Complications in primary anterior cruciate ligament reconstruction surgery: rates of occurrence, prevention, and management

By

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STUDENT DECLARATION

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Abstract

In anterior cruciate ligament (ACL) reconstruction surgery a graft is used to replace the torn ligament. Understanding the complications of ACL reconstruction surgery is vital for the surgeon to help guide clinical practice.

This synoptic commentary presents eight articles the overall aim of which was to explore complications of ACL reconstruction surgery, consider how their occurrence may be minimised through preventive measures, and how they can be managed once they occur.

The stage was set out by a narrative review which looked at the spectrum of intraoperative complications encountered in ACL reconstruction surgery as well as their causes and management. Following this, an article presented a narrative overview of hamstring tendon harvesting and the substantial variability that exists in the anatomy of these tendons that are frequently used as ACL reconstruction grafts. Subsequently, a third article reported a clinical study on the rate of inadequate hamstring graft harvesting whilst a fourth article reported on a cadaveric study that showed that the hamstring tendon graft quality is related to the type of tendon harvester utilised to obtain the graft. Two systematic reviews and meta-analyses were conducted to assess infection in ACL reconstruction surgery. One reported on the rate of infection in ACL reconstruction, its relation to graft type as well as its relation to vancomycin presoaking. This article demonstrated a higher risk of infection associated with hamstring grafts as compared to other graft types and showed that vancomycin graft presoaking minimised this infection risk. The other article analysed the effectiveness of arthroscopic washout and antibiotic treatment with graft salvage and showed this to be a successful option in most cases of bacterial infection post-ACL reconstruction. The seventh article of this commentary reported a systematic review of complications of femoral suture button fixation of the ACL graft. It showed the potential for misplacement of the femoral suture button and the need to consider additional intraoperative measures, such as radiological screening or arthroscopic inspection of the button, to try and avoid this. The final article reported a study which used artificial bones and looked at the relation between the type of reamer used to create the tibial tunnel in ACL reconstruction and tunnel morphology. It showed that misdirection of the reamer may influence the morphology of the outer aperture of the tibial tunnel, and that such change in aperture morphology is reamer type dependent.

In conclusion, the articles of this commentary provided knowledge to enhance the ability of the surgeon to obtain a graft of adequate dimensions, minimise the risk of infection, and enhance the graft fixation to the femur and tibia. This knowledge may also improve the ability of the surgeon to manage postoperative infection once encountered. The commentary's articles also emphasise the need to recognise that surgical complications occur and that by discussing these and sharing experiences in an open and transparent way, surgeons and other professionals can learn and develop further.

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Acknowledgements

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Structure of the synoptic commentary

Initially a list of the articles included in this synoptic commentary as well as other articles related to the topic to which the author has contributed are presented. This is followed by chapter one which is the introduction that sets the stage for the topic of complications in anterior cruciate ligament (ACL) reconstruction surgery and provides the specific hypotheses that the articles included in this commentary assessed. The subsequent 5 chapters each addresses a specific area of complications in ACL reconstruction surgery. Each of these chapters examines the main findings of the articles and their contributions to knowledge. Each chapter provides a critical discussion of each article and, where relevant, compares the findings to other more recent related evidence, with recommendations for further research made. Chapter 7 concludes the analysis and gives an overall discussion based on the findings of the presented articles.

List of articles included in the synoptic commentary

1. *Management of intraoperative complications in arthroscopic primary anterior cruciate ligament reconstruction. Charalambous CP, Alvi F, Sutton PM. J Knee Surg. 2015 Apr;28(2):165-74. doi: 10.1055/s-0034-1373739.*

2. *Anatomical considerations in hamstring tendon harvesting for anterior cruciate ligament reconstruction. Charalambous CP, Kwaees TA. Muscles Ligaments Tendons J. 2013 Jan 21;2(4):253-7. PMID: 23738306*

3. *Rate of insufficient ipsilateral hamstring graft harvesting in primary anterior cruciate ligament reconstruction. Charalambous CP, Kwaees TA, Lane S, Blundell C, Mati W. J Knee Surg. 2021. doi: 10.1055/s-0041-1726421*

4. *Hamstring tendon harvesting--Effect of harvester on tendon characteristics and soft tissue disruption; cadaver study. Charalambous CP, Alvi F, Phaltankar P, Gagey O. Knee. 2009 Jun;16(3):183-6. doi: 10.1016/j.knee.2008.11.010. PMID: 1927278*

5. *Relationship of Graft Type and Vancomycin Presoaking to Rate of Infection in Anterior Cruciate Ligament Reconstruction: A Meta-Analysis of 198 Studies with 68,453 Grafts. Kuršumović K, Charalambous CP. JBJS Rev. 2020 Jul;8(7):e1900156. doi: 10.2106/JBJS.RVW.19.00156. PMID: 32759615*

6. *Graft salvage following infected anterior cruciate ligament reconstruction: a systematic review and meta-analysis. Kuršumović K, Charalambous CP. Bone Joint J. 2016 May;98-B(5):608-15. doi: 10.1302/0301-620X.98B5.35990. PMID: 27143730.* Errata. Bone Joint J. 2016 Aug;98-B(8):1151-2. doi: 10.1302/0301-620X.98B8.38074c. Erratum for: Bone Joint J. 2016 May;98-B(5):608-15. PMID: 27482032.

7. *Complications following Suture Button Use for Femoral Graft Fixation in Arthroscopic Anterior Cruciate Ligament Reconstruction: A Systematic Review. Yassa R, Adam JR, Charalambous CP. J Knee Surg. 2021 Jun;34(7):755-763. PMID: 31905415. doi: 10.1055/s-0039-3400753. PMID: 31905415*

8. *Comparison of Acorn and Fluted Reamers on Tibial Tunnel Outer Aperture Dimensions in ACL Reconstruction. Gerrard AD, Jump CM, Sutton P, Charalambous CP. J Knee Surg. 2022 Apr;35(5):534-538. PMID: 32898901. doi: 10.1055/s-0040-1716372.*

List of related articles authored or co-authored by CP Charalambous

In addition to the studies considered in this synoptic commentary the author contributed to several other peer reviewed articles on ACL surgery and complications in ACL reconstruction as well as book chapters:

1. Tibial Tunnel Cyst Formation after Anterior Cruciate Ligament Reconstruction Using a Non-Bioabsorbable Interference Screw. Joshi YV, Bhaskar D, Phaltankar PM, Charalambous CP. Knee Surg Relat Res. 2015 Dec;27(4):269-73

2. Pseudogout: A Rare Cause of Acute Arthritis Following Arthroscopic Anterior Cruciate Ligament Reconstruction. Zaman M, Sabir N, Mills SP, Charalambous CP. Knee Surg Relat Res. 2015 Sep;27(3):194-6

3. Accessory bands of the hamstring tendons: A clinical anatomical study. Yasin MN, Charalambous CP, Mills SP, Phaltankar PM. Clin Anat. 2010 Oct;23(7):862-5

4. Surface Modification of Interference Screws Used in Anterior Cruciate Ligament Reconstruction Surgery. Charalambous CP, Kwaees TA, Sutton PM. In: Ahmed W., Jackson M. (eds) Surgical Tools and Medical Devices. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-33489-9_20

5. Anterior Cruciate Ligament Knee Instability. Charalambous CP. In The Knee Made Easy pp 741-766. Springer, Cham, (2021). ISBN: 978-3-030-54506-2

CP Charalambous also contributed to several other peer reviewed articles in soft tissue surgery of the knee:

1. Timing of Anterior Cruciate Ligament Reconstruction and Relationship with Meniscal Tears: A Systematic Review and Meta-analysis. Prodromidis AD, Drosatou C, Thivaios GC, Zreik N, Charalambous CP. Am J Sports Med. 2021 Jul;49(9):2551-2562

2. Relationship Between Timing of Anterior Cruciate Ligament Reconstruction and Chondral Injuries: A Systematic Review and Meta-analysis. Prodromidis AD, Drosatou C, Mourikis A, Sutton PM, Charalambous CP. Am J Sports Med. 2021 Sep 15:3635465211036141. doi: 10.1177/03635465211036141

3. Purely intra-articular versus general anaesthesia for proposed arthroscopic partial meniscectomy of the knee: a randomized controlled trial. Charalambous CP, Tryfonidis M, Alvi F, Kumar R, Hirst P. Arthroscopy. 2006 Sep;22(9):972-7

4. Double-bundle medial patellofemoral ligament reconstruction with hamstring tendon autograft and mediolateral patellar tunnel fixation: a meta-analysis of outcomes and complications. Singhal R, Rogers S, Charalambous CP. Bone Joint J. 2013 Jul;95-B(7):900-5

5. Platelet-Rich Plasma Injections as a Treatment for Refractory Patellar Tendinosis: A Meta-Analysis of Randomised Trials. Dupley L, Charalambous CP. Knee Surg Relat Res. 2017 Sep 1;29(3):165-171

6. Arthroscopic Excision of Medial Knee Plica: A Meta-Analysis of Outcomes. Gerrard AD, Charalambous CP. Knee Surg Relat Res. 2018 Dec 1;30(4):356-363

CHAPTER 1- INTRODUCTION

A. **Anatomical structures of the knee**

The knee is the joint between the bottom end of the femur bone, the top end of the tibia bone, and the posterior surface of the patella. The bottom end of the femur is referred to as the distal femur, the top part of the tibia is referred to as the proximal tibia, whereas the outer and inner border of these bones are referred to as the lateral and medial borders respectively. The distal femur and proximal tibia have round like protuberances known as the medial and lateral condyles. The part of the distal femur that runs between the most inferior part of the lateral condyle and the most inferior part of the medial condyle is the femoral notch, which is shaped like an arch. The knee has two parts, the tibiofemoral and patellofemoral articulations. The tibiofemoral articulation is the articulation between the distal condyles of the femur and the proximal condyles of the tibia. The patellofemoral articulation is the articulation between the posterior surface of the patella and the anterior surface of the femur. The articulating surfaces of the knee are lined with hyaline cartilage which is smooth fibrous tissue (Sinnatamby, 2011, Flandry and Hommel, 2011). Between the femoral and tibial condyles are the medial and lateral menisci which are cartilage cushion like structures (Fox et al., 2015).

Surrounding the bones of the knee is soft tissue which includes muscles and ligaments. Of the muscles crossing the knee, the ones considered within this commentary are the quadriceps muscles, the hamstring muscles and gracilis. The quadriceps consists of four muscles and is located at the front of the thigh. Its components are the rectus femoris, vastus lateralis, vastus medialis, and vastus intermedius. Rectus femoris is the most superficial and covers the other three quadriceps muscles. Vastus lateralis is located on the lateral part of the thigh whereas vastus medialis is located medially. Between vastus lateralis and vastus medialis is vastus intermedius. The quadriceps muscles join to form the quadriceps tendon which attaches onto the top part of the patella and then continues over the anterior surface of the patella to give rise to the patellar tendon. The patellar tendon attaches onto the anterior part of the proximal tibia. The hamstrings are muscles located at the posterior part of the thigh and are the semimembranosus, semitendinosus, and biceps femoris. The tendon of semitendinosus attaches onto the proximal and medial end of the tibia along with the tendon of the gracilis muscle. The gracilis is a muscle located on the medial side of the thigh (Charalambous, 2021, Sinnatamby, 2011, Mochizuki et al., 2004).

Ligaments are fibrous structures that connect two bones to provide stability. The main ligaments to consider in the knee are the collateral and cruciate ligaments. The medial collateral and lateral collateral ligaments are located on each side of the knee, whereas the cruciate ligaments are in the centre of the knee. There are two cruciate ligaments, the anterior cruciate ligament (ACL) and the posterior cruciate ligament (PCL) (Laprade et al., 2015, Saavedra et al., 2013, Sinnatamby, 2011, Flandry and Hommel, 2011).

The ACL passes from the anterolateral aspect of the femoral notch to the anteromedial aspect of the tibia (figure 1.1). It consists of two groups of fibres referred to as bundles each of which has a distinct femoral and tibial insertion. These bundles are known as the anteromedial and the posterolateral bundle. The anteromedial bundle passes from the proximal part of its femoral origin to the anteromedial part of its tibial insertion. The posterolateral bundle passes from the distal part of its femoral origin to the posterolateral part of its tibial insertion. The mean width of the ACL is about 8mm (range 5-14mm), whilst its length is about 32mm (range 23-45mm) (Charalambous, 2021, Hassebrock et al., 2020, Sinnatamby, 2011).

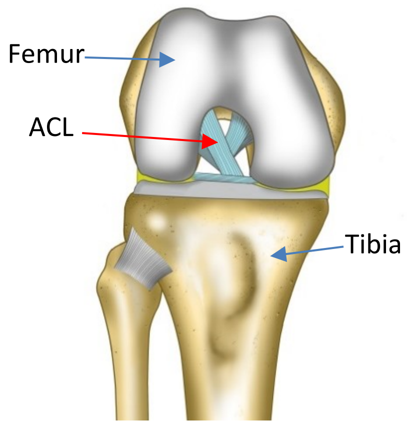

Figure 1.1 Schematic view of the ACL in relation to the knee bones

B. **Stability of the knee joint**

Stability of a joint refers to the ability of a joint to maintain the normal relation of the articulating surfaces throughout its range of motion. Instability is a condition whereby one articulating surface moves out of normal position in relation to another articulating surface. Stability is provided by static and dynamic stabilisers. Static stabilisers are structures that are constant in shape and size, and these cannot be controlled in association to the challenges of stability. These include the shape of the articular surfaces, as well as ligaments. Ligaments are static stabilisers as they cannot actively change their shape or size to limit motion. Instead, when a force is applied, all they can do is stretch from a resting lax state to a taut state.

Dynamic stabilisers are structures that can alter the force they exert across a joint as the situation demands. Muscles are dynamic stabilisers which attach via their tendons to bones and thus when they contract they can achieve bone and joint movement. Control of muscle contraction is referred to as motor control. Motor control is mediated by nerve signals that pass from the central nervous system to the muscles, as well as by signals from local reflexes (Riemann and Lephart, 2002a). Nerve signals which bring about complex or voluntary movements at conscious or subconscious level, originate in the brain and then pass via the spinal cord in groups of nerve fibers that include the corticospinal tracts and through nerve endings to the muscles to influence their contraction. The activity of brain centres involved in motor control is fine-tuned by sensory input such as visual and auditory input as well as sensory input received from mechanoreceptors located in or around joints, like the knee joint (Johansson, Sjölander and Sojka, 1991). These mechanoreceptors detect movement and joint position in space which is known as proprioception (Riemann and Lephart, 2002b). The ability to control muscle contraction is also influenced by other brain activities such as awareness of the environmental context in which motor activities take place, which is known as situation awareness (Piskin et al., 2021, Kakavas et al., 2019). The brain may modify its processing of motor control in response to long-term changes in sensory input and this is known as neuroplasticity (Kakavas et al., 2019, Zarzycki et al., 2018).

As stability is influenced by several static and dynamic stabilisers in addition to ligaments (Charalambous, 2021, Shelburne, Torry and Pandy, 2006), it is possible for a joint to remain functionally stable and the patient to be able to carry out activities with no or minimal instability even if one or more ligaments are torn (Noyes et al., 1983a, Noyes et al., 1983b).

C. **ACL functions**

As a static stabilizer of the knee, the ACL provides mechanical stability by limiting anterior translation and, to a lesser extent, rotational displacement of the tibia on the femur (Amis, 2017, Butler, Noyes and Grood, 1980). The anteromedial bundle of the ACL is the primary restraint to anterior tibial translation at 90° of knee flexion, whereas the posterolateral bundle is the primary restraint towards full knee extension (Dargel et al., 2007, Petersen and Zantop, 2007).

The ACL also contributes to dynamic stability as it is the source of sensory nerve signals that can modulate the control of muscles around the knee. The ACL contains mechanoreceptors that detect movement and position of the knee joint in space (Banios et al., 2022) contributing to proprioception (Kim, Lee and Lee, 2017).

D. **ACL tears**

ACL tears are common with an estimated annual incidence of about 69 per 100,000 person-years reported for a population in the United States of America (USA) (Sanders et al., 2016). The incidence was shown to be higher in males than in females and in younger as compared to older individuals (Sanders et al., 2016). ACL tears are often the result of sports injuries such as basketball and football (Bram et al., 2021, Kaeding, Leger-St-Jean and Magnussen, 2017, Gornitzky et al., 2016). ACL injuries may occur secondary to contact injuries whereby the knee or ipsilateral leg encounter another surface (Takahashi et al., 2019, Salem et al., 2018, Peterson and Krabak, 2014) or secondary to non-contact injuries whereby the knee or ipsilateral leg do not contact another surface, such as in leg twisting (Boden and Sheehan, 2021, Arendt and Dick, 1995).

