.23 (95% CI, 46.42-56.04; P < .0001). ACLR websites with HONcode certification demonstrated a mean JAMA score of 3.67 (95% CI, 3.13-4.21), whereas websites without HONcode certification had a mean score of 1.60 (95% CI, 1.28-1.92; P < .0001). No significant difference was found in ACLR-specific content scores between websites with HONcode certification and websites without (12.75; 95% CI, 10.77-14.73 vs 10.73; 95% CI, 8.92-12.54; P = .1006). One ALLR website contained HONcode certification.

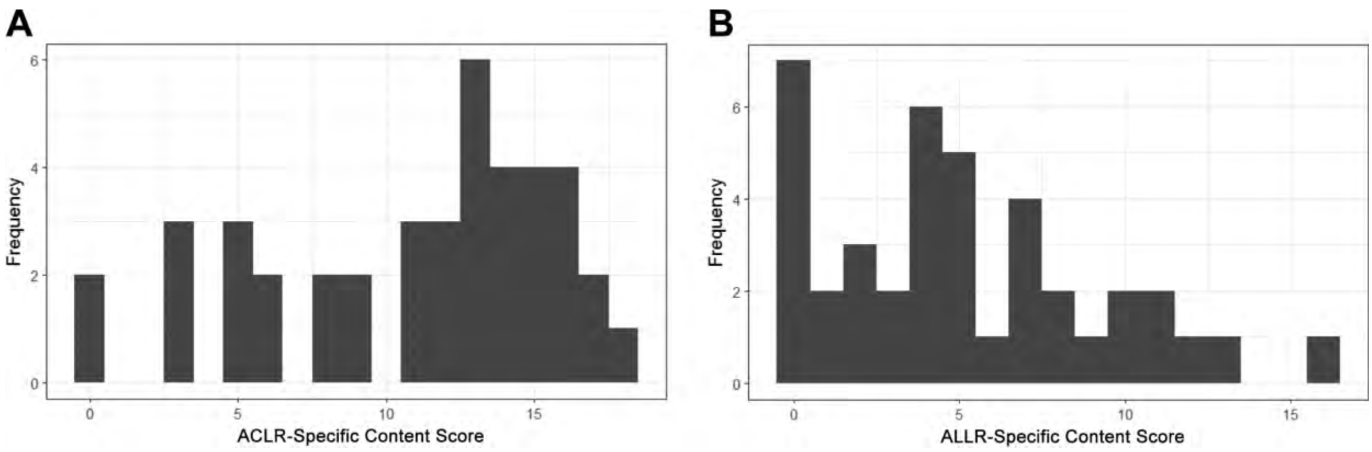

Figure 6. The frequency distribution of pathology-specific content scores among websites. (A) Anterior cruciate ligament reconstruction (ACLR)–specific content score. (B) Anterolateral ligament reconstruction (ALLR)–specific content score.

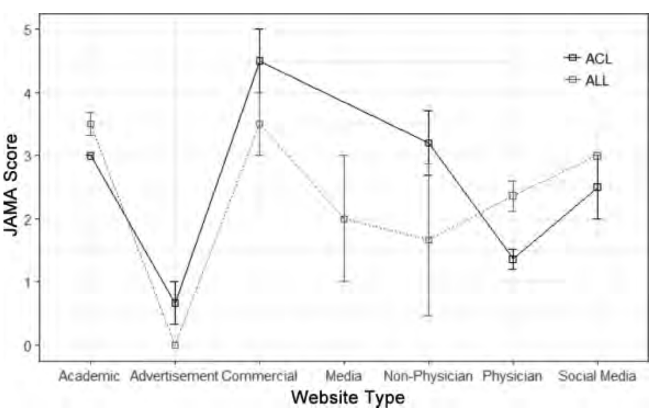

Figure 7. JAMA score by website type returned for anterior cruciate ligament (ACL) and anterolateral ligament (ALL) reconstruction searches.

DISCUSSION

The main finding of this study was that the quality of information found on the internet by Australian users was significantly better for ACLR compared with ALLR over a variety of website types.

The vast majority of patients undergoing ACLR who were surveyed used the internet preoperatively to research their operation. The primary source of internet information on ACLR was from physician-produced websites, while information on ALLR was predominantly from academic websites. Despite this, only 2 of 40 websites related to ALLR were considered to be a useful and appropriate source of information, while 8 had serious shortcomings according to the DISCERN quality criteria for consumer health information. Interestingly, a marked contrast was noted in terms of the countries where the ACLR and ALLR websites were generated. The overwhelming majority of ALLR websites were international (92.5%), coming from Europe and North America, while the ACLR websites were predominantly from Australia (56%). This perhaps reflects that ALLR is not an established practice but an emerging procedure, which is being championed mainly in Europe and North America, whereas ACLR is more common in Australia and is the topic of a greater majority of local websites.

An assessment of the informational value using a pathology-specific content score for each procedure revealed that compared with ACLR websites, ALLR websites were notably lacking in information related to the indications for treatment and potential complications of the procedure. Interestingly, industry-sponsored (commercial) websites had the highest ALLR-specific content score. The content pathology-specific score used was found to be reliable and correlated well with the DISCERN scores for both ACLR and ALLR. These findings raise concerns regarding the quality of information on the internet related to ALLR.

The internet has created a unique conduit through which new research, which previously remained in the domain of academic journals and scientific meetings until its validity had been debated, is rapidly released into mainstream circulation. This poses a distinct risk that patients are exposed to incomplete information and the promise of emerging treatments that have not undergone rigorous assessment. The ubiquity of this information is borne out in the current study, where an analysis of 50 postoperative ACLR patients revealed that 32% had prior knowledge of the ALL, most of whom had found this information through the internet.

A comprehensive array of analytic methods was used to assess the quality of information on the internet for the chosen surgical techniques. This was done to account for the fact that no single assessment tool was designed to cover all areas, such as the credibility of the websites, the validity and quality of the information, and the relevance of the specific content. Interestingly, each of the analysis methods yielded unique findings that, when considered together, provided a detailed assessment of the website value. Although both ACLR and ALLR websites were considered credible sources of information according to JAMA benchmark criteria, we found a substantial gulf in quality of information provided on the websites, as assessed by DISCERN and specific content scoring systems as well as the presence of an HONcode certification. The use of ACLR as a benchmark proved appropriate in this study, as the information available on the ACLR websites was generally of high quality. In contrast, the pathology-specific content information related to ALLR contained a disproportionate amount of information on the anatomic features and function of the ALL without adequately informing the patient about the indications for treatment, treatment options other than surgery, and, critically, the potential complications of surgical reconstruction.

This lack of credible material is an area of concern and has the potential to lead to *cyberchondria*, which is defined as an undue level of stress or anxiety brought about through a patient's exploration of health symptoms via the internet.[2] It has been suggested that this misinformation can affect the patient-doctor relationship, as the doctor may be required to dispel mistruths and re-educate the patient as part of a routine consultation, which is not always an easy task.[4]

The internet is used not only as a source of information but also as a platform for marketing. To this end, in a very competitive marketplace, physicians are increasingly using personalized websites to promote their practices and the procedures they offer.[20] Our study clearly demonstrated this trend in the percentage of physician-produced websites providing information on ACLR (56%), which is perhaps one of the most competitive areas in orthopaedics. In an attempt to gain market share, surgeons often seek to offer new, state-of-the-art procedures with the potential for improved outcomes.[20] This was seen in our study, where the second-largest internet source of information on ALLR was from physician-produced websites (27.5%).

An assessment of the quality of information on physician-produced sites using a specific content tool revealed that although the information for ACLR was consistently of good quality, the same could not be said for ALLR. One of the major criticisms of the recent interest in ALLR is that it was potentially industry driven, without rigorous clinical outcomes or comprehensive follow-up.[15] The current study does not entirely support this claim, as industry-sponsored websites accounted for only 2 of 40 websites. Furthermore, the highest quality of information on ALLR was found on one of these industry-sponsored websites.

The poor quality of information from the most commonly accessed source of information for ALLR—the academic sites—is a cause for concern. This finding is in contrast to previous studies, which determined that academic websites were typically sources of high-quality information.[4,24] An explanation for this shortfall in quality could relate to perceived urgency to remain current and provide readable information. Studies have demonstrated that patients are more inclined to seek out information that is simply displayed and easy to understand.[12] The reader demographic should also be considered, which in the setting of ACLR is typically young patients. Küçükdurmaz et al[12] investigated the readability of internet health information on femoroacetabular impingement by using a formula that calculated sentence length and syllables per word. Their study concluded that the websites intended to attract patients searching for information are providing a highly accessible, readable information source but do not appear to be quite so rigorous when it comes to inclusion of scientific literature. The findings of the current study are consistent with those of Küçükdurmaz et al[12] and suggest that "dumbing down" information for a lay audience can result in omission of many critical elements.

In the current study, the specific content scores were found to be a valuable addition to the DISCERN score to provide a more specific analysis of the quality of website material. Although the DISCERN score is well recognized and is useful in determining the reliability and quality of the content being presented, the score does not entirely address the relevance of the information. Exploring the correlation between the 2 scoring systems highlighted this point; 2 outliers were clearly identified that scored highly on the DISCERN but scored very poorly on the ALLR-specific content score. The reason for this was that only 1 of 16 questions in the DISCERN score refers to the general relevance of the information being assessed. The websites in question contained all the appropriate headings, but the content was completely unrelated to ALLR.

ALLR is an emerging procedure and as such lacks long-term follow-up that may affect the pathology-specific content score. But one would expect that this very fact should be mentioned by a source that is providing pathology-specific content outlining the evidence for treatment or expectations from surgery. While other lateral extra-articular procedures have been described, they were not included in this study as a search term because they do not purport to reconstruct the ALL anatomically or otherwise but were used originally to control anterolateral instability. Whether the ALL alone is integral in controlling anterolateral instability remains a contentious issue. Furthermore, many of these lateral extra-articular procedures were in use long before the ALL was initially described and have not been the topic of "viral trending" in recent times or the subject of the same promotion.

Limitations

We acknowledge that this study has limitations. The assessment of quality was performed at a single time point and did not take into consideration temporal trends that exist on the internet. Also, this study was conducted in a single country; therefore, national websites may have achieved a greater representation than if the study had been performed in a different country. The specific websites related to ACLR are likely to have differed to a greater extent between countries given that the majority were Australian sites (56%). Although the search term *ACL reconstruction* was chosen based on the results of the patient questionnaire, we chose the search term *anterolateral ligament reconstruction* because the patients surveyed lacked a consistent level of knowledge of the structure. A search for *ALL reconstruction* would likely have resulted in a different website yield because of the ubiquity of the acronym *ALL*. Finally, the readability of the websites was not determined.

CONCLUSION

This study found that the majority of patients undergoing ACLR in Australia use the internet to research the procedure. The quality of information on the internet relating to ALLR was significantly inferior to the information regarding ACLR. The majority of ALLR websites failed to include crucial information about the indications for surgery, treatment options, prognosis, and potential complications. Given the recent viral trends of dubious information being disseminated through the internet, orthopaedic surgeons should be aware of the information to which their patients are exposed and should be proactive in directing patients to appropriate websites.

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Epilogue

"There is no such thing as bad publicity except your own obituary"

\- *Brendan Behan*

One of the real concerns within the orthopaedic community following the emergence of techniques to reconstruct the ALL was that the device industry was using the discovery of the ALL as an opportunity to sell their products to reconstruct it. This was in the absence of convincing evidence to support the role the ALL had in controlling rotational laxity of the knee or any advantage which might be gained by reconstructing it. To many this appeared to be a case of the tail wagging the dog, as evidenced by a sensational headline in the New York Times which stated: *"Surgery Fixes a Ligament (If It Exists): Does It Fix the Knee?" (21).* In the article, the journalist uses the example of ALL reconstruction to describe how *"an untested treatment can quickly make its way from the pages of an obscure publication to the operating room."*

However, the current study has revealed that industry-sponsored websites accounted for only 2 of 40 websites found when searching for ALL reconstruction through standard search engines. What is more, the highest quality of information on ALL reconstruction was found on one of these industry-sponsored websites. This finding was an unexpected and surprising to me, which perhaps reflected my own personal scepticism and doubt regarding the motives of the orthopaedic device industry that I held at the outset of this study. And, while it does not entirely clear them of the allegation of unsubstantiated promotion of an unproven technique it would suggest that some responsibility has been taken in trying to provide relevant details on the indication for ALL reconstruction and the potential complications associated with it. Perhaps, what is more concerning is that physician-websites, which represented the second most common website group (11/40 websites – 27.5%), provided content which was lacking detail on the indications for and complications related to ALL reconstruction.

So, six years on from the publication of the first ALL reconstruction technique and following sustained and staunch criticism, one might have thought its use would have died off(13, 65, 66, 132, 134, 135). However, the opposite appears to be the case with its popularity increasing(22). It goes to show there is no such thing as bad publicity, but perhaps, with all things considered, it might be best to choose a surgeon who reads the scientific journals and not just the newspapers.

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Chapter 10: What is the role for lateral extra-articular augmentation procedures in the setting of primary anterior cruciate ligament reconstruction?

Introduction

"Fake news" or *"alternative facts"*?

The term "Fake news" has entered the modern lexicon over the past number of years, largely due to its frequent usage by the President of the United States of America, Donald Trump. The phrase describes stories which are deliberately used to misinform or to deceive the reader(136). "Alternative facts" is another expression which was coined by Kellyanne Conway, adviser to the President, during an interview in which she defended a false statement about the attendance numbers at Donald Trump's inauguration as President of the United States of America.

There has been a huge amount of condemnation regarding claims about the importance of the ALL, let alone its existence in the first place(21); this has included its discovery being described as "Fake news" during presentations at meetings – a charge of which I am personally guilty. But, as has been outlined so far in this thesis, according to the definition of the term, to label the ALL as "Fake news" would be disingenuous and inaccurate considering there was certainly no deliberate intent by authors to misinform or deceive the readers following publication(1). However, what has emerged from the furore of criticism is perhaps the "alternative fact" and the realisation that injury to the anterolateral aspect of the knee may be of crucial importance following ACL injury(13). Whereas the emergence and popularity of ALL reconstruction was arguably a little hasty, it has been shown to have a beneficial effect when performed in conjunction with ACL reconstruction in terms of decreased rates of re-injury(21, 137-139). This in itself raises a few questions: Why is the reconstruction of a structure which assumes, at best, a secondary role within the anterolateral complex effective? And, what are indications for its use?

It is important to realise that the ALL reconstruction is simply another version of a lateral extra-articular augmentation procedure(135). Surgeons have used procedures on the lateral side of the knee for the treatment of ACL-deficient knees long before intra-articular ACL reconstructions were devised and performed(28). The ability of these procedures to control rotation of the knee has been well recognised(48). Therefore, to further understand when a lateral extra-articular tenodesis (LEAT) may be of benefit in addition to an ACL reconstruction, it is probably worth trying to learn from the mistakes and successes of the past. The following study aims to achieve this through a systematic review of the literature with meta-analysis and best-evidence synthesis.

The manuscript is published in the Orthopaedic Journal of Sports Medicine as:

> *Devitt BM, Bell SW, Ardern CL, Hartwig T, Porter TJ, Feller JA, Webster KE.*
> *The Role of Lateral Extra-articular Tenodesis in Primary Anterior Cruciate Ligament Reconstruction: A Systematic Review With Meta-analysis and Best-Evidence Synthesis.*
> *Orthop J Sports Med. 2017 Oct 24;5(10):2325967117731767.*

This review was awarded the Douglas W. Brown award for best review paper by the American Orthopaedic Society for Sports Medicine

Contribution

Mr Devitt, Dr Ardern, and Professor Webster contributed to the conception and design of this manuscript. Mr Devitt, Mr Bell and Dr Ardern carried out the systematic review. Mr Devitt and Professor Webster performed the meta-analysis and best-evidence synthesis of the data. Mr Devitt wrote the manuscript. Mr Devitt, Mr Bell, Dr Ardern, Mr Hartwig, Ms Porter, Professor Webster and Professor Feller revised the manuscript for important intellectual content.

Conference presentations

This work was presented at a national conference:

Devitt BM, Bell SW, Ardern CL, Hartwig T, Porter TJ, Feller JA, Webster KE. The Role of Lateral Extra-articular Tenodesis in Primary Anterior Cruciate Ligament Reconstruction: A Systematic Review With Meta-analysis and Best-Evidence Synthesis. Australian Knee Society Meeting. October 2017, Noosa, Queensland.

The Role of Lateral Extra-articular Tenodesis in Primary Anterior Cruciate Ligament Reconstruction

A Systematic Review With Meta-analysis and Best-Evidence Synthesis

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Investigation performed at OrthoSport Victoria, Epworth Healthcare, Melbourne, Australia, and the School of Allied Health, La Trobe University, Melbourne, Australia

Background: The role of lateral extra-articular tenodesis (LEAT) to augment primary anterior cruciate ligament reconstruction (ACLR) remains controversial.

Purpose: To determine whether the addition of LEAT to primary ACLR provides greater control of rotational laxity and improves clinical outcomes compared with ACLR alone and to assess the impact of early versus delayed ACLR.

Study Design: Systematic review; Level of evidence, 3.

Methods: Two reviewers independently searched 7 databases for randomized and nonrandomized clinical studies comparing ACLR plus LEAT versus ACLR alone. Animal, cadaveric, and biomechanical studies; revision or repair procedures; and studies using synthetic ligaments and multiligamentous-injured knees were excluded. Risk of bias was assessed with a modified Downs and Black checklist. The primary outcome was postoperative pivot shift. These data were pooled by use of a fixed-effects meta-analysis model. The studies were divided into delayed (>12 months) and early (≤12 months) reconstruction groups for meta-analysis. A best-evidence synthesis was performed on the remaining outcome measures.

Results: Of 387 titles identified, 11 articles were included (5 of high quality). Meta-analysis of postoperative pivot shift in 3 studies of delayed primary ACLR showed a statistically significant difference for the pivot-shift test in favor of ACLR with LEAT (odds ratio [OR], 0.44; 95% confidence interval [CI], 0.24-0.81; $P = .008$; $I^2 = 0$). Meta-analysis of 5 studies of early primary ACLR found no statistically significant difference with the addition of LEAT (OR, 0.60; 95% CI, 0.33-1.09; $P = .10$; $I^2 = 33\%$). Insufficient evidence was available to determine whether the addition of LEAT had any effect on clinical, objective, subjective, and functional outcomes.

Conclusion: In primary ACLR, no evidence is available showing additional benefit of LEAT in reducing the postoperative pivot shift in early reconstructions (≤12 months); however, LEAT may have a role in delayed ACLR. Strong evidence exists that a combined ACLR and LEAT reduces lateral femoral translation, but there is insufficient evidence to identify any benefit for other clinical outcomes.

Keywords: lateral extra-articular tenodesis; primary anterior cruciate ligament reconstruction; surgical timing; pivot shift

Interest in the concept of anterolateral rotatory instability of the knee has been renewed following recent descriptions of the anatomic features of the anterolateral ligament (ALL).[6,7,13,14,26] Hughston et al[24] postulated that this type of instability was caused by a tear of the middle one-third of the lateral capsular ligament but may be accentuated by other tears, principally rupture of the anterior cruciate ligament (ACL). Investigators have reported that anterolateral rotatory instability was most accurately demonstrated by the jerk test, a variation of the pivot-shift maneuver.[24,27]

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It has since been established that the lateral one-third of the lateral capsule and the ALL are continuous.[6]

Surgeons have long recognized that extra-articular augmentation procedures offer a powerful tool to control rotation of the knee.[42] The concept of combining a lateral extra-articular augmentation with an intra-articular reconstruction for the treatment of ACL injury emerged with the objective of decreasing the failure rate of either technique carried out in isolation.[8,50,62] The approach became popular in the 1980s and was adopted by a number of surgeons using a variety of extra-articular augmentation procedures.[16,17] Although most of these procedures diminished or obliterated the pivot shift, extra-articular augmentation fell out of favor when reports emerged about its unpredictability and unsatisfactory results.[18,25,58] Biomechanical and clinical studies suggested that intra-articular reconstruction of the ACL alone would be sufficient in the treatment of knee instability following isolated ACL tear and that extra-articular procedures added little to the overall functional outcome.[1,2,37,38,51] As the incidence of ACL reconstruction (ACLR) has increased significantly over the past 2 decades, so too have the revision rates for this procedure, which now represent a significant surgical burden.[20,28,29,39,55,59] Consequently, interest has been renewed in lateral extra-articular tenodesis (LEAT) in combination with ACLR in the primary setting as a way of potentially reducing the rate of reinjury.

Two recent systematic reviews have been conducted on this topic.[21,48] Hewison et al[21] systematically reviewed all comparative studies to determine whether the addition of LEAT to ACLR would provide greater functional stability and improved clinical outcomes compared with ACLR alone. Although the results are comprehensive, the studies included were quite heterogeneous, consisting of multiple extra-articular reconstructions performed in combination, revision procedures, the use of synthetic ligaments, and nonconventional ACLR grafts. In the other systematic review, Song et al[48] included all levels of evidence and focused on the clinical outcomes of combined LEAT and intra-articular ACLR in both primary and revision ACLR addressing the high-grade pivot-shift phenomenon. While these reviews are helpful, they do not answer 2 key questions: Is there a role for LEAT in combination with intra-articular ACLR in primary ACL surgery? What impact does the interval from ACL injury to primary reconstruction have on the effectiveness of LEAT to control rotational stability?

The primary aim of this systematic review was to determine whether the addition of LEAT to a primary ACLR would result in improved rotational stability and clinical outcomes compared with ACLR in isolation. The secondary aim was to determine whether the time interval between injury and surgery influenced postoperative rotational stability.

METHODS

This systematic review with meta-analysis followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines.[30]

Search Strategy

Articles were identified via a search of the electronic databases MEDLINE, CINAHL, EMBASE, SPORTDiscus, the Cochrane Library, AusportMed, and PEDro. Database entries were searched from the earliest reported date (January 1950 for Medline) to April 2016. Search terms were mapped to relevant MeSH terms or subject headings where possible.

Search terms were entered into the database under 2 concepts: Concept 1—“anterolateral ligament,” “anterior oblique band,” “lateral capsular ligament,” “ALL,” “extra-articular,” “extraarticular procedure,” “lateral tenodesis,” “Segond,” “Lemaire,” “Losee,” “MacIntosh,” “Ellison,” “iliotibial band,” “knee,” “reconstruction”; Concept 2—“follow up,” “objective,” “subjective,” “patient reported outcome,” “clinical outcome.” Keywords in each concept were grouped with the “OR” operator. The results from each concept were then combined with the “AND” operator to produce the search strategy and the final yield. To supplement the electronic database search, the reference lists of relevant papers were cross-checked, and forward citation tracking via the Web of Science electronic database was conducted.

Publication details from all studies identified in the literature search were exported to bibliographic software.

Selection Criteria

The following inclusion criteria were applied to the final yield:

- Published peer-reviewed study: either randomized controlled trial (RCT) or case-control study (CCS)
- Outcome data presented following primary ACLR combined with LEAT procedure
- Minimum 2 years of follow-up

If a study included primary and revision ACL reconstruction with LEAT, it was only included if the number of primary ACL reconstructions accounted for more than 80% of the total cohort. In addition, only procedures performed on skeletally mature patients and reported in the English language were included. All criteria had to be satisfied for inclusion.

The exclusion criteria were as follows:

- Extra-articular procedure performed in isolation
- Synthetic graft used for ACLR or LEAT
- Cases with more than 2 surgically treated knee ligaments
- ACLR combined with alignment knee surgery
- ACL repair in conjunction with LEAT
- Reports on guidelines, technical notes, reviews, or systematic reviews

When the selection criteria were applied, the title and abstract of each study were initially reviewed. In the cases where it was not clear from the review of the title and abstract whether a study was appropriate for inclusion, the full text of the article was examined. Two reviewers applied the selection criteria independently (B.M.D. and S.W.B.).