There as several clinical features used to describe an ACL tear. Partial ACL tears involve some of the ligament fibres whilst complete tears involve all ligament fibres (Stone, Marx and Conley, 2021, Barrack et al., 1990). ACL tears may also be described as single or double bundle tears according to the number of ACL bundles that are torn (Kushare et al., 2021, Fok and Yau, 2014). The anteromedial bundle or posterolateral bundle may tear in isolation or alternatively both bundles may be torn. Isolated tears of the posterolateral bundle can lead to rotatory laxity of the knee, while tears involving the anteromedial bundle can lead to anteroposterior laxity of the knee (Papalia et al., 2014). The ACL may tear by avulsing from its femoral or tibial bony insertions or by tearing through the ligament itself which is referred to as mid-substance tear (figure 1.2) (Kushare et al., 2021, Griffith et al, 2004). Moreover, ACL tears may occur in isolation or in association with other knee injuries such as a collateral ligament (Shelbourne and Porter, 1992) or PCL tear (Logan et al., 2018), meniscal tear, chondral damage (Ciatti et al., 2021, Park et al., 2020, Sayampanathan et al., 2017, Ralles et al., 2015), or patellar tendon tear (Matthews, Fraser and Parkinson, 2018).

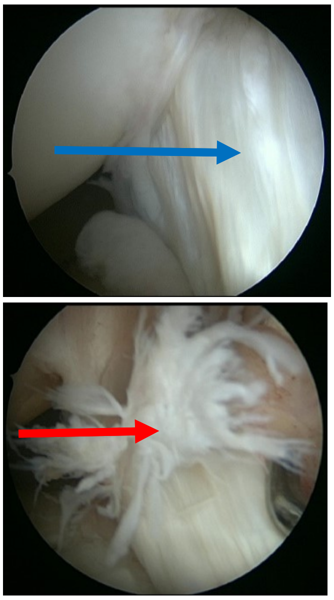

Figure 1.2 Arthroscopic view of intact (blue arrow) and torn (red arrow) ACL

Spontaneous healing in an anatomic position of a complete ACL tear is considered to occur very rarely (Malanga, Giradi and Nadler, 2001, Bagsby, Gantsoudes and Klitzman, 2015). ACL avulsions from the femur may attach and heal onto the PCL but this does not restore normal ACL anatomy and function (Crain et al., 2005). Hence, ACL tears may lead to chronic knee instability which impairs knee function. Patients with knee instability complain of the knee giving way or buckling especially on turning or twisting (Diermeier et al., 2021, Noyes, McGinniss and Mooar, 1984). This may limit the ability of the patient to return to work-related activities or recreational activities and sports (Noyes et al., 1983a, Noyes et al., 1983b).

Knee instability may also lead to further meniscal and chondral injuries (Prodromidis et al., 2021a, Prodromidis et al., 2021b) which in turn could predispose to early knee osteoarthritis

(Wang et al., 2020, Lohmander et al., 2007). Aberrant knee biomechanics in ACL tears may also predispose to early arthritis. A previous radiography study (Chen et al., 2013) showed increased posterior translation of the lateral femoral condyle and increased external femoral rotation in ACL deficient knees as compared to knees with an intact ACL. This posterior subluxation of the lateral condyle may increase the shear forces on the medial part of the knee, increasing the risk of meniscal tears and chondral injuries. Abnormal motion of the lateral femoral condyle may also increase the local contact pressure in the outer part of the knee which may predispose to degenerative changes. It was also suggested that abnormal translation of the femur in relation to the tibia unloads certain parts of the knee which may in turn lead to cartilage thinning and degeneration (Andriacchi, Koo and Scanlan, 2009).

E. **Management of ACL tears**

The management of ACL tears aims to improve knee function. The aim is to enable function as close as to the preinjury level by minimising knee instability and pain, as well as regaining knee strength and range of motion. Knee function may be assessed by questioning the patient as to their ability to carry out specific day to day activities or sport activities. Alternatively, knee function may be assessed by functional score systems that are used in the evaluation of knee disorders. These include the Lysholm knee score (Lysholm and Gillquist, 1982), the Tegner knee score (Tegner and Lysholm, 1985) and the International Knee Documentation Committee (IKDC) score (Irrgang et al., 2001). The Lysholm knee score, is a 100-point scoring system that examines a patient's knee symptoms including mechanical locking, instability, pain, swelling, stair climbing, squatting as well as the presence of limping and need of support in walking. The Tegner score grades the patient’s activity based on work and sports activities. These are graded on a scale of 0 to 10, with 0 representing disability because of the knee problems whilst 10 represents ability to participate in competitive soccer at national or international level. The IKDC score is a patient subjective scale. It has 3 components that assess knee symptoms, sports activities, and overall knee function. The symptoms component includes evaluation of knee pain, stiffness, swelling, locking, and giving way. The sports activities component focuses on the ability to carry out tasks that include going up and down stairs, rising from a chair, squatting and jumping. The knee function component asks to rate the function of the knee with regards to performing any of the patient’s usual daily activities including sports and compares the current state of the knee versus to that prior to the injury or intervention examined.

Improvements in knee function following an ACL tear may be achieved by non-surgical or surgical means, with no consistently reported superiority of one management option over the other (Beard et al., 2022, Reijman et al., 2021, Frobell et al., 2015). Non-surgical means includes the strengthening of the hamstring muscles, enhancement of the neuromuscular control of the muscles around the knee, and utilization of knee braces. The hamstring muscles pull the tibia backwards upon contraction limiting anterior translation of the tibia in relation to the femur, which is analogous to the function of the intact ACL (Liu and Maitland, 2000).

Hence, hamstring muscle strengthening can compensate for the lost function of the torn ACL. Neuromuscular control of the knee to improve knee stability can be achieved by proprioceptive training to compensate for the loss of sensory input from mechanoreceptors located in the torn ACL (Monk et al., 2016, Secrist et al., 2016). This enables muscles to work in a more balanced and coordinated way. Knee braces may also be utilized as part of ACL non-surgical management. Braces are external devices which can improve knee stability by exerting a mechanical force to control the position of one bone in relation to another, such as limiting the anterior translation of the tibia in relation to the femur that occurs in ACL tears (Papannagari et al., 2006, Li et al., 1999). Alternatively, braces may not exert a mechanical force but instead augment the neuromuscular control of the knee by enhancing proprioception (Charalambous, 2021, LaPrade et al., 2017).

ACL surgery to improve knee instability may be in the form of ACL repair or ACL reconstruction. ACL repair is a procedure whereby the avulsed ACL is reattached back to its femoral or tibial origin, but this is a much less commonly performed procedure and evidence on its long-term outcomes is limited (Hopper et al., 2022, van der List et al., 2019, Hoogeslag et al., 2019). ACL reconstruction is a procedure whereby a graft is used to replace the torn ACL (figures 1.3 and 1.4) and is a procedure which is increasingly frequently performed. In a study of national databases in the USA it was reported that the incidence of ACL reconstruction rose from about 86,687 in 1994 to about 129,836 in 2006 (Mall et al., 2014). In England, using national hospital episode data, it was shown that the rate of ACL reconstruction increased 12-fold from about 2 (95% CI 1.9 to 2.1) per 100,000 population in 1997-1998 to about 24.2 (95% CI 23.8 to 24.6) per 100,000 in 2016-2017 (Abram et al., 2020).

ACL reconstruction has been shown to confer long term successful outcomes, but a substantial proportion of patients may have less than optimal results or develop complications following this procedure. In a recent evaluation of 2,042 ACL reconstructions carried out at the Hospital of Special Surgery in New York (Randsborg et al., 2022) it was shown that patients had an 87% chance of their knee feeling stable during daily and athletic activities after an average of 8 years post-surgery. However, only about 70% of patients returned to sport after an average of about 8 years, with fear of reinjury quoted as the most common reason for not doing so. Along similar lines, in a systematic review of 20 articles investigating a total of 2,348 athletes the overall rate of returning to sports was about 73%, with only 49% returning to preinjury levels of performance (DeFazio et al., 2020). ACL reinjury rates may also be high after ACL reconstruction with about 1/3rd of patients who return to competitive sports sustaining a further injury within 3 to 5 years from surgery (Webster, Feller and Klemm, 2021). A delay to return to sports may not protect from further injuries as the reinjury rates were shown to be similar in patients who returned to competitive sports before or after 12 months post-surgery (33% vs 32%, respectively) (Webster, Feller and Klemm, 2021).

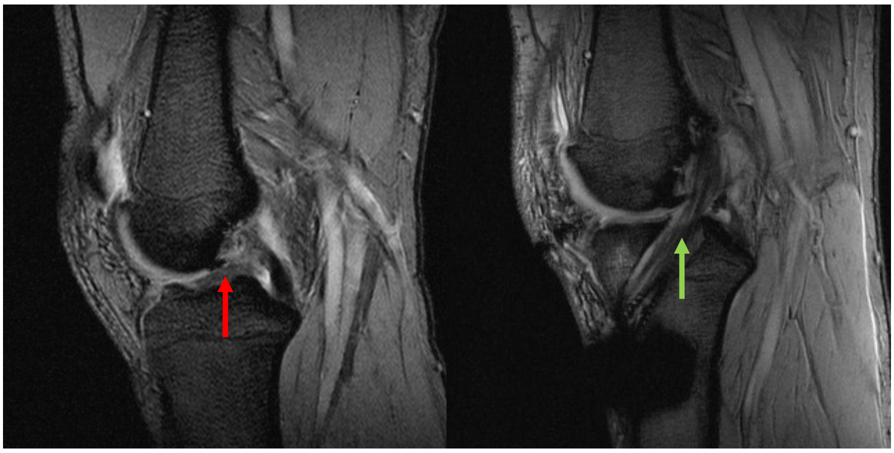

Figure 1.3 Magnetic Resonance Imaging of a torn ACL (red arrow) and reconstructed ACL (green arrow)

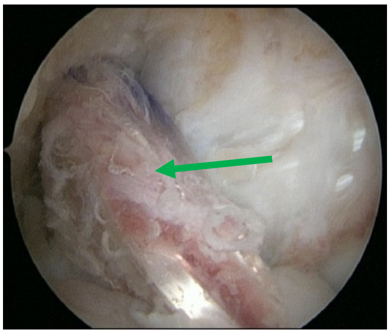

Figure 1.4 Arthroscopic view of reconstructed ACL (green arrow) using a hamstring tendon autograft

F. **ACL reconstruction surgery**

In ACL reconstruction surgery a graft is used to replace, that is reconstruct, the torn ligament. Like the native ACL which passes between the femur and tibia in the centre of the knee, the reconstructed graft is secured to the femur and tibia, passing between the two, and is placed in a configuration that resembles the obliquity of the native ligament (Mayer et al., 2019, Guler et al., 2016). The surgical technique may vary with regards to various parameters including the ones described below:

- Graft type use
- Number of bundles reconstructed
- Open or arthroscopic procedure
- Technique of femoral and tibial tunnel creation
- Means of securing the graft on the femoral and tibial side
- Antibiotic prophylaxis to reduce the risk of surgery related infection

ACL reconstruction may be described according to the type of graft that is used to replace the torn ACL. The graft may be biological tissue or a synthetic ligament. Biological tissue is usually a tendon obtained either from the same patient and referred to as an autograft or from another human and referred to as an allograft. Autograft tendons may be obtained from the reconstructed or opposite knee. Allograft tendons may be sourced from a cadaver or from a living donor (Baawa-Ameyaw et al., 2021). Commonly used tendon grafts include the hamstring, the patellar and quadriceps tendons. The hamstring tendons refer to semitendinosus along with gracilis (Frank et al., 2017) whereas the patellar tendon is harvested with a bone block from its patellar origin and tibial insertion and is referred to as a bone-patellar tendon-bone graft (Frank et al., 2017). The quadriceps tendon is harvested with a bone block from its patellar insertion (Cohen et al., 2021, Malinowski et al., 2021).

ACL reconstruction surgery aims to reconstruct one or both bundles of the ACL. In single bundle reconstruction the graft is constructed and positioned in such a way as to reconstruct the anteromedial bundle. In double bundle ACL reconstruction, the two bundles are reconstructed separately with part of the graft, such as one hamstring tendon, used to reconstruct the anteromedial bundle and the other part of the graft, that is a second tendon, used to reconstruct the posterolateral bundle. A double bundle reconstruction technique aims to create a graft that resembles the anatomy of the native ACL but is a technically a more complex and challenging procedure. Clinical studies have not consistently shown any benefits of double over single bundle reconstruction with regards to clinical outcomes and function (Björnsson et al., 2015).

ACL reconstruction may be carried out as an open surgical procedure which involves incising the knee to visualize its interior. Alternatively, ACL reconstruction may be carried out by arthroscopic surgery (Veltri, 1997). In arthroscopic surgery small incisions are made through which a camera is inserted to visualise the knee and instruments are passed to carry out the procedure. In arthroscopic surgery the knee is inflated with normal saline fluid to improve the view and minimise bleeding. The potential benefit of arthroscopic surgery over open surgery is that it is less invasive and potentially it allows earlier rehabilitation (Cameron, Wilson and St Pierre, 1995) although such an advantage has not been consistently proven (Shelbourne et al., 1993, Raab et al., 1993).

The ACL reconstruction graft may be attached to the femur or tibia by inserting part of the graft in a passage in the bone referred to as a bone tunnel. The graft is secured in the bone tunnel by a surgical fixation device that holds the graft in place until the surrounding bone grows onto the graft and permanently secures it in place. Alternatively, the graft may be secured by attaching the graft onto the bone surface which again allows the formation of links between the bone and graft.

A bone tunnel may be created at the distal femur and the proximal tibia using a reamer which is a power tool that has a round tip at the end of a shaft. The reamer rotates and removes the surrounding bone creating a tunnel. Although various types of reamers are available there is limited evidence about the effect of their individual characteristics on the morphology of the bone tunnels they create. In cases where bone tunnels are used, the tunnels may be created by reaming in an antegrade or a retrograde manner (Bhimani et al., 2021). Antegrade reaming for the tibia involves reaming from the outer surface of the tibia towards the joint, and for the femur involves reaming from within the joint towards the outer surface of the femur. In arthroscopic ACL reconstruction the femoral tunnel may be created by using a trans-tibial or an antero-medial portal technique. The trans-tibial technique involves reaching the femur through the tibial tunnel whereas the antero-medial portal technique involves reaching the femur through an incision made on the antero-medial part of the knee joint (Mao et al, 2021, Bowman et al, 2021). The latter technique may allow better control as to the position of the femoral tunnel and better clinical functional outcomes (Smith 2021, Moorthy, Sayampanathan and Tan, 2021, Mao et al., 2021).

Once the bone tunnels are created, the graft is pulled into the tunnels. The graft must then be held securely in the tunnel until permanent connection through bone to tendon healing is achieved. Several graft fixation techniques are available and can be broadly divided into suspensory or interference fixation. In suspensory fixation the graft is looped around the fixation device which suspends it in the bone tunnel. Such suspensory devices include suture button fixation and cross pin fixation. In interference fixation the graft is pressed against the tunnel walls by a device inserted alongside the graft and this includes interference screw fixation (figure 1.5) (Pereira et al., 2021, Speziali, 2014).

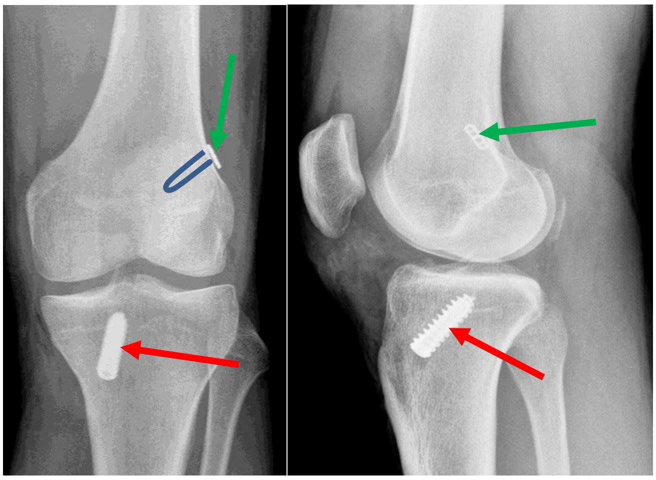

Figure 1.5 Plain radiographs and schematic representation showing ACL reconstruction - femoral fixation is with a suture button (green arrows) onto which the button loop (blue schematic representation) attaches. Tibial fixation is with a metallic interference screw (red arrows).

In patients having surgery whereby prosthetic implants such as screws or other fixation devices are utilized, prophylactic antibiotics are administered immediately before and after surgery to reduce the risk of infection. Such antibiotics are usually administered intravenous or orally. Antibiotics may also be applied locally as topical antibiotics. In ACL surgery topical antibiotic administration may be in the form of presoaking the graft in an antibiotic solution prior to inserting the graft in the bone tunnels. Alternatively, topical administration may be as antibiotics mixed in the normal saline fluid that is used to inflate the knee during knee arthroscopy. Vancomycin and gentamycin are two antibiotics administered topically in ACL reconstruction surgery (Moriarty et al., 2021, Yazdi et al., 2019, Carney et al., 2018, Vertullo et al., 2012) but there is controversy as to their exact role in minimising the risk of infection.