TABLE 1
Summary of Extracted Data[a]

Study Details	Surgery Details	Outcome Measures				
		Clinical	Objective	Subjective	Functional	Radiographic
Type of study	Time injury to surgery	ROM	KT-1000/2000	IKDC	Lysholm	Plain radiograph
Number of patients	Type of LEAT	Pivot shift	Cybex	HSS	Tegner	Dynamic/stress
Study period	Type of ACLR	Other	Other	Other	Other	
Country	Rehabilitation					
Follow-up						

[a]ACLR, anterior cruciate ligament reconstruction; HSS, Hospital for Special Surgery; IKDC, International Knee Documentation Committee; LEAT, lateral extra-articular tenodesis; ROM, range of motion.

Consensus was used to resolve any disagreements between reviewers, and a third reviewer was consulted if consensus could not be reached. In the case of multiple reports on the same patient cohort with an increasing duration of follow-up, only the article with the longest follow-up was included.

Risk of Bias

The risk of bias of the included articles was independently assessed by 2 reviewers (B.M.D. and S.W.B.) using a modified version of the Downs and Black scale.[15] The Downs and Black scale is reliable for cohort and case-control study designs.[15] The modified version used in this study had a maximum score of 16, as previously reported; a score of ≥12 was defined as high quality, 10-11 as moderate quality, and ≤9 as low quality.[31,32] Any disagreements in initial ratings of methodological quality assessment were discussed until a consensus was reached between the 2 reviewers.

Data Extraction

Two independent reviewers extracted data using a data-extraction form specifically designed for this review. The primary outcome of interest was the assessment of rotational stability as measured by the pivot-shift test. The secondary outcomes were clinical, objective, subjective, functional, and radiographic outcomes. The descriptive data extracted are outlined in Table 1.

Data Synthesis and Analysis

A meta-analysis was performed when sufficient homogenous data were reported in the outcome measures. Data were analyzed by use of ReviewManager (RevMan, Version 5.3). A P value of less than .05 was considered statistically significant.

To address the primary aim, pivot-shift data were dichotomized to positive postoperative pivot shift (grade 1, 2, or 3) or negative pivot shift and were compared between patients who had ACLR alone and those who had ACLR with LEAT. A pooled odds ratio with 95% confidence interval (CI) was used. The Cochran Q statistic and the I^2 index were used to assess heterogeneity.[22] A larger I^2 index indicates that a greater amount of the variability in the results is due to heterogeneity rather than to chance.[23] Where there was large statistical heterogeneity ($I^2 < 50\%$), a fixed-effects meta-analysis model was used.

A subgroup analysis was performed to examine the influence of time between injury and surgery on the pivot-shift data. Patients who had early reconstruction (mean interval ≤12 months)[2,4,11,60,61] were compared with those who had delayed reconstruction (mean interval >12 months)[3,35,37,53] based on the time period from injury to surgery (Table 2). Studies in which the time period from injury to surgery was not clear or not listed were not included in the analysis.[5,54]

Best-Evidence Synthesis

To assist with evaluating the outcome findings that could not be assessed through meta-analysis due to the limited availability of homogenous data, a best-evidence synthesis combining RCTs and CCSs was performed. The method, proposed by Van Tulder et al[56] and adapted by Steultjens et al,[49] was used to ascribe levels of evidence of effectiveness, taking into consideration study design, methodological quality, and statistical significance of the findings (Appendix).

RESULTS

Search Results

The database search retrieved 364 records, and an additional 23 studies were found after reference checks. Following title and abstract screening, 128 potentially relevant studies were obtained in full text. A total of 117 studies were excluded for the following reasons: no LEAT performed (n = 40), noncomparative cohort study (n = 22), isolated LEAT without ACLR (n = 11), synthetic ligament used with LEAT or ACLR (n = 11), outcome not applicable to the study (n = 11), multiple combined procedures performed (n = 10), technical note (n = 4), revision ACLR with LEAT (n = 2), ACL repair (n = 3), and systematic review (n = 2); 2 separate studies[37,38] reported on the same cohort of patients, so O'Brien et al[38] was excluded (Figure 1).

Therefore, a total of 11 studies reporting on comparative studies of ACLR versus ACLR with LEAT were included for qualitative and/or quantitative synthesis (Table 3).

TABLE 2
Summary of Clinical Outcomes[a]

				Clinical Examination				Objective Testing		Subjective Outcomes			Functional Outcomes			
Study	Patients	Follow-up	Comparative Groups	ROM	Lachman	Pivot Shift	Other	KT-1000	Other	IKDC	HSS	Other	Lysholm Score	Tegner Scale	Other	Radiographic Evaluations
Time From Injury to Surgery ≤12 Months																
Anderson et al[2]	102	Mean 35.8 mo	BPTB, ST-GT(DS), ST-GT(DS) + LEAT	NS	BPTB	NS	PFC—NS	BPTB	Cybex-II—NS	BPTB	NS					
Barrett and Richardson[4]	70	Mean 2.9 y	BPTB + LEAT, BPTB	NS	NS	NS		NS				Satisfaction—NS	NS	NS		NS
Zaffagnini et al[60] (2008)	72	Mean 3.9 y	ST-GT(DS) + LEAT, DB HS	NS		DB		KT-2000 DB		DB				NS	Activity Rating Scale—DB Time to RTS—DB	
Zaffagnini et al[61] (2006)	75	Mean 5 y	BPTB, ST-GT, ST-GT(DS) + LEAT	ST-GT, LEAT	NS	BPTB and LEAT	One-leg-hop—NS; thigh muscle circumference—BPTB; pain increased—BPTB	KT-2000—BPTB and LEAT	QAT—BPTB and LEAT IKDC Objective—NS	BPTB and LEAT				NS	Time to RTS—LEAT	NS
Dejour et al[11]	75	Mean 25.3 mo	BPTB, DBH, BPTB + LEAT			NS	Less sensory deficit—DBH; less kneeling pain—DBH			NS		Ant knee pain—NS			RTS—NS	Tunnel enlargement ST-GT
Time From Injury to Surgery >12 Months																
Barber-Westin and Noyes[3]	84	Mean 37 mo	Allo BPTB, Allo BPTB + LEAT													
Noyes and Barber[35]	104	Mean 35 mo	Allo BPTB, Allo BPTB + LEAT					NS	PFC—NS			Cincinnati—NS			Level of sports activity—LEAT	
O'Brien et al[37]	80	Mean 4 y	BPTB + LEAT, BPTB				NS	NS	Pain LFC—LEAT		NS					
Trichine et al[53]	107	Mean 24 mo	BPTB, BPTB + LEAT			NS			Pain LFC—12% LEAT	NS					RTS—NS	Dynamic radiographic laxity—MFC: NS; LFC: BPTB + LEAT decreased laxity
Time From Injury to Surgery Not Indicated																
Branch et al[5]	18	Median 9 y	BPTB + LEAT, BPTB		NS	NS		NS	Robotic testing—BPTB + LEAT decreased ER vs normal limb; reduced total axial rotation; reduced IR	NS		KOOS—NS, VAS—NS				
Vadala et al[54]	60	Mean 45.2 mo	ST-GT, ST-GT + LEAT		NS	LEAT		NS	IKDC objective—NS	NS		VAS—NS	NS	NS		

[a]Allo, allograft; Ant, anterior; BPTB, bone–patellar tendon–bone; DB, double bundle; DBH, double-bundle hamstring graft; DS, double-strand; ER, external rotation; GT, gracilis tendon; HS, hamstring; HSS, Hospital for Special Surgery; IKDC, International Knee Documentation Committee; IR, internal rotation; KOOS, Knee injury and Osteoarthritis Outcome Score; LEAT, lateral extra-articular tenodesis; LFC, lateral femoral condyle; MFC, medial femoral condyle; NS, not significantly different; PFC, patellofemoral crepitus; QAT, Quadriceps Activity Test; ROM, range of motion; RTS, return to sport; ST, semitendinosus; VAS, visual analog scale.

Methodological Quality

The methodology quality scores ranged from 5 to 14 out of a possible score of 16 (Table 4). Five studies were considered high quality; 4 of these were RCTs,[2,53,60,61] and 1 was a CCS.[11] A further 4 studies were rated as moderate quality,[3,5,35,54] and 2 studies were rated as of low quality.[4,37] Two studies scored positively on item 14 (sample size calculation), while 5 studies reported blinding of assessors with respect to the postoperative pivot-shift assessment. None of the studies provided information on the possibility of selection bias.

Demographic Characteristics

The 11 included studies reported on 847 patients (66% men) (Table 3). The median age at surgery was 26 years (interquartile range [IQR], 4.1 years). A wide variation was noted in time from injury to surgery, with a median time period of 12.3 months (IQR, 33.5 months). In 1 study, time between injury and surgery was not reported,[5] and in 1 study a minimum time interval between injury and surgery was reported, which was 2 months.[54] In the early ACLR studies, the median interval between injury and surgery was 6.5 months (IQR, 6.8 months), and the

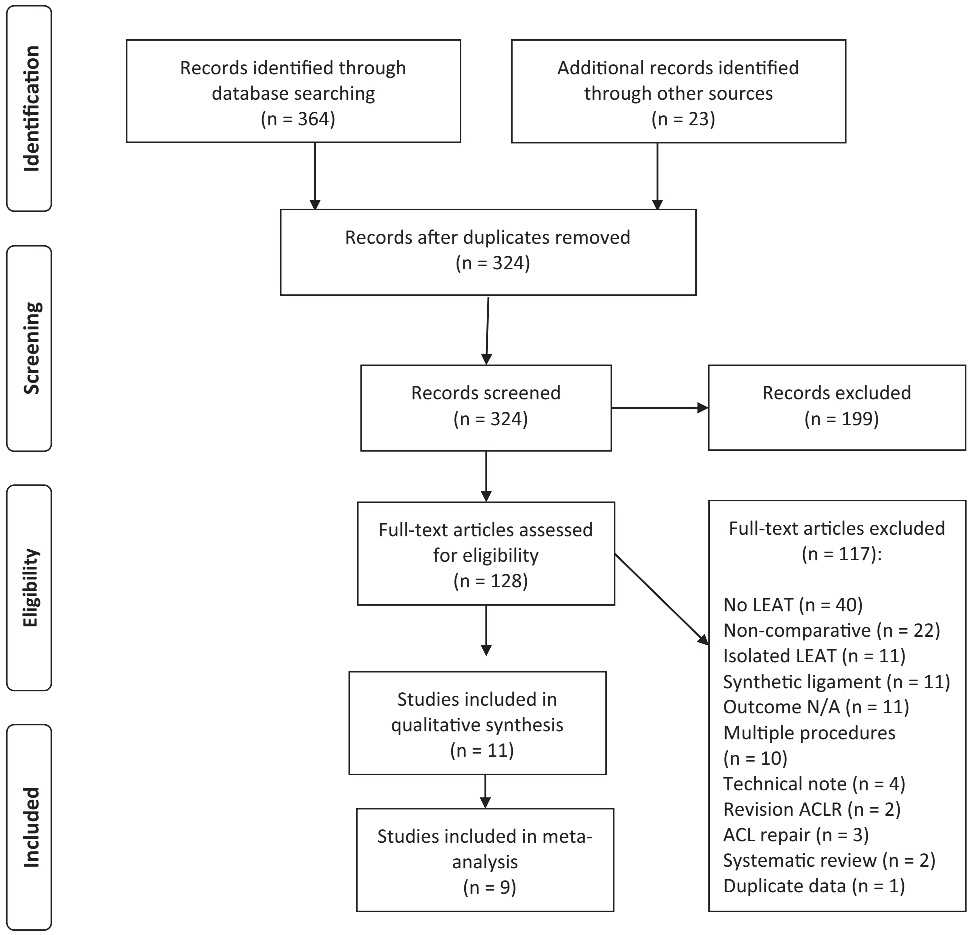

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram. ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; LEAT, lateral extra-articular tenodesis; N/A, not applicable.

delayed reconstruction studies had a median interval of 37.8 months (IQR, 5 months).

Nine of the 11 studies included data exclusively on patients undergoing primary ACLR. The other 2 studies[3,35] included data within their cohort of some patients who had undergone a prior ACLR, but these represented less than 20% of the total study population. Specifically, in the study by Barber-Westin and Noyes,[3] 9 of 52 (17%) patients in the ACLR group and 5 of 32 (16%) of patients in the ACLR with LEAT group had a failed ACLR. Noyes and Barber[35] included 9 of 64 (14%) patients in the ACLR group and 8 of 40 (20%) patients in the ACLR with LEAT group who had failed ACLR. Only the study by Noyes and Barber[35] was included in the delayed reconstruction meta-analysis data.

Meta-analysis Data

Due to the heterogeneity of the outcome data, a meta-analysis was possible only for pivot-shift data. A fixed-effects model was used as a result of I^2 values being less than 50% in all cases.

Primary Analysis—All Studies Regardless of Time From Injury to Surgery. Of the 11 studies included, 9 reported postoperative pivot-shift test findings (738 patients). Five were of high quality, 2 of moderate quality, and 2 of low quality. The odds of having a positive postoperative pivot shift were 52% lower in patients who had ACLR and LEAT compared with patients who had ACLR alone (odds ratio 0.48; 95% CI, 0.32-0.71; $P = .0003$; $I^2 = 22\%$; 95% CI for I^2) (Figure 2).

Subgroup Analysis—Early ACL Reconstruction (≤12 Months From Injury). Five studies reported on ACLR plus LEAT that was performed within 12 months of the index ACL injury (394 patients). Four of these studies were of high quality and 1 was of low quality. No statistical difference was found in the number of patients with a positive postoperative pivot-shift test between those who had a combined ACLR plus LEAT and those who had an isolated ACLR (odds ratio, 0.60; 95% CI, 0.33-1.09; $P = .10$; $I^2 = 33\%$) (Figure 3).

Subgroup Analysis—Delayed ACL Reconstruction (>12 Months From Injury). Three studies reported on ACLR plus LEAT that was performed more than 12 months

TABLE 3
Comparative Studies: ACLR Versus ACLR + LEAT[a]

Study	Design	N	Country	Study Period	Time From Injury to Surgery	Type of LEAT	Type of ACLR	Rehabilitation	Follow-up	Outcome Measures	Study Recommendation
Anderson et al[2]	RCT	102	USA	1991-1993	<0.5 mo (28 pts); 0.5-3 mo (45 pts); >3 mo (32 pts)	Losee extra-articular ITB tenodesis	Arthroscopic—Group 1: central third BPTB; group 2: ST and GT + LEAT; group 3: ST and GT	Brace (functional)—PWB. FWB 3 wk. Full and equal ROM 6 wk	ACL + LEAT: 35.7 ± 12.1 mo; ACL (ST): 35.9 ± 11.7 mo; ACL (PT): 34.6 ± 11.4 mo	Clinical: PS, PFC. Objective: KT-1000, Cybex. Subjective: IKDC Radiographic	LEAT not recommended for routine ACLR
Trichine et al[53]	RCT	107	Algeria	2007-2010	Group 1 (BPTB), 37.8 mo; group 2 (BPTB + LEAT), 35.4 mo	ITB fixed at LFC socket—"Kenneth Jones" technique	Arthroscopic—Central third BPTB	Brace—ROM, functional strengthening. PWB 3 wk. FWB after 4 wk.	Group 1 (BPTB): 24.5 mo (range, 6-63 mo); group 2 (BPTB + L): 23.4 mo (range, 6-45 mo)	Clinical: Lachman, PS, passive dynamic radiograph. Subjective: IKDC. Radiographic	Addition of LEAT reduced pivot shift and lateral translational in chronic ACL rupture
Zaffagnini et al[60] (2008)	RCT	72	Italy	2000-2002	ACLR + LEAT, mean 8.2 mo (range, 1-48 mo); ACLR, mean 6.9 mo (range, 1-48 mo)	OTT extra-articular augmentation using ST and GT	Group 1: Marcacci technique, ST and GT OTT, Pes intact + LEAT; group 2: double-bundle ST and GT	Brace—PWB 1 wk. FWB 3 wk.	Mean 3.9 y (range, 3-5 y)	Clinical. Objective: KT-2000. Functional: Tegner.	Double-bundle ACLR resulted in slightly higher knee stability and faster recovery of sport activity compared with single-bundle plus lateral plasty technique
Zaffagnini et al[61] (2006)	RCT	75	Italy	1998	Mean 6 mo (range, 4-12 mo)	OTT extra-articular augmentation using ST and GT	Group 1: central third BPTB; group 2: 4-strand ST and GT; group 3: Marcacci technique, ST and GT OTT, Pes intact.	PWB 2 wk. ROM, quadriceps muscle active exercises.	Mean 5 y	Clinical: Lachman, PS, ROM. Objective: KT-2000C. Subjective: IKDC. Functional: Tegner. Radiographic.	Superior outcome with single hamstring and extra-articular augmentation
Dejour et al[11]	CCS	75	France	2005	Group 1 (DBH), 16.54 mo; group 2 (BPTB), 12.96 mo; group 3 (BPTB + LEAT), 10.78 mo	Modified Lemaire extra-articular recons-truction using free GT	Arthroscopic—Group 1: central third BPTB; group 2: DB ST and GT; group 3: Central third BPTB + LEAT.	Full ROM and physical therapy immediately	Group 1 (DBH): 24.9 mo; group 2 (BPTB): 25.4 mo; group 3 (BPTB + LEAT): 25.6 mo	Clinical: PS, kneeling, and squat. Subjective: IKDC. Radiographic: Telos.	Addition of Lemaire extra-articular surgery showed superior stability in patients compared with non-Lemaire ACL reconstruction
Barber-Westin and Noyes[3]	CCS	84	USA	1985-1987	ACLR, 53 mo (range, 3-182 mo); ACLR + LEAT, 40 mo (range, 4-223 mo)	Losee extra-articular ITB tenodesis	Arthroscopic-assisted—Central third Allo BPTB	CPM. PWB 7-10 days. Four-phase structured rehabilitation program.	Group 1: 37 mo (range, 23-65 mo); group 2: 36 mo (range, 24-54 mo)	Clinical: Lachman, PS, ROM. Objective: KT-1000. Functional: Sports Activity Scale.	Significant difference between the 2 groups for final mean AP displacement: ACLR + LEAT was better than ACLR
Branch et al[5]	CCS	18	France	1998-1999	Not listed	GT free graft — fixation within bone block of the BPTP graft in the femoral tunnel within the LFC. Tibial attachment bone tunnel PT	Arthroscopic—Central third BPTB	Not listed	Median 9 y (range, 8-19 y)	Clinical: Lachman, PS. Objective: KT-1000, robotic testing. Subjective: KOOS, IKDC, VAS.	Addition of LEAT reduces internal rotation of the tibia compared with ACLR alone
Noyes and Barber[35]	CCS	104	USA	1985-1987	ACLR, mean 54 mo (range, 3-282 mo); ACLR + LEAT, mean 41 mo (range, 4-223 mo)	Losee extra-articular ITB tenodesis	Arthroscopic-assisted—Central third Allo BPTB	CPM. PWB day 7. Bledsoe brace 8 wk. FWB 8 wk.	Mean 35 mo (range, 23-54 mo)	Clinical: PS. Objective: KT-1000, Biodex. Subjective: questionnaire analysis.	Combined intra-extra reconstructions were successful in decreasing tibial displacement, although the allograft alone showed better results for the treatment of acute ruptures
Vadala et al[54]	RCT	60	Italy	2005-2006	Minimum interval 2 mo	Cocker-Arnold modified MacIntosh extra-articular ITB tenodesis	Arthroscopic—4-strand ST and GT	Brace—Full extension 1 wk. 0°-90° of flexion 2 wk, PWB. Removal of brace 2 mo.	Mean 45.2 mo (range, 38-50 mo)	Clinical: Lachman, PS. Objective: KT-1000. Subjective: IKDC, VAS. Functional: Lysholm, Tegner.	Combination of MacIntosh + ACL reduces rotational instability of the knee in female athletes
Barrett and Richardson[4]	CCS	70	USA	1988-1991	ACL + LEAT, 12.3 mo (13 >6 wk, 19 Acute); ACL, 4.3 mo (4 >6 wk, 34 acute)	Isometric screw fixation of ITB at LFC	Open—Central third BPTB	Aggressive rehabilitation program—passive and active ROM	ACL + LEAT: 2.9 y (range, 20-56 mo); ACL: 2.8 y (range, 22-48 mo)	Clinical: Lachman, PS. Objective: KT-1000. Subjective: VAS. Functional: Lysholm, Tegner.	LEAT not necessary to successfully reduce the symptoms of ACL insufficiency. No correlation with acuity of injury
O'Brien et al[37]	CCS	80	USA	1980-1985	Mean 36 mo	ITB "lateral sling" augmentation	Open—Central third BPTB	Cast 30° of flexion. NWB 6 wk.	Mean 4 y (range, 2-7 y)	Clinical: Lachman, PS, AD. Objective: KT-1000. Subjective: questionnaire.	ACLR + LEAT not recommended. LEAT group exhibited evidence of chronic pain and swelling in 40% of patients

[a]ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; AD, anterior drawer; Allo, allograft; AP, anteroposterior; BPTB, bone–patellar tendon–bone; CCS, case-control study; CPM, continuous passive motion; DB, double bundle; DBH, double bundle hamstring graft; FWB, full weightbearing; GT, gracilis tendon; IKDC, International Knee Documentation Committee; ITB, iliotibial band; KOOS, Knee injury and Osteoarthritis Outcome Score; LEAT, lateral extra-articular tenodesis; LFC, lateral femoral condyle; NWB, non-weightbearing; OTT, over-the-top; Pes, pes anserinus; PFC, patellofemoral crepitus; PS, pivot shift; PT, proximal tibia; pts, patients; PWB, partial weightbearing; RCT, randomized controlled trial; ROM, range of motion; ST, semitendinosus; VAS, visual analog scale.

TABLE 4
Quality Assessment Tool: Modified Downs & Black[a]

Study	Aim	Patient	Sample	Bias	Comparison	Outcomes	Valid	Blinding	Findings	Random	Statistics	Confounders	Adjustment	Sample Calc.	Power	Total	Quality
Anderson et al[2]	1	1	1	0	1	1	1	0	1	1	1	2	1	1	1	14	High
Trichine et al[53]	1	1	1	0	1	1	1	0	1	1	1	2	1	1	1	14	High
Zaffagnini et al[60] (2008)	1	1	1	0	1	1	1	1	1	1	1	2	1	0	1	14	High
Zaffagnini et al[61] (2006)	1	1	1	0	1	1	1	1	1	1	1	2	1	0	1	14	High
Dejour et al[11]	1	0	1	0	1	1	1	1	1	1	1	2	1	0	1	13	High
Barber-Westin and Noyes[3]	1	1	1	0	1	1	1	0	1	0	1	1	1	0	1	11	Moderate
Branch et al[5]	1	1	1	0	1	1	1	1	1	0	1	1	0	0	1	11	Moderate
Noyes and Barber[35]	1	1	1	0	1	1	1	0	1	0	1	1	1	0	1	11	Moderate
Vadala et al[54]	1	1	1	0	1	1	1	1	1	1	1	0	0	0	1	11	Moderate
Barrett and Richardson[4]	0	1	1	0	1	1	1	0	1	0	1	1	1	0	0	9	Low
O'Brien et al[37]	0	0	1	0	1	1	1	0	1	0	0	0	0	0	0	5	Low

[a]Adjustment, adequate adjustment for cofounding; Aim, aim of study; Bias, selection bias present; Blinding, attempt to blind measurers; Comparison, comparison group identified; Confounders, clearly described distributions of principle cofounders; Findings, main findings of study; Outcomes, clearly described outcomes; Patient, patient characteristics; Power, sufficient power in study; Quality, ≥12 = high quality, 10-11 = moderate quality, ≤9 = low quality; Random, estimates of random variability; Sample, sample is representative; Statistics, statistical tests used; Sample calc., reported sample size calculation; Valid, measures are valid and reliable.