Several studies looked at the preferred surgical technique of surgeons when carrying out ACL reconstruction surgery (Sherman et al., 2021, Arnold et al., 2021, Grassi et al., 2018). The ACL study group is an international group of orthopaedic surgeons who have an interest in the ACL. In a survey (Sherman et al., 2021) of 140 members of the ACL study group examining the global trends in ACL reconstruction, it was reported that most surgeons, about 90%, used a single-bundle technique. Most surgeons, 53% of respondents, used hamstring autograft tendons. Furthermore, 50% of respondents used suspensory graft fixation on the femur. In a further study (Arnold et al., 2021) exploring the preferences of the ACL study group it was shown that the choice of graft evolved with time. It was reported that whilst in 1992 the most frequent graft for primary ACL reconstruction was the bone-patellar tendon-bone autograft, used by about 90% of surgeons, in 2020 over 50% of surgeons used hamstring tendon autografts and only 40% used a bone-patellar tendon-bone graft. It was also shown that the use of quadriceps tendon autografts increased since 2014.

Along similar lines, a systematic review of national surveys was carried out and explored the preferences of orthopaedic surgeons on ACL reconstruction techniques (Grassi et al., 2018). That systematic review included 3 surveys from Europe, 3 from North or Latin America, and 2 from Asia. The included surveys were published over a 5-year period from 2011 to 2016 and reported on the preferences of 1,495 surgeons. All included surveys reported that the surgeons' preferred graft was a hamstring tendon autograft accounting for 45-89% of respondents, followed by bone-patellar tendon-bone autograft, accounting for 2-41% of respondents, with allograft accounting for only 2-17%. The most preferred technique for reconstruction was single-bundle reconstruction. Similarly, the most preferred method for fixation of the graft to the femur was a suspensory device, whilst for the tibia was the use of interference screws.

G. **Outcomes in ACL reconstruction surgery**

ACL reconstruction has been shown to confer long term successful outcomes in terms of achieving knee stability and a desirable activity level, but a substantial proportion of patients may have less than optimal results or develop complications following this procedure. In a recent evaluation of 2,042 ACL reconstructions carried out at the Hospital of Special Surgery in New York (Randsborg et al., 2022) it was shown that patients had an 87% chance of their knee feeling stable during daily and athletic activities after an average of 8 years post-surgery. However, only about 70% of patients returned to sport after an average of about 8 years, with fear of reinjury quoted as the most common reason for not doing so. Along similar lines, in a systematic review of 20 articles investigating a total of 2,348 athletes the overall rate of returning to sports was about 73%, with only 49% returning to preinjury levels of performance (DeFazio et al., 2020). ACL reinjury rates may also be high after ACL reconstruction with about 1/3rd of patients who return to competitive sports sustaining a further injury within 3 to 5 years from surgery (Webster, Feller and Klemm, 2021). A delay to return to sports may not protect from further injuries as the reinjury rates were shown to be similar in patients who returned to competitive sports before or after 12 months post-surgery (33% vs 32%, respectively) (Webster, Feller and Klemm, 2021).

In cases where the ACL graft fails, either by structurally retearing or functionally by not achieving its intended purpose of improving knee stability and function, further surgery in the form of revision ACL reconstruction surgery may be necessary (Miller et al., 2021). In a prospective study of the Norwegian and Swedish National Knee Ligament Registries the ACL revision within 2 years of primary surgery was about 2.8% whilst in the New Zealand ACL registry the revision rate was 2.4% with a mean follow up of about 23 months. In a study of 54,275 primary ACL reconstructions performed in England with at least 5 years' follow-up the ACL revision rate was 3.2% (Abram et al., 2019). However, the revision rate may increase with time from initial surgery, reported as 7% after 9 years of follow up at the Hospital of Special Surgery in New York (Randsborg et al., 2022). Revision reconstruction surgery is an extensive and costly procedure (Ruelos et al., 2021) which compared to primary ACL reconstruction has worse short- (Marx et al., 2021) and long-term outcomes (Grassi et al., 2017, Wright et al., 2012).

Outcomes of ACL reconstruction surgery have been linked to several factors which may be described as patient-, injury-or treatment technique- related. A systematic review of the Scandinavian knee ligament registers explored the relationship between such factors and patient reported clinical outcomes (Hamrin Senorski et al., 2019). Amongst the factors examined, a younger age at the time of ACL reconstruction, male sex, not smoking and having a hamstring tendon autograft were related to better outcomes. In contrast, patients who had articular cartilage or meniscal injuries along with their ACL tear reported inferior subjective knee function compared with patients who had an isolated ACL tear. Knee function was reported to improve more in patients who received specialised preoperative and postoperative rehabilitation as compared to standard care (Hamrin Senorski et al., 2019). Along similar lines a systematic review looked at physical factors in predicting outcome following ACL reconstruction and concluded that there was low-level evidence to suggest that postoperative degenerative changes in the knee and deficient lower-limb strength were related to poorer long-term outcomes (Middlebrook et al., 2022). Alongside physical factors, neuromuscular control of the knee and in particular proprioception were related to outcomes following ACL reconstruction. Knee proprioception was previously shown to diminish following an ACL tear (Pap et al., 1999, Barrack, Skinner and Buckley 1989) but was shown to improve following ACL reconstruction surgery with the extent of this improvement related to patient satisfaction (Reider et al., 2003). It was thus suggested that failure to improve proprioception following ACL reconstruction may account for poor functional outcomes in some patients, even when the mechanical stability of the knee is restored (Fremerey et al., 2000).

Psychological factors are also increasingly recognised to be related to functional outcomes following ACL reconstruction surgery such as the ability to return to sport. In a systematic review and meta-analysis of 3,744 patients it was shown that those who returned to sport after ACL reconstruction had higher psychological readiness and lower kinesiophobia, that is fear of movement and activity, as compared with those who did not return to sport (Xiao et al., 2022). In a cohort of 635 athletes who had an ACL reconstruction it was shown male patients who had a frequent participation in sports prior to ACL tear had higher psychological readiness whereas females had a more negative outlook and were less likely to return to sport (Webster et al., 2018).

Several factors have also been linked to the risk of ACL revision surgery. In a systematic review using studies on the Scandinavian knee ligament registers it was reported that adolescent age, defined as less than 20 years old, was the most common factor associated with revision ACL reconstruction (Svantesson et al., 2019). Furthermore, the use of a hamstring tendon graft versus a patella tendon graft, the use of an antero-medial portal versus trans-tibial technique for drilling the femoral tunnel, a smaller graft diameter and utilisation of suspensory fixation devices were also associated with an increased risk of ACL revision. Patient's sex was not related to the likelihood of ACL revision. However, in contrast to the findings above male sex was reported as risk factors for ACL revision surgery using insurance data on 15,212 primary ACL reconstructions in New Zealand (Sutherland et al., 2019).

Alongside the multiple patient, injury and treatment technique related factors described above, surgery related complications may also influence patient outcomes and may also lead to further revision ACL reconstruction or other knee surgery. Surgery related complications may be described as any deviation from the ideal intraoperative or postoperative course of a surgical procedure. The potential complications of ACL reconstruction surgery are considered next.

H. **Complications in ACL reconstruction surgery**

Complications in ACL reconstruction surgery may be technical or may be unrelated to the surgical technique (Shen et al., 2021, Vermeijden et al., 2020). Furthermore, these may be technique specific, such as those related to the graft fixation implants (Xu et al., 2021, Kramer et al., 2020), or may be encountered across various techniques, such as the occurrence of infection (Figueroa and Figueroa, 2022). Complications may occur during surgery and are referred to as intraoperative or following surgery and are referred to as postoperative. They may be the result of events occurring during surgery or following surgery; infection may be the result of contamination occurring intraoperatively or be due to haematogenous seeding occurring after surgery (Barberán, 2006).

Complications are clinically important as they may have substantial consequences for the patient including pain, instability, impairment of knee function and the need for further surgical procedures (Lindanger et al., 2021, Jameson et al., 2012). Such further procedures may be in the form of non-ACL surgery or ACL-surgery (Melbye et al., 2022, Lord et al., 2020). Further non-ACL surgery to the same knee has been reported to be as high as 13% (Randsborg et al., 2022) and includes procedures to remove misplaced fixation devices causing soft tissue irritation or mechanical blockage to the knee (Kramer et al., 2020) and procedures to deal with further meniscal tears or chondral damage (Ding, Tucker and Rugg, 2022, MOON knee group et al., 2020, Abram et al., 2019). In cases where the ACL graft fails, revision ACL reconstruction surgery may be necessary (Miller et al., 2021).

A successful ACL reconstruction requires a graft which is adequate in thickness and length, maintains its integrity, and provides sufficient tension. Hence, any complication which affects the graft dimensions, graft integrity, or tension may compromise the clinical outcome of ACL reconstruction surgery. Thus, complications in ACL reconstruction may include inadequate graft harvesting, graft disintegration by processes such as infection, inadequate graft tensioning or loss of tension. A systematic review (Vermeijden et al., 2020) was performed to identify failure modes of ACL reconstruction and included 24 cohort studies and 4 registry-based studies reporting on 3,657 reconstruction failures. Causes of failure were described as occurring secondary to new trauma (38%), technical errors (22%), combined causes (19%) and biological failures such as infection or laxity occurring without traumatic or technical factors (8%). Of the technical failures femoral tunnel misplacement was the most reported cause seen in 63% of cases. Technical errors were more common following trans-tibial as compared to antero-medial portal techniques, accounting for 49% of the causes of failure in the former versus 26% in the latter. Along similar lines, an investigation was performed using prospectively, routinely collected data (Jameson et al., 2012) to assess significant complications encountered following ACL reconstruction surgery in the English National Health System (NHS). National rates of 30-day wound infection following primary ACL reconstruction were identified in 13,941 procedures. It was shown that 0.75% of cases had a surgical wound complication and 0.25% had a further procedure to wash out the knee due to infection.

Understanding the complications that may occur in ACL reconstruction surgery is vital for the surgeon as it allows prevention strategies to minimise the risk of their occurrence as well as allow planning of how to manage them once encountered. Such alternative plans must be carefully considered prior to surgery to ensure the availability of surgical instruments, surgical equipment, grafts, or implants. Furthermore, such preplanning allows the surgeon to discuss alternative plans with the patient as part of the consent process and facilitates shared decision making.

Raising awareness amongst surgeons of potential complications may also create a more transparent culture in bringing forwards such events. Such a transparent culture may educate surgeons that complications are encountered by all and is often not a sign of insufficient surgical technique. Furthermore, as some complications are rare, one may learn from the experiences of others, rather than waiting to encounter one for the first time to learn how to manage it. In a recent review by a group of sport medicine doctors (Taylor, Caldwell and Pearson, 2022) there was a description of complications occurring in common sports medicine procedures one of which was ACL reconstruction surgery. The authors of that article referred to the need for a "reality check" and a recognition of the high rates of complications encountered in sports medicine procedures, even though many of these are carried out with minimally invasive techniques, such as arthroscopic surgery. Accepting that complications occur and communicating such complications may be an important component of professional behaviour and development. As it was previously stated "there are two types of doctors who never have surgical complications: those who do not operate and those who are not quite fully truthful" emphasizing that "no matter how rare, all surgeons have complications" (Devgan, 2018).

The candidate is currently an Orthopaedic Consultant surgeon practising in the National Health System in England, whose practice involves ACL reconstruction surgery. The candidate aims through surgery to improve the clinical and functional outcomes of patients whilst minimising harm. Thus, the subject of surgery related complications is integral to the candidate's day to day clinical practice, hence the selection of the overall topic for this thesis. The candidate identified areas to investigate and research questions to explore through personal experiences initially as an orthopaedic trainee and fellow in ACL reconstruction surgery, and subsequently as an Orthopaedic Consultant surgeon in independent clinical practice. The candidate identified areas where there was a gap in evidence to guide best clinical practice, or areas where there was substantial controversy in best clinical management. The candidate recognises the need to be able to discuss complications in an open and transparent way, enabling clinicians to learn from each other to improve clinical care. By collating original research articles that explored complications in ACL reconstruction surgery the candidate also hopes to raise the profile of the overall topic and the impact of research findings addressed by the individual articles.

I. **Knowledge gap**

Although previous work extensively evaluated complications associated with ACL reconstruction surgery (Fay, 2011, Busam, Provencher and Bach, 2008, Lee et al., 2008, Safran and Greene, 2006, Shelbourne and Patel, 1996, Graf and Uhr, 1988), at the time of performing the research studies which are reported by the articles presented in this commentary, there were substantial gaps in knowledge with regards to specific complications. The research studies reported by the articles of this commentary were designed to address this knowledge gap.

The knowledge gap included evidence with regards to complications related to hamstring graft harvesting, and the prevention and management of infection in ACL reconstruction. There was a gap in knowledge around the rate of inadequate hamstring graft harvesting in a UK population, as well as the relation between graft quality and the type of tendon harvester utilised to obtain the hamstring graft. Furthermore, there was no substantial systematic evidence assessing the rate of infection in ACL reconstruction surgery, its relation to graft type, as well as its relation to vancomycin presoaking, nor was there systematic evidence determining the effectiveness of arthroscopic washout and antibiotic treatment with graft salvage to tackle bacterial infection post ACL reconstruction. Similarly, there was a lack of systematic evaluation of reported complications of suture button fixation of the ACL graft, and a lack of knowledge as to the relation between the type of tunnel reamer and the resultant morphology of the tibial tunnel outer aperture in ACL reconstruction surgery.

J. **Aims**

The aim of this work was to explore the rate and nature of complications seen during ACL reconstruction and to consider how these may be minimised through preventive measures and how they may be managed when they occur.

K. **Objectives**

The objectives were:

1) To determine the rate of inadequate hamstring graft harvesting in ACL reconstruction surgery and explore whether the type of tendon harvester utilised influences the length and quality of the graft obtained.

2) To determine the relationship between infection rate and type of graft utilised in ACL reconstruction surgery and explore whether presoaking the graft with vancomycin is associated with a reduction in infection rate.

3) To determine whether arthroscopic washout with graft salvage is an effective measure in dealing with infections in ACL reconstruction surgery.

4) To determine the complications related to the use of femoral suture button fixation of the graft in ACL reconstruction surgery.

5) To determine whether the morphology of the tibial tunnel used in graft fixation in ACL reconstruction is influenced by the type of reamer utilised.

L. **Hypotheses**

To meet the above-described objectives, the following specific hypotheses were tested:

1) Inadequate graft harvesting in ACL reconstruction is a recognised complication, but its rate is low.
2) A graft blade harvester causes less soft tissue disruption as compared to a closed tendon stripper.
3) A graft blade harvester produces a shorter graft as compared to a tendon stripper.
4) Hamstring tendon grafts are associated with a higher infection rate than bone-patellar tendon-bone autografts in ACL reconstruction surgery.
5) Allografts are associated with a higher infection rate as compared to autografts in ACL reconstruction surgery.
6) Vancomycin presoaking of hamstring grafts is associated with a lower infection rate as compared to no graft presoaking in ACL reconstruction surgery.
7) Arthroscopic washout along with antibiotic treatment and graft salvage is an effective way of managing septic arthritis following ACL reconstruction surgery in most cases.
8) Suture button misplacement is one of the most frequently reported complications when using a suture button to fix the graft onto the femur in ACL surgery.
9) The morphology of the outer tibial tunnel aperture would change less when using an acorn reamer compared to a fluted reamer in creating the tibial tunnel, particularly when deviations occur between the desired and actual line of reaming.

The stage to explore the overall aim was set out by an article that reported a narrative review which looked at the spectrum of intraoperative complications encountered in ACL reconstruction as well as their causes and management. Following this (as summarized in figure 1.6), the background for the 1st, 2nd and 3rd hypotheses was set by an article which presented a narrative review of the morphological characteristics and anatomical variations of hamstring grafts used in ACL reconstruction surgery. Subsequently, the 1st hypothesis was specifically examined by one article reporting a clinical study that addressed the rate of inadequate hamstring graft harvesting amongst 50 patients who had ACL reconstruction surgery under the care of a UK practicing surgeon. Similarly, the 2nd and 3rd hypotheses were specifically evaluated by an article reporting on a cadaveric study that looked at the relation between graft quality and the type of tendon harvester utilised to obtain the graft. The 4th and 5th and 6th hypotheses were examined by an article that reported a systematic review and meta-analysis that evaluated the rate of infection in ACL reconstruction surgery, its relation to graft type as well as its relation to vancomycin presoaking. The 7th hypothesis was examined by an article that analysed through a systematic review and meta-analysis the effectiveness of arthroscopic washout and antibiotic treatment with graft salvage in tackling bacterial infection post ACL reconstruction. The 8th hypothesis was assessed by an article that reported a systematic review of complications of femoral suture button fixation of the ACL graft in reconstructive surgery, whilst the 9th hypothesis was assessed by an article that reported a study which looked at the relation between the type of reamer used in creating the tibial tunnel with tunnel morphology in artificial bones.

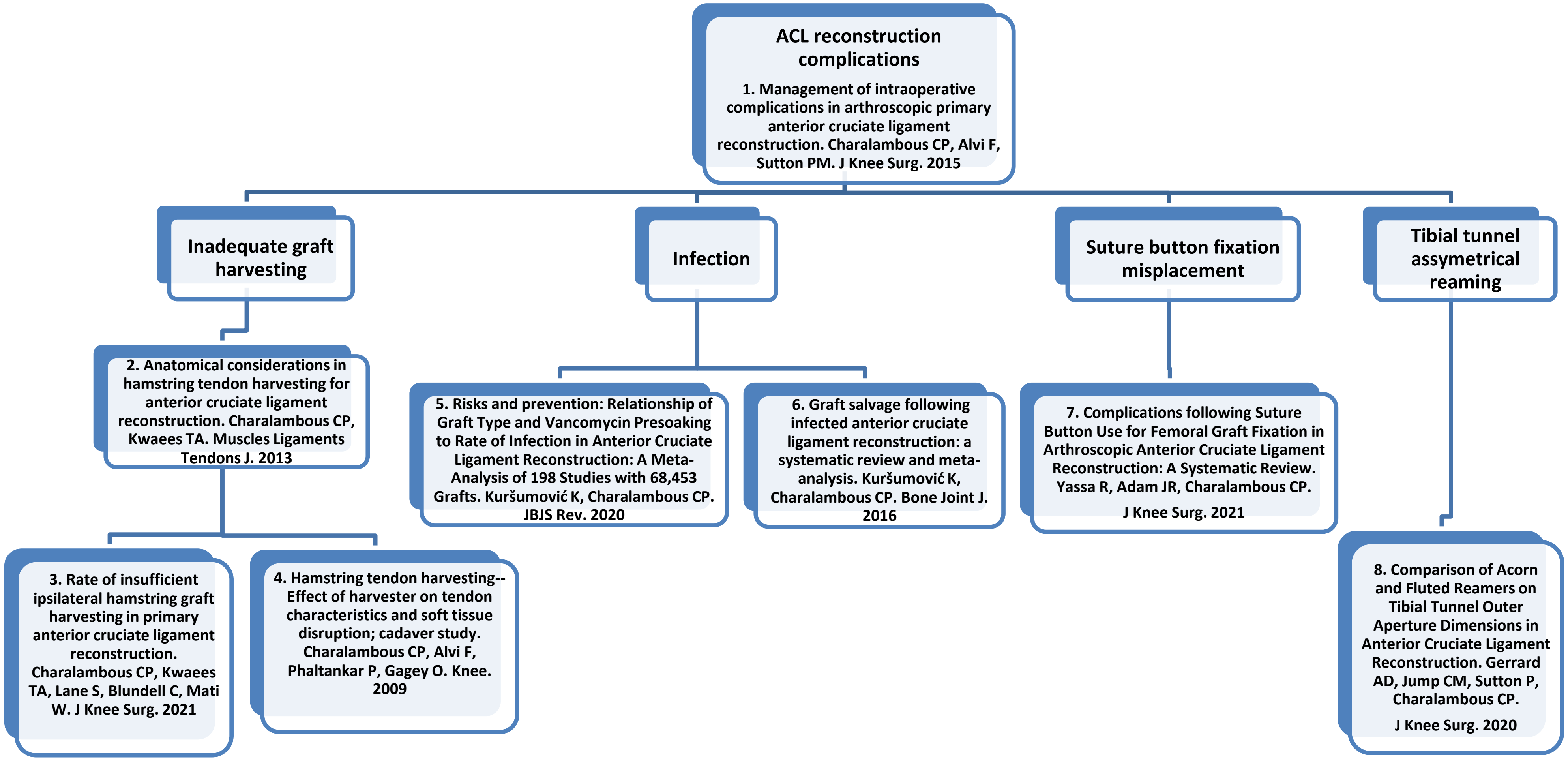

Figure 1.6 The eight articles (numbered 1-8) testing the hypotheses assessed in this commentary

CHAPTER 2 - INTRAOPERATIVE COMPLICATIONS IN ACL RECONSTRUCTION

A. Background

As described in the introduction chapter, complications in ACL reconstruction may occur during surgery or following surgery. Intraoperative complications may occur at any of the multiple steps of the ACL reconstruction surgical procedure. Although some complications, such as accidental graft contamination, may be generic and observed across a broad spectrum of ACL reconstruction techniques, others are more specific to the type of graft harvested and the techniques used to fix that graft. The hamstring and bone-patellar tendon-bone (BPTB) grafts are commonly used (Sherman et al., 2021, Arnold et al., 2021), hence dealing with the complications that may be encountered when these grafts are employed would apply to most ACL reconstruction procedures.

B. Knowledge gap

At the time when this article was prepared there were existing reviews describing intraoperative complications and pitfalls of ACL reconstruction surgery, referring to various grafts and fixation devices (Fay, 2011, Busam, Provencher and Bach, 2008, Lee et al., 2008, Safran and Greene, 2006, Matava, 2006, Phelan, Cohen and Fithian, 2006, Sekiya, Ong and Bradley, 2003, Cain, Gillogly and Andrews, 2003, Allum, 2003, Shelbourne and Patel, 1996, Graf and Uhr, 1988). However, as surgical techniques evolve, with the refinement of graft harvesting techniques and development of fixation devices, the spectrum and specifics of intraoperative complications related to these may also change. Hence, there was a need for an updated review of the complications of ACL reconstruction surgery and their management.

C. Objective

The objective of this study was to set the stage of ACL reconstruction complications by describing those encountered when using hamstring and bone-patellar tendon-bone (BPTB) grafts and to provide an up-to date review of their occurrence and management.

D. Commentary article 1 - *Management of intraoperative complications in arthroscopic primary anterior cruciate ligament reconstruction. Charalambous CP, Alvi F, Sutton PM. J Knee Surg. 2015 Apr;28(2):165-74.*

https://www.thieme-connect.com/products/ejournals/abstract/10.1055/s-0034-1373739. doi: 10.1055/s-0034-1373739

a. Contribution by CP Charalambous

Developed the concept of the article, carried out the literature search, and led the writing of the article.

b. Article description – Full article

This was a narrative review of the spectrum of intraoperative complications in arthroscopic primary ACL reconstruction surgery and described ways in which such complications may be dealt with during surgery. Complications related to both hamstring tendon grafts as well as patellar tendon grafts were considered. This article discussed the complications encountered during graft harvesting, bone tunnel creation and graft fixation, as well as the possibility of intraoperative graft contamination. A copy of the full article is presented next.

Original Article

Management of Intraoperative Complications in Arthroscopic Primary Anterior Cruciate Ligament Reconstruction

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J Knee Surg

Abstract

Arthroscopic anterior cruciate ligament reconstruction is a commonly performed procedure which is technically demanding and involves multiple surgical steps with the potential for a wide range of intraoperative complications. In this article, we review these potential complications and give algorithms for dealing with them based on our experience and published evidence. We discuss the use of both bone-patellar tendon-bone and hamstring grafts and examine complications associated with suspensory button and interference screw fixation.

Keywords
- knee
- reconstruction
- ACL
- complications

Reconstruction of the anterior cruciate ligament (ACL) is a frequently performed procedure. It may be performed as an open procedure but is increasingly performed arthroscopically assisted.[1–3] Arthroscopic ACL reconstruction involves multiple surgical steps and at each stage of the procedure, there is potential for intraoperative complications. These complications may arise for reasons of technical inexperience but may also occur in experienced hands despite the use of safe and meticulous surgical techniques. Surgeons who perform this procedure infrequently may not have encountered all potential complications associated with ACL reconstruction and may not be aware of methods to deal with these.

In this article, we review the potential intraoperative complications of arthroscopically assisted ACL reconstruction and discuss how they may be prevented and managed. Complications can also occur during the postoperative period, which we will not be addressing. We discuss the use of hamstring and bone-patellar tendon-bone (BPTB) grafts and the use of suspensory button and interference screw fixation, as these are commonly used grafts and fixation methods. In a recent international survey of orthopedic surgeons,[4] 63% chose a hamstring tendon graft and 26% chose a patellar tendon graft. The most preferred surgical approach for drilling the femoral tunnel was via the anteromedial portal (68%), followed by the transtibial (31%) and open approach (1%).

We have classified intraoperative complications chronologically according to the operation stage at which they are encountered (►**Table 1**).

Cruciate Ligament Graft Contamination

Graft contamination most commonly occurs by graft dropping on the operating floor and is a well-recognized complication. Precautions may be taken to avoid accidental graft dropping and minimize contamination should it occur. When harvesting a hamstring graft, leaving the tendons attached at their tibial insertion permanently or until the graft is to be passed through the tunnels may reduce the risk of this complication.[5] If the graft is detached, its coverage in a saline-soaked swab or placement in a closed container minimizes contamination if dropped.

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Table 1 Charalambous classification of intraoperative complications in ACL reconstruction according to the stage they occur

Stage at which complication encountered	
Any stage	Graft contamination
Femoral tunnel preparation	Too short Too long Too anterior Too vertical Lateral cortex perforation Posterior blowout Drill/wire bent/broken
Tibial tunnel preparation	Too short Too long Too anterior Too posterior Drill/wire bent/broken
Graft harvesting	Patellar fracture Bone block fracture Too long graft Too short graft Hamstring amputation
Graft passage	Suture breakage
Graft fixation	Flipping in soft tissues Flipping in tunnel Graft laceration Screw breakage Intra-articular screw penetration Losing a screw in knee Poor quality bone Failure of fixation device to engage graft (devices such as transfix)

When faced with a contaminated graft, there are several management options including graft cleaning, harvesting an alternate autograft, using allograft, or abandoning the procedure. Our approach would be graft cleaning and continuing the procedure, which is justified by the available literature.

In a survey of 196 surgeons performing ACL reconstructions, 25% reported encountering at least one graft contamination.[6] No surgeons reported infections following cleaning and using the contaminated grafts. Of the surgeons not encountering graft contamination, most would clean the graft and continue with the procedure had they faced this complication.

Several studies examined the microbiology of graft contamination and the efficacy of various sterilization techniques. One study[7] cultured irradiated allografts dropped on the operating floor that were either untreated or soaked in antibiotic for 15 minutes. Sixty percent of untreated and 30% of treated specimens were culture positive, leading the authors to conclude that 15 minutes of antibiotic soaking was insufficient to sterilize contaminated grafts. In another study,[8] grafts were contaminated with either two species of coagulase-negative staphylococci or with five organisms (*Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, and *Enterococcus faecalis*). The grafts were soaked in various sterilizing agents for 30 minutes. For the coagulase-negative staphylococcal contamination, 10% povidone–iodine and a triple antibiotic solution (gentamycin, clindamycin, and polymyxin) were 100% ineffective, whereas 4% chlorhexidine gluconate was 100% effective in decontaminating the grafts. With multiorganism contamination, 4% chlorhexidine gluconate successfully eliminated all organisms except *K. pneumoniae*, while a combination of a 30-minute soak with 4% chlorhexidine gluconate followed by a broad-spectrum or triple antibiotic solution was 100% effective in eliminating multiorganism contamination. These results are similar to those of a study[9] assessing sterilization of native ACLs dropped on the theater floor for 15 seconds during knee arthroplasty. Soaking in an antibiotic solution (neomycin–polymyxin B) reduced contamination to 6% of the specimens, treatment with 10% povidone–iodine to 24%, and chlorhexidine gluconate to 2%. Plante et al[10] cultured six groups of hamstring tendons obtained from excess tendon not used in ACL reconstruction. *Staphylococcus aureus* was the most common isolate. Grafts rinsed in bacitracin or 4% chlorhexidine were less likely to be culture positive, supporting the practice of decontaminating a dropped ACL hamstring autograft using either of these solutions.

In a clinical study, Pasque and Geib[11] reported three grafts dropped on the theater floor, treated by suture removal, chlorhexidine soaking for 15 minutes followed by further soaking in a triple antibiotic solution for 15 minutes and normal saline rinsing. The authors replaced the suture material, reconfirmed the graft size, and postoperatively prescribed antibiotics for 10 days. No cases became infected.

Interestingly, Hantes et al[12] demonstrated that autograft contamination occurred during ACL reconstruction in 12% of

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autografts that had not contacted an unsterile surface. The most common contaminant was *Staphylococcus epidermidis* followed by *S. aureus*. However, no infections occurred, and there were no differences in clinical outcome or inflammatory markers between contaminated or uncontaminated graft cases. These results[12] are in accord with Nakayama et al[13] who demonstrated a 2% contamination rate of uncomplicated ACL grafts.

On the basis of the available evidence, we recommended treatment of contaminated grafts by removal of suture material, obtaining a culture swab, and graft soaking in 4% chlorhexidine solution for 15 minutes, as this solution is readily available in surgical theaters. The graft is then rinsed in normal saline and the suture material replaced before the graft implantation as normal. Postoperatively, broad-spectrum antibiotics, or antibiotics guided by intraoperative cultures, are administered for 7 days.

Complications Occurring during Graft Harvesting

Bone-Patellar Tendon-Bone Harvesting

Patella Fracture

Intraoperative patella fractures are well described[14,15] secondary to BPTB harvesting, being usually longitudinal and minimally displaced. The risk of such fractures may be reduced by harvesting a wedge-shaped graft, using a blade with limited penetration depth, and pre-drilling the corners of the planned osteotomy (►**Fig. 1**). If recognized intraoperatively, patella fractures should be stabilized according to their configuration using wiring techniques or screws to allow early mobilization and not hinder ACL rehabilitation. Bone grafting the fracture site with bone harvested during tibial tunnel reaming may aid patella fracture union.

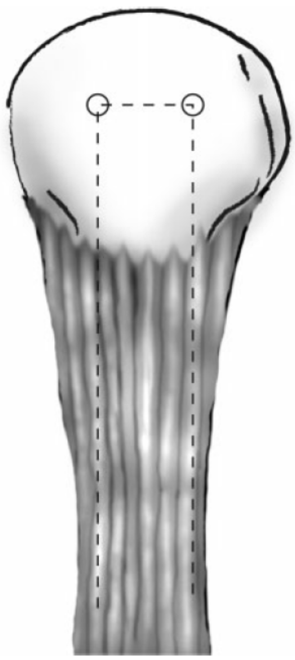

Fig. 1 Drilling holes at the corners of the planned osteotomy during patella-bone tendon-bone harvesting may reduce the risk of intraoperative patellar fracture.

Bone-Patellar Tendon-Bone Block Fracture

The bone block of the BPTB graft is drilled to allow suture passage to pull the graft through the tibial and femoral tunnels. Bone block fracture may occur[16] during drilling the suture holes, bone block harvesting, or insertion of the graft into the tunnels. This complication may be managed by placing a whipstitch into the adjacent part of the patellar tendon to pull the graft into the tibial and femoral tunnels (►**Fig. 2**). If possible, the fractured bone block should be left in place to encourage bone-to-bone healing. If the bone block is poor, the soft tissue component of the graft can be fixed with an interference screw; however, additional fixation may be needed to augment tunnel fixation. This may be achieved by tying the suture ends of the whipstitch over a cortical screw placed outside the tunnel.

Bone-Patellar Tendon-Bone Graft Too Short or Too Long

A BPTB graft may be harvested that is unusually too short or, more commonly, longer than the total tunnel and intra-articular length.[17–19] Typically, the intra-articular portion of an ACL graft is 30 to 35 mm; however, a greater total length is needed to secure tunnel fixation. In our practice, the minimum acceptable graft length for an adult patient is 75 mm. With a short BPTB graft, both tunnels may be deliberately shortened. It is important to note that the tunnels need to be reamed to a depth corresponding to the minimum interference screw length, to avoid a prominent screw. This length varies by screw manufacturer being commonly 20 to 25 mm. The tibial tunnel length may be reduced by drilling in a more medial and less vertical position (►**Figs. 3** and **4**). If the tibial tunnel remains long and interference screw fixation is used, care must be taken to ensure a sufficiently long screw is used and that it engages the bone block and the graft close to the articular aperture of the tunnel.

A too long BPTB graft is more common than a too short one. This may result in a bone block which partially or completely protrudes through the distal aperture of the tibial tunnel. If the mismatch is not excessive, the options are to further recess the femoral tunnel to accommodate a greater

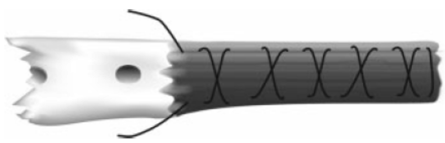

Fig. 2 If bone block fracture occurs in patella-bone tendon-bone harvesting, placing a whipstitch through the tendon adjacent to the fractured bone block can allow pulling of the graft through the tunnels.

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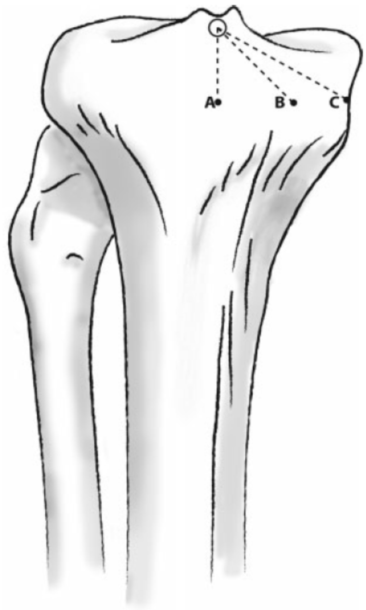

Fig. 3 Moving the tibial tunnel extra-articular drilling point in a more medial position can increase tibial tunnel length.