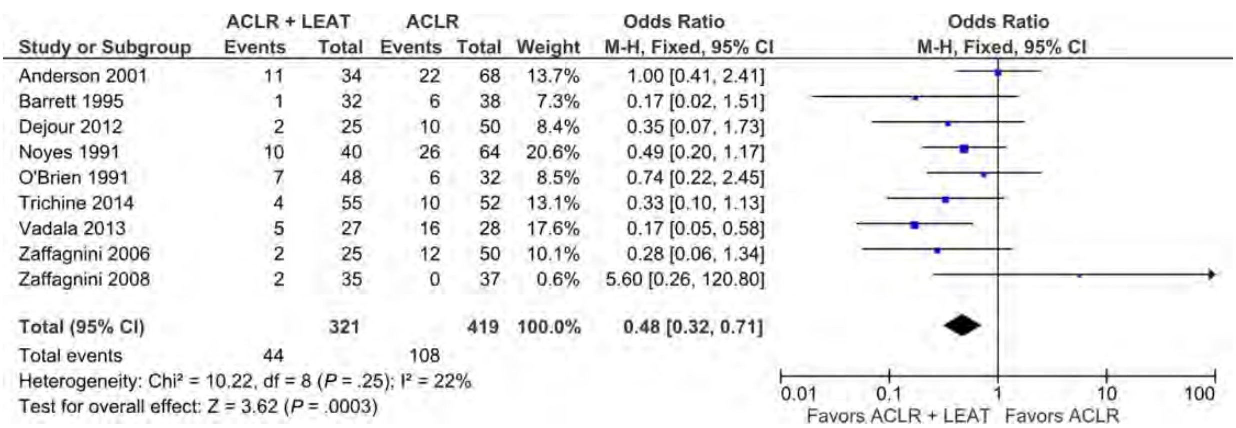

Figure 2. Meta-analysis using fixed-effects model to compare the pivot-shift test of anterior cruciate ligament reconstruction (ACLR) with lateral extra-articular tenodesis (LEAT) versus ACLR alone for all studies. M-H = Mantel-Haenszel test.

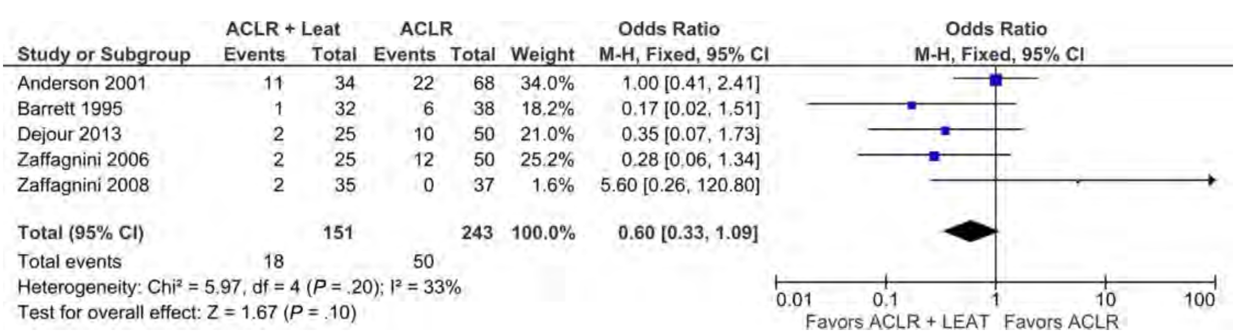

Figure 3. Meta-analysis using fixed-effects model to compare the pivot-shift test of anterior cruciate ligament reconstruction (ACLR) with lateral extra-articular tenodesis (LEAT) versus ACLR alone for early reconstruction (≤12 months from injury). M-H = Mantel-Haenszel test.

following index ACL injury (291 patients). One was of high quality, 1 of moderate quality, and 1 of low quality. The odds of having a positive postoperative pivot shift were 44% lower in patients who had ACLR plus LEAT compared with patients who had ACLR alone (odds ratio, 0.44; 95% CI, 0.24-0.81; $P = .008$; $I^2 = 0$) (Figure 4).

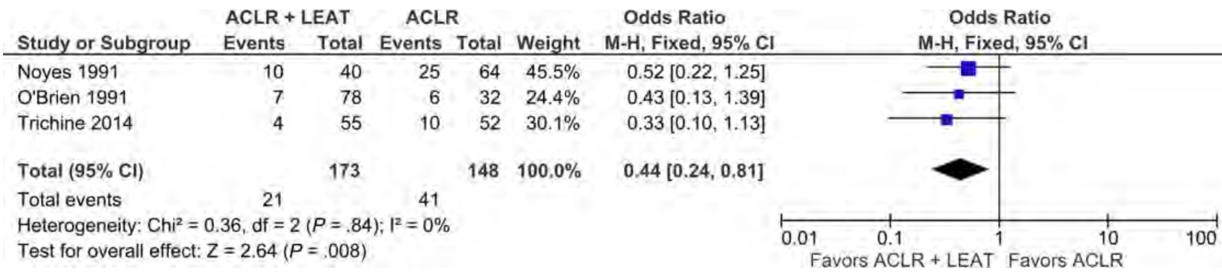

Figure 4. Meta-analysis using fixed-effects model to compare the pivot-shift test of anterior cruciate ligament reconstruction (ACLR) with lateral extra-articular tenodesis (LEAT) versus ACLR alone for delayed reconstruction (>12 months from injury). M-H = Mantel-Haenszel test.

Clinical Outcome

The results of the clinical outcome measures used by each study and the significant findings are outlined in Table 2. A best-evidence synthesis was performed on all outcome measures that were not suitable for meta-analysis.

Best-Evidence Synthesis

A summary of the best-evidence synthesis is listed in Table 5.

Clinical Examination. Four studies (3 RCTs) reported on range of motion,[2,4,60,61] and a further 6 studies (2 RCTs) detailed postoperative Lachman testing.[2,4,5,37,54,61] Insufficient evidence was found to indicate whether the addition of LEAT to ACLR affected postoperative range of motion or Lachman testing.

Objective Testing. Nine studies (3 RCTs) carried out an objective assessment of anterior translation using the KT-1000 or KT-2000 arthrometer.[2-5,36,37,54,60,61] There was insufficient evidence to suggest that the addition of LEAT to ACLR improved anterior laxity as measured with an arthrometer. Two studies (1 RCT) assessed quadriceps and hamstring strength.[2,35] Insufficient evidence was found to suggest whether the addition of LEAT had any effect on postoperative quadriceps or hamstring strength following ACLR.

Subjective Outcome. Eleven studies (4 RCTs) reported on subjective outcomes. Seven studies reported International Knee Documentation Committee (IKDC) scores, 3 studies reported Hospital for Special Surgery (HSS) scores, and 6 studies reported a variety of subjective outcome scores. The evidence was insufficient to indicate whether the addition of LEAT to primary ACLR results in improved subjective outcome.

Functional Outcome. Functional outcome was assessed with Tegner score in 4 studies (2 RCTs)[4,54,60,61] and Lysholm score in 2 studies.[4,54] No statistical differences were found in any of the reported studies. There was insufficient evidence that the addition of LEAT to primary ACLR affects functional outcome scores.

Two studies (1 RCT and 1 CCS) specifically detailed return to sport (RTS) as a functional outcome and found no significant difference based on the addition of LEAT.[11,53] Therefore, the evidence was insufficient to indicate whether the addition of LEAT affects RTS following primary ACLR. Two high-quality studies detailed the time to RTS.[60,61] Zaffagnini et al[60] found that the time to RTS was improved in double-bundle ACLR compared with double-strand hamstring with LEAT. In an earlier study,[61] the same authors reported that patients receiving double-strand hamstring ACLR returned to sport earlier compared with patients receiving bone–patellar tendon–bone (BPTB) and 4-strand hamstring ACLR. Therefore, insufficient evidence was found to suggest whether the addition of LEAT to a primary ACLR results in an improved time to RTS.

Radiographic Evaluation. Three studies (3 RCTs) studied postoperative radiographic evaluation.[2,60,61] The evidence was insufficient to indicate whether the addition of LEAT to primary ACLR affects short-term radiographic outcome.

Radiological stress testing was carried out in 2 high-quality studies. Trichine et al[53] reported decreased laxity of the lateral femoral condyle in the BPTB and LEAT reconstruction compared with BPTB alone. Similarly, Dejour et al[11] found that the addition of LEAT to BPTB ACLR was superior in reducing the anterior tibial translation of the lateral compartment as measured by Telos stress radiography. Therefore, strong evidence was found that the addition of LEAT results in decreased translation of the lateral compartment of the femur as measured by stress radiographs.

DISCUSSION

This systematic review identified time from injury to surgery as an important factor in determining the effectiveness of adding LEAT to a primary ACLR to reduce the postoperative pivot shift. Meta-analysis of the pivot-shift data acquired from 5 studies comparing ACLR alone versus ACLR with LEAT in primary procedures performed within 12 months of injury revealed that the addition of LEAT did not significantly reduce the odds of having a postoperative pivot shift. However, when the same analysis was performed on 3 studies in which the ACLR was delayed in excess of 12 months following injury, the addition of the LEAT did reduce the pivot shift.

Of the 11 studies included for data synthesis, 5 were of high quality, 4 moderate quality, and 2 low quality.

Based on a best-evidence synthesis of outcome measures, evidence is insufficient to establish whether the addition of LEAT to a primary ACLR improves clinical examination

TABLE 5
Summary of Best-Evidence Synthesis of Secondary Outcomes Comparing the Addition of ACLR With LEAT to ACLR in Isolation[a]

Outcome	Best Evidence
Clinical examination	Insufficient evidence of improvement
Objective testing	Insufficient evidence of improvement
Subjective testing	Insufficient evidence of improvement
Functional testing	Insufficient evidence of improvement
Radiographic outcome	Insufficient evidence of improvement
Stress radiographs	Strong evidence of ACLR with LEAT reduces lateral translation

[a]ACLR, anterior cruciate ligament reconstruction; LEAT, lateral extra-articular tenodesis.

findings, objective testing, or subjective and functional outcomes. There is, however, strong evidence to suggest that LEAT performed with ACLR reduces lateral compartment translation as measured by stress radiography.

Although the LEAT procedure has re-emerged as an adjunct surgical option for the treatment of ACL-deficient knees, clear indications for its use are still lacking. This systematic review demonstrated that the addition of LEAT to ACLR may improve rotational stability in a delayed reconstruction but does not offer the same benefit in early reconstruction. In addition, there is insufficient evidence to establish whether LEAT improves other clinical outcomes in primary ACLR.

The use of LEAT procedures has fluctuated over the years and, like many things in orthopaedics, has followed something of a trend. This is highlighted in this systematic review if one considers the time periods in which the studies were undertaken and published. Six studies emerged from the United States in the 1980s and early 1990s, but none have been published since then. The discontinuation of LEAT may be explained by the publication of seminal articles from high-profile institutions in the United States claiming that this procedure was unnecessary, especially in the acute setting, and might be potentially harmful.[35,37,46] Another explanation relates to the emerging technology of the era, particularly the increasing availability of magnetic resonance imaging (MRI) and the move to arthroscopic ACLR[9,10,19,40,41,57]; the former facilitated an earlier and more accurate definitive diagnosis of ACL rupture, while the latter possibly steered surgeons away from making big incisions around the knee, which had previously been done.

One of the other concerns related to LEAT was the potential to overconstrain the lateral compartment of the knee, which raised fears regarding the development of lateral compartment osteoarthritis. This review has highlighted the strong evidence that the translation of the lateral compartment is reduced with the addition of LEAT. These clinical findings are supported by biomechanical studies that demonstrate an overconstraint of the lateral compartment with both anatomic ALL reconstruction and LEAT procedures.[44,47] However, a recent systematic review reported that there is no increase in the long-term rates of osteoarthritis with the addition of LEAT to ACLR.[12]

Two recent systematic reviews of this topic have reported findings similar to those of the current study.[21,48] Both studies concluded that the addition of LEAT to ACLR was effective in eliminating pivot shift, particularly high-grade preoperative pivot shift. These results are consistent with our meta-analysis findings regarding delayed reconstruction but differ from our meta-analysis findings regarding early reconstruction. This difference may be explained in part by the use of different inclusion criteria. Song et al[48] included all levels of evidence but only ACL-deficient knees with a manual pivot-shift grade 2 (clunk) or grade 3 (locking). A study with exclusively revision cases was also included. In contrast, Hewison et al[21] included not only primary ACLR and comparative studies but also studies that used synthetic ligaments, multiple extra-articular reconstructions, and nonconventional ACLR grafts. As such, the patients included in these reviews may not be representative of the typical primary ACL-injured patient. However, the main reason for the difference is probably that, in the current review, a deliberate distinction was made between early and delayed reconstruction, which was not done in either of the other systematic reviews. We believe this distinction is important because a chronically ACL-deficient knee may have a much higher grade of pivot shift due to multiple subluxation events. For people with chronic ACL deficiency, the control offered by ACLR alone may be insufficient to diminish the pivot shift.[35] In contrast, people with a recent, primary ACL injury could be expected to have less rotational instability.[45] Therefore, adding LEAT to ACLR might not be warranted.

Although regarded as one of the most sensitive ways to diagnose ACL insufficiency, the pivot-shift test is subjective, and variability between examiners has been noted in previous studies.[34] However, despite much promise in attempting to objectify this measure with mechanical and optical tracking devices, the pivot-shift maneuver is still the most widely used method to assess rotational stability.[33,52] Moreover, all the studies included in this systematic review used the pivot shift to compare primary ACLR with and without LEAT. It is possible that the angle at which the LEAT was fixed may have affected the grade of pivot shift, as previously suggested with anatomic ALL reconstruction.[43] Unfortunately, of the 11 studies included, only 4 listed these details, which precludes any further analysis on the impact of these variables in the current study.

Limitations

Strict, predefined inclusion criteria were used in this study, and as a result some studies were excluded due to low subject numbers or the lack of controls. The search strategy included only studies published in the English language, and it is possible that studies published in other languages may have met the other inclusion criteria. There is, therefore, a risk of language bias in this systematic review. The results of this review are limited by the lack of consistent methods for collecting patient-reported outcomes and by a lack of long-term outcomes studies. Due to the heterogeneity of the data, a meta-analysis could be performed only on postoperative pivot-shift data. We acknowledge that the postoperative immobilization and rehabilitation techniques included in one of the early studies in this systematic review may not reflect modern practices.[37] Further, 2 studies included data on patients who had undergone a prior failed ACLR,[3,35] although this represented less than 20% of the individual study population, and only 1 of these studies[35] was included in the meta-analysis. In addition, 2 studies included data on ACLR performed through an open technique, which is no longer common.[4,37] Finally, the placement of the ACL graft in many of the studies may not be in keeping with current anatomic reconstruction techniques; however, we believe this reflects the diversity of ACLR techniques internationally.

CONCLUSION

The results of this systematic review revealed that the addition of LEAT to ACLR does not provide additional benefit in early primary reconstructions ($\leq$12 months) but is effective in reducing the postoperative pivot shift in a delayed ACLR. A best-evidence synthesis determined that there is insufficient evidence to determine whether the addition of LEAT to a primary ACLR resulted in improved clinical, objective, subjective, or functional outcomes. However, there was strong evidence that LEAT results in decreased laxity of the lateral compartment as measured by stress radiography.

These results suggest that in the setting of primary ACLR, there is a limited role for LEAT. This procedure is likely to benefit only those patients undergoing delayed reconstruction with significant rotational instability.

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APPENDIX

Best-Evidence Synthesis[a]

Strong evidence	Provided by consistent, statistically significant findings in outcome measures in at least 2 high-quality RCTs.
Moderate evidence	Provided by consistent, statistically significant findings in at least 1 low-quality RCT or high-quality CCS.
Limited evidence	Provided by consistent, statistically significant findings in outcome measures in at least 1 high-quality RCT or provided by consistent, statistically significant findings in outcome measures in at least 2 high-quality CCS (in the absence of high-quality RCTs).
Indicative findings	Provided by consistent, statistically significant findings in outcome and/or process measures in at least 1 high-quality CCS or low-quality RCT (in the absence of high-quality RCTs) or provided by consistent, statistically significant findings in outcome and/or process measures in at least 2 noncontrolled studies with sufficient quality (in the absence of RCTs and CCS).
No or insufficient evidence	In the case that results of eligible studies do not meet the criteria for 1 of the above-stated levels of evidence or in the case of conflicting (statistically significant positive and statistically significant negative) results among RCTs and CCS or in the case of no eligible studies.
	If the number of studies that show evidence is <0% of the total number of studies found within the same category of methodological quality and study design (RCT, CCS, or other design), no evidence will be stated.

[a]CCS, case-control study; RCT, randomized controlled trial.

Epilogue

"A stitch in time saves nine!"

The above proverb quite nicely synopsizes the main finding of the current study. As has been demonstrated in this systematic review, by addressing ACL injury in a timely manner (< 1 year from injury to surgery) an isolated ACL reconstruction is usually sufficient and demonstrates comparable clinical and functional results to a combined ACL reconstruction and LET. However, if the ACL injury is chronic and surgical reconstruction has been delayed beyond 1 year from injury then the addition of a LET is beneficial in reducing the pivot shift postoperatively.

Time has been a recurring theme in this thesis to date. But, in the context of ACL injury although time is important it is not the only thing. The time from injury to surgery reflects the period of vulnerability of the knee to further injury. To this end, it has been demonstrated that secondary meniscal tears after ACL injury are most common among patients undergoing delayed surgical or nonoperative treatment of their primary ACL injuries(140). Also, biomechanical analysis comparing nonoperatively treated knees with ACL deficiency and those that underwent ACL reconstruction revealed that peak medial compartment contact forces were higher in the nonoperatively managed group(141). Moreover, the surgeons who coined the phrase '*the pivot shift test'* to describe the manual manoeuvre did so because it resembled a "*pivot shift phenomenon*" which occurred in patients with ACL deficient knees(84). It has been reported that these '*pivot shift'* events during this period of vulnerability without an ACL are responsible for injury or attenuation to the secondary stabilisers, which include the menisci and the anterolateral complex(87). It has been proposed that it is the cumulative effect of injury that gives rise to a higher grade of pivot shift on manual testing and as this systematic review has revealed an ACL reconstruction alone is insufficient to control the anterolateral laxity caused by such sustained damage(142).

At the risk of exhausting the pun, it is important to acknowledge that times have changed since most of the studies included in this systematic review were conducted. The diagnosis of ACL injury is more rapid nowadays with the improved radiological diagnosis that MRI offers and treatment with ACL reconstruction is typically more acute(143). Therefore, one could assume that there is a further reduced role for LET in primary ACL reconstruction. However, this is not the case. Recent case control studies reporting on the latest LET iteration, the ALL reconstruction, have shown improved results in high risk patients and are suggesting an ever-increasing indication for its use, which includes meniscal ramp lesions repair and ACL repair(138, 139, 144, 145). In addition, a recent multi-centred randomised control trial revealed that the addition of LET to a single-bundle hamstring tendon autograft ACL reconstruction in young patients at high risk of failure results in a statistically significant, clinically relevant reduction in graft rupture and persistent rotatory laxity at 2 years after surgery(122). It would appear that these results would conflict with findings of the current study but it is important to consider that in each of these aforementioned studies the addition of a LET was performed in high risk groups. It was not possible, in this systematic review, to determine and differentiate between the risk of the patients included in each study.

So, maybe the proverb could also be interpreted as, the timely addition of a LET to primary ACL reconstruction in high risk patients reduces the chances of further injury and the possibility for subsequent surgery!

Chapter 11: Does the combination of a lateral extra-articular tenodesis and an intra-articular anterior cruciate ligament reconstruction increase the risk of developing osteoarthritis?

Introduction

"Eagerly pursuing all the latest fads and trends
'Cause he's a dedicated follower of fashion"

- "*Dedicated Follower of Fashion*" – The Kinks

The above lyrics are well-known and were written by the British band, the Kinks, in 1966. The song, in which they are contained, lampoons the contemporary British fashion scene and mod culture in general. But, these words could easily have been written to describe the fickle and fleeting nature of orthopaedic surgeons when it comes to trying out different techniques and using new instruments in surgery. You see, being human (yes, it's true!), orthopaedic surgeons often get bored by doing the same thing over and over again. Added to that, as a nascent specialty, in the field of orthopaedic sports medicine there are multitude of technology advancements. This essentially means we get a lot of toys to play with.

As alluded to in *Chapter 10*, the 1980s and early 1990s represented probably the greatest period of change in practice of Sports knee surgery to-date(28). Up until this point, most ACL reconstructions were performed through open techniques and were often carried out in patients with chronic injuries, which had failed to resolve with non-operative management(28, 146). The paradigm shift was largely due to the development of two new technologies, MRI and arthroscopy. MRI facilitated an earlier diagnosis of injury, while arthroscopy allowed surgery to be performed through a *'key-hole'* which enhanced visualisation and reduced morbidity(147, 148). Much the same as when fashion shifted from the flares in the 1970s to figure-hugging jeans in the 1980s, so too did the trend in knee surgery move from big incisions to less invasive arthroscopic procedures(149). Couple with this, evidence began to emerge from highly respected and influential institutions claiming that the lateral extra-articular (LET) procedure was unnecessary, especially in the acute setting, and might be potentially harmful(39, 40, 146). One of the major concerns which emerged from biomechanical studies was that LET procedures, which were often combined with ACL reconstruction at the time, caused overconstraint of the lateral compartment of the knee with the potential to increase the risk of developing osteoarthritis(44, 150). If another excuse was needed to give up on this procedure, this was it.

The interesting thing about fashion is that it differs drastically between countries. Whereas there was a major move away from using LET procedures in North America, the vogue continued in Europe(149). French and Italian surgeons adopted the "*if it's not broke, don't fix it!*" mentality and continued with this tried and trusted technique, regarding it as a timeless classic(151, 152). As a result, using the long-term results which are available largely from Europe, in the following study we have tried to answer the longstanding question: Does the combination of a LET and an intra-articular ACL reconstruction increase the risk of developing osteoarthritis? Similar to the opportunistic situation discussed in Chapter 4, the completion of this systematic review was significantly aided by the presence of both a Danish (Kristoffer Barfod) and a French surgeon (Nicholas Bouguennec) working with us at the time. This allowed for the inclusion of studies in English, German and French. So, "Bitte lesen Sie weiter" et "profitez-en!" (translation: Please, read on and enjoy it!)

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Contribution

Mr Devitt, Professor Feller and Professor Webster contributed to the conception and design of this manuscript. Mr Devitt, Mr Barfod, and Mr Bouguennec carried out the systematic review. Mr Devitt and Professor Webster analysis and best-evidence synthesis of the data. Mr Devitt and Ms Porter wrote the manuscript. Mr Devitt, Mr Bouguennec, Mr Barfod, Ms Porter, Professor Webster and Professor Feller revised the manuscript for important intellectual content.

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Devitt BM. Comparison of Lateral Extra-articular Tenodesis Techniques: Which one should we choose? Asia-Pacific Knee, Arthroscopy and Sports Medicine Society (APKASS) meeting. June 2018, Sydney.

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KNEE

Combined anterior cruciate ligament reconstruction and lateral extra-articular tenodesis does not result in an increased rate of osteoarthritis: a systematic review and best evidence synthesis

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Abstract
Purpose The role of lateral extra-articular tenodesis (LEAT) as an augment to primary anterior cruciate ligament reconstruction (ACLR) remains controversial. However, concerns exist regarding the risk of development of osteoarthritis due to over constraint of the knee. To systematically review the literature to analyse the long-term incidence of osteoarthritis in patients who had an LEAT performed in isolation or in combination with intra-articular ACLR for the treatment of ACL deficiency.
Methods Two reviewers independently searched five databases for randomized controlled trials (RCTs), non-randomized comparative, and retrospective cohort studies (CS) with long-term radiological follow-up of patients with ACL deficiency treated with ACLR combined with LEAT or LEAT in isolation. Risk of bias was performed using a modified Downs & Black's checklist. The primary outcome was the development of osteoarthritis. The studies were divided into those with moderate/severe osteoarthritis at between 5 to 10 years and >10-year follow-up. The rate of meniscal pathology at the time of the index surgery was recorded. A best evidence synthesis was performed.
Results Eight studies reported on 421 patients in which an LEAT procedure was carried out. There were two high-quality RCTs and six low-quality CS. The follow-up was between 5- and 10-years in 5 studies and >10-years in 3. The presence of moderate/severe osteoarthritis was not detected in three studies and was found in 4/44 (9%) and 13/70 (18.6%) patients in the other two. At 11 year follow-up, one study demonstrated no osteoarthritis, while the other two studies reported rates of 54/100 (54%) and 17/24 (71%) respectively at >24 years. In the latter two cases, the rate of meniscal pathology was >50%. A best evidence synthesis revealed that there was insufficient evidence that the addition of a LEAT to an ACLR resulted in an increased rate of osteoarthritis.
Conclusion The best available evidence would suggest that the addition of a LEAT to ACLR does not result in an increase rate of osteoarthritis of the knee. In knees that have undergone a combined ACLR and LEAT, the incidence of osteoarthritis was low up to 11 years but increased thereafter. The presence of meniscal injury at the index surgery was reported to be greater predictor of the development of osteoarthritis.
Level of evidence IV.

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Introduction

The recent resurgence in interest in the anterolateral ligament (ALL) of the knee has brought back into focus the concept of anterolateral rotatory instability [9, 13, 19, 20, 32]. Surgeons have long appreciated the powerful role that a lateral extra-articular tenodesis (LEAT) can play in controlling anterolateral instability and reducing the pivot shift [39]. However, concerns exist about the potential of this procedure to over constrain the knee and increase the risk of osteoarthritis [38].

Initially, used in isolation, the notion of combining a LEAT with an intra-articular reconstruction for the treatment of an anterior cruciate ligament (ACL) injury emerged with a view to decrease the failure rate of either technique carried out in isolation [14, 44, 50]. The approach, popularised in the 1980s, was adopted by a number of surgeons using a variety of extra-articular substitution procedures [21, 22]. Although most of these procedures diminished or obliterated the pivot shift, LEAT was not universally adopted on the back of reports related to unpredictable and unsatisfactory results [28, 31, 47]. One of the key issues is related to the level of constraint of the lateral compartment as a result of the LEAT. The potentially deleterious effect of the LEAR has been proposed based on a number of biomechanical studies performed on cadavers [21, 23]. The assertion was that the non-isometric LEAT altered the kinematics of the knee, placing the tibia in abnormal external rotation on flexion, which may predispose the lateral compartment to increase load, thereby increasing the risk of osteoarthritis [21, 23, 36].

It has been well established that patients who suffer an ACL rupture are at a greater risk of developing osteoarthritis later in life anyway [5, 29]. Unfortunately, ACL reconstruction (ACLR) has not been shown to improve the prognosis for knee osteoarthritis and is evident in up to 50% of patient following ACLR [37]. Seon et al. determined that the greatest predictor of risk for the development of osteoarthritis was whether a meniscectomy had been carried out or not [41]. Increased time period from injury to surgery was also an independent risk factor in addition to the age of the patient at the time of surgery [41]. However, to date, there is limited information on the impact that a LEAT has on the development of osteoarthritis. Therefore, the aim of this paper was to systematically review the literature to analyse the long-term incidence of osteoarthritis in patients who had a LEAT performed in isolation or in combination with intra-articular ACLR for the treatment of ACL deficiency.

Materials and methods

The study was performed as a systematic review of the current literature following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [35].

Search strategy

The search was conducted the 12th of February 2016 in the following databases: PubMed, Embase, Cinahl, Cochrane Central Register of Controlled trials, and AusportMed. The search was performed using the following two concepts combined with an AND: Concept 1: "anterior cruciate ligament" OR "acl" AND "reconstruction" AND "knee" AND "outcome". Concept 2: "extraarticular" OR "extra-articular"OR "Lemaire" OR "ellison" OR "Macintosh" OR "ALL" OR "anterolateral" OR "anterior oblique band" OR "lateral tenodesis" OR "lateral capsule ligament" OR "segond" OR "iliotibial band". To supplement the electronic database search, the reference list of relevant papers was also crosschecked for any missing papers. The search results were uploaded to EndNote X7.4 ©Thomson Reuters 2015. Duplicates were removed and papers were excluded by title before full-text assessment of the remaining papers was performed.

Selection criteria

The following inclusion criteria were applied to the final yield:

- Published peer-reviewed study: either randomized controlled trials (RCT), non-randomized comparative studies, and retrospective cohort studies.
- Radiological outcome data relating to the development of osteoarthritis after an LEAT alone or in combination with an ACLR—only studies with radiologic classification systems were included.
- Minimum of 5-year follow-up.
- Minimum of 80% of patients with radiographic follow-up.
- Studies in English, German, and French languages.

All criteria must have been satisfied in order for inclusion for review.

The exclusion criteria were:

- Reports on guidelines, technical notes, reviews, or systematic reviews.
- Synthetic grafts used for ACL reconstruction or LEAT.

When applying the selection criteria, the title and abstract of each study were initially reviewed. In the cases where it was not clear from the review of the title and abstract whether a study was appropriate for inclusion, the full text of the article was examined. Two reviewers applied the selection criteria independently (KB and NB). Consensus was used to resolve any disagreements between reviewers, with a third reviewer consulted if consensus was not achieved (BD). In the case of multiple reports on the same patient cohort with an increasing duration of follow-up, only the latest publication (i.e., the article with the longest follow-up) was included.

Quality appraisal

The methodological quality of the remaining papers was assessed by use of the modified Downs and Black score, which is appropriate for cohort study designs and has previously been found to be reliable [2]. The modified version used in this study has a maximum score of 16; a total score ≥ 12 is thought to be high quality, 10 or 11 to be moderate quality, and ≤9 low quality [3, 4]. The methodological quality of each article was stratified, and any disagreements in the initial ratings of methodological quality assessment were discussed and consensus was reached between the three reviewers (BD, NB and KB).

Data extraction

Data extraction was performed individually by the three reviewers (BD, NB, and KB) and entered into a specifically designed spreadsheet containing headings for the chosen outcomes. The following outcome data were extracted from the papers: Study type, number of patients, sex, age, time from injury to surgery, primary/revision procedure, type of LEAT, type of ACLR, rehabilitation protocols, follow-up time, percentage of cohort with radiographic evaluation with more than 5-year follow-up, type of radiograph, classification used for reporting degree of osteoarthritis, radiographic findings, and rate of meniscal pathology at time of surgery.

Data synthesis and analysis

To allow for analysis of the primary outcome of the study, which was 'development of osteoarthritis', a simplification of the parameter 'degree of osteoarthritis' was made. The classification systems which were used (IKDC, Ahlbäck, Hospital for Special Surgery (HSS), Kellgren–Lawrence, and Fairbank) were converted into two broad categories; (1) Normal-to-mild osteoarthritis; or (2) moderate-to-severe osteoarthritis. This stratification was based on the presence of joint narrowing in the original classification systems [5–7]. The conversion method is outlined in Table 1.

Data are presented as numeric values mean/median (range) and percentages where possible. No statistical synthesis of results was possible and, as such, no measures of consistency were calculated.

Best evidence synthesis

To assist with evaluating the outcome findings that could not be assessed through meta-analysis due to the limited availability of homogenous data, a best evidence synthesis using RCTs was performed. The method proposed by Van Tulder et al. [46] and adapted by Steultjens et al. [43] was used to ascribe levels of evidence of effectiveness, taking into consideration study design, methodological quality, and statistical significance of the findings ("Appendix 1").

Results

Search results

The database search retrieves 3579 records, and an additional 6 articles were found after reference checks. Following removal of duplicates and title and abstract screening,

Table 1 Categorisation of osteoarthritis classification systems based on the degree of osteoarthritis

<table>
<tr><th></th><th colspan="4">Normal to mild osteoarthritis</th><th colspan="5">Moderate to severe osteoarthritis</th></tr>
<tr><td rowspan="2">IKDC</td><td colspan="2">A</td><td colspan="2">B</td><td colspan="2">C</td><td colspan="3">D</td></tr>
<tr><td colspan="2">Normal</td><td colspan="2">Minimal changes (small osteophytes, slight sclerosis or femoral condyle flattening) and narrowing of the joint space that is just detectable</td><td colspan="2">Grade B+and joint space narrowing (joint space of 2 to 4 mm side or up to 50% joint space narrowing)</td><td colspan="3">Grade C+Severe changes include a joint space of less than 2 mm or greater than 50% joint space narrowing</td></tr>
<tr><td rowspan="2">Ahlback</td><td colspan="4">0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td colspan="4">Normal</td><td>Narrowing of joint space (joint space<3mm)</td><td>Obliteration of joint space</td><td>Minor bone attrition and bone erosion<5mm</td><td>Moderate bone attrition and 5mm<erosion<10mm</td><td>Major bone attrition, often with subluxation and secondary lateral arthrosis and erosion >10mm</td></tr>
<tr><td rowspan="2">Kellgren-Lawrence</td><td colspan="2">0</td><td>1</td><td>2</td><td colspan="2">3</td><td colspan="3">4</td></tr>
<tr><td colspan="2">Normal</td><td>Doubtful joint space narrowing and possible osteophytic lipping</td><td>Definite osteophyte and possible narrowing of the joint space</td><td colspan="2">Moderate multiple osteophytes, definite joint space narrowing, some sclerosis and possible deformity of bone ends</td><td colspan="3">Large osteophytes, marked joint space narrowing, severe sclerosis, and deformity of bone ends</td></tr>
<tr><td rowspan="2">Fairbank</td><td>0</td><td>1</td><td colspan="2">2</td><td colspan="2">3</td><td colspan="3">4</td></tr>
<tr><td>Normal</td><td>Squaring of tibial margin, spurring of the tibial spines</td><td colspan="2">Flattening of femoral condyle, squaring and sclerosis of tibial margin, marginal osteophytes</td><td colspan="2">Joint space narrowing, hypertrophic changes, or both</td><td colspan="3">All of the above changes to a more advanced degree</td></tr>
</table>

77 potentially relevant articles were obtained in full text (Fig. 1). Sixty articles were removed for the following reasons: no LEAT was performed ($n=21$), no radiographic follow-up ($n=7$), radiographic follow-up <5-years ($n=16$), radiographic follow-up of <80% of patients ($n=4$), no radiographic classification ($n=2$), same cohort of patients ($n=3$), synthetic ligaments used for reconstruction ($n=4$), technical notes ($n=2$), clinical review article ($n=2$), and miscellaneous ($n=8$). Four studies reported on the same cohort of patients [4, 10, 17]; only the study by Pernin et al. was included as it contained the greatest follow-up [38]. Finally, 8 articles reporting on >5-year radiographic outcome of LEAT and ACLR were included for qualitative synthesis.

Methodological quality

Table 2 illustrates the assessment of methodological quality according to the Downs and Black criteria. The methodology quality scores ranged from 8 to 14 out of maximum possible score of 16. Only two studies were considered high quality, both of which were randomized controlled trials [1, 49]. The rest of the studies were considered of low quality [2, 6, 11, 34, 48]. None of the studies scored positively on item 14 (sample size calculation). Three studies provided information on the possibility of selection bias within the study [1, 11, 38]. A comparative group and an estimation of random variability were only provided by the two randomized controlled trials [1, 49]. Five of the eight studies detailed that an attempt was made to blind those measuring the main outcomes of the intervention [1, 2, 6, 48, 49].

Demographic characteristics

Eight articles reported on 421 patients in which a LEAT procedure was carried out. Of that group, 410 (97%) were reviewed with radiographs at a more than 5-years follow-up. The population characteristics are listed in Table 3. The male to female ratio was 3:1—one study did not list the gender [38]. The mean age at surgery was 25.4 years (range 14–60 years). The time from injury to surgery ranged from <1 month to 19 years. All of the procedures were primary ACLR.

Fig. 1 Prisma flow diagram

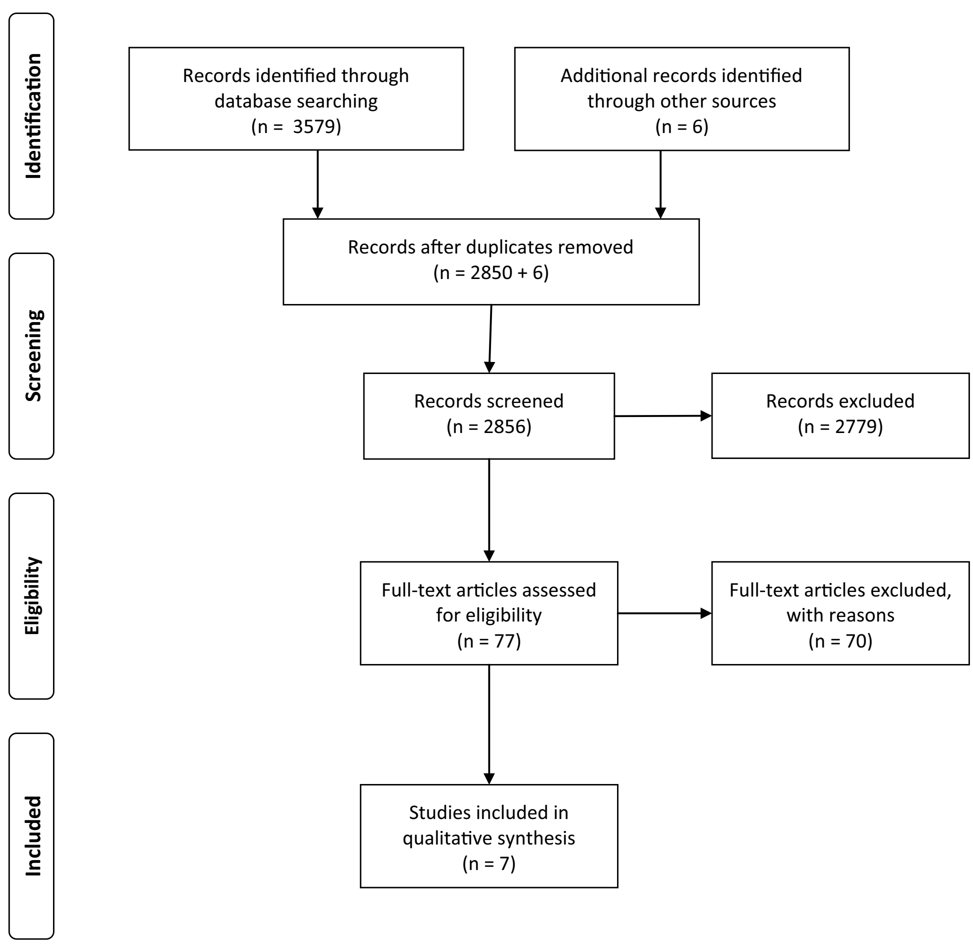

Table 2 Quality assessment tool: Modified Downs and Black

Paper	Aim	Patient	Sample	Bias	Comparison	Outcomes	Valid	Blinding	Findings
Zaffagnini	1	1	1	0	1	1	1	1	1
Acquitter	1	1	1	1	1	1	1	1	1
Marcacci	1	1	1	1	0	1	1	0	1
Pernin	1	1	1	1	0	1	1	0	1
Yamaguchi	1	1	1	0	0	1	1	1	1
Anderson	1	1	1	0	0	1	1	1	1
Aglietti	1	1	1	0	0	1	1	1	1
Paper	**Random**	**Statistics**	**Confounders**	**Adjustment**	**Sample calc.**	**Power**	**Total**	**Quality**	
Zaffagnini	1	1	2	1	0	1	14	High quality	
Acquitter	1	1	1	0	0	1	12	High quality	
Marcacci	0	1	1	0	0	0	9	Low quality	
Pernin	0	1	0	0	0	1	9	Low quality	
Yamaguchi	0	1	0	0	0	1	9	Low quality	
Anderson	0	1	0	0	0	1	9	Low quality	
Aglietti	0	1	0	0	0	1	9	Low quality	

Aim aim of study, *Patient* patient characteristics, *Sample* sample is representative, *Bias* selection bias present, *Comparison* comparison group identified, *Outcomes* clearly described outcomes, *Valid* measures are valid and reliable, *Blinding* attempt to blind measurers, *Findings* main findings of study, *Random* estimates of random variability, *Statistics* statistical tests used, *Confounders* clearly described distributions of principle cofounders, *Adjustment* adequate adjustment for cofounding, *Sample calc*. reported sample size calculation, *Power* sufficient power in study

≥12 = high quality, 10 to 11 = moderate quality, ≤9 = low quality

Radiographic analysis

A variety of radiographic classifications were used, including the International Knee Documentation Committee (IKDC) radiographic assessment tool, Fairbank, Ahlbäck, Hospital for Special Surgery (HSS) ACL radiographic score, and a numerical measurement of difference in millimetres between pre- and post-operative radiographs (Table 1). The type of radiographs used was described in all but one study [1], and typically involved flexed knee weight-bearing postero-anterior views.

Radiographic outcome

The radiographic outcomes in terms of the presence of moderate-to-severe osteoarthritis and the rates of meniscal pathology at the time of surgery are displayed in Table 4. Five studies reported results between 5 and 10 years [1, 2, 6, 11, 49], while three studies had a greater than 10-year follow-up [34, 38, 48].

5-to-10-year follow-up

The presence of moderate-to-severe osteoarthritis varied considerably ranging from 0 to 18.6%. Three studies reported no osteoarthritis between 5 and 10 years [1, 11, 49]. The rate of meniscal pathology at the time of surgery was highly variable within these groups. Zaffagnini et al. excluded patients with meniscal injury [49]. Acquitter et al. identified meniscal pathology on the medial side in 22 cases and lateral in 16. Christodoulou had a lesser rate of meniscal pathology and identified 7 medial meniscal tears and 1 lateral that required partial meniscectomy at the index surgery.

Anderson et al. and Aglietti et al. reported an overall rate of osteoarthritis of 13/70 (18.6%) and 4/44 (9%), respectively, at an average follow-up of 7 years [2, 6]. Anderson et al. did not detail the location of the osteoarthritis, but Aglietti et al. found more osteoarthritis medially than laterally [3/44 (7%) versus 1/44 (2%)]. Anderson et al. reported a high rate of meniscal pathology (49/70 medial and 27/70 lateral), which had previously been treated or was treated at the time of surgery with subtotal meniscectomy [6]. Aglietti et al. documented a lower rate of menical pathology −10 medial and 1 lateral [2].

More than 10-year follow-up

Marcacci et al. reported no moderate or severe arthritis in any patient at 11-year follow-up [34]; this was despite 20 medial, 3 lateral, and 6 medial and lateral meniscectomies being performed at the index procedure. The presence of a medial meniscectomy reduced the medial joint space significantly; however, it was not less than 3 mm at final radiographic follow-up.

Table 3 Qualitative data

Paper	Study type	No. of Pts	Sex	Age at injury (years)	Injury to surgery (range)	Primary or revision	Type of LEAT	Type of ACL
Zaffagnini	RCT	75 (25 LEAT)	49M:26F	30 (15–49)	6 m (4 to 12)	P	OTT extraarticular augmentation using ST and GT	Group 1 = BTB; Group 2 = 4-strand hamstrings; Group 3 = Marcacci Technique (Hamstrings with lateral tenodesis)
Acquitter	RCT	100 (50 LEAT)	72M:28F	27 (16–59)	29 m ± 37	P	Group 1 : 50 BTB / Group 2 : 50 MacIn-Jones	Arthroscopic technique with BTB
Marcacci	CS	54	42M:12F	(15–50)	26 acute (<3 weeks), 28 chronic	P	OTT extraarticular augmentation using ST and GT	ST and GT OTT
Pernin	CS	100	Not listed	25 (14–43)	35 m (1 to 232)	P	Modified Lemaire and Combelles extraarticular tenodesis	Open technique with BTB
Yamaguchi	CS	26	32M:13F	25 (16–42)	33 m (1 to 218)	P	Extraarticular ITB tenodesis - distally attached ITB - transfemoral fixation LFC	Open over-the-top technique with ITB
Anderson	CS	70	47M:23F	20 (22–60)	<1 m—28 patients; 1 to 3 m—14 patients; >3 m—28 patients	P	Extraarticular ITB tenodesis—Modified Losee	Open technique with hamstrings
Aglietti	CS	44	42M:2F	21 (16–33)	>6 m	P	Lemaire extraarticular ITB tenodesis	Open technique with BTB

Paper	Rehabilitation	Follow-up (range)	% Radiograph	Radiographs	Classification	Radiographic findings
Zaffagnini	Mobilized and weight-bearing from day one	5-years	100%	AP, lateral and Rosenberg views	Measurement of tibiofemoral space on Rosenber.g view: Degenerative change ≥ 2 mm change in joint space btw pre- and post-op radiographs	"Regarding arthritic changes, only one case in group II showed narrowing of the medial cartilage space of more than 2 mm comparing the pre-operative Rosenberg views with those at final follow-up"

Table 3 (continued)

Paper	Rehabilitation	Follow-up (range)	% Radiograph	Radiographs	Classification	Radiographic findings
Acquitter	Mobilized and weight-bearing from day one	5-years	100%	Not listed	IKDC	Group 1 : $A=34$ patients, $B=15$, $C=1$, $D=0$ and Group 2 : $A=34$ patients, $B=16$, $C=0$, $D=0$
Marcacci	Mobilized and progressive weight-bearing from day one	11-years	90%	Weight-bearing PA and 30° lateral flexion	Ahlbäck	Significant narrowing of medial joint space in medial meniscectomized group. No degenerative change at final follow-up
Pernin	1978 to 1980 = immobilized. From 1981 = mobilized day one	24.5-years (21–28)	100%	Bilateral 45° anteroposterior weight-bearing, lateral, and patellar skyline views	IKDC	$A=39\%$, $B=7\%$, $C=27\%$, $D=27\%$
Yamaguchi	Immobilized for 4–8 weeks. Weight-bearing from week 4	24-years	92%	Bilateral weight-bearing radiographs with the knee at 45 of flexion	IKDC	$A=8\%$, $B=21\%$, $C=25\%$, $D=46\%$
Anderson	Immobilized for 3–4 weeks. Weight-bearing from day one	7-years (5–9)	100%	AP, lateral and tunnel roentgenograms views	Fairbank	Fairbank 0 = 32 patients, Fairbank 2 = 25 patients, Fairbank 3 = 13 patients
Aglietti	Immobilized for 4 weeks. Weight-bearing from week 7	7-years (4–10)	100%	Standing AP, lateral and Merchant views	Hospital for Special Surgery (HSS) ACL radiographic score	Normal—17 pts (39%) Mild OA—19 pts (43%) Moderate OA—8 pts (18%)

Table 4 Prevalence of moderate or severe tibiofemoral osteoarthritis at long-term (5–10 years) or very long-term (>10 year) follow-up

Studies	Moderate/severe osteoarthritis			Meniscal damage at the time of surgery	
	Overall (%)	Medial	Lateral	Medial	Lateral
5-to-10-year follow-up					
Zaffagnini 2006: 5-years	0% (0/25)	0% (0)	0% (0)	0/25	0/25
Acquitter 2003: 5-years	0% (0/50)	0% (0)	0% (0)	22/50	16/50
Anderson 1994: 7-years	18.6% (13/70)	–	–	49/70	27/70
Aglietti 1992: 7-years	9% (4/44)*	7% (3/44)	2% (1/44)	10/44	1/44
More than 10-year follow-up					
Marcacci 2009: 11 years	0% (0/54)	0% (0)	0% (0)	26/54	9/54
Pernin 2010: 11.5 years	24% (24/100)	–	–	57/100	NA
17 years	44% (44/100)	–	–	57/100	NA
24.5 years	54% (54/100)	54 (50/92)	–	57/100	NA
Yamaguchi 2016: 24 years	71% (17/24)	59 (14/24)	41% (10/24)	23/26	8/26

*Defined as joint space narrowing ≤2 mm

Two studies reported the rate of osteoarthritis increased with the time from surgery [38, 48]. Pernin et al. reported the rate of moderate-to-severe osteoarthritis increased from 24/100 (24%) to 44/100 (44%) from 11.5 to 17 years, and to 54/100 (54%) at 24.5 years [38]. It is interesting to note that, in this cohort, the proportion of patients with a normal knee (without degenerative changes) remained globally unchanged from 11.5 to 24.5 years. 50/92 (54%) of the patients had medial compartment osteoarthritic changes. The rate of medial meniscal damage at the time of the index surgery was 57/100 (57%).

Yamaguchi et al. at 24-year follow-up reported the rate of moderate-to-severe osteoarthritis was 17/24 (71%) [48]. Medial and lateral compartment osteoarthritis was identified in 14/24 (58%) and 10/24 (41%) of patients, respectively. Medial meniscal damage was identified in 23 of 26 cases, while lateral meniscal damage was present in 8 of 26 cases. Notably, 84% of the contralateral knees were considered normal or nearly normal.