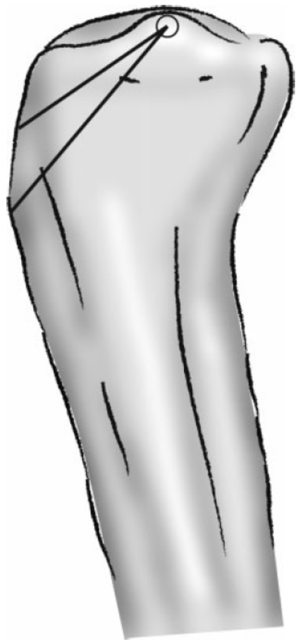

Fig. 4 Moving the tibial tunnel extra-articular drilling point in a more distal position can increase tibial tunnel length.

proportion of the graft length or if tibial fixation is secure with a shortened bone block, by simply excising the protruding bone after fixation. In situations where the majority of the bone block protrudes, the graft may be shortened by folding the distal bone block through 180 degrees back onto the patella tendon and securing it with sutures (►**Fig. 5**). The graft should be re-sized and if necessary the tibial tunnel enlarged. An alternative technique is to develop a trough on the anterior tibia using a burr into which the bone block is fixed with staples or screws.

Hamstring Tendon Harvesting

During hamstring ACL reconstruction, semitendinosus and gracilis are commonly harvested and formed into a four-strand graft. However, successful results may be achieved with triple- or double-strand grafts. Premature tendon amputation at harvesting resulting in a short graft is a potential complication. This may be due to laceration of the tendons with scissors or tendon harvester, often due to inadequate release of the intertendinous bands.[20–22] This may be anticipated in patients with extensive hamstring scarring due to previous injury or surgery. Use of a closed blade harvester, as compared with a tendon stripper, may give longer and better quality tendon lengths while minimizing soft tissue disruption.[21] If the proximal end of an amputated tendon can be seen through the wound, it may be retrieved with tendon forceps, whip stitched in situ and harvested. However, in our experience, when the graft is amputated, the proximal end retracts and cannot usually be retrieved.

When using a hamstring graft, a minimum of 160 mm of tendon length is necessary (75–80 mm looped graft) to obtain secure fixation at both femoral and tibial tunnels. If premature amputation of the tendons does not provide adequate graft length, then the options are to use a double- or triple-stranded hamstring graft, harvest BPTB from the same knee, harvest the hamstrings from the opposite knee, and use an allograft or a synthetic ligament.[23] Our preferred technique is to fashion the available graft into a double or triple graft. However, if the available tendon is too short for a

Fig. 5 The patellar tendon bone graft may be effectively shortened by rotating the distal bone block through 180 degrees and securing it to the patellar tendon with cerclage stitches.

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75-mm-long graft or insufficient to allow at least a 7-mm-diameter graft, we would use an alternative graft or augment the hamstring graft with a synthetic ligament. We advise discussion of the management options of this potential complication with the patient before surgery. If this has not been discussed with the patient, termination of surgery and reschedule of the procedure may be appropriate.

Femoral Tunnel Creation

Until recently, the accepted femoral tunnel site was in a posterior position on the lateral wall of the femoral notch. Early arthroscopically assisted ACL reconstructions aimed to place the graft at this site in a relatively vertical position often described as the 11 AM (in a right knee) or 1 PM (in a left knee) positions using an imaginary clock face. In biomechanical tests, this graft position has been shown to provide good control of sagittal plane laxity but less control of tibial rotation. In an attempt to improve not only anteroposterior but also rotatory stability, placement of the femoral tunnel in a less vertical position (10 AM or 2 PM) is now considered preferable.[24–27] Recently, the site of the native ACL has been further questioned and techniques of "anatomic" ACL reconstruction have been described.[28–30]

Tunnel malposition is a common cause of failure after ACL reconstruction. Femoral tunnel malposition is more common than tibial tunnel malposition. To avoid femoral tunnel malposition, thorough clearance of soft tissue from the posterolateral part of the femoral notch should be performed. A bone ridge (referred to as "resident's ridge") at the junction of the middle and posterior third of the femoral notch may be confused for the most posterior margin.[31,32] This prominence may need removing to allow adequate exposure of the posterior margin of the lateral femoral condyle, an essential landmark for accurate tunnel placement. Offset guides that hinge on the posterior cortex of the lateral femoral condyle or direct anatomical guides that aid femoral tunnel positioning are commercially available.[33] The authors use a "starter" hole prepared with a curette or awl to determine accurate tunnel placement. Initial drilling with a small diameter (4–4.5 mm) drill before reaming allows further visual check of tunnel position. If despite these measures the femoral tunnel position is unsatisfactory and this is recognized intraoperatively, then the tunnel should be repositioned with care to ensure a bone bridge remains between the two tunnels. This may be achieved by altering the direction of any "second" tunnel to diverge from the initial one.

The femoral tunnel may be drilled via the tibial tunnel or using a low anteromedial portal. The former may compromise appropriate femoral tunnel placement.[34,35] Cadaveric studies showed that moving the intra-articular aperture of the femoral tunnel from the 12-o'clock to 9-o'clock position (in a right knee) progressively shortens the femoral tunnel.[36] Less than 30 mm tunnel may provide inadequate length when using a fixed length suspensory fixation device such as an Endobutton (Smith and Nephew, London, UK). However, there is very little literature indicating the minimum length of graft that should be placed in either tibial or femoral tunnels.

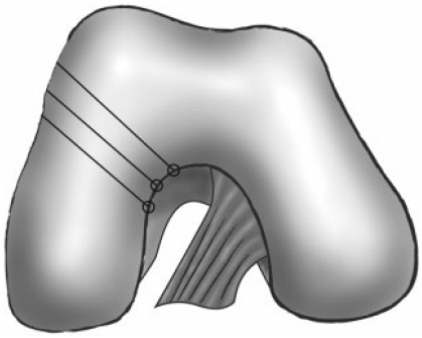

Fig. 6 Moving the femoral tunnel intra-articular drilling point to a more vertical position can effectively increase the femoral tunnel length.

The available evidence indicates that graft incorporation occurs at the tunnel aperture[37] and provided the graft is securely fixed only a small amount may be required within the tunnels. If the femoral tunnel is considered too short, repositioning the entry point in a more vertical position and aiming to drill more anteriorly and vertically will result in a longer tunnel (►**Figs. 6** and **7**),[38] but possibly at the expense of reducing control of abnormal tibiofemoral rotation. Alternatives would include variable length suspensory methods such as the ACL tightrope (Arthrex, Naples, FL), interference screw fixation, or pin fixation. When planning ACL surgery, it is essential to ensure availability of different graft fixation methods and be familiar with their use. The authors therefore favor anteromedial portal drilling and to maintain the short tunnel and avoid the use of a fixed length suspensory fixation.[34,35,38]

Drilling the femoral tunnel in an excessively vertical position may give a long femoral tunnel which is probably of little importance but may result in the passing pin emerging outside the draped area of the thigh or into a thigh tourniquet. If this occurs, the pin is removed by "nonscrubbed" theater staff and discarded. This is followed by repositioning of the

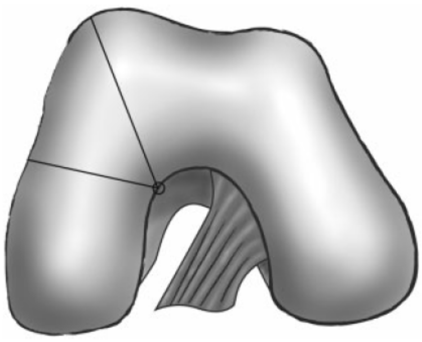

Fig. 7 Drilling in a more vertical direction can effectively increase the femoral tunnel length even if the intra-articular drilling point remains constant.

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femoral tunnel with a new pin aiming for a less vertical and more anterior direction.

As we aim to position the femoral tunnel as posteriorly as possible, disruption of the posterior tunnel wall may occur, known as "posterior femoral blowout."[39,40] This complication may be avoided by passing a guide pin and drilling the femoral tunnel with the knee in hyperflexion, thereby drilling from the posterior margin of the femoral notch toward the anterior femur. This ensures that even if the posterior cortical wall is disrupted around the tunnel aperture, there will be a complete bony tunnel more proximally. This is made possible by drilling the femoral tunnel via an anteromedial portal. When drilling the femoral tunnel via the tibial tunnel, the knee typically needs to be extended from a hyperflexed position to allow posterior femoral tunnel placement. The resulting tunnel tends to run in a more posterior direction increasing the risk of a femoral blowout. In this situation, the use of an interference screw is unlikely to provide adequate graft fixation and a suspensory or transfixion method of fixation is needed.

Lateral blowout of the femoral tunnel may occur if the reamer is advanced too far, compromising lateral cortex suspensory fixation with most standard fixation devices. If this occurs, we recommend using an alternative method of femoral fixation such as suspensory fixation that does not rely on an intact lateral cortex or aperture fixation with an interference screw. As an alternative to this approach, there are commercially available devices, such as the ex-Endobutton extension (Smith and Nephew), that allow extension of a standard suspensory fixation device allowing it to hold over a large aperture on the lateral cortex. Recent biomechanical evidence suggests that tunnels of 8 mm or less can be drilled through the lateral femoral cortex while still using a suspensory device for graft fixation.[41]

While passing a guide pin or drilling with a narrow drill through the femoral tunnel, flexion or extension of the knee may cause breakage of the wire/drill in the lateral femoral condyle. If this occurs, an attempt should be made to pull out the broken metal work using a heavy wire holder. If this proves unsuccessful, over drilling the wire with the smallest available reamer can aid pulling out the broken wire/drill.

Tibial Tunnel Creation

Positioning of the tibial tunnel is critical to avoid graft impingement or damage to the posterior cruciate ligament. Malplacement of the intra-articular tibial tunnel aperture may result in impingement of the graft on the lateral or superior wall of the femoral notch, limiting extension or damaging the graft. If the graft is placed too posteriorly in the notch, the PCL may be damaged during reaming or the graft may kink excessively about the PCL during flexion. Numerous studies have reported various methods of determining the correct intra-articular tibial tunnel aperture.[42–47] We favor positioning of the tibial tunnel in the posterior part of the ACL footprint 5 to 8 mm anterior to the PCL and just lateral to the medial tibial spine. Commercially available ACL guides should be used to ensure correct placement of a guide wire before reaming the tibial tunnel. Once the guide wire emerges in the knee joint, we suggest removal of the guide and further advancement of the guide wire. The knee is then extended carefully while observing the position of the guide wire and specifically assessing for possible impingement. It should be noted that the graft will typically extend 2 to 4 mm beyond the position of the guide wire depending on the graft diameter. If it is felt the wire position will lead to graft impingement, the wire can be repositioned before the tunnel is reamed. If the guide wire requires repositioning, changing the sagittal angle on the guide by 5 to 10 degrees helps avoid inadvertent passage of the wire into the previously drilled hole.

Placement of the extra-articular aperture of the tunnel toward the anterior tibial border midline can result in a short tibial tunnel and placement toward the medial border of the tibia in a long tunnel (►**Fig. 4**). In addition, if the tibial tunnel is placed close to the posteromedial tibial border, there is a risk of blowout of the extra-articular aperture of the tibial tunnel which may compromise interference fixation. As with the intra-articular guide wire position, we advocate that after placing the initial guide wire the position of the planned extra-articular tibial aperture is examined and if necessary repositioned before tunnel preparation.

Graft Fixation

There are multiple graft fixation options for both BPTB and hamstring grafts. These may be broadly classified as suspensory, transfixion, and aperture fixation methods. Each is associated with recognized intraoperative complications. In this article, we limit the discussion to the possible complications with the use of a button suspensory fixation method or interference screw fixation.

Suspensory Button Fixation

There are several devices for using this fixation method.[48,49] The original design is the Endobutton (Smith and Nephew), but other manufacturers produce similar devices. These act as a suture sling suspended from the lateral femoral cortex by a metal button. The graft is looped through the sling, and the button is pulled through the femoral tunnel and flipped so that it holds on the outer femoral cortex. The metal buttons are usually preloaded with sutures allowing the device and graft to be pulled through the tunnels. The Endobutton has two holes through which suture strands are passed. The suture that passed through one hole is used to pull the Endobutton through the femoral tunnel and the other to flip the button. This design means that once the Endobutton has passed through the femoral tunnel and flipped, alternate pulling on the two sutures causes the button to toggle confirming that it is flipping. There are several potential pitfalls with these devices. The button may fail to deploy, may deploy in the bone tunnel, or may be pulled too far into the lateral soft tissues and deploy on the fascia lata. Before pulling the graft into the knee, we routinely mark the graft and suspensory construct at the appropriate length

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corresponding with the tunnel length. This allows reassurance that the button is sat on the lateral cortex. Failure to achieve this may lead to subsequent migration of the suspensory device.[50–53] Specifically when using an Endobutton, if toggling is not detectable, it may be that the button has not been pulled fully free of the femoral tunnel or is caught in soft tissues out of the femoral tunnel held away from the femoral cortex. In dealing with this, we initially pull back on the graft as firmly as possible. If the button has not flipped out of the femoral tunnel, then the graft will be pulled back into the knee and a further attempt to pull the graft through and flip the button is made. If repeated attempts do not allow flipping, then the length at which the femoral tunnel has been reamed must be reassessed, as the most likely cause of this is a too short femoral tunnel. If while pulling backward on the graft, the graft remains firm, it is probable that the button is successfully abutting the lateral femoral cortex and is not toggling because of soft tissue entrapment. This will be confirmed if the graft mark corresponds to the tunnel length. If doubt about the deployment position of a suspensory button, the options include making a stab incision on the lateral thigh dissecting along the sutures to the button and confirming by palpation that it has flipped and radiographic screening or using a supplementary aperture fixation with an interference screw.

The sutures used to pull the suspensory button may break during graft passage. If this occurs, the button is pulled back out of the knee, reloaded with sutures, and repulled through the tunnels.

Interference Screws

Interference screws may be metal or biodegradable. Their use carries several potential intraoperative complications.[54–59] Graft laceration may occur during insertion of an interference screw into the femoral or tibial tunnels. This is more commonly encountered when using BPTB graft and the graft is lacerated at the bone block tendon junction. If this occurs, removal of the screw and graft is essential. The graft can often be tubularized by application of a whipstitch, then passed again into the femoral tunnel and fixed either with another screw or with a transfixion method. Complete laceration of a hamstring graft is a less common but recognized complication. Again if this occurs, graft removal is necessary. If the remaining graft is of sufficient length to proceed with reconstruction, further application of a whip stitch and use of the remaining graft may be possible. If not of sufficient length, then use of an alternative graft is considered. When choosing fixation devices, it should be noted that there are screw designs available to reduce the risk of this complication. Graft laceration in the tibial tunnel is also possible. As with femoral tunnel laceration, management of this complication depends on whether there is sufficient remaining graft to allow stable tibial fixation. If not, graft removal and use of an alternate graft is essential. It is important to recognize differences in screw design and characteristics. For example, some screws are designed to be placed on the side of the graft and their use in a central position between tendons may cause graft laceration.

Bioabsorbable screws have the theoretical advantage of resorption. A recognized complication of bioabsorbable screws is breakage during insertion.[54] This may be due to poor technique such as improper sitting of the screw on the screwdriver or attempting to insert the screw in a line divergent from the tunnel. It may also occur in hard bone if the screw is excessively oversized relative to the corresponding tunnel. If this complication occurs, we initially attempt to remove the broken screw. If screw removal is not possible and the graft is well fixed, we would accept the fixation and supplement it with a soft tissue staple over the protruding graft ends. If there is insufficient graft protruding from the tibial aperture, fixation may be supplemented by tying the graft whipstitch sutures over a cortical screw and washer. In this situation, a protective brace for 6 weeks is used postsurgery. If the graft is poorly fixed, then the graft is removed with relative ease and the broken screw is removed. Broken bioabsorbable screw may require removal by reaming. The tunnel may then be reprepared and the graft refixed.

Following tibial screw insertion, a visual assessment of the joint should be performed to ensure there is no intra-articular screw protrusion. If the screw has been advanced too far, then it should be backed out; however, if only the tip of the screw is visible, its position may be accepted. Late intra-articular screw advancement is a recognized phenomenon after ACL surgery and this complication should be considered if patients present with mechanical symptoms following ACL reconstruction.[56–58]

Screw loss into the posteromedial or posterolateral recess of the knee is a described complication when inserting an interference screw into the femoral tunnel. If this occurs, screw retrieval should be attempted either via the anteromedial or an accessory portal.[59] However, if safe retrieval is not possible, leaving the screw in a posterior recess is acceptable as it may be asymptomatic.