Best evidence synthesis

Two RCTs reported on a comparison of ACLR and ACLR with a LEAT at a mean of 5-year follow-up. Zaffagnini et al. found no significant difference between bone-patellar-tendon-bone (BPTB), four-strand hamstring, and an intra-articular hamstring graft with a LEAT. Likewise, Acquiter et al. did not demonstrate any significant radiological difference at 5 years between a BPTB performed in isolation and with the addition of a LEAT. Therefore, there was insufficient evidence that the addition of a LEAT to a primarily ACLR resulted in an increased rate of osteoarthritis.

Surgical technique and rehabilitation

A variety of ACLR and LEAT were used in the eight studies included. Regarding the type of ACLR, both open and arthroscopic procedures were included using three graft types: BPTB, hamstring, and iliotibial band. In the two high-quality studies, Zaffagnini et al. compared three groups (BPTB, 4-strand hamstring, and hamstring with LEAT), while Acquitter et al. compared two (BPTB and BPTB with a modified MacIntosh tenodesis). Several types of LEAT were carried out which are listed in Table 3.

There was considerable variability in post-operative rehabilitation regimens, which ranged from immobilisation and non-weighted bearing for 4–8 week post-operatively to active rehabilitation and full weight-bearing the day following surgery (Table 3).

Discussion

This systematic review identified that there is insufficient evidence that the addition of a LEAT to a primary ACLR resulted in an increased rate of osteoarthritis at long-term follow-up. Specifically, radiographic follow-up 5–10-years following a combined ACLR and LEAT demonstrated very low rates of lateral compartment osteoarthritis. Although the rate of osteoarthritis increased at ultra-long follow-up (11.5–24.5 years), the medial compartment was more frequently affected compared to the lateral compartment of the knee. Moreover, the rate of osteoarthritis was closely correlated to the presence of meniscal pathology at the time of the index surgery.

Knee osteoarthritis after ACL injury is well recognised and the prevalence increases with time from injury [29].

Rates of over 50% have been reported 10 to 20 years following ACL rupture [33]. Meniscal injury commonly occurs in conjunction with ACL injury and also has been directly linked to the development of osteoarthritis [8, 24, 30]. Controversy exists, however, whether reconstruction of the ACL can reduce the rate of development of osteoarthritis. Ajuied et al., in a recent systematic review and meta-analysis, reported that nonoperatively treated ACL-injured knees had a significantly higher relative risk (RR) of developing any grade of osteoarthritis compared with those treated with reconstructive surgery (RR, 3.62: $P<0.0001$) [5]. Interestingly, investigation of progression to moderate or severe osteoarthritis after 10 years showed that ACL-reconstructed knees had a significantly higher RR (RR, 4.71: $P<0.0001$) compared with non-operative management. The authors contend that returning to sports activities after ACL reconstruction may exacerbate the development of arthritis.

Barenius et al., in a long-term randomized controlled trial comparing graft types, determined that osteoarthritis of the medial compartment was most common, occurring in 57% of cases at a mean follow-up of 14 years [7]. Using regression analysis, they reported that an initial meniscus resection was a strong risk factor for osteoarthritis. A number of further studies have alluded to the causal role of meniscectomy and the development of osteoarthritis [12, 15, 18]. These results would be consistent with the findings of the current study, where not only did the rate of arthritis increased with greater follow-up but was also more commonly found in the medial compartment and correlated with a previous meniscectomy as reported by Pernin et al. and Yamaguchi et al [38, 48]. Interestingly, Marcacci et al. did not demonstrate the same progression to moderate or severe arthritis at 11-year follow-up [34]. However, they did report a significant decrease in joint space associated with medial meniscectomy and discussed the correlation with the development of arthritis. It is also interesting to note that almost half of the cases included in the study by Marcacci et al. were performed less than 3 weeks following surgery, while the interval between injury and surgery by Pernin et al. and Yamaguchi et al. that was in the other two ultra-long-term studies was on average 35 and 33-months respectively. Seon et al. in a study of 58 ACLRs using patellar tendon at an average of 11.2-year follow-up reported that an interval of more than 6 months from injury to surgery was a significant independent predictor of osteoarthritis [41].

The addition of a LEAT has been shown in radiological studies to reduce the translation of the lateral compartment [16, 45]. This has been supported by biomechanical studies, where Schon et al. demonstrated that an anatomical anterolateral ligament reconstruction leads to over constraint of internal rotation [40]. However, to date, no studies have demonstrated that over constraint leads to an increased rate of osteoarthritis of the lateral compartment following combined ACLR and LEAT. In contrast, Trichine et al. have suggested that a lack of control of anterior translation of the lateral compartment is a risk factor of osteoarthritis of the lateral compartment [45]. In reality, it can be difficult to get a true reflection of the prevalence of lateral knee osteoarthritis from the literature. Cases of lateral knee osteoarthritis are often pooled with medial knee osteoarthritis or excluded from studies [27, 42]. A key example of this is the study, included in this review by Pernin et al., which only detailed the rates of medical compartment osteoarthritis [38]. It is also important to consider that the development of lateral compartment arthritis is not as common as medial osteoarthritis and its aetiology is multifactorial. Felson et al. have reported rates of non-traumatic lateral osteoarthritis of 11% of women and 9% of men [25]. In a series of 117 post-operative ACLR patients at 10-year follow-up, Ahn et al. reported lateral osteoarthritis in 9.3% of cases, which was correlated to higher body mass index [3]. Valgus malalignment has also been shown to increase the incidence of lateral osteoarthritis, which has been attributed to an increased risk of meniscal damage [26]. The findings of this study would suggest that there is a low risk of developing lateral osteoarthritis of the knee with the addition of a LEAT to an ACLR at 5 to 10 years post-operatively [1, 49]. In the longer term, although the rate of lateral osteoarthritis is higher, there is insufficient evidence to derive a causal relationship with a LEAT, particularly given the high rate of concurrent lateral meniscal pathology.

Strict, predefined inclusion criteria were used in this study, and as a result, some studies were excluded due to short or insufficient follow-up or the lack of a radiographic classification. The results of this review are limited by the lack of consistent radiographic classifications used and, therefore, a simplified classification incorporating four classifications was employed. In addition, due to the heterogeneity of the data, a meta-analysis could not be performed. Aside from two randomized controlled trials, the methodological quality of the majority of the studies included in this systematic review was low. The authors acknowledge that the post-operative immobilisation and rehabilitation techniques included in many of the studies in this systematic review may not reflect modern practice. In addition, four of the studies included data on ACLR performed through an open technique, which is no longer commonplace, and one included a LEAT in isolation [2, 6, 11, 38, 48]. Finally, the placement of the ACL graft in many of the studies may not be in keeping with current 'anatomical' reconstruction techniques; however, the authors believe that this reflects the diversity of ACLR techniques internationally.

Conclusion

The best available evidence would suggest that the addition of a LEAT to ACLR does not result in an increase rate of osteoarthritis of the knee. In knees that have undergone a combined ACLR and LEAT, the incidence of osteoarthritis is very low up to 11 years. Although these rates increase beyond this period, the presence of meniscal injury requiring meniscectomy at the time of ACLR has been reported as a greater predictor of the development of osteoarthritis.

Appendix 1

Best evidence synthesis.

Strong evidence	Provided by consistent, statistically significant findings in outcome measures in at least two high-quality RCTs
Moderate evidence	Provided by consistent, statistically significant findings in least one low-quality RCT or high-quality CCS
Limited evidence	Provided by consistent, statistically significant findings in outcome measures in at least one high-quality RCT or provided by consistent, statistically significant findings in outcome measures in at least two high-quality CCS (in the absence of high-quality RCTs)
Indicative findings	Provided by consistent, statistically significant findings in outcome and/or process measures in at least one high-quality CCS or low-quality RCT (in the absence of high-quality RCTs) or provided by consistent, statistically significant findings in outcome and/or process measures in at least two noncontrolled studies with sufficient quality (in the absence of RCTs and CCS)
No or insufficient evidence	In the case that results of eligible studies do not meet the criteria for one of the above stated levels of evidence or in the case of conflicting (statistical significant positive and statistical significant negative) results among RCTs and CCS or in the case of no eligible studies If the number of studies that show evidence is <0% of the total number of studies found within the same category of methodological quality and study design (RCT, CCS, or other design), no evidence will be stated

RCT random controlled trial, *CCS* case–control study

Compliance with ethical standards

Conflict of interest None of the authors declare that they have any conflict of interest related to this work.

Ethical approval This article is a systematic review and does not contain any studies with human participants or animals performed by any of the authors.

Informed consent For this type of study formal consent is not required.

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Epilogue

"It is better to wear out than to rust away!"

This was the response I recently received from a 62-year old patient when I broke the news that he would require a total knee replacement. He had been diagnosed with osteoarthritis 15 years previously and although he had lived with it and remained very active in the intervening years eventually the pain became so unrelenting that he knew he required something done. His history was a familiar one; a keen footballer (Australian Rules Football) in his teenage years, he had suffered an ACL rupture just prior to his 18th birthday. As was the common at the time, he was treated nonoperatively initially and returned to sport within a few months. He managed to play but as he put it, "*he was never the same player*". He went on to sustain a further injury at 20 years of age, and on that occasion, he suffered a locked knee. This necessitated surgical intervention and he went on to have an ACL reconstruction with lateral extra-articular tenodesis (LET) and a medial meniscectomy. He did manage to return to football and played into his late twenties but had to stop when family and work commitments took over. Nevertheless, he continued to be active with his children and was able to run around with them and kick football in the park throughout their childhood. Quite nonchalantly, he also pointed out the he had "*a couple of clean-ups"* (knee arthroscopy with likely meniscal/chondral debridement)*;* one in his early thirties and another in his late forties. On questioning, he acknowledged that continuing to play football is likely to have contributed to his current disability but he did not regret it and, indeed, he was grateful for the opportunity to have been able to do so.

It is well recognised that knee osteoarthritis following ACL injury is very common and the prevalence increases with the time from injury(46). Meniscal injury frequently occurs in conjunction with ACL injury and is directly linked to the development of osteoarthritis(153-155). However, as has been discussed in the current study, there is evidence that although the relative risk of developing any grade of osteoarthritis is higher in nonoperatively treated ACL-injured knees compared to ACL reconstructed knees, the rate of progression to moderate or severe osteoarthritis after 10 years is higher following ACL reconstruction(45).

The proposed reason is returning to sporting activities which may have exacerbated the development of osteoarthritis, as illustrated in the case example above.

This brings up the ethical dilemma that physicians are frequently faced with: do the risks of treatment outweigh the benefits? Considering the facts of the above case, one could objectively conclude that the result of treatment to stabilise the patient's knee allowed the patient to return to an activity that caused further damage. It could be argued that if the knee was left untreated and the patient advised to give up sport, thereby removing him from harm's way and the risk of further injury, the likelihood of developing osteoarthritis could potentially have been lowered. However, to do so is to ignore another central tenet of medical ethics which is the primacy of patient autonomy. In this context, assuming informed consent has been obtained, the patient is required to make two key decisions: 1. To pursue an operative or non-operative course of treatment; 2. To return to sport or not following treatment. In many ways, it is often the answer to the latter question that perhaps truly determines the risk of the development of osteoarthritis in the long-term following ACL injury. The role of the surgeon is to provide the patient with a stable knee which may facilitate a return to sport, but the decision to do so is of the patient's own volition. Furthermore, as has been revealed in the current study, the best evidence would suggest that the presence of meniscal injury requiring meniscectomy at the time of ACL reconstruction is a greater predictor of the long-term risk of developing osteoarthritis and not the addition of a LET.

In my opinion, the risk-benefit quandary in this setting is best summed up by the divine words of Pope Pius XII, "*To live without risk is to risk not living!*"

Chapter 12: Biomechanical assessment of a distally fixed lateral extra-articular augmentation procedure in the treatment of anterolateral rotational laxity of the knee

Introduction

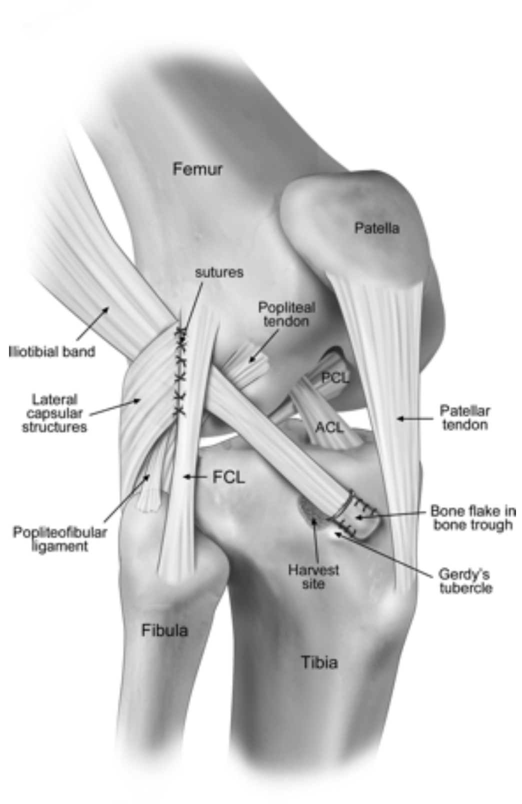
"If everyone is thinking alike, then someone isn't thinking."

- General George Patten

The ultimate study of this thesis is certainly my favourite. It incorporates many of the findings of the previous studies and includes them in a biomechanical simulation to test the effectiveness of a lateral extra-articular augmentation procedure, which is quite different to many of those described in the previous chapters. Ellison, who first described the procedure and after whom it is named, was someone who liked to 'think different', as Steve Jobs would say. He essentially turned the conventional proximally fixed tenodesis on its head and decided to fix the strip of ITB distally. His rational was to try to utilise the potential dynamism that the ITB offered by virtue of its attachment to the tensor fascia lata and gluteus maximus muscle(33, 50). This logic was not without criticism(35), but as is typical of individuals who go against the grain, Ellison was not to be deterred.

My first exposure to the Ellison procedure was in 2014 while on fellowship in Melbourne, Australia with Julian Feller, one of my supervisors on this thesis and now colleague. The procedure had been modified somewhat from Ellison's original description with a smaller lateral incision and minimal proximal release of the ITB(33) (Figure 1). But, in principle it was pretty much the same: A 1 cm strip of tissue was taken from the midportion of the ITB, but instead of amputating it proximally it was detached from Gerdy's tubercle along with a sliver of bone. Once mobilised free of any tissue proximally, the graft was then passed down under the LCL and re-inserted to its bony bed on Gerdy's tubercle once again.

Figure 1: *Ellison procedure (33, 48) – Distally based extra-articular tenodesis. (ACL, anterior cruciate ligament; FCL, fibular collateral ligament; PCL, posterior cruciate ligament.)*



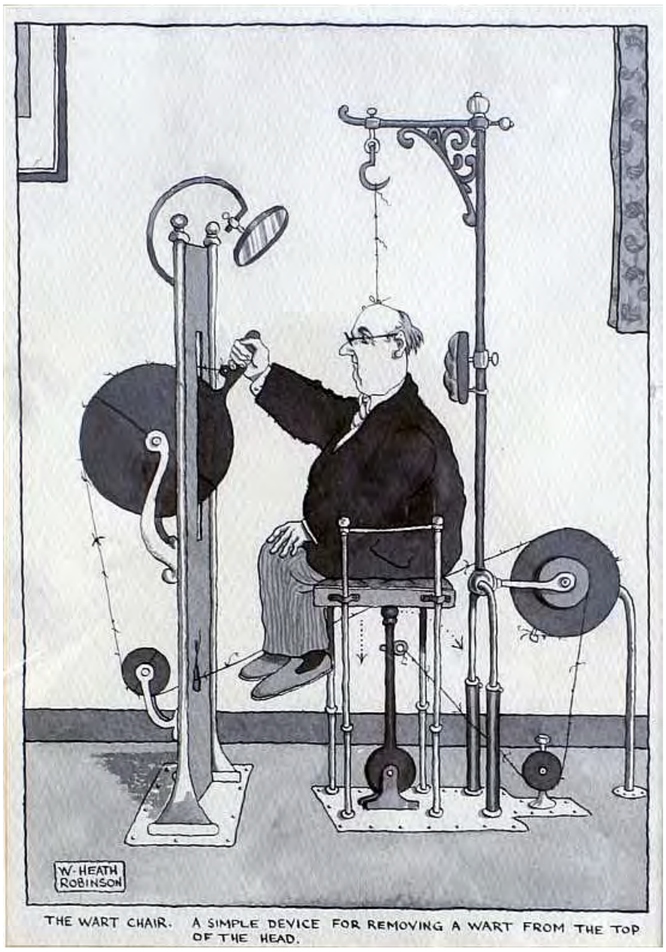
The procedure was very appealing to me; not only was it slick and relatively simple but it obviated the need to hold the knee flexed at a particular angle and apply tension to the graft prior to fixing it, as is the case with other LET procedures. In my ignorance, I was fully convinced that Ellison was an Australian surgeon, as things are notoriously the other way round down in the antipodes, and considering its popularity in these parts. John Bartlett, a well-known Melbourne orthopaedic surgeon and mentor to Julian Feller, who had known Ellison, relieved me of my ignorance and informed me that he was in fact American, much to my disappointment.

As I learned, Ellison was indeed a great thinker and the analogy he used to describe the control of rotation of the knee is one of the best, in my opinion. He considered the ACL to be “*located virtually at the axis or pivot of the knee and as such it is at the hub of the wheel*”(156). This, as Ellison claimed, “*places it in a superb location to guide rotational movement but at a very disadvantageous position to restrict rotation*”. He, therefore, saw distinct advantages in stabilising the knee on the outside rather than to reconstruct the ACL, based on his thinking that "*it is easier to control rotation of a wheel at its rim than at its hub*".

It would appear that Ellison procedure was not adopted as widely internationally compared to other proximally based LET procedures, given the absence of literature on its use. Aside from Australia that is, where it seemed to have a greater appeal with surgeons. Subsequently, when myself and Julian met to discuss the plan for my thesis we decided it would be interesting to study the modified Ellison procedure more closely. Julian spoke about a prior conversation he had had at a meeting with Andrew Amis, Professor of Biomechanics at Imperial College in London. During the chat, Julian had bemoaned the fact that in Professor Amis' latest study, comparing the effectiveness of a variety of LET procedures, the modified Ellison had not been included(20). And so it was, emails were written, plans were made, and I was dispatched to the biomechanics laboratory at Imperial College in London to conduct a biomechanical assessment of the modified Ellison procedure.

In Imperial College London, I collaborated with Breck Lord, a PhD candidate and orthopaedic trainee at the time, and now orthopaedic surgeon. The biggest challenge we faced was finding a way to load the ITB, which is the fundamental principle upon which the Ellison procedure is based. Unfortunately, the knee specimens that are used in these type of studies do not involve the whole lower limb and consisted of just the knee, with transection at the level of the mid-femur and mid-tibia, to allow placement in the robot. Hence, we had to devise a way to apply a consistent load to the ITB throughout knee flexion. Breck, who incidentally is originally from farming stock in New South Wales, Australia, proved himself quit adept at manufacturing contraptions. But, far more impressive was his command of his newly acquired British vernacular, which was eloquently demonstrated by his description of the pulley system we had created to load the ITB: "*I must say,* it's *a bit Heath Robinson, mate!",* he exclaimed. I nodded earnestly in response, trying not to appear completely clueless. The term, I later learned, was in reference to William Heath Robinson, an English cartoonist, illustrator and artist, best known for drawings of whimsically elaborate machines to achieve simple objectives. Needless to say, the experience that followed was stimulating, exhausting, hilarious, and frustrating in equal measure, but, ultimately well worthwhile. As for our contraption, it does look remarkably like one of the aforementioned cartoons, but I'll let you be the judge! (Figure 2)

Figure 2: *Health Robinson cartoon – the inspiration for the contraption to load the iliotibial band!*



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Contribution

Mr Devitt, Mr Lord, Mr Williams, Professor Amis, and Professor Feller contributed to the conception and design of this manuscript. Mr Devitt and Mr Lord carried out the biomechanical laboratory study. Mr Lord and Mr Devitt performed the analysis of the data. Mr Devitt and Mr Lord wrote the manuscript. Mr Devitt, Mr Lord, Mr Williams, Professor Amis and Professor Feller revised the manuscript for important intellectual content.

Conference presentations

This work was presented at an international conference:

Devitt BM, Lord BR, Williams A, Amis AA, Feller JA. Biomechanical Assessment of a Distally Fixed Lateral Extra-articular Augmentation Procedure in the Treatment of Anterolateral Rotational Laxity of the Knee. Anterior Cruciate Ligament Study Group. January 2018, Queensland, New Zealand.

Biomechanical Assessment of a Distally Fixed Lateral Extra-articular Augmentation Procedure in the Treatment of Anterolateral Rotational Laxity of the Knee

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Andrew A. Amis,[‡||] BSc, PhD, DSc(Eng) FREng, and Julian A. Feller,[†] FRACS
Investigation performed at Department of Mechanical Engineering, Imperial College London, London, United Kingdom

Background: Most lateral extra-articular tenodesis (LET) procedures rely on passing a strip of the iliotibial band (ITB) under the fibular (lateral) collateral ligament and fixing it proximally to the femur. The Ellison procedure is a distally fixed lateral extra-articular augmentation procedure with no proximal fixation of the ITB. It has the potential advantages of maintaining a dynamic element of control of knee rotation and avoiding the possibility of overconstraint.

Hypothesis: The modified Ellison procedure would restore native knee kinematics after sectioning of the anterolateral capsule, and closure of the ITB defect would decrease rotational laxity of the knee.

Study Design: Controlled laboratory study.

Methods: Twelve fresh-frozen cadaveric knees were tested in a 6 degrees of freedom robotic system through 0° to 90° of knee flexion to assess anteroposterior, internal rotation (IR), and external rotation laxities. A simulated pivot shift (SPS) was performed at 0°, 15°, 30°, and 45° of flexion. Kinematic testing was performed in the intact knee and anterolateral capsule–injured knee and after the modified Ellison procedure, with and without closure of the ITB defect. A novel pulley system was used to load the ITB at 30 N for all testing states. Statistical analysis used repeated measures analyses of variance and paired *t* tests with Bonferroni adjustments.

Results: Sectioning of the anterolateral capsule increased anterior drawer and IR during isolated displacement and with the SPS (mean increase, 2° of IR; $P < .05$). The modified Ellison procedure reduced both isolated and coupled IR as compared with the sectioned state ($P < .05$). During isolated testing, IR was reduced close to that of the intact state with the modified Ellison procedure, except at 30° of knee flexion, when it was slightly overconstrained. During the SPS, IR with the closed modified Ellison was less than that in the intact state at 15° and 30° of flexion. No significant differences in knee kinematics were seen between the ITB defect open and closed.

Conclusion: A distally fixed lateral augmentation procedure can closely restore knee laxities to native values in an anterolateral capsule–sectioned knee. Although the modified Ellison did result in overconstraint to isolated IR and coupled IR during SPS, this occurred only in the early range of knee flexion. Closure of the ITB defect had no effect on knee kinematics.

Clinical Relevance: A distally fixed lateral extra-articular augmentation procedure provides an alternative to a proximally fixed LET and can reduce anterolateral laxity in the anterolateral capsule–injured knee and restore kinematics close to the intact state.

Keywords: extra-articular tenodesis; ellison; anterolateral rotatory instability; knee kinematics

Anterior cruciate ligament (ACL) rupture typically occurs because of sudden axial loading of the knee in conjunction with a coupled valgus and rotational moment about the tibia.[25,26,34] The ACL is not the only structure damaged during this mechanism of injury, and studies have shown that the anterolateral complex of the knee is also commonly involved.[6,15,32,44] The anterolateral complex has been reported to consist of the superficial and deep iliotibial band (ITB), the capsulo-osseous layer of the ITB, and the anterolateral capsule.[17] Within this complex, some authors have identified a capsulo-osseous band: the anterolateral ligament (ALL).[6,9] Biomechanical studies have established that the anterolateral complex plays a role as a secondary stabilizer to control anterolateral rotational laxity.[14,19,22,36]

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Indeed, it has been suggested that failure to address the anterolateral injury at the time of ACL reconstruction may increase the risk of graft failure owing to persistent anterolateral rotational laxity.[1,5,19,22,35,36,41]

The concept of combining a lateral extra-articular tenodesis (LET) or augmentation with an intra-articular reconstruction for the treatment of ACL injury emerged with a view to decrease the failure rate of either procedure carried out in isolation.[10,27,31] The approach became popular in the 1980s and was adopted by a number of surgeons using a variety of extra-articular augmentation procedures, all nonanatomic in nature.[10,21,27-29] However, after recent reports describing the ALL of the knee, anatomic anterolateral reconstructions have also been reported.[4,40,41,42]

The majority of LET procedures are based on a proximally fixed construct, typically with a strip of ITB, which remains attached to its insertion at or near to the Gerdy tubercle.[40] The free proximal end passes either deep or superficial to the fibular collateral ligament (FCL) and is typically fixed to the femur posterior and proximal to the lateral epicondyle. However, a distally fixed ITB transfer, originally described by Ellison,[10] has also been used. This technique uses a strip of ITB, which is elevated from the Gerdy tubercle with a sliver of bone and reflected proximally and then passed deep to the FCL and reattached to the region of the Gerdy tubercle. The proposed advantage of this technique was that it maintained an element of dynamic control of rotation by virtue of its continuity with the tensor fascia lata muscle at the hip joint.[10] Therefore, by not fixing the strip of the ITB proximally but keeping it in continuity with the rest of the ITB and passing it under the fixed point of the femoral origin of the FCL, the construct would tend to tighten in extension, as it deviates from its natural alignment around the FCL, and slacken as the knee flexes.[25] Theoretically, it is most effective at lower flexion angles where the pivot-shift phenomenon occurs, with minimal or no effect with more flexed knee positions, thereby not interfering with natural rotatory laxities as well as avoiding excess tightness.

One of the concerns regarding proximally fixed LET procedures is that they potentially increase the "constraint" of the lateral compartment, which may have a long-term effect on the knee.[33] To date, biomechanical studies comparing LET procedures have focused on proximally fixed techniques and anatomic ALL reconstructions. There is limited biomechanical information exploring the knee kinematics with a distally fixed lateral extra-articular augmentation procedure, which may cause less constraint of the lateral compartment owing to the absence of proximal fixation to the femur.

The primary aim of this study was to investigate the effect of a modified Ellison procedure in restoring native kinematics of the ACL-intact knee after complete sectioning of the anterolateral capsule. The secondary aim was to assess the effect of closure of the ITB graft harvest site on knee kinematics. We hypothesized that a distally fixed LET procedure would restore native knee kinematics after sectioning of the anterolateral capsule and that closure of the ITB defect would decrease rotational laxity of the knee as compared with leaving it open.

METHODS

Specimen Preparation

Twelve fresh-frozen human cadaveric knees without evidence of prior injury, abnormalities, or surgery were used in this study (6 female and 6 male; 4 left and 8 right; mean ± SD age, 55 ± 7.5 years; range, 42-64 years). A power calculation based on previous studies determined that a sample size of 8 would allow the identification of changes in translation and rotation of 2 mm and 1.2°, respectively, with 80% power and 95% confidence.[22,24,30] However, to detect potentially small differences in laxity, the sample size was increased to 12 knees.[24]

The specimens were procured from a tissue bank after approval from the local research ethics committee. Each specimen was thawed for 24 hours before use. The femur was sectioned 190 mm from the joint line and the soft tissues resected from the proximal 80 mm, leaving 110 mm of ITB and soft tissue remaining. The tibia was sectioned 160 mm from the joint line and the soft tissue resected from the distal 60 mm. The fibula was transfixed to the tibia with a tricortical screw.

A longitudinal lateral incision was made from the Gerdy tubercle to the proximal skin edge, and the superficial fat was reflected to expose the ITB. The ITB was identified, and the proximal 20 mm was reinforced with a cotton patch to avoid suture pullout. Two strands of No. 2 suture (Ultrabraid; Smith & Nephew Endoscopy) were whipstitched to the anterior and posterior borders of the ITB to facilitate tensioning during robotic testing (Figure 1). This was necessary because, in the Ellison technique,[10] there is no proximal fixation of the ITB, as it relies on the dynamic effect of the tensor fasciae latae on the ITB.

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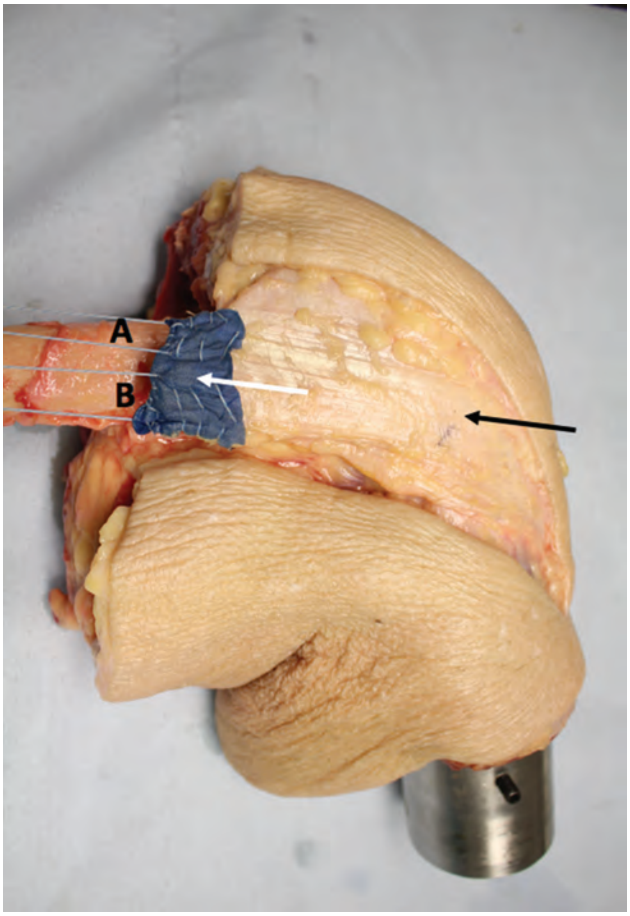

Figure 1. A right knee experimental specimen. The iliotibial band (black arrow) was identified, and the proximal 20 mm was reinforced with a cotton patch (white arrow) to avoid suture pullout. Two strands of No. 2 suture were whipstitched on the anterior (*A*) and posterior (*B*) borders of the iliotibial band to facilitate tensioning during robotic testing.

The tibia was cemented into a 60 mm–diameter stainless steel pot with polymethylmethacrylate (Simplex Rapid). The long axis of the cylinder was perpendicular to the joint surface in the coronal plane and parallel to the long axis of the bone in the sagittal plane. With the tibia fixed into the end effector of the robot, 0° of flexion was defined when 3.2-mm guide wires were parallel as drilled posteroanteriorly through the tibia and femur at 70 mm and 100 mm from the joint line, respectively.[16] A 60-mm pot was mounted on the base plate with anterior and posterior polyethylene tubes passed through it, aligned with the borders of the ITB; these were lubricated with food-grade silicone lubricant (Chemical Rubber Company [CRC]) to minimize the friction during dynamic testing. With the femur and the tubes cemented with the knee in extension, the ITB loading sutures were tied in loops and passed through the appropriate tube, and a 30-N tensile load was applied parallel to the femoral axis[42] (Figure 2). Tension was applied to the ITB during all testing states.

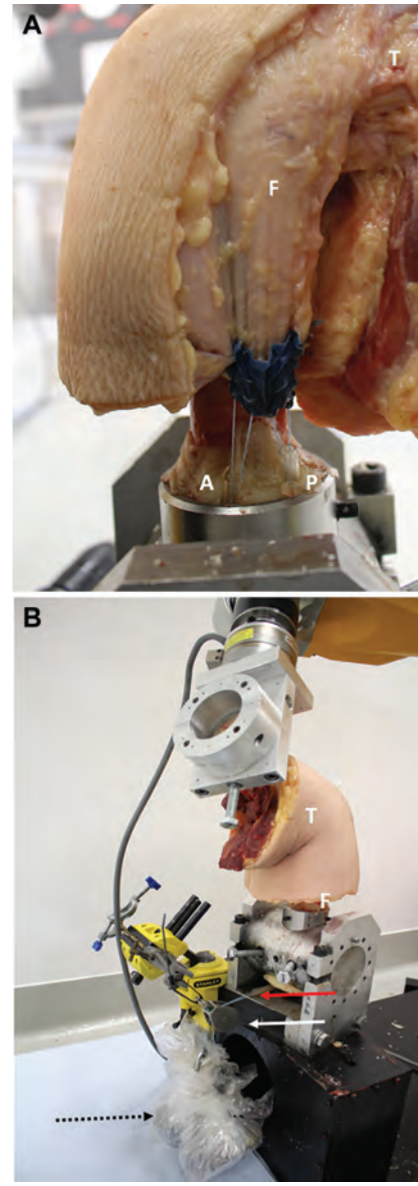

Figure 2. A right cadaveric knee with the femur (*F*) mounted on the base plate and the tibia (*T*) connected to the robotic arm. (A) A lateral view of the specimen demonstrates the iliotibial band (ITB) under tension with the sutures running through anterior (*A*) and posterior (*P*) polyethylene tubes aligned with the respective borders of the ITB. (B) The sutures fixed to the ITB pass through the polyethylene tubes (red arrow), which are lubricated with silicone to reduce friction, and are passed over a pulley (white arrow) and fixed to weights applying a 30-N tensile load (dashed arrow).

Robotic System

The robotic biomechanical testing system comprised a 6 degrees of freedom (DOF) robotic manipulator (TX90; Stäubli Ltd) and a 6-axis universal force-moment sensor (Omega 85; ATI Industrial Automation), with custom-designed tibial and femoral fixtures (Figure 2B). The force

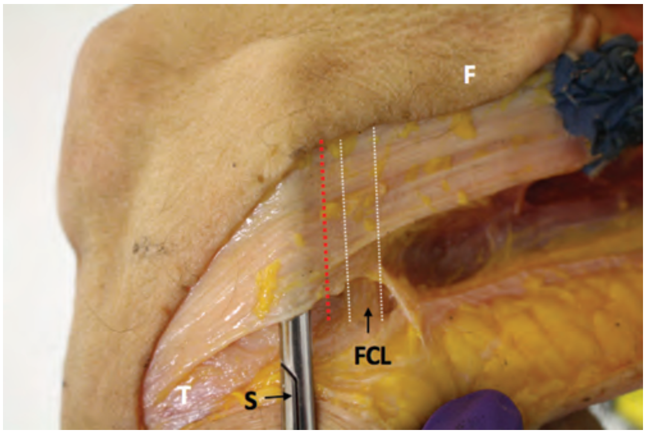

Figure 3. A left knee specimen with the femur (*F*) and tibia (*T*) marked. The iliotibial band was undermined distal to the fibular collateral ligament (*FCL*; outlined with fine dashed lines) and is being elevated with scissors (*S*). A blade was used to transect the anterolateral capsule of the knee distal to the FCL without violating the iliotibial band, as depicted by the red dashed line.

sensor had a resolution of 0.3 N, 0.3 N, and 0.4 N for X-, Y-, and Z-axis forces, respectively, and 0.01 N·m for X-, Y-, and Z-axis torques. The robotic system had a load capacity of 200 N and a test-retest SD of ±0.10 mm and ±0.12° in translation and rotation between the bone mountings.

Biomechanical Testing

Maintaining 0° of knee flexion, the system minimized the forces and torques in the remaining 5 DOF and recorded a known starting point for the intact knee. From this point, the force sensor guided the passive path of knee flexion from 0° to 90° while minimizing the 5 remaining forces and torques. Three cycles of flexion-extension were performed to minimize error from the inherent stress-relaxation properties of soft tissue.[18] As in previous work with this platform,[30] knee laxity was quantified by holding a fixed degree of flexion along the passive path while imposing a rotatory/translational displacement and neutralizing the remaining 4 DOF: 90 N for anterior tibial translation, 5 N·m for internal rotation (IR) and external rotation, and coupled moments of 4-N·m IR with 8-N·m valgus to simulate the pivot-shift laxity.[21] The anterior, IR, and external rotation laxities were evaluated at 0°, 30°, 60°, and 90° of flexion.[3,14,24,46] A simulated pivot shift (SPS) was performed at 0°, 15°, 30°, and 45° of flexion[3,12,46] and the coupled tibial displacement divided into IR and anterior tibial translation components.

Transection of Anterolateral Capsule

After assessment of the intact state, the knee was held in 90° of flexion. The FCL was identified deep to the ITB. The ITB was retracted with a Langenbeck retractor, and with a Beaver blade (Smith & Nephew Endoscopy), the anterolateral capsule was incised by making an incision directly anterior to the anterior border of the FCL; the cut was approximately 20 mm in length and extended from the femoral attachment of the FCL to the joint line, as previously described.[23] The release was confirmed with a hemostat forceps to ensure that all fibers had been transected (Figure 3).

Surgical Technique

A modified Ellison procedure was performed in line with current clinical practice among the authors. The modifications of the technique were that the anterolateral capsule was neither repaired nor plicated, and the distal end of the strip of ITB was reduced anatomically and fixed, rather than shifted anteriorly and proximally as advocated in the original description.[10] To focus purely on the effect that the anterolateral capsule pathology and Ellison procedure had on knee kinematics, the ACL was left intact to represent a "perfect" ACL reconstruction.[20]

The knee was held in 60° of flexion and neutral tibial rotation. The bony landmarks of the lateral femoral epicondyle and the Gerdy tubercle were identified, and the posterior border of the ITB was clearly exposed. An incision was made 10 mm anterior and parallel to the posterior border of the ITB starting distally at the Gerdy tubercle and extending proximally to a point proximal to the femoral attachment of the FCL. A second parallel incision was made 10 mm anterior to the first to develop a strip of ITB. At the Gerdy tubercle, a 10-mm osteotome was used to remove a sliver of bone with the distal insertion of the ITB strip. The ITB strip was mobilized and reflected in a proximal direction. The FCL was identified and isolated by making incisions anterior and posterior to the ligament. The distal end of the ITB strip was then passed deep to the FCL from proximal to distal and secured anatomically to the bone attachment site with a 5-mm titanium anchor with high–tensile strength nonabsorbable sutures (Smith & Nephew Endoscopy). When performed, primary closure of the ITB graft donor site was with a continuous stitch with a 1-Vicryl suture (Ethicon).

With regard to the secondary aim of the study to assess the effect to closure of the ITB on knee kinematics, the order of testing of the "open" versus "closed" ITB defect was randomly selected for each knee.

Statistical Analysis

The kinematic data of the intact and deficient states were analyzed with a paired-sample *t* test to evaluate the effect of anterolateral capsule transection. All kinematic data were subsequently analyzed with a 2-factor repeated-measures analysis of variance with Bonferroni corrections. The 2 factors assessed were the state of the anterolateral side of the knee and the flexion angle of the knee. Pairwise comparisons with a paired *t* test were performed where appropriate. The level of significance was set at $P < .05$ for a single comparison. Statistical analysis was performed in SPSS (v 21, IBM Corp).

TABLE 1
Translational and Rotational Differences Relative to the Intact State[a]

Flexion Angle	Translation/Rotation at Intact State	Differences From Intact: ALC Sectioned	"Closed" Modified Ellison	"Open" Modified Ellison
Anterior tibial translation, mm				
0°	2.5 ± 0.6	0.2 ± 0.1[b]	0.0 ± 0.1	–0.1 ± 0.1[c]
30°	4.4 ± 0.6	0.2 ± 0.2[b]	0.1 ± 0.3	–0.1 ± 0.2
60°	4.6 ± 1.1	0.2 ± 0.2[b]	0.2 ± 0.3	0.0 ± 0.2
90°	3.4 ± 1.0	0.1 ± 0.2[b]	0.2 ± 0.4	0.1 ± 0.3
Simulated pivot shift				
Anterior tibial translation, mm				
0°	0.7 ± 0.5	0.1 ± 0.1[b]	–0.3 ± 0.2[b,c]	–0.4 ± 0.3[b,c]
15°	1.3 ± 1.8	0.2 ± 0.3[b]	–0.6 ± 0.4[b,c]	–0.7 ± 0.4[b,c]
30°	2.1 ± 2.4	0.3 ± 0.5	–0.5 ± 0.4[b,c]	–0.5 ± 0.4[b,c]
45°	2.5 ± 2.5	0.3 ± 0.6	–0.4 ± 0.4[c]	–0.3 ± 0.4[c]
Internal tibial rotation, deg				
0°	7.3 ± 4.7	1.1 ± 1.7[b]	0.1 ± 1.8[c]	–0.1 ± 1.8[c]
15°	11.3 ± 16.5	1.4 ± 2.0[b]	–1.5 ± 1.8[b,c]	–1.9 ± 1.4[c]
30°	14.6 ± 21.7	2.0 ± 2.3[b]	–1.7 ± 1.8[c]	–2.2 ± 1.9[c]
45°	15 ± 24.3	2.4 ± 2.1[b]	–1.2 ± 1.7[c]	–1.8 ± 2.4[c]
Internal tibial rotation, deg				
0°	7.1 ± 3.8	1.2 ± 0.5[b]	–0.5 ± 0.9[c]	–0.9 ± 0.8[b,c]
30°	15.6 ± 18.8	1.7 ± 0.7[b]	–1.5 ± 1.3[b,c]	–1.6 ± 1.4[b,c]
60°	15.9 ± 21.4	1.9 ± 0.8[b]	–0.6 ± 1.6[c]	–0.4 ± 1.5[c]
90°	14.4 ± 20.0	1.9 ± 0.7[b]	0.6 ± 1.4[c]	1.3 ± 0.9[b,c]

[a]All values are given as mean ± SD. ALC, anterolateral capsule.
[b]$P < .05$ vs the intact state.
[c]$P < .05$ vs the ALC-sectioned state.

RESULTS

The data for the intact state, anterolateral capsule–sectioned state, and ITB-open and ITB-closed modified Ellison procedures are displayed in Table 1.

Compared with the intact state, transection of the anterolateral capsule resulted in statistically significant increases in internal tibial rotation (mean increase, approximately 2°) and anterior tibial translation (mean change, approximately 0.2 mm) when measured as isolated displacements or as part of the SPS ($P < .05$, apart from coupled anterior tibial translation in the SPS testing mode).

The modified Ellison procedures gave rise to a significant reduction in IR in isolation and during the SPS as compared with the anterolateral capsule–sectioned state ($P < .05$). In some instances, the IR was reduced to less than that of the intact state; this overconstraint occurred at 30° of knee flexion for the closed and open modified Ellison procedures (Figure 4) but only for the closed procedure during the SPS (Figure 5). Although the closure of the ITB resulted in a statistically significant reduction in coupled IR during SPS at 15° and 30° as compared with the intact state, there were no significant differences when the open or closed modified Ellison procedure was compared at any flexion angle.

DISCUSSION

The main finding of this study was that in the ACL-intact knee, the modified Ellison procedure significantly reduced tibiofemoral motion as compared with the anterolateral capsule–sectioned state and restored kinematics close to the intact state. However, both the closed and the open modified Ellison procedures resulted in a significant reduction in isolated internal tibial rotation as compared with the intact knee at 30° of knee flexion. In addition, the closed modified Ellison procedure resulted in decreased internal tibial rotation during SPS at 15° and 30° of knee flexion, but a comparision of the effect of closure and nonclosure of the ITB on knee kinematics found no significant differences in knee kinematics at any flexion angle. This study demonstrates that the modified Ellison procedure is capable of controlling anterolateral rotatory laxity of the ACL-intact knee.

A number of in vitro biomechanical studies have been performed to assess knee kinematics after lateral augmentation or reconstructive procedures.[41] These studies have focused mostly on proximally fixed LET procedures or ALL reconstruction and have reported varying results.[19,37] A recent controlled laboratory study by Geeslin et al,[14] using a 6-DOF robotic system, determined that both a modified Lemaire and an ALL reconstruction combined with an

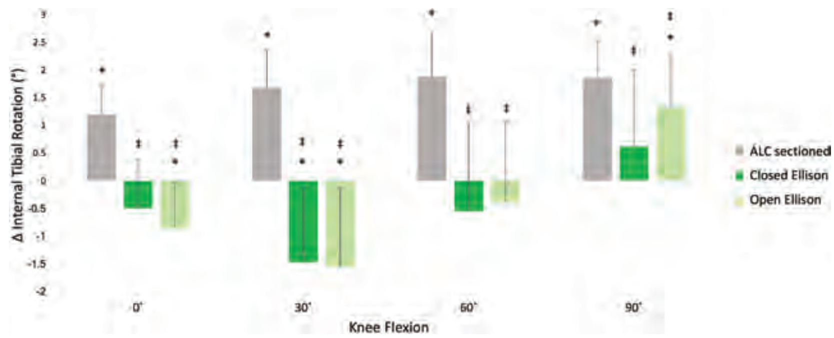

Figure 4. The mean ± SD difference from the laxity of the intact knee in degrees of tibial internal rotation at 0° to 90° of flexion after anterolateral capsule sectioning and a modified Ellison lateral augmentation procedure (with and without closure of the iliotibial band) during isolated internal rotation testing. ALC, anterolateral capsule. *$P < .05$ vs intact knee. ‡$P < .05$ vs ALC-sectioned state.

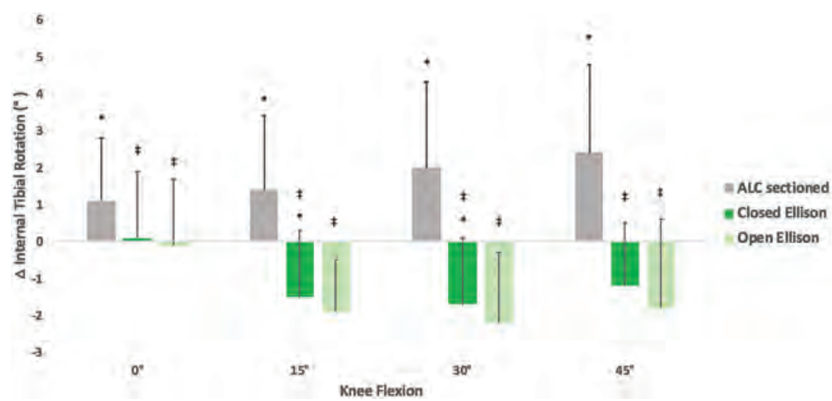

Figure 5. The mean ± SD difference in degrees of tibial internal rotation between 0° and 45° of flexion after anterolateral capsule sectioning and a modified Ellison lateral augmentation procedure (with and without closure of the iliotibial band) as compared with the intact knee during simulated pivot shift. ALC, anterolateral capsule. *$P < .05$ vs intact knee. ‡$P < .05$ vs ALC-sectioned state.

ACL reconstruction resulted in significant reductions in tibiofemoral motion at most knee flexion angles, although overconstraint was also identified. The current study found a reduction in isolated IR with the modified Ellison procedure across 0° to 90° of flexion. Similarly, during an SPS, the coupled IR was significantly reduced at 15° and 30° of knee flexion as compared with the native knee with a modified Ellison procedure when the ITB was closed. These findings are similar to the results of Geeslin et al during SPS when the modified Lemaire or ALL reconstruction had a fixation angle of 30°, albeit with less overconstraint at 30° of knee flexion. It is important to note that there were methodological differences between the studies despite the use of a similar robotic testing model. In the study by Geeslin et al, the distal Kaplan fibers were cut as part of their sectioning of the anterolateral complex; an ACL reconstruction was performed in conjunction with the LET; and there was no loading of the ITB. In the current study, the ITB was loaded for all testing states to facilitate testing of a distally fixed LET, which relies on proximal tension in the ITB.[45] Furthermore, the ACL was left intact in the current study to represent a "perfect" ACL reconstruction.