Poor quality bone may occur in the femur or tibia. In such cases, over sizing the screw by 2 mm relative to the reamed tunnel improves fixation strength for both hamstring and BPTB grafts. If it is felt that fixation is still not adequate, then supplementary fixation with a staple or sutures tied over a cortical screw may be considered.[60]

Conclusion

Arthroscopically assisted ACL reconstruction is a technically demanding procedure with a steep learning curve. It consists of multiple surgical steps each of which is associated with potential complications that may occur despite the surgeon practicing safe and meticulous techniques. Surgeons performing ACL surgery should have a working knowledge of the more commonly occurring complications, as this allows their anticipation, potential prevention, and the ability to deal with them should they occur. Before embarking on ACL surgery in addition to the requisite surgical knowledge and ability, it is essential that appropriate equipment is available to deal with unexpected intraoperative events.

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c. Contribution to knowledge

This article aimed to increase the awareness amongst surgeons with regards to intraoperative complications in ACL reconstruction and provided step to step guidance on how to deal with them. The strength of this article is based on its combination of the surgical experience of practising soft tissue knee surgeons with an up-to date evidence-based review. The article also introduced a classification for intraoperative complications. In this classification complications were described according to the stage of the procedure including, during femoral or tibial tunnel preparation, graft harvesting, graft passage or graft fixation. This classification should help surgeons structure their preoperative planning and aid communication between clinicians in teaching, presentations or written manuals. Furthermore, this classification could provide an objective tool to aid qualitative and quantitative reporting of complications in scientific research studies assessing ACL reconstruction surgery.

This review helped identify areas in which there was an evidence gap, and thus needed additional evaluation. Based on this initial review new areas of investigation were highlighted and subsequently explored further within the ensuing articles presented in this commentary.

d. Article limitations

There are certain methodological limitations to this article. Firstly, there was a lack of a systematic approach to the review of the literature. Hence, it is possible that relevant bibliography was not presented. A systematic review would have aimed to capture all or most of the available evidence on the topic. Nevertheless, despite being a narrative review, the topic was explored broadly, and alternative management options were presented.

The article only considered complications of arthroscopically assisted ACL reconstruction when using hamstring tendons or patellar tendon grafts, assessing only complications related to suspensory button and interference screw fixation methods. Therefore, other complications related to open ACL reconstruction surgery as well as to other grafts and fixation devices were not considered. This limits the extent to which the information provided by the article can be relevant to the wider surgical community and particularly to surgeons who use other types of grafts or fixation devices. This narrative review was based on the experiences of 2 soft tissue knee surgeons. Collaboration with a larger group of surgeons in preparing the article could have allowed alternative management options to be considered for the complications described, based on their possible wider knowledge and personal experiences.

The classification of intraoperative complications in ACL reconstruction described in the article was descriptive and originated from the personal experience of the authors rather than developed in a more structured way based on a review of a case series of complications or using a consensus approach of a wider group of experts. The ability of this classification to capture the spectrum of ACL reconstruction complications encountered in clinical practice as well as its inter- and intra-related variability were thus not determined.

A final limitation of this article was that it reviewed intraoperative but not postoperative complications, but it must be noted that complications that become apparent post-ACL reconstruction surgery may be due to technical events occurring during surgery.

e. Relevant work since the article was published

Since this article was published, several other studies reported on the intraoperative complications of ACL reconstruction surgery. In a prospective cohort study of 54 patients who had primary ACL reconstruction using quadruple semitendinosus and gracilis tendon graft performed by one surgical team (Alsaad et al., 2018), it was reported that 14 cases (26%) developed complications, 7 (13%) of whom had cartilage injury, 2 (4%) had bleeding, 2 (4%) screw breakage, 1 (2%) screw mal-direction, and 2 (4%) premature graft division leaving a short tendon. In that article, potential ways of minimising the risk of the complications occurring were presented. Furthermore, an analysis of the incidence of ACL reconstruction complications in a single Orthopaedic Department in Greece was reported (Papastergiou et al., 2018). That analysis examined 1,972 ACL reconstructions carried out over a 27-year period, with a follow up of up to 2 years post-surgery. In 1,244 cases a hamstring autograft was used and in 728 bone-patellar tendon-bone autografts were utilised. These authors (Papastergiou et al., 2018) reported a similar intraoperative complication rate of about 22%. Furthermore, intraoperative complications were subdivided into those occurring during graft harvesting, during tunnel placement, graft passage, or during graft fixation. This subdivision was in line with the classification of intraoperative complications described in the review article presented in this chapter (Charalambous, Alvi and Sutton, 2013).

f. Further research

This article may form the basis to further identify areas of intraoperative complications to be explored in greater depth. As described above this article introduced a classification for intraoperative complications that may be encountered in ACL reconstruction and described these according to the stage of the procedure at which they may occur. Future work may evaluate the reliability of the complications' classification described in the article, to determine its ability to capture the spectrum of ACL reconstruction complications encountered in clinical practice as well as its inter- and intra-related variability.

The review article presented in this chapter concluded that surgeons performing ACL surgery should have a working knowledge of the more commonly occurring complications, as this allows their anticipation, potential prevention, and the ability to deal with them should they occur. It also recommended that prior to embarking on ACL surgery it is essential that appropriate equipment should be sought to deal with unexpected intraoperative events. Although such parameters may be part of the continuous professional development and training of individual surgeons, a more objective and reliable approach can be through the development of surgical management cards which can be drawn upon intraoperatively. This concept is already applied to emergency procedure checklists used in the aviation industry, but also in other aspects of healthcare (Clay-Williams and Colligan, 2015). Surgical management cards could act as a memory aide and guide the surgeon in a step-by-step way on how to deal with a given encountered complication, but also structure the preoperative planning to ensure all necessary equipment are available to handle such a situation. Surgical management cards could also form the basis of defending ones' actions once a well-accepted and described management plan is implemented. Such management cards may be of relevance to low volume ACL reconstruction surgeons and can be developed through a Delphi study of experts so to give a range of options of dealing with a particular complication.

CHAPTER 3 – COMPLICATIONS IN HAMSTRING TENDON HARVESTING IN ACL RECONSTRUCTION

A. Background

Hamstring tendons are the graft of choice of a substantial proportion of ACL reconstruction surgeons (Sherman et al., 2021, Arnold et al., 2021, Grassi et al., 2018). The hamstring tendon utilised is the semitendinosus which along with the gracilis tendon have a common insertion onto the medial part of the proximal tibia. Their insertion along with the insertion of the sartorius tendon is known as the pens anserinus, which in Latin means "gooses foot" as the three tendons' insertion resembles that structure. Apart from these main tendon insertions onto the tibia, the semitendinosus and gracilis tendons also have attachments to the gastrocnemius muscle and the fibrous envelope of the leg which is known as the leg fascia. These attachments of the hamstring tendons occur via fibrous bands referred to as accessory bands (Yasin et al., 2010, Candal-Couto and Deehan, 2003).

Hamstring tendon harvesting is performed using a surgical instrument known as a tendon harvester. During harvesting the tendon's insertion onto the tibia is exposed through a surgical incision and any accessory bands are divided to free and mobilise the tendon. Identification and division of the accessory bands is essential as they may inadvertently misdirect the tendon harvester causing premature division of the harvested tendon (Candal-Couto and Deehan, 2003). Once the accessory bands are divided, the tendon harvester is passed along the tendon, upwards into the thigh. The tendon harvester may strip the tendon from its muscle attachment at the musculotendinous junction and this type of harvester is referred to as a tendon stripper. Alternatively, a tendon harvester may use a blade to cut the tendon close to the musculotendinous junction and this type of harvester is referred to as a blade harvester. The tendons are then detached from their tibial insertion, folded, and sutured as part of constructing the ACL graft, a process which is referred to as graft preparation (Deehan and Pinczewski, 2002).

Successful ACL reconstruction surgery relies on a graft which is of adequate thickness and length. The strength of hamstring grafts was previously shown to be related to graft diameter (Boniello et al., 2015) with smaller diameter grafts associated with an increased risk of failure and poorer clinical outcomes (Conte et al., 2014, Mariscalco et al., 2013). Similarly, an adequate graft length is needed so it can allow adequate graft insertion in the femoral and tibial bone tunnels and hence more secure graft fixation in these tunnels. Hence, any complication which affects the graft dimensions may compromise the clinical outcome of ACL reconstruction surgery. If an adequate graft cannot be obtained from the desired source an alternative graft may need to be sourced. This may be an autograft from a different site, such as the hamstring tendons from the opposite knee, or bone-patellar tendon-bone from the ipsilateral or opposite knee. Alternatively, it may be an allograft or a synthetic ligament. In addition to providing a graft of adequate dimensions, the process of obtaining the graft needs to be one that does not confer substantial disruption to the surrounding soft tissues such as muscle damage. Soft tissue disruption could lead to muscle scarring and leg pain or weakness (Palazzolo et al., 2018, Weenders, Pietretti and de Kroon, 2015).

Understanding the rate of inadequate hamstring tendon harvesting from the desired source is vital as it can allow surgical planning and can also inform the consent process whereby the surgeon discusses with the patient the risks of surgery. It also allows the surgeon to consent the patient as to additional procedures which may need to be undertaken such as obtaining a graft from the opposite knee. Along the same lines, understanding the relation between the type of harvester and graft length or quality can guide the surgeon when choosing a surgical technique.

B. **Knowledge gap**

At the time when the studies presented in this chapter were carried out there was not sufficient knowledge about the rate of inadequate hamstring graft harvesting in a UK population, although rates of premature division of the hamstring tendons were described in a series of Iraqi (Alsaad et al., 2018) and a series of Greek (Papastergiou et al., 2018) patients. As anatomical characteristics may vary in different patient populations, understanding the rate of inadequate hamstring graft harvesting in a western population would be of great value. Similarly, there was no information concerning the relation between graft quality and the type of tendon harvester used to obtain the hamstring graft.

C. **Objectives**

Given the knowledge gap, the objectives of the studies included in this chapter were to determine the rate of inadequate hamstring graft harvesting in ACL reconstruction surgery in a UK population and explore whether the type of tendon harvester influenced the length and quality of the graft obtained.

D. **Hypotheses**

To meet the objectives described the following hypotheses were explored:

1) Inadequate graft harvesting in ACL reconstruction is a recognised complication, but its rate is low.
2) A graft blade harvester causes less soft tissue disruption as compared to a closed tendon stripper.
3) A graft blade harvester produces a shorter graft as compared to a tendon stripper. It was hypothesised that as the blade harvester cuts the tendon off the muscle, rather than stripping it off the muscle, the length of usable tendon may be shorter.

This area under investigation was examined initially by a narrative review of the morphological characteristics and anatomical variations of hamstring grafts used in ACL reconstruction surgery. Subsequently, the 1st hypothesis was examined by a clinical study that determined the rate of inadequate hamstring graft harvesting amongst patients who had

ACL reconstruction surgery under the care of a UK practicing surgeon. The 2nd and 3rd hypotheses were evaluated by a cadaveric study that looked at the relation between graft length and quality with the type of tendon harvester used to obtain the graft.

E. **Commentary article 2 - *Anatomical considerations in hamstring tendon harvesting for anterior cruciate ligament reconstruction. Charalambous CP, Kwaees TA. Muscles Ligaments Tendons J. 2013 Jan 21;2(4):253-7. PMID: 23738306***

http://www.mltj.online/wp-content/uploads/2019/01/Anatomical-considerations-in-hamstring-tendon-harvesting-for-anterior-cruciate-ligament-reconstruction.pdf.

a. Contribution by CP Charalambous

Developed the concept of the article, carried out the literature search, and led the writing of the article.

b. Article description – Full article

This was a narrative review of hamstring tendon harvesting which concentrated on the anatomical characteristics of hamstring tendons, the anatomical variations that may exist between patients, and their implications with regards to preventing or managing complications when these tendons are harvested. It was shown that graft length and diameter was highly variable between patients and could not be reliably predicted at an individual level using preoperative patient characteristics or radiological investigations. Similarly, it was noted that there was a substantial variability in the accessory bands of these tendons close to their insertion onto the tibia. Based on these findings the article highlighted that there are several anatomical issues that the surgeon must be aware of and consider when performing hamstring tendon harvesting, to minimise intraoperative as well as postoperative complications in ACL reconstruction surgery. A copy of the full article is presented next.

Anatomical considerations in hamstring tendon harvesting for anterior cruciate ligament reconstruction

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Summary

Hamstring tendons are widely used for anterior cruciate ligament (ACL) reconstruction of the knee. Certain anatomical considerations must be taken into account when harvesting the hamstring tendons to be used in ACL reconstruction. These anatomical considerations are discussed in this review article.

Key words: hamstring, tendon, harvesting, ligament reconstruction, anterior cruciate ligament.

Introduction

Hamstring tendons are one of the most commonly used grafts in anterior cruciate ligament (ACL) reconstruction of the knee, either as an autograft or allograft. Hamstring tendon grafts when compared to patellar - bone - tendon - bone grafts allow harvesting through a minimal skin incision, minimal donor site morbidity, and less extensor mechanism dysfunction with equally successful long term clinical results[1-4]. However, certain anatomical considerations must be taken into account when harvesting the hamstring tendons.

Pes anserinus insertion

Semitendinosus, gracilis and sartorius, have a common insertion into the anterior-medial aspect of the tibia, the *pes anserinus*[5]. These muscles act as flexors of the knee but also provide tibial rotation and act as rotatory and valgus constraints to the knee. Semitendinosus and gracilis are used in ACL reconstruction. Gracilis originates from the inferior ramus of the pubis and is a long fusiform muscle, that gives rise to a cylindrical tendon, and is innervated by the obturator nerve. Semitendinosus originates from the ischial tuberosity, is a fusiform muscle that about halfway down the thigh gives rise to a tubular tendon, and is innervated by the tibial branch of the sciatic nerve. Sartorius originates form the anterior superior iliac spine, and its tendon becomes thin and flat, like a fascial layer[6]. Gracilis and semitendinosus lie between layers one (that includes the sartorius fascia) and two (that includes the medial collateral ligament) of the medial structures of the knee[7]. Although gracilis and semitendinosus are separate structures proximally, they converge prior to their insertion onto the tibia. The insertion of gracilis is superior to that of semitendinosus. The *pes anserinus* insertion is about 19 mm (range 10-25 mm) distal and 22.5 mm (range 13-30 mm) medial to the apex of the tibial tuberosity[8]. The convergence of Sartorius and gracilis is described as being 2.2+/- 0.7 cm distal and 4.5+/-0.6 cm medial to the tibial tuberosity[9]. The *pes anserinus* insertion is closely related to the infrapatellar branch of the saphenous nerve and to the main saphenous nerve itself (Fig. 1). The sartorius fascia must be incised in order to expose the underlying semitendinosus and gracilis tendons which can be seen closely attached to the sartorius fascia. It is also important to note that semitendinosus and gracilis are, unlike the medial collateral ligament, are not adherent to bone, except at their attachment, a characteristic which can help distinguish these structures (Fig. 2). Furthermore, once the converging attachment of gracilis and semitendinosus the tibia is identified, this must be traced

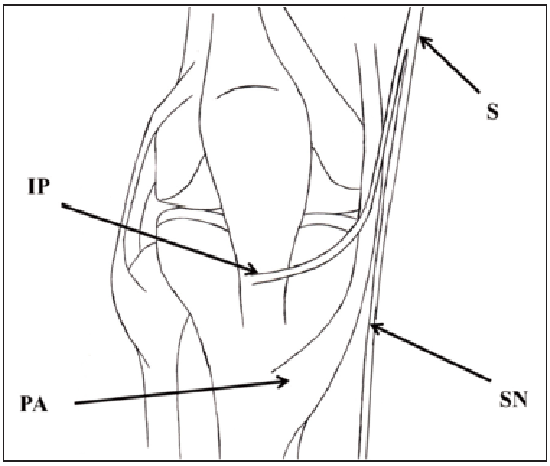

Figure 1. Anterior illustration of the right knee demonstrating the anatomical relationship between the PA: *Pes Anserinus*, S: Saphenous Nerve, SN: Sartorial nerve and the IP: Infrapatellar nerve.

more proximally to identify the two separate tendons prior to their convergence, and thus harvest them individually.

Graft Size

When using a patellar - bone - tendon - bone graft, the graft diameter can be reproducibly determined by the surgeon. However, when using hamstring tendons the graft diameter is predetermined by the natural diameter of the tendons of each individual and the surgeon has no influence on that. Hence it is possible to obtain a graft of too small diameter, which potentially could be associated with less mechanical resistance. Grafts greater than 7 mm in diameter are usually preferred. Graft length is also important, in order to allow adequate femoral and tibial fixation. It is estimated that a length of 9 cm for a looped graft (18 cm for un-looped) is needed, to give about 3 cm of intra-articular graft, 4.5 cm in the tibia and 2.5 cm in the femur. Again, the hamstring graft length that can be obtained is predetermined by each individuals natural anatomy.