It is evident from the literature that a distally fixed LET is less widely used than a proximally fixed procedure.[8,39] The operative technique of a distal ITB transfer was described by Ellison[10] in 1979 and used in isolation for the treatment of ACL-deficient knees with anterolateral rotatory instability. The technique described was more extensive than the modified version detailed in the current study. The theory behind this technique was that the broad-based shape of the strip of ITB preserves the blood supply to the fascia and the dynamic pull of the tensor fasciae latae and part of the gluteus maximus.[10] This theory was disputed by Kennedy et al[21] in 1978, who reported relatively poor results using this technique in isolation of or combined with other reconstructive procedures. The authors claimed that they could not prove the dynamic function clinically, and the subjective results did not suggest that such a function existed. Lipscomb and Anderson[28] and Lipscomb et al[29] reported on a series of 75 knees with chronic ACL deficiency, which were treated with a semitendinosus and gracilis intra-articular ACL reconstruction, posteromedial and lateral capsular ligament reefing, and an Ellison LET. The authors contended that the distally fixed LET did not adequately prevent anterolateral instability.[10,31] However, no objective evidence to support this assertion was presented in their studies. They subsequently went on to use a proximally fixed Losee procedure, which they claimed was static and therefore more effective.[33]

In the context of LET, it is important to consider what is the appropriate amount of constraint and what represents "overconstraint." The latter term is usually used to imply that there may be long-term consequences of osteoarthritis from a procedure that "overconstrains" the knee. However, authors rarely define what constitutes overconstraint. It could mean loss of normal flexion range, loss of normal rotational laxity, or increased articular contact pressure. Furthermore, biomechanical studies are limited by the fact that they assess the laxity of a joint at time zero (ie, immediately after surgery) but fail to account for laxity that may occur as a result of elongation of tissues over time. In a systematic review, Slette et al[39] suggested that after a period of initial stability, LET procedures have often shown a tendency to elongate, with return of anterolateral rotatory instability in the ACL-deficient knee. However, the studies to support this claim focused on LET procedures performed in isolation for the treatment of chronic ACL deficiency.[2,7,21,39] It is notable that 2 of these studies included distally fixed Ellison LET procedures, which is perhaps why this procedure fell out of favor. However, Engebretsen et al[11] showed that when an LET is performed in conjuction with an ACL reconstruction, the ACL graft is subjected to less load, which suggests a more synergistic effect. However, Schon et al,[38] in a controlled laboratory study, demonstrated that an anatomic ALL reconstruction performed in conjunction with an ACL reconstruction significantly overconstrained IR of the knee beyond 30° of knee flexion regardless of the fixation angle of the graft. Nevertheless, no long-term clinical studies have demonstrated an increased incidence of osteoarthritis with a LET performed in conjuction with ACL reconstruction versus ACL reconstruction alone.[9,13]

Kittl et al[23] demonstrated that the superficial ITB, in addition to the deep layers, plays an integral role in controlling anterolateral rotatory laxity. Based on this finding, the postulated hypothesis was that closure of the ITB defect would result in further restriction of IR owing to anteriorization of the iliotibial tract. This study rejected this hypothesis: closure of the ITB defect did not have a significant effect on rotational laxity. Interestingly, in the original description of the Ellison procedure, complete closure of the ITB defect was considered an essential step.[10] On a practical level, closure of the defect may prevent muscle herniation of the vastus lateralis and make for a more cosmetically acceptable appearance. Although it would seem logical that closure of an ITB defect may also increase the contact pressure placed on the lateral facet of the patella, this has been found only with a proximally fixed ITB graft excessively tensed to 80 N and thereby causing fixed external rotation of the tibia—increased contact pressure was not observed with lower levels of tension and a neutral position of fixation of the tibia.[20] It would be unlikely to occur with the minimally tensioned and distally fixed procedure.

Limitations

We acknowledge that there are study limitations. The specimens were 55 ± 7.5 years old—higher than the patient group that typically experiences an ACL rupture but comparable to previous similar cadaveric studies.[19,30] The results presented are representative of only a "time zero" state and do not take into account subsequent healing, cyclic loading, and rehabilitation. The clinical pivot shift is a dynamic examination through a range of motion. With use of a single robotic manipulator, this and other studies have not replicated in vivo kinematics but only the coupled laxities.[16,22,30] However, the advantages of this study design include loading of the ITB to simulate any dynamic effect that it might have in a lateral augmentation. However, it should also be considered that the loading of the ITB in this model is with a fixed weight, which, though mobile through a range of flexion by means of a pulley, is not actively dynamic as may occur with muscle contraction. Because the optimal ACL reconstruction technique continues to be debated, leaving the native ACL intact avoids any variations in technique or prejudice against a particular ACL reconstruction.[43] It is also important to note that the differences in tibial anterior translation were <1 mm in all cases, reflecting the dominant role of the ACL and raising the question of the clinical relevance of using a lateral procedure to control anterior translation despite the statistical differences found.

CONCLUSION

A distally fixed lateral augmentation procedure can closely restore knee laxities to native values in an ACL-intact anterolateral capsule–sectioned knee. Although the modified Ellison did result in overconstraint to isolated IR and coupled IR during SPS, this occurred only in the early range of knee flexion. No significant difference was found between closing and leaving the ITB defect open in the modified Ellison procedure.

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Epilogue

"The proof of the pudding is in the eating!"

In my opinion, the above proverb is quite appropriate as the banner for the final epilogue of this thesis. In essence, it reminds us as surgeons that the real value of something can be judged only from practical experience or results and not from appearance or theory. In many ways, the Ellison procedure has long been a staple on the surgical menu, we just needed to clarify that by modifying a few ingredients to the recipe that the quality hadn't been altered. This study demonstrated, using a robotic model of anterolateral capsule deficiency, that a modified Ellison procedure is effective in reducing anterolateral rotatory laxity of the knee. It also revealed that closure of the ITB defect had no effect on controlling internal rotation in isolation or as part of a simulated pivot shift. Notwithstanding these conclusions, the real insight this study provides can be found by exploring the methods used to create a unique testing model.

To test the modified Ellison procedure, it was necessary to load the ITB. Aside from the technical challenges this presented, or perhaps as a consequence of these challenges, it required that the previous biomechanical models that had been employed to assess anterolateral rotatory laxity of the knee were researched and analysed in detail(15, 19, 20, 70). Admittedly, no model is perfect, but there were two key elements of the previous models that were a source of concern; Firstly, the vast majority of cadaveric studies performed used knees that were transected at the level of the mid-femur and mid-tibia – as such, the ITB band had no proximal attachment and its only distal attachment to the femur was through the Kaplan fibres; Secondly, in an attempt to create "*the worst case scenario*" of injury the Kaplan fibres were sectioned along with the anterolateral capsule and the ALL. This effectively removed any load through the ITB and effectively rendered it defunct as a secondary stabiliser to the knee(85).

But, as we have learned from Losee, Galway, MacIntosh and Larson, one of the perquisites for eliciting a pivot shift clinically is to have an intact ITB(84-86). So, how can anterolateral rotatory laxity be assessed in the absence of a functional ITB?

In cadaveric, biomechanical models it is difficult to recreated the complex, dynamic movement of a pivot shift test, therefore, it is typically broken down into coupled movements of internal rotational and anterior tibial translation which only really simulates the manoeuvre(78). In doing so, the crucial contribution that the ITB makes clinically in reducing the anterolateral aspect of the tibia is obviated(86). This potentially results in a model where the other secondary stabilising structures of the anterolateral complex assume a greater degree of importance in relative terms compared to the native knee.

Finally, it is also important to recognise that the loads used to test laxity in the laboratory are low and are used to simulate the forces subjected to the knee during clinical examination and not during sporting activity(86). The cutting and pivoting that takes place while participating in sport places the knee under much greater loads, and hence put the knee at increased risk of injury(78). Therefore, it is important not to lull ourselves into a fall sense of security with time-zero, biomechanical studies alone to assess the effectiveness of a procedure. It is critical to field test these reconstructions to truly determine their worth.

Chapter 13: Reflections, Discussion and Conclusion

Throughout the course of this thesis, I have sat down to write nine discussions, not to mention an editorial and a Three-Minute-Thesis presentation. As with most scientific writing, it typically follows a formula; the opening sentence should ideally be succinct and impactful, detailing the main findings of the study. So, how does one summarise a collection of diverse work, with many quite varying themes, albeit with a central thread? To do so in a coherent manner, which is after all the objective of a thesis, I believe it helpful to not only re-iterate the questions and objectives that I had starting out on this task but also to consider the impact the answers to these questions have had on my practice as an orthopaedic surgeon. By means of context, I started my PhD candidature in 2016, which was the same year I became a consultant orthopaedic surgeon.

Starting as a new consultant is a daunting experience in many ways. It marks a distinct transition from being somewhat responsible to being completely responsible for decision-making on often very serious issues; as such, paranoia and anxiety are constant companions. But, it also provides a natural pause in one's career to reflect on what has been learned and how best this knowledge should be applied in one's practice. And so, to my astonishment having been a doctor for almost 15 years, I had more questions it seemed than answers. Nonetheless, as I came to realise, these questions were not the same naïve questions I had as an intern. The questions I was now asking were pointed; they sought valid and compelling reasoning to justify performing a procedure which might affect the welfare of my patient. I also quickly became aware that I had developed a healthy scepticism, which I had obviously adopted from some of my mentors. Accordingly, my clinical and scientific olfactory senses had been honed sufficiently to be able to smell the proverbial rat, or something altogether more pungent.

The questions when I started out were as follows:

1. Does the anterolateral ligament (ALL) really exist and, if so, what does it do?
2. What is the aetiology of anterolateral rotatory laxity of the knee?
3. How can anterolateral rotatory laxity of the knee be diagnosed?
4. What is the most effective method of treating anterolateral rotatory laxity of the knee through surgical reconstruction?

Does the anterolateral ligament really exist and, if so, what does it do?

"*The truth is rarely pure and never simple*"

- Oscar Wilde

The above quote, in my opinion, is a perfect prelude to answer this my opening question. Simply put, yes, the ALL does exist. However, the structure described by Claes et al, which is contained within capsule of the anterolateral aspect of the knee, is quite different from the structure described by others authors but bears the same name(1). Kaplan, originally, and later Terry et and Vieira et al, defined the ALL as a component of the distal ITB, consisting of the deep, capsulo-osseous and superficial layers(51, 56, 57). These findings are indeed consistent with the first description of a structure purported to be the ALL by Segond in 1879(4). As for its role, it has been shown to make only a small contribution in restraining the pivot shift in an ACL-deficient knee, whereas the majority of restraint is provided by the ITB itself(157). It has been suggested that the ALL is merely one component of a confluence of structures on the anterolateral aspect of the knee, referred to as the anterolateral complex (13); the other structures include the superficial and deep aspects of the iliotibial band (ITB) with its Kaplan fibre attachments on the distal femur and the anterolateral capsule(14).

What is the aetiology of anterolateral rotatory laxity?

So, if it is not the ALL what is it? Once again, the answer is complex and multifactorial. An understanding of the kinematics of the anterolateral rotatory laxity have been greatly enhanced through cadaveric, sectioning studies of the knee using 6-degree-of-freedom robots to simulate knee motion(70, 157). It has been clearly demonstrated that injury to the structures of the anterolateral complex in the setting of ACL-deficiency contribute to the pathological state of anterolateral rotatory laxity(14). Not surprisingly, therefore, the ITB has been found to play an integral role in this process, as it controls rotation and anterolateral translation of the knee(76). So too, the Kaplan fibres have been shown to be instrumental in controlling internal rotation of an ACL-deficient knee in high-flexion, more so than the ALL in fact(70). Nevertheless, it is important to be mindful of the inherent limitations of biomechanical models. Knee motion in vivo is fluid and dynamic, and is influenced by a variety of factors, such as muscle loading and ground reaction forces, which are very difficult to replicate in the biomechanical assessment of laxity(78). Also, what is examined in a laboratory is cadaveric tissue and provides time-zero data which does not account for other soft tissue changes that occur as a result of healing or graft attenuation during rehabilitation or sport as would occur in vivo(48, 78). Therefore, the inconvenient truth remains that anterolateral rotatory laxity is not simply caused by injury to one structure or even a number of structures, it is caused by a variable and complex array of factors related bony morphology, joint physiology, pathological injury and biomechanical loading patterns(13); this involves both intra-articular and extra-articular pathology.

How can anterolateral rotatory laxity be diagnosed?

The definition of laxity is the quality or condition of being loose. It originates from the Latin word, ‘laxitatem’, which means "width, spaciousness”. Therefore, in order to diagnose it, one would expect to require a measurement of some sort. The issue is that measurement of anterolateral rotation alone requires a composite assessment of a number of different movements: Anterolateral translation and internal rotation of the tibia relative to the femur, each of which should ideally be quantified through a range of motion (158). In many ways, it is easy to understand why the term ‘Anterolateral Rotatory Instability’ is still used, as it refers to the subjective assessment and not the objective measurement, which remains very challenging(59).

The pivot shift test, since its inception, has been used as a surrogate measure of anterolateral laxity and remains the gold standard for clinical assessment of ACL-deficiency (86, 159). Although the manoeuvre to carry out the pivot shift test involves internal rotation of the tibia relative to the femur, the feedback provided during the test is actually the reduction of the subluxed lateral tibia, which is guided back into position by the ITB as the knee is flexed under compressive load(85, 86, 159). So, if the test measures the grade or magnitude of the reduction of the tibia, what determines the extent of subluxation aside from the ACL?

The early proponents of the manoeuvre recognised the importance of the secondary stabilisers of the knee (anterolateral complex) and the impact they had on the pivot shift(142, 160). In his review on physical examination of rotatory instability, Larson commented that "*their integrity (secondary stabilisers) will decrease the magnitude of the instability demonstrated by the clinical test"*(86). Indeed, he postulated that the accuracy of the pivot shift examination was negatively affected by having intact secondary stabilisers(86). Taken another way, this can be interpreted positively to infer that a lesser injury to the anterolateral structures results in less anterolateral laxity and, therefore, a lesser pivot shift grade. However, also contained in Larson's review are other salutary remarks which are pertinent to the limitations of the pivot shift: "*The patient may also reflexly resist the particular test for instability because it is painful. The examiner cannot produce the magnitude of force that occurs during physical activity*."(86) Nowadays, where the majority of patients present within days or weeks of ACL injury, it is important to consider the possibility of underlying injury to the anterolateral structures, even in the absence of obvious clinical examination findings. But surely, with the advances of modern radiological technology, we can do better in terms of diagnosis than a 50-year old, largely subjective, manual test?

It would appear not. *Section 2* within this study focused on the ability of MRI to identify the two components of the anterolateral complex, namely the ALL and the Kaplan fibre complex of the ITB. The studies, using standard MRI scans as would be used in conventional orthopaedic practice, also examined whether injury to these structures could be diagnosed in the setting of ACL injury. Overall the utility of MRI was found to be underwhelming. *Study 2* demonstrated that that MRI alone should not be relied upon to make a diagnosis of ALL injury in the setting of concomitant ACL injury due to the inability to accurately visualize this structure consistently in its entirety. *Study 3*, however, found that MRI was in fact useful in identifying the Kaplan fibres of the ITB, which according to biomechanical studies are more important in controlling anterolateral rotatory laxity of the knee than the ALL anyway(70). Interestingly, and contrary to previous studies, *Study 4* revealed that the prevalence of injury to the Kaplan fibre complex in the setting of acute ACL injury (<90 days from injury-to-MRI) was 23.7% and only 6.4% in chronic injury (>90 days from injury-to-MRI). However, *Study 5* found no correlation with radiological evidence of Kaplan fibre injury in acutely injured knees (<60 days between injury, MRI and surgery) and the grade of pivot shift at the time of ACL reconstruction under general anaesthetic, which represents the ideal conditions for this test. Therefore, in the setting of acute primary ACL reconstruction, MRI has limited value in predicting those patients with increased anterolateral rotatory laxity.

What is the most effective method of treating anterolateral rotatory laxity of the knee through surgical reconstruction?

"Love many, trust few, always paddle your own canoe"

My grandfather was the youngest of 11 children. He left school at the age of ten to work on the family farm. He was not a highly educated man but he was very wise. He had many great sayings but the one above, although not his own, was one of his favourites. It is particularly appropriate when considering the final question of this thesis. In general, if things seem too good to be true it is probably because they are too good to be true. In *Study 6*, a novel review of the information available on the internet related to reconstruction of the ALL was performed and revealed that quality of information on the internet relating to ALL reconstruction was significantly inferior to information about ACL reconstruction. Specifically, it exposed that there was a failure to include crucial information about the indication or options for treatment, prognosis, and potential complications, which likely reflects the dearth of clinical studies supporting its use at the time(21). The proposed benefits of reconstruction of the ALL were improved stability of the knee and a reduced chance of rupture of the ACL graft when it was performed concomitantly(135, 161, 162). Subsequent clinical studies have revealed that despite the tertiary role the ALL plays in controlling anterolateral rotation of the knee, the clinical outcomes following ALL reconstruction are comparable to more traditional LET procedures(144). Consequently, the indications for ALL reconstruction have been expanded in the setting of primary ACL reconstruction to include its use with medial meniscal repair, ACL repair and in patients with hypermobility(138, 163, 164). The problem is that the champions of this approach and primary authors of the manuscripts advocating an expanded list of indications are all paid consultants for the company that makes the proprietary devices described in the operative techniques(138, 163, 164).

In order to make up my own mind about the role of a LET procedures in the setting of primary ACL reconstruction, I carried out a systematic review. The inclusion criteria were particularly rigorous and only randomised and nonrandomised clinical studies comparing ACL reconstruction with LET versus ACL reconstruction alone were included. The review revealed that there was no evidence available showing an additional benefit of LET in reducing the postoperative pivot shift in early ACL reconstructions (<12months); however, LET may have a role in delayed ACL reconstruction with strong evidence suggesting that a combined ACL reconstruction and LET reduces lateral femoral translation. The rational to explain this is reasonably straightforward; patients with chronic ACL deficiency are more likely to have undergone multiple pivot shift events, thereby attenuating the secondary stabilisers on the anterolateral aspect of the knee with the resultant effect of increasing rotational laxity(142, 165). Following this study, I have implemented these findings into my own practice and included a high grade pivot shift preoperatively as one of the indications for a LET in the setting of primary ACL reconstruction. In 2019, the Anterolateral Complex Consensus Group made a similar recommendation(14).

Primum non nocere

One of the central tenets of medicine is non-maleficence, or as it is more commonly phrased, "*First, do no harm!*". As an orthopaedic surgeon, my principal motivation when facing a patient with an ACL injury is one of beneficence, with the primary aim to '*do good*' for the patient by treating the injury and trying to prevent any further harm. However, inevitably conflicts arise between beneficence and maleficence, and the LET procedure is a good example and is the basis for the question which is answered in *Chapter 11*: Does the combination of a lateral extra-articular tenodesis and an intra-articular anterior cruciate ligament reconstruction increase the risk of developing osteoarthritis?

A systematic review of studies with long-term radiological follow-up of patients with ACL deficiency treated with ACL reconstruction combined with LET or LET in isolation was conducted. The study revealed that the best available evidence would suggest that the addition of a LET to an ACL reconstruction does not result in an increase rate of osteoarthritis. The incidence of osteoarthritis remained low up to 11 years it did increase thereafter, although the presence of the presence of meniscal injury at the index surgery was reported to be a greater predictor of the development of osteoarthritis. These findings are in keeping with the findings of a recent study by Castoldi et al, which was published after the current systematic review(166); the authors conducted a randomised control trial comparing the long-term (19 years) results of patients treated with an isolated bone patellar tendon bone ACL reconstruction to those with a combined bone patellar tendon bone and LET procedure. The results revealed that although the functional results were the same in each group, there was a higher rate of lateral osteoarthritis in patients who had a combined ACL reconstruction and LET. However, this finding was associated with a higher number of lateral meniscectomies in these patients. Interestingly, there was also a trend towards a higher graft failure rate in the isolated ACL reconstruction group, although the study was underpowered to prove this.

Notwithstanding the reassurance that our study provides, I was very keen assess the effectiveness of the lateral extra-articular augmentation procedure I had embraced and performed since my fellowship, the modified Ellison procedure. Unfortunately, it was not one of the techniques included in either of the aforementioned systematic reviews and there was a paucity of information available regarding the kinematics of the knee following the procedure. Hence, I had to '*paddle my own canoe*' all the way to Imperial College London, and find out for myself. The study presented many challenges, not least trying to load the ITB consistently throughout testing, but ultimately it revealed quite reassuring results. The main finding of the study was that the modified Ellison procedure can closely restore knee laxities to native values in an anterolateral capsule–sectioned knee. Notably, the results did reveal that the procedure resulted in slight over constraint to isolated internal rotation and coupled internal rotation and anterior translation during a simulated pivot shift. It remains to be seen whether this is indeed protective and, of course, it only reflects time-zero biomechanical values.

Limitations and future research

Each of the individual studies contained in this thesis had limitations which are discussed separately in their respective manuscripts. In terms any limitations in providing an overall coherent story within the thesis, I suppose the absence of clinical follow-up of my own personal cases is probably one. However, I have not been in full-time practice for an adequate period of time to make this follow-up meaningful. I am always mindful of the immortal words of Jack Hughston who said, "*nothing ruins results quite like follow-up!*" Therefore, I currently, and intend to continue to, follow up my patients prospectively to assess their clinical and functional outcomes, the results of which will be included in future research. In addition, I intend to continue to explore the Kaplan fibres and the potential effects of iatrogenic injury to these structures during ACL reconstruction as a result of the femoral tunnel drilling and during distal femoral osteotomies.

Conclusion

This thesis provides a comprehensive answer to the four clinical questions I had as a knee surgeon at the start of my consultant career. Indeed, these answers have revealed that the questions I started out with were certainly more complex than I first appreciated but ultimately have shaped my practice as an orthopaedic surgeon. A succinct answer to these four questions is provided below:

The ALL is a capsular structure within the anterolateral capsule of the knee and is merely one component of the anterolateral complex, which consists of the superficial and deep aspects of the ITB with its Kaplan fibre attachments on the distal femur. A loss of integrity in the setting of ACL deficiency can contribute to anterolateral rotatory laxity of the knee which is diagnosed clinically with the pivot shift manoeuvre. MRI is not reliable in identifying injury to the ALL following ACL rupture but it can diagnose injury to the Kaplan fibres of the ITB. However, the prevalence of injury to the Kaplan fibre complex is low (16.4% -23.37%) in the setting of acute ACL rupture. Also, there is no correlation between the grade of pivot shift at the time of surgery and the radiological presence of injury to the Kaplan fibres. With respect to the surgical management of anterolateral rotatory laxity, there is strong evidence that the addition of a LET to an ACL reconstruction in chronic ACL-deficiency reduces lateral femoral translation. The best available evidence would suggest that the addition of a LET to an ACL reconstruction does not result in an increase rate of osteoarthritis. Finally, a distally based lateral extra-articular augmentation procedure (the modified Ellison) can closely restore knee laxities to native values in an anterolateral capsule–sectioned knee and should be considered a good alternative to more proximally based LET procedures.

Appendix I: Ethics Approval Statements

Chapters 4: Study 2: MRI is not reliable in diagnosing of concomitant anterolateral ligament and anterior cruciate ligament injuries of the knee

Chapter 5: Study 3: The Kaplan fibres of the iliotibial band can be identified on routine knee magnetic resonance imaging

Epworth HREC study number 57012

Chapters 6: Study 4: Radiological identification of injury to the Kaplan fibers of the iliotibial band in association with anterior cruciate ligament injury

Chapter 7: Study 5: Association between radiological evidence of Kaplan fibre injury, intraoperative findings and pivot shift grade in the setting of acute anterior cruciate ligament injury

Epworth HREC study number LR 183-14

Chapter 11: Study 9: Biomechanical assessment of a distally fixed lateral extra-articular augmentation procedure in the treatment of anterolateral rotational laxity of the knee

Imperial College Healthcare : Tissue Bank application number R15091-1A

Epworth HealthCare
Post Approval Submission - Acknowledged

Mr Tim Whitehead
Dr Brian Devitt
OrthoSport Victoria,
Level 5, 89 Bridge Road
Richmond Vic 3121

06 July 2018

Dr Brian Devitt,

Research Project: The anterolateral ligament of the knee: an MRI study
Reference Number: LR 183-14

Thank you for your post-approval submission dated 15 January 2018 regarding the above referenced research project. The below document was acknowledged on the **06 July 2018.**

Documents:

Noted:

- **Project Final Report / Site Closure Report (HREC)** signed & dated by Principal Investigator 15 January 2018

The Epworth Human Research Ethics Committee and Low Risk Sub-Committee are constituted and operate in accordance with the National Health and Medical Research Council's (NHMRC) National Statement on Ethical Conduct in Human Research (2007) in addition to adherence to the Guidelines of Good Clinical Practice and the Australian Code for the Responsible Conduct of Research.