Being able to predict graft length and diameter in each individual could allow preoperative planning particularly with regards the use of alternate grafts in those with anticipated short length or small diameter hamstrings. Several studies have investigated potential patient characteristics that could predict graft length and diameter. Chiang et al.[10] evaluated 100 patients who had double bundle ACL reconstruction with autologous hamstring tendons. Height and leg length were correlated with the lengths of gracilis and semitendinosus. Both tendons were longer in Caucasians as compared to Chinese. None of the anthropometric measures examined in that study were strong predictors of hamstring diameter. Along similar lines Tuman et al.[11] showed that the quadruple hamstring graft diameter was related to height, mass, age, and sex but not BMI. Height was the parameter mostly correlated with graft diameter, especially in females. In a study by Pinheiro et al.[12] involving 80 patients having ACL reconstruction with hamstring tendons in a quadruple graft, graft diameter was related to height, sex, leg and thigh length, weight and thigh diameter. Females had smaller grafts than males. Males taller than 1.85 m had an average graft diameter greater than the whole group and a greater proportion of 9 mm grafts. Ma et al.[13] found that males had significantly larger diameter hamstring grafts than females. Sex was related to graft diameter, but not age or weight. Height was a predictor of graft diameter in males. None of the parameters assessed predicted graft diameter in females. 42% of females had graft diameters of 7 mm or less. However, although correlations have been shown between certain anthropometric data and graft length/diameter it is not possible to accurately predict the diameter and length of a graft in a particular individual. Nevertheless there seems to be a consensus that females tend to have small diameter grafts, which may explain reports of postoperative graft laxity more often seen in females.

Previous studies have also examined the use of preoperative imaging in predicting graft length and cross sectional area in terms of three dimensional computed tomography

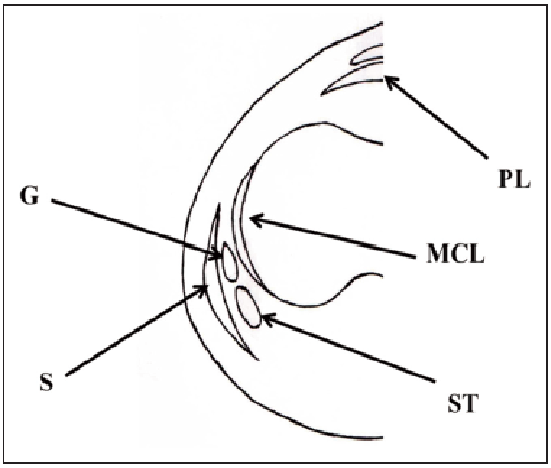

Figure 2. Cross-sectional illustration demonstrating the anatomical relationship of McL: Medial collateral ligament, G: gracilis, S: Sartorius, ST: Semitendinosus, PL: Patellar ligament.

(3-D CT) or Magnetic Resonance Imaging (MRI). There was a positive correlation between the total length of harvested semitendinosus tendon with the pre-operative length measured by 3-D CT scanning. However when the cross sectional area of semitendinosus tendon was examined there was no correlation between 3D-CT scan and intra-operative measurements[14]. Similarly MRI has been unable to accurately assess cross sectional area accurately in a particular individual[15].

It has also been suggested that the kind of tendon harvester used may influence the length of hamstring tendon obtained. Charalambous et al.[16] harvested 36 semitendinosus and gracilis tendons using either a closed stripper or a blade harvester in 18 cadaveric knees. The blade harvester gave longer lengths of usable tendon as compared to a closed stripper.

With the mainly caucasian population of the United Kingdom, graft length is not a major concern, however graft diameter can be. One must have the availability of using graft augmentation techniques such as the LARS (Ligament Augmentation & Reconstruction System), when faced with small diameter grafts. Such techniques have recently been reported to give good middle term functional results[17,18]. Alternatively, augmentation with a hamstring tendon from the opposite knee, or intra-operative conversion to a different graft may be essential.

Accessory insertions and fascial bands

Apart from the main hamstring tendon insertion to the *pes anserinus* there may be accessory tendon insertions, particularly for semitendinosus. In addition there are variable numbers of thick fascial bands that pass between semitendinosus and gracilis and also from these hamstring tendons to gastrocnemius, popliteal, pre-tibial and superficial fascia[19] (Fig. 3). Recognising these accessory insertions and fascial bands and dividing them is essential. If these are not recognised and divided they can divert the tendon stripper into the main tendon leading to premature tendon amputation and short graft.

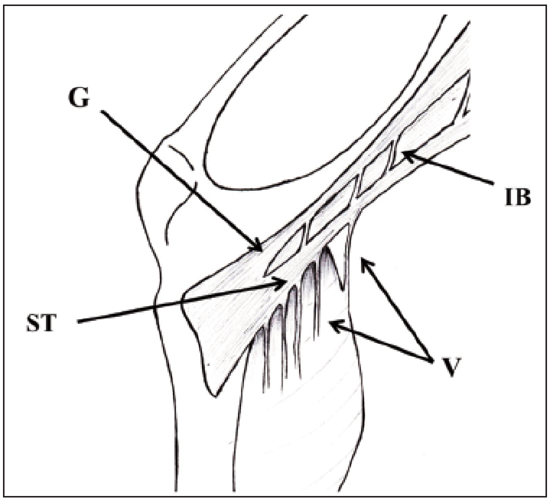

Figure 3. Simplified illustration or the medial aspect or the right knee demonstrating the anatomical relationship of Vincula to other structures in the knee. G: Gracilis, ST: Semitendinosus, IB: Interconnecting bands, V: Vincula.

Cadaveric studies by Candal-Couto and Deehan[19] and Tuncay[20] reported the existence of several accessory bands of gracilis and semitendinosus. Tuncay et al.[20] studied the anatomy of the fascial bands between semitendinosus and gastrocnemius in 23 cadaveric knees. They found that the mean width of the main band was 2.6 cm (1-4 cm) and the mean distance from the semitendinosus insertion to this fascial band was 7 cm (6-8 cm). However Candal-Coutoand Deehan[19] in another cadaveric study, found that accessory bands originated at greater than 10 cm from the tibial insertion of 8/10 semitendinosus and 2/10 gracilis tendons, contrary to the common belief that 10 cm proximal to the insertion of pes anserinus is a safe distance to avoid encountering such a band. This has been confirmed more recently by Yasin et al.[21] *in vivo*. They studied the number of accessory bands and their location in 25 patients undergoing ACL reconstruction using hamstring tendons. For gracilis the most common number of accessory bands was 2 (range 0-3). The average distance of the most proximal band from the common insertion was 5.14 cm with none of the gracilis accessory bands being more than 10 cm proximal to the tibial crest attachment. For semitendinosus tendons the most common number of accessory bands was 3 (range 1-4), the average distance of the most proximal band from the tibial crest insertion was 8.14 cm. However, 5 semitendinosus tendons had accessory bands located more than 10 cm proximal to the tibial crest attachment.
In a cadaveric study, Sanders et al.[22] described 3 zones with the knee in 90° flexion and the femur parallel to the floor. Zone A included the area anterior-superior to gracilis, zone B between gracilis and semitendinosus and zone C, posterior-inferior to semitendinosus. They described that proximally semitendinosus had variable slips inserting onto the crural fascia and gastrocnemius. Distally there were reproducible accessory tendon slips. In zone A, a membranous band originating from the medial epicondyle of the femur was found to insert on the intratendinous fascia of gracilis and semitendinosus. In zone B fibrous bands existed between the two tendons, reproducibly found at 2.5 cm, 5.5 cm and 6.5 cm form the distal tendon insertion. Zone C included the only true accessory insertional tendon from the semitendinosus at 5.1 cm which was preceded by a variable band at 3.8 cm.

Saphenous nerve

The saphenous nerve and its branches are closely related to the medial hamstring tendons and could potentially be damaged during hamstring tendon harvesting. Such nerve damage may occur during skin incision and dissecting beneath the skin or at deeper dissection and harvesting of the tendons. The saphenous nerve is a sensory nerve that supplies the intra-articular part of the knee and skin on the medial aspect of the knee, lower leg and ankle. It arises from the posterior division of the femoral nerve at the upper part of the thigh, traverses the adductor canal and divides into its two terminal branches, the infra-patellar and sartorial branch. The infra-patellar branch curves anteriorly to supply the anterior-medial aspect of the knee whereas the sartorial branch pierces the sartorial fascia to become subcutaneous. The sartorial branch continues distally alongside the great saphenous vein, giving sensation to the medial aspect of the lower leg[6]. The infrapatellar branch of the saphenous nerve may be described as posterior, penetrating, parallel and anterior according to its relationship to sartorius[23]. The posterior type (nerve emerges under the posterior border of Sartorius) is the most common, seen in 62% of cases. The infrapatellar branch passes between the inferior pole of the patella and the tibial tuberosity in 98.5% and distal to the tuberosity in 1.5% of cases. It passes as one branch in 25%, 2 branches in 62%, 3 branches in 10% and 4 branches in 1.5% of cases[24].
Sanders et al.[22] found that the saphenous nerve frequently run parallel and closely to gracilis on the deep surface of sartorius crossing gracilis from lateral to medial at 11.8 cm (range 7-13.2 cm) from its distal insertion. It then continued distally on the posterior-medial side of the tendon. The sartorial branch left the sartorius fascia at a mean of 7.2 cm (range 6.4 cm-9.3 cm) from the distal gracilis insertion to become subcutaneous, hence it was closely related to gracilis for 4.6 cm prior to leaving layer 1 of the knee.
In a review of 164 patients that had ACL reconstruction, Sanders et al.[22] reported a 19% rate of isolated infra-patellar nerve injury following hamstring harvesting through a 1.5-2 cm vertical incision over pes-anserinus. There was also a 23% isolated injury rate of the sartorial branch, and a 32% injury rate of both branches.
Luo et al.[25] examined the relationship between skin incision and injury of the infra-patellar branch during ACL reconstruction. A vertical incision was used in 35 and an oblique incision in 25 cases. 23 (65.7%) in the vertical incision and 6 (24%) in the oblique incision group had evidence of infra-patellar nerve injury. The skin area of altered sensation was greater in the vertical as compared to the oblique incision group. Four cases developed medial lower leg paraesthesia, suggestive of damage to the sartorial branch.

Papastergiou et al.[26] carried out a retrospective study of 230 ACL reconstructions using hamstring tendons. In one group harvesting was through a 3 cm vertical incision, and in a second group through a 3 cm horizontal incision. There was a 39.7% rate of sensory changes in the area innervated by the infrapatellar branch in the first group a 14.9% rate in the second group.

Boon et al.[27] tried to determine safe areas and angles for skin incisions for harvesting semitendinosus and gracilis by looking at 40 cadaveric knees. They reported that when the knee is placed in flexed position, a horizontal line was drawn on the plane of the tibial tuberosity. In the right knee the safe area was between 3.7 and 5.5 cm from the tibial tuberosity with a safe incision line at an angle of 51.6°. In left knee the safe area was between 3.6 and 4.9 cm from the tibial tuberosity with the safe incision line being at an angle of 52.5°. However such measurements may be difficult to reproduce intra-operatively.

Both the infra-patellar and sartorial branches of the saphenous nerve are at risk of damage during hamstring tendon harvesting. Careful dissection and harvesting, as well as a horizontal or oblique skin incision may reduce the injury rate. In addition placing the knee in 90° flexion with the hip externally rotated (by placing the leg in the figure of 4 position) may reduce the risk of damage to the saphenous nerve. Explaining this potential complication to the patient pre-operatively is essential.

Medial collateral ligament

The MCL lies deep to the semitendinosus and gracilis, closely adherent to bone. Care must be taken to avoid damaging this or mistaking it for a hamstring tendon. Its close adherence to bone is one way of distinguishing the MCL from the tendon.

Conclusions

In conclusion, hamstring tendons can give good functional results when used for ACL reconstruction with minimal donor site morbidity. However there are several anatomical issues which must be taken into account when performing hamstring tendon harvesting in order to minimise intraoperative as well as post-operative complications.

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c. Contribution to knowledge

This article contributed to literature in that it identified and discussed the clinical relevance of the variation in anatomy existing between patients with regards to the semitendinosus and gracilis tendons. It thus provided information to increase awareness amongst surgeons as to how anatomical variation may affect the surgical technique of ACL reconstruction using hamstring tendon grafts. It also provided a thorough assessment of the limitations of the ability to accurately predict the size and quality of the hamstring tendons prior to surgery based on patient clinical and radiological parameters. This review helped identify the need for clinical studies to assess the rate of inadequate ipsilateral graft harvesting and its causes, and this was thus further evaluated by the commentary's 3rd article (Charalambous et al., 2021) described next in this chapter.

d. Article limitations

This article was a narrative review without a systematic literature search. This raises the possibility that some relevant information was not presented. Furthermore, there were only two authors of the article. Involvement of a larger group of contributors could allow a broader consideration of the clinical implications of variations in the anatomy of hamstring tendons, as contributors would be able to draw on their personal knowledge and surgical experiences.

The information with regards to the anatomical variation of hamstring tendons was presented only in a descriptive way, and statistical analysis, such as meta-analysis of quantitative data, was not performed. Statistical pooling of data across studies could have quantified with greater confidence the anatomical variation that exists in hamstring tendons with regards to their dimensions and to the number and location of their accessory bands.

e. Relevant work since the article was published

Since this article was published several other studies evaluated the anatomy of the distal hamstring tendon insertion and their findings were in line with the commentary's 2nd article (Charalambous and Kwaees, 2012).

In a dissection study of Caucasian cadavers fixed in formalin solution the insertion of the hamstring tendons onto the proximal tibia was evaluated using high quality photos (Olewnik et al., 2019) and a new classification of pes anserinus morphology was proposed. This classification included 6 types of pes anserinus according to the distribution of tendons and accessory bands which further emphasised the substantial anatomical variability that exists with regards to the pes anserinus insertion. However, what was of greater surgical interest was that in this classification the morphology of the insertion of the pes anserinus tendons onto the tibia was also divided into three types - a short tendinous insertion, a band-shaped or a fan-shaped insertion. This distinction is clinically important as it may be harder to recognize the correct tendon in a fan shaped insertion and thus to expose the point where the tendon harvester is introduced. Hence, the surgeon needs to be aware of this when exposing the hamstring tendons and considering where to introduce the harvester.

The anatomy of the accessory bands of semitendinosus and gracilis was further evaluated in a study of human fresh cadavers (Reina et al., 2013). This aimed to identify anatomical factors that may increase the risk of complications during tendon harvesting and determine anatomical parameters that could predispose to premature tendon division (Reina et al., 2013). This article provided further new information that can improve the quality of the harvesting process and minimise the risk of premature tendon division. The authors reported that semitendinosus always had at least one accessory band, whilst in about 23% of cases semitendinosus had 2 and in one case it had 3 bands. It was also shown that the first band was located at a mean of about 5cm from the tendon's tibial insertion but ranged from 0 to about 10cm. The second band was located at a mean distance of about 7cm with a range of about 4 to 13cm from the tibial insertion. The semitendinosus bands were found to be thick, strong, and tendinous and passed distally to the fascia of gastrocnemius muscle at an acute angle. In contrast, gracilis had up to 3 bands which were weak and aponeurotic in nature. All the bands of gracilis ran distally at an acute angle in about 60% of cases and at an obtuse angle in about 40% of cases. Most bands attached to the semitendinosus tendon or the gastrocnemius fascia whilst some bands ran anteriorly to the tibial periosteum or the surrounding aponeurosis. Based on these findings it was suggested that 3 anatomical parameters of the accessory bands, that is their macroscopic type, site of insertion, and angle at which the accessory band fibres attach to the tendon, may be risk factors for failure during harvesting. A strong tendinous as compared to an aponeurotic band, an insertion onto the gastrocnemius fascia or another tendon as compared to an insertion onto the surrounding aponeurosis, and an angle of attachment relative to the distal part of the tendon of less than 90°, were associated with a higher risk of misdirection of the harvester and premature tendon division. As these morphological parameters can be directly assessed by the surgeon during harvesting, they could guide precautionary measures to minimise the risk of premature tendon division.

f. Further research

The article evaluated here (Charalambous and Kwaees, 2012) may form the basis of future cadaveric or radiological studies aiming to assess hamstring tendon morphology. As the quality of radiological imaging improves, further radiological studies may be used to evaluate the hamstring tendons preoperatively to guide precautionary measures to minimise complications in graft harvesting.

F. **Commentary article 3 - *Rate of insufficient ipsilateral hamstring graft harvesting in primary anterior cruciate ligament reconstruction. Charalambous CP, Kwaees TA, Lane S, Blundell C Mati W. J Knee Surg. 2021. PMID: 33853149.***

https://www.thieme-connect.com/products/ejournals/abstract/10.1055/s-0041-1726421. *doi: 10.1055/s-0041-1726421*

a. Contribution by CP Charalambous

Developed the concept of the article, designed the methodology, collected, analysed the data, led the writing of the article.

b. Article description

This article reported a clinical study which assessed the rate of insufficient ipsilateral hamstring graft harvesting in primary ACL reconstruction surgery as encountered in clinical practice. It retrospectively assessed 50 primary ACL reconstructions performed by a single surgeon in the UK. This study demonstrated that insufficient ipsilateral hamstring graft harvesting is a recognised, yet unusual intraoperative complication in primary ACL reconstruction for which adequate presurgical planning is essential. It was shown that in 3 of the 50 (6%) patients there was insufficient ipsilateral hamstring graft harvesting and a contralateral hamstring graft was obtained. This was either due to premature division of the ipsilateral hamstring tendons (observed in 3/100 harvested tendons, 95% CI: 1.0–8.5%), or due to abnormality in the tendon morphology (in 1 case the central part of the tendon was too thin). The latter was identified in a retrospective examination of magnetic resonance images obtained prior to surgery, suggesting a potential role of such investigations in identifying tendon morphological variants. Hence, the findings of this study proved the hypothesis that inadequate graft harvesting in ACL reconstruction is a recognised complication, but its rate is low. A copy of the full article is presented next.

Original Article

Rate of Insufficient Ipsilateral Hamstring Graft Harvesting in Primary Anterior Cruciate Ligament Reconstruction

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J Knee Surg

Abstract

Anterior cruciate ligament (ACL) reconstruction, using an ipsilateral hamstring graft, may necessitate an alternative graft source if the obtained graft is insufficient with regards to length or diameter. The study aims to determine the rate of insufficient ipsilateral hamstring graft harvesting in primary ACL reconstruction. Retrospective review of 50 consecutive primary ACL reconstructions performed by a single surgeon in the United Kingdom. In 3 of 50 cases, there was insufficient ipsilateral hamstring graft harvesting and a contralateral hamstring graft was used. In two cases, this was due to premature division of the ipsilateral hamstring tendons (3/100 harvested tendons). In one case, an adequate length of semitendinosus was obtained, but its central portion was too thin. Retrospective review of preoperative magnetic resonance imaging identified the thin part of the tendon in the latter case. Insufficient ipsilateral hamstring graft harvesting is a recognized, yet unusual intraoperative complication in primary ACL reconstruction. Presurgical planning as to how to manage such complications is essential.

Keywords
- anterior cruciate
- hamstring
- harvesting

Anterior cruciate ligament (ACL) reconstruction is commonly performed by using an ipsilateral hamstring tendon graft, whereby the semitendinosus and gracilis tendons are harvested and then folded to give a four-strand graft construct. This may then be secured to femoral and tibial bone tunnels by using suspensory or aperture fixation. Such a hamstring graft must be of adequate length and diameter to facilitate fixation in the femoral and tibial bone tunnels and provide sufficient strength to resist tensile and torsional forces.

Insufficient tendon graft length may be due to inherent patient characteristics or due to premature tendon division during harvesting; this may be secondary to previous hamstring tendon injury and scarring or due to insufficient release of the hamstring tendons accessory bands. Hamstring tendon graft diameter is usually inherent to the patient and may be related to sex and ethnicity but may also be influenced by the harvesting process.[1–7]

In cases where an insufficient ipsilateral hamstring tendon graft is obtained, an alternative graft may be considered (including a contralateral hamstring tendon graft, bone patellar bone or quadriceps graft, allograft or synthetic ligament). Hence, determining the rate of ipsilateral tendon graft harvesting insufficiency is important as it may guide arrangements for alternative graft availability and can

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inform the consent process. The aim of this study was to determine the rate of insufficient ipsilateral hamstring graft harvesting in primary ACL reconstruction.

Materials and Methods

The study was performed in a Teaching hospital in the United Kingdom and approval was granted by the Research and Development department of our institution. Fifty consecutive primary ACL reconstructions, performed under the care of the senior author, were identified through surgical logbooks. Their records were reviewed to determine the site of hamstring graft harvested, graft characteristics, and patient demographics. Preoperative MRI scans of patients in whom an insufficient graft was obtained were retrospectively reviewed by a senior musculoskeletal radiologist to look for abnormalities in the semitendinosus and gracilis tendons.

Surgical Technique

Patients were consented for hamstring tendon harvesting from the ipsilateral knee (or from the contralateral knee if needed). Both knees were prepared and draped. The ipsilateral knee was placed in 90 degrees of flexion (supported by a foot post) and in slight external rotation. A thigh tourniquet was placed around the thigh, but was usually not inflated during graft harvest.

Gracilis and semitendinosus were harvested as follows: the pes anserinus insertion was palpated and a short vertical incision was made, so the insertion of the hamstring tendons was located at the distal part of the incision and centered on the medial tibial surface. Where the hamstring tendon insertion was not palpable, this incision was performed approximately four finger breaths distal to the medial part of the tibiofemoral joint. The underlying fat was incised and lifted off the underlying sartorius fascia by using a swab. The gracilis and semitendinosus insertion was then identified, and the sartorius fascia was incised obliquely to identify the underlying gracilis and semitendinosus tendons. A tendon hook was used to pull the tendon through the surgical wound and any accessory bands were released using dissecting scissors. This release was confirmed by palpation and also by pulling on the hamstring tendon while observing any pulling on the gastrocnemius. A blade harvester (ConMed Linvatec, UK), set in stripper mode, was used to harvest each tendon. In very few cases where this could not be achieved, a tendon striper was utilized (Smith and nephew or Mitek). Following harvesting, the tendons were folded forming a four-strand graft and were inspected and measured with regard to their length and diameter. Graft diameter was measured at 0.5 mm intervals. Insufficient hamstring harvesting was defined as a tendon that with folding would provide less than 80 mm of tendon length or less than 7 mm diameter.

The graft was secured to the femur by using suspensory fixation (femoral suture button, Endobutton, Smith and Nephew, UK or fixed length Rigidloop, DePuy International, UK) and to the tibia using an interference screw (supplemented on occasions with a soft tissue staple).

Table 1 Demographics of included cases

Age	Mean = 27.9 y Median = 26 y Range = 15.8–56 y
Sex	Female = 14 Male = 36
Ethnicity	British White = 47 White other = 1 Not stated = 2
Knee side	Left = 22 Right = 28
Graft diameter (femoral end)	Size (no. of knees) 7 mm (8) 7.5 mm (12) 8 mm (16) 8.5 mm (4) 9 mm (3) Not available (7)
Graft diameter (tibial end)	7 mm (4) 7.5 mm (5) 8 mm (20) 8.5 mm (10) 9 mm (3) 9.5 mm (1) Not available (7)

Statistical Analysis

Rates of insufficient ipsilateral graft harvesting and 95% confidence intervals (CI) were calculated by using the Wilson score interval method.

Results

Patient demographics are summarized in ►**Table 1**.

In three cases (95% CI: 1.0–8.5), the ipsilateral graft was deemed insufficient and a hamstring graft was obtained from the opposite knee (►**Table 2**). In one case (operated 7 months postinjury), premature division of the semitendinosus tendon resulted in a 90-mm long graft. In one case (operated 7 years postinjury), it was felt that there was extensive scarring at the insertion site that led to premature division of the hamstring tendons' tibial insertion. Retrospective evaluation of the preoperative MRI scans of both of these cases did not identify any changes in the hamstring tendons that could have predicted the harvesting difficulties.

Table 2 Rates of encountered premature hamstring tendon division

Tendon	Premature division rate (%)	% (95% CI)
Gracilis	1/50 (2%)	0.4–10.5
Semitendinosus	2/50 (4%)	1.1–13.5
Gracilis or semitendinosus	3/100 (3%)	1.0–8.5

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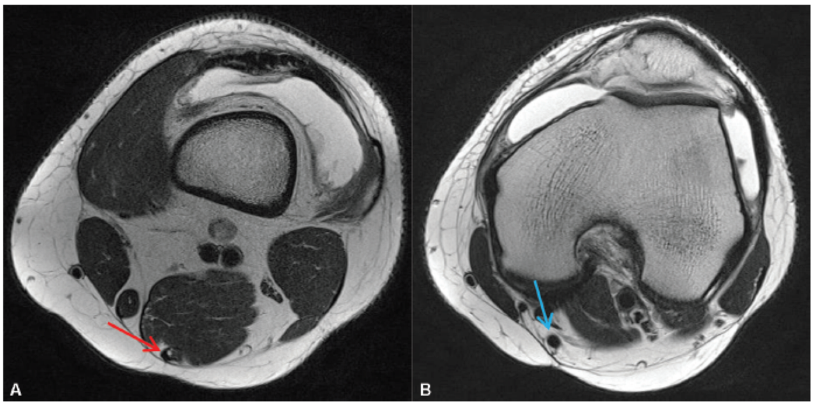

Fig. 1 Cross-section of the knee showing a narrow semitendinosus tendon just distal to the musculoskeletal junction (**A**), as compared with the distal broader part of the tendon (closer to its insertion, **B**).

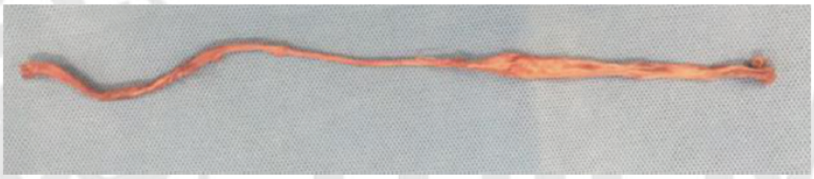

Fig. 2 Photograph of the harvested semitendinosus tendon, of adequate length, with a thin central part.

In one case (operated 5 months postinjury), an adequate tendon length of semitendinosus was harvested, but its central part was very thin (►**Fig. 1**), and when combined with the harvested gracilis, it provided a graft diameter of less than 7 mm. Retrospective evaluation of the preoperative MRI scan of this case showed indentation of the semitendinosus and gracilis tendons by surrounding fat and also demonstrated that the thickness of the central part of semitendinosus tendon (just distal to the semitendinosus musculotendinous junction) was much lower than that just proximal to the tendon's tibial insertion (►**Fig. 2**).

In all cases, a four-strand hamstring graft was constructed and sized. The diameters of its femoral and tibial ends are summarized in ►**Table 1**.

Discussion

One of the potential intraoperative complications of ACL reconstruction is the inability to obtain the preferred graft in sufficient length and diameter from the preferred source. Our results suggest that this is an unusual, yet recognized occurrence in primary ACL reconstruction using an ipsilateral hamstring graft. As this is encountered intraoperatively, a plan must be in place for an alternative graft or graft source or for a surgical technique adjustment.

Semitendinosus, gracilis, and sartorius have a common insertion onto the anterior-medial part of the tibia known as the pes anserinus. Semitendinosus and gracilis are used as ACL reconstruction grafts. When using a patellar-bone-tendon-bone or quadriceps tendon graft, the graft diameter may be reliably determined by the surgeon. However, when using hamstring tendons, the graft diameter is predetermined by the natural diameter of the tendons of each individual. Grafts with diameter more than 7 mm are usually preferred due to the higher failure rate reported for thinner grafts.[8–10]

Graft length is also important to allow adequate femoral and tibial fixation. It is estimated that a length of 80 mm for a looped graft (160 mm for unlooped) is needed. Again, the hamstring graft length that can be obtained is predetermined by each individual's natural anatomy. Graft length has been related to patient height, leg length, and race, whereas the diameter of a quadruple hamstring graft diameter has been shown to be related to body height and sex. Nevertheless, accurate prediction of hamstring tendon graft diameter and length at an individual level based on anthropometric studies is not possible. Similarly, preoperative radiological imaging has not been shown to accurately predict the intraoperative determined graft measurements.[11–15]

A short graft length may also occur due to premature division (amputation) of the harvested hamstring tendon. Premature division of a hamstring tendon may occur due to inadequate tendon mobilization caused by previous tendon injury and scarring or due to inadequate release of fascial

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bands connecting the distal part of the tendons to surrounding structures. There are variable numbers of thick fascial bands that pass between semitendinosus and gracilis and also from these hamstring tendons to gastrocnemius and to the popliteal, pretibial, and superficial fasciae. Cadaveric studies have shown the existence of several accessory bands of gracilis and semitendinosus. These have been shown to be wide (Tuncay et al[16] reported a mean width of the main band of 2.6 cm, range = 1–4 cm) and originate at greater than 10 cm from the tibial insertion of most semitendinosus and some gracilis tendons.[17,18] If these fascial bands are not sufficiently released, they can divert the tendon stripper or harvester into the main tendon substance, leading to premature tendon division and short graft. If during advancement of the tendon stripper, excessive resistance is felt, the surgeon must palpate for additional bands which are released before continuing with tendon stripping. On occasions, however, such bands may be quite proximal beyond the extent of palpation through the surgical wound.

The type of tendon harvester per-se may influence the length and quality of hamstring tendon obtained as well as soft tissue disruption. Charalambous et al[19] harvested 36 semitendinosus and gracilis tendons using either a closed stripper or a blade harvester in 18 cadaveric knees and showed that the blade harvester gave longer lengths of usable tendon as compared with a closed stripper and minimized the stripping of muscle and of any nonusable tendon. This blade harvester was routinely utilized in our series reported here.

The chronicity of ACL insufficiency may also influence the quality of hamstring autografts. Naik and Acharya[20] examined whether there is a correlation between the duration of ACL injury and the quality and length of harvested hamstring graft in 40 consecutive patients who underwent ACL reconstruction (23 with chronic injury of more than 3 months duration and 17 with an acute injury of less than 3 months duration). In 13 chronic cases, the surgeon reported difficulty in advancing the tendon stripper beyond the musculotendinous junction, but this problem was not encountered in any of the acute group ACL disruptions. The proximal end of the harvested tendon was classified as ragged in 10 of 23 cases with chronic injury but in only 2 of 17 cases with an acute ACL injury. The mean percentage of usable tendon was lower in the chronic as compared with the acute group (89.1 vs. 93.9%). Similarly, the risk of harvesting a shorter graft was higher in chronic ACL as compared with acute ACL injury (odds ratio: 5.7). The challenges in hamstring harvesting seen in chronic cases may be related to fibrosis at the musculotendinous junction related to knee instability and further injury.

Recognizing the potential complication of insufficient tendon graft may inform the consent process and aid surgical planning. Several options are available, including the sourcing of an alternative graft (contralateral hamstring, bone patellar bone, quadriceps bone graft, allograft, or synthetic graft). Alternatively, surgical technique modification (such as quadrupling rather than double folding the semitendinosus tendon) may be utilized.

In our series, cases were routinely consented for the possibility of harvesting a contralateral hamstring graft and (more recently) also for using a synthetic graft (such as the ligament augmentation and reconstruction system [LARS ligament, Corin, United Kingdom]); both of which allow the same surgical technique to be used as when using an ipsilateral hamstring graft (with regard to tunnel reaming and fixation with a suture button on the femoral side and interference screw fixation on the tibial side).[21,22]

There is limited previous evidence in literature as to the rate of insufficient ipsilateral graft harvesting. Alsaad et al[23] described 54 male patients with a mean age of 27.7 years, who underwent ACL reconstruction using a hamstring tendon graft in Baghdad. They reported that 14 of 54 patients (26%) had developed intraoperative complications, including 2 (3.7%) a short graft due to premature division. Papastergiou et al[24] investigated the incidence of ACL reconstruction complications in a single orthopedic department in Greece. They reported seven cases among 1,244 (0.56%) ACL reconstructions that had short hamstring tendons due to early transection (►**Fig. 1**). However, this was a retrospective database study, with no reference made to whether one or both tendons were involved and no description of graft diameter. Nevertheless, anatomical variations in hamstring tendon diameter and length may exist across ethnicities; hence, the findings of this evaluation in a population in the United Kingdom are of particular value.

Limitations of this study include the retrospective nature of the analysis. However, this was a single series, performed by a single fellowship trained surgeon, which adds to the strength of the results. Learning curve factors may have contributed to our findings; hence, we looked at the first 50 cases performed by the senior author to include such learning curve factors into account and hence provide a "worst case scenario."

In conclusion, our findings have shown that an insufficient hamstring graft is an unusual but recognized complication of hamstring tendon harvesting, which must be anticipated so that alternative plans are put in place for its successful management.

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Conflict of Interest
None declared.

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c. Contribution to knowledge

This article contributed to literature in that it demonstrated the rate of insufficient tendon harvesting in routine clinical practice in a UK population. It aimed to increase awareness amongst surgeons with regards to this potential intraoperative encounter and guide them as to the necessary preoperative planning that is the need to consider alternative grafts and graft fixation techniques as well as in the consent of patients prior to surgery with regards to this possibility.

d. Article limitations

In the introduction section, the background was described, the clinical problem stated, and the overall aim articulated, but specific hypotheses were not presented. The main methodological limitation of this study is that the findings related to the work of one surgeon rather than multiple surgeons. It is thus difficult to extrapolate the findings of this study to the rate of the inadequate graft harvesting encountered by other surgeons in the UK. The 4% rate of inadequate hamstring tendon length presented in this article (Charalambous et al., 2021) is in line with a 3.7% rate reported in a series of patients in Iraq (Alsaad et al., 2018) but it is higher than the rate of 0.56% presented in a series of patients in Greece (Papastergiou et al., 2018). Although differences in the methodology of these studies may account for some of the observed variation, this variation highlights the need to gather data for the wider surgical