If you have any questions regarding this letter, please contact the Research Development and Governance Unit.
Telephone: (03) 9426 8630
Email: HREC@Epworth.org.au

Yours Sincerely,

Kerrie Lawrence
Research Development and Governance Unit

Epworth HealthCare Ethics Committee, Mailbox #4, 89 Bridge Road, Richmond, VIC 3121
Phone: (03) 9426 8806 HREC@Epworth.org.au

Epworth HealthCare

Human Research & Ethics Committee
Certificate of Approval

Project Title:	**Factors influencing short and long term outcomes of anterior cruciate ligament reconstruction**
Principal Investigator:	**Prof Julian Feller**
Epworth study no:	**57012**
HREC Meeting date:	**5 December 2012**
Board of Management approval:	**19 December 2012**
Duration of Project:	**01/03/2013 to 31/12/2026**

Alan R. Kinkade
Group Chief Executive

Terms and conditions of approval:
The Principal Investigator is required to notify the Human Research Ethics Committee of the following;

All Projects:

1. Must comply with the Australian code for Responsible Conduct of Research (2007) – http://www.nhmrc.gov.au/publications/synopses/files/r39.pdf
2. Any proposed changes to the protocol or approved documentation or the addition of documents (including flyers, brochures, advertising materials etc) must be submitted to the Human Research Ethics Committee for approval prior to implementation
3. The Principal Investigator must notify HREC of
   a. Any serious adverse effects of the study on participants and steps taken to deal with them
   b. Any unforeseen events (e.g. protocol violations or complaints)
   c. Investigators withdrawing from or joining the project
4. A Progress Report must be submitted annually and at the conclusion of the project
5. Epworth HealthCare HREC approval must remain current for the entire duration of the project. If the project is not completed in the allocated time a renewal request must be submitted to the HREC. Investigators undertaking projects without current HREC approval risk their indemnity, funding and publication rights

Clinical Trials:

6. Must comply with Good Clinical Practice (GCP) http://www.tga.gov.au/docs/pdf/euguide/ich/ich13595.pdf
7. Must report all internal (occurring at Epworth HealthCare) Serious Adverse Events (SAE) to the sponsor and the HREC within 72 hours of occurrence
8. Must report all Suspected Unexpected Serious Adverse Reactions (SUSARS) to the Therapeutic Goods Administration (TGA). For sponsored studies, the sponsor may take this responsibility

I, ...Julian Feller......, accept the terms and conditions set out above.

Signature of Researcher: .... Date: ...20/12/12......

Imperial College Healthcare Tissue Bank
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ICHTB HTA licence: 12275
REC Wales approval: 12/WA/0196

Professor Andrew Amis
Mechanical Engineering Department
Imperial College London
South Kensington Campus
SW7 2AZ

7th April 2017

Dear Professor Amis

Re: Tissue Bank application number R15091-1A;
Project title: Evaluation of the iliotibial tract / fascia lata graft for anterior cruciate ligament reconstruction

I am pleased to confirm that the Imperial College Healthcare Tissue Bank has received and approved the following amendment;

- Amendment 1A – extension of project time for a further 12 months.

In order to satisfy HTA tracking requirements, would you please ensure the samples you use are reported to the tissue bank via the online database and sub-collection, along with any publications you produce, that should contain the acknowledgment wording as per the signed MTA.

Yours sincerely,

Professor Gerry Thomas
DI, HTA Research Licence.

Cc: TM/tissue bank file

Imperial College London

Appendix II: Confirmation of Authorship

Study One:

Statement from the author's supervisor confirming authorship contribution of the PhD candidate:

As co-author of the publication, " *The Origin of the Knee Anterolateral Ligament Discovery: A Translation of Segond's Original Work With Commentary. Murgier J, Devitt BM, Sevre J, Feller JA, Cavaignac E. Arthroscopy. 2019 Feb;35(2):684-690."* we certify that Brian Devitt made the following contributions:

- Conception and design of the study
- Collation and editing of the translation
- Writing the manuscript and response to reviewers' comments

Professor Julian A Feller

29th June 2020

Study Two:

Statement from the author's supervisors confirming authorship contribution of the PhD candidate:

As co-authors of the publication, "*MRI is not reliable in diagnosing of concomitant anterolateral ligament and anterior cruciate ligament injuries of the knee. Devitt BM, O'Sullivan R, Feller JA, Lash N, Porter TJ, Webster KE, Whitehead TS. Knee Surg Sports Traumatol Arthrosc. 2017 Apr;25(4):1345-1351."* we certify that Brian Devitt made the following contributions:

- Conception and design of the study
- Reading of MRI scans
- Analysis of data
- Writing the manuscript and response to reviewers' comments

Professor Julian A Feller

29th June 2020

Professor Kate Webster

29th June 2020

Study Three:

Statement from the author's supervisors confirming authorship contribution of the PhD candidate:

As co-authors of the publication, *"The Kaplan Fibers of the Iliotibial Band Can Be Identified on Routine Knee Magnetic Resonance Imaging. Batty L, Murgier J, O'Sullivan R, Webster KE, Feller JA, Devitt BM. Am J Sports Med. 2019 Oct;47(12):2895-2903."* we certify that Brian Devitt made the following contributions:

- Conception and design of the study
- Reading of MRI scans
- Analysis of data
- Writing the manuscript and response to reviewers' comments

Professor Julian A Feller

29th June 2020

Professor Kate Webster

29th June 2020

Study Four:

Statement from the author's supervisors confirming authorship contribution of the PhD candidate:

As co-authors of the publication, "*Radiological identification of injury to the Kaplan fibers of the iliotibial band in association with anterior cruciate ligament injury. Batty L, Murgier J, O'Sullivan R, Webster KE, Feller JA, Devitt BM.*" we certify that Brian Devitt made the following contributions:

- Conception and design of the study
- Reading of MRI scans
- Analysis of data
- Writing the manuscript and response to reviewers' comments

Professor Julian A Feller

29th June 2020

Professor Kate Webster

29th June 2020

Study Five:

Statement from the author's supervisors confirming authorship contribution of the PhD candidate:

As co-authors of the publication, "*Association between radiological evidence of Kaplan fiber injury, intraoperative findings and pivot shift grade in the setting of acute anterior cruciate ligament injury. Devitt, BM, Al'khafaji I, Blucher N, Batty L, Murgier J, O'Sullivan R, Webster KE, Feller JA.*" we certify that Brian Devitt made the following contributions:

- Conception and design of the study
- Reading of MRI scans
- Analysis of data
- Writing the manuscript and response to reviewers' comments

Professor Julian A Feller

29th June 2020

Professor Kate Webster

29th June 2020

Study Six:

Statement from the author's supervisors confirming authorship contribution of the PhD candidate:

As co-authors of the publication, "*Comparison of the Source and Quality of Information on the Internet Between Anterolateral Ligament Reconstruction and Anterior Cruciate Ligament Reconstruction: An Australian Experience. Devitt BM, Hartwig T, Klemm H, Cosic FT, Green J, Webster KE, Feller JA, Baker JF..Orthop J Sports Med. 2017 Dec 7;5(12):2325967117741887.*" we certify that Brian Devitt made the following contributions:

- Conception and design of the study
- Internet search
- Analysis of data
- Writing the manuscript and response to reviewers' comments

Professor Julian A Feller

29th June 2020

Professor Kate Webster

29th June 2020

Study Seven:

Statement from the author's supervisors confirming authorship contribution of the PhD candidate:

As co-authors of the publication, "*The Role of Lateral Extra-articular Tenodesis in Primary Anterior Cruciate Ligament Reconstruction: A Systematic Review With Meta-analysis and Best-Evidence Synthesis. Devitt BM, Bell SW, Ardern CL, Hartwig T, Porter TJ, Feller JA, Webster KE. Orthop J Sports Med. 2017 Oct 24;5(10):2325967117731767.*" we certify that Brian Devitt made the following contributions:

- Conception and design of the study
- Systematic review
- Meta-analysis and best evidence synthesis
- Writing the manuscript and response to reviewers' comments

Professor Julian A Feller

29th June 2020

Professor Kate Webster

29th June 2020

Study Eight:

Statement from the author's supervisors confirming authorship contribution of the PhD candidate:

As co-authors of the publication, "*Combined anterior cruciate ligament reconstruction and lateral extra-articular tenodesis does not result in an increased rate of osteoarthritis: a systematic review and best evidence synthesis. Devitt BM, Bouguennec N, Barfod KW, Porter T, Webster KE, Feller JA. Knee Surg Sports Traumatol Arthrosc. 2017 Apr;25(4):1149-1160.*" we certify that Brian Devitt made the following contributions:

- Conception and design of the study
- Systematic review
- Data analysis and best evidence synthesis
- Writing the manuscript and response to reviewers' comments

Professor Julian A Feller

29th June 2020

Professor Kate Webster

29th June 2020

Study Nine:

Statement from the author's supervisor confirming authorship contribution of the PhD candidate:

As co-authors of the publication, "*Biomechanical Assessment of a Distally Fixed Lateral Extra-articular Augmentation Procedure in the Treatment of Anterolateral Rotational Laxity of the Knee. Devitt BM, Lord BR, Williams A, Amis AA, Feller JA.. Am J Sports Med. 2019 Jul;47(9):2102-2109..*" I certify that Brian Devitt made the following contributions:

- Conception and design of the study
- Biomechanical laboratory study
- Data analysis
- Writing the manuscript and response to reviewers' comments

Professor Julian A Feller

29th June 2020

Appendix III: 3-Minute Thesis

Introduction

"*Brevity is the best recommendation of speech, whether in a senator or an orator*."

- Marcus Tullius Cicero

One of the most challenging aspects of scientific writing is delivering a clear message concisely. The same is especially true of scientific presentations. When writing a thesis, the burden of succinctness is somewhat reduced given the expectation to begin with is to provide a substantial body of work on a chosen topic. Notwithstanding the volume of information required for a thesis, clarity of thought and communicating a distinct message is essential. As Einstein wisely mused, "*if you can't explain it simply, you don't understand it well enough.*" It was perhaps with this in mind that the 3-Minute Thesis (3MT) competition was created; it is essentially an *'elevator pitch'* of one's PhD thesis, summarising the key points in a three minute spoken presentation. The presentation is unassisted by props or other materials, and can be accompanied only by a single PowerPoint slide.

I entered the competition at the suggestion of my supervisor, Kate Webster. To say the preparation was a challenge, is an understatement in the extreme. I think it was at some time between my 10^{th} and 15^{th} of drafts that I was reminded of the comment by Mark Twain in a letter to his friend: "*I apologise for writing such a long letter – I didn't have time to write a short one*." But, in the end the experience was instrumental in providing me with the chance to really consolidate my thoughts and communicate them in a simple and comprehensible manner. Find below my speaker's notes and the single slide I used:

Speaker's notes

The anterolateral ligament (ALL) of the knee came to prominence in 2013 when a young Belgian surgeon claimed to have discovered a new ligament which was integral to the stability of the knee. With the advent of social media, within days of the scientific release, details of this so called monumental scientific discovery went viral. The ALL was heralded as the great panacea in the treatment of knee ligament injury, and given its location at the front and outside of the knee was thought to control knee rotation knee that could not be achieved by the anterior cruciate ligament (ACL) alone which was located in the centre. It finally explained why patients with ACL injuries despite reconstruction went on to further rupture because they had likely damaged the ALL unbeknownst to themselves or the treating surgeons.

Knee surgery is big business nowadays. Within months of this discovery, opportunistic orthopaedic surgeons, heavily backed by industry, released techniques to reconstruct the ligament, which here-to-fore nobody knew existed. Unfortunately, lost in the manic race for market share, the rigor of scientific proof was somewhat neglected. As a young surgeon starting off in my career, and admittedly being a little SCEPTICAL, I asked myself a number of questions, which ultimately formed the basis of my thesis proposal:

Does the anterolateral ligament truly exist? Or is fake news perpetuated by industry to encourage us to perform a reconstruction of questionable benefit.

I started with the premise that: "*Those who do not learn from history are doomed to repeat it*".

The first thing I learned was that this was not a new discovery at all. The structure had been recognized by a French surgeon slightly earlier, in 1879, and others since. I then consulted Dr GOOGLE and performed a quality of information on the internet assessment focusing on ALL Reconstruction. I found that the information was woefully deficient regarding the indication and complications of surgery and was largely produced by individual surgeons with industry backing.

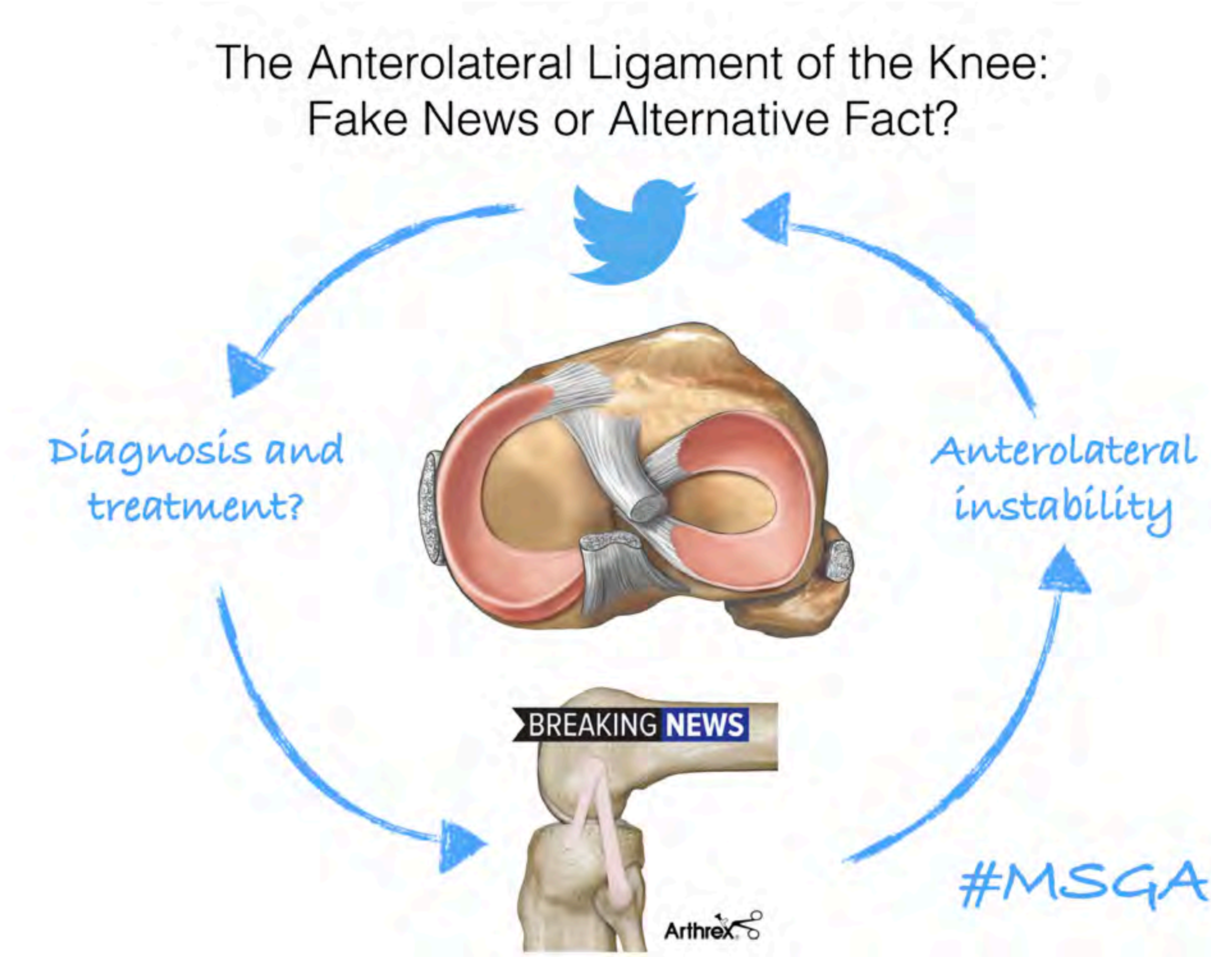
I asked myself if this structure is so important, surely we should be able to see it on MRI to diagnose injury?

We performed a radiological study with MRI comparing normal individuals and also patients with known ACL injury. This little ligament proved elusive and could only be identified in normal individuals 50% of the time and less in those with ACL injury.

It was starting to sound like fake news!

Although the ALL may or may not exist, what this discovery has done is remind us about is the **ALTERNATIVE FACT** – the concept of anterolateral instability, which is abnormal rotation of the knee, is very real and may in fact explain some of the causes of re-injury following ACL reconstruction. Surgeons have long recognized the value of performing a procedure on the outside of the knee to control rotation but it fell out of favour because of the concerns it caused early osteoarthritis. The key question is to identify those patients in which it is beneficial. But we don't have to reinvent the wheel to do so. We looked back into the past again and performed a systematic review and found that only patients with very loose knee or chronic ACL injury benefited from the procedure and not those with recent injuries. We also found that contrary to former belief, this procedure did not result in an increased rate of arthritis. We have since gone on to perform biomechanical and clinical testing to refine this technique so we can restore normal knee motion following injury.
So, just as we shouldn't believe everything we read in the newspaper, the same is even more true for social media. SCIENCE BEFORE SENSATION. I urge you to MAKE SCIENCE GREAT AGAIN!

Slide



This presentation was the winner of the 3MT competition in the School of Allied Health at La Trobe University.

Appendix IV: Editorial

The following editorial was written by me and co-authored by Dr Ian Alk'hafaji at the request of the Editor-in-Chief of Arthroscopy (The Journal of Arthroscopic and Related Surgery) in response to the following publication:

Young BL, Ruder JA, Trofa DP, Fleischli JE. Visualization of Concurrent Anterolateral and Anterior Cruciate Ligament Injury on Magnetic Resonance Imaging. Arthroscopy. 2020 Apr;36(4):1086-1091.

The manuscript is published in Arthroscopy Journal as:

Al'khafaji I, Devitt BM. Editorial Commentary: Magnetic Resonance Imaging Evaluation of the Anterolateral Complex-Is Seeing Really Believing?. Arthroscopy. 2020;36(4):1092-1094. doi:10.1016/j.arthro.2020.01.040

Editorial Commentary: Magnetic Resonance Imaging Evaluation of the Anterolateral Complex—Is Seeing Really Believing?

Ian Al'khafaji, M.D., and Brian M. Devitt, M.D., F.R.C.S., F.R.A.C.S

Abstract: The anatomic and biomechanical role of the anterolateral complex (ALC) of the knee has gained increased interest in recent years. Specifically, a keen focus has been on magnetic resonance imaging (MRI) evaluation of the ALC in the setting of anterior cruciate ligament injury. Although many of these studies are well designed and conducted, they are based on a foundation of controversial gross anatomy and MRI protocols and scanners not typically used in standard practice. Ultimately, there is a lack of correlation between MRI evidence of injury to the ALC and clinical evaluation of anterolateral rotatory laxity. So, do we believe in what we see or believe in what we feel?

See related article on page 1086

I often see through things right to the apparition itself.
Grace Paley

The anterolateral ligament (ALL) appeared like an apparition in 2013 when a Belgian surgeon, Dr. Stephen Claes, claimed to have discovered a new ligament that was integral to the stability of the knee.[1] After its discovery, the ligament was heralded as the great panacea in the treatment of the injured knee, and given its location on the anterolateral aspect of the knee, it was thought to control knee rotation that could not be achieved by the anterior cruciate ligament (ACL) alone with its central location.[1] It provided a plausible reason to explain why patients with ACL injuries, despite reconstruction, went on to further injury because they had also likely injured this ligament unbeknownst to themselves or the treating surgeons. Although conceivable, this simple explanation for persistent knee laxity caused by injury to one solitary structure was too good to be true for many surgeons. Consequently, with respect to the ALL, 2 distinct groups of surgeons emerged: the believers and the nonbelievers!

The current article "Visualization of Concurrent Anterolateral and Anterior Cruciate Ligament Injury on Magnetic Resonance Imaging" by Young, Ruder, Trofa, and Fleischli[2] describes the radiographic features of the ALL using conventional 1.5-T magnetic resonance imaging (MRI). The study is well designed and evaluates the ALL in ACL-injured and -uninjured knees. In doing so, the authors clearly describe the radiographic location of the ALL in the uninjured knee using MRI, which is later used as a reference in the setting of ACL injury. However, one of the fundamental challenges in establishing the radiographic anatomy of the ALL is the lack of a clear consensus on the gross anatomic location of the structure based on cadaveric dissection.[1,3-5] To provide clarity on this issue, a focus group of believers and nonbelievers was established to discuss not only the anatomy of the ALL but also its role in controlling anterolateral rotatory laxity.[6-8] The consensus decreed that no single structure is responsible for controlling anterolateral rotatory laxity; rather, anterolateral rotatory laxity is controlled by the anterolateral complex (ALC) of the knee, which consists of the superficial and deep aspects of the iliotibial tract with its Kaplan fiber attachments on the distal femur, along with the ALL, a capsular structure within the anterolateral capsule.[8] It would appear that the anterolateral structures are complex by name and complex by nature, which raises

Richmond, Australia

The authors report no conflicts of interest in the authorship and publication of this article. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

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a question as to how one can define a clinically significant injury based on radiographic findings alone.

In an attempt to answer this question, Monaco et al.[9] correlated MRI features with surgical exploration in a study of 26 patients with acutely injured knees. They determined that MRI has low sensitivity, specificity, and accuracy for the diagnosis of iliotibial band injury and there was only fair agreement with surgical findings and MRI. These findings are similar to those in the current study by Young et al.,[2] who reported excellent inter-rater agreement ($\kappa = 0.92$) for visualization of at least part of the ALL on over 95% of MRI scans irrespective of ACL integrity. However, the inter-rater agreement dropped significantly in the setting of an ACL-injured knee ($\kappa = 0.38$).[2] It should be noted that although this inter-rater agreement was much higher than previously reported, as an accurate diagnostic tool MRI appeared to be below par in the diagnosis of injury to the ALC.[10,11] But, why is this the case when MRI is very sensitive for the diagnosis of ACL injury?

There are a number of potential reasons. First, the specific MRI protocols used are configured to best identify the ACL with most MRI scanners.[10,12] Although Young et al.[2] used a specific protocol that localized the femoral attachment, it is important to note that the criterion for visualization of the ALL was only that at least one-third of the ligament was viewed; this would hardly be acceptable for ACL injury diagnosis.

Second, one must consider what is the definition of radiologic evidence of injury; Young et al.[2] determined that "ALL injury was defined as increased signal, overt tear or avulsion fracture at the femoral or tibial attachment sites, if visible." Admittedly, these criteria are similar to those used in other studies.[13,14] However, the presence of widespread edema is a frequent finding in acutely injured knees, particularly in the lateral aspect of the knee, and can be associated with capsular injury, meniscal injury, or posterolateral corner injury.[15-17] It is interesting to note that Young et al. reported that the most common abnormality associated with ALL injury on MRI was an effusion (80.00% for rater 1 and 100% for rater 2) but lateral capsule injury was also reported in a large number of cases (38.00% for rater 1 and 59.52% for rater 2).

Finally, the time from injury to MRI is an important factor in establishing a diagnosis, particularly considering that the presence of increased signal within tissues is a key diagnostic factor. It is likely that the closer the time from injury, the greater the amount of edema in the tissue. Nevertheless, the presence of edema may not necessarily represent discontinuity of a ligamentous structure. Likewise, if MRI is delayed, it is feasible that a previous injury may not be detectable in the absence of edema.[10] Furthermore, considering the close relation of the structures of the ALC, a seemingly intact ligament may in fact be attenuated and functionally redundant.[11]

It is important not to lose sight of the fact that radiologic investigations have a tertiary role in the diagnosis of knee injuries, a distance behind a thorough history and physical examination. To quote the words of Professor Apley,[18] one of the great orthopaedic educators, written in an editorial entitled "Intelligent Kneemanship," published in 1964: "Because radiographs have a lot to contribute, the whole of diagnosis is often put upon their shoulders, and the large (often unique) contribution of clinical examination is overlooked." Although we have made many advances in orthopaedic sports surgery in the over half a century since this was written, we need only substitute the word "radiographs" with "MRI scans" and take the same salutary lesson today. Yes, we can continue to look to MRI to aid us in our diagnosis of knee injuries but it is in our hands we must believe!

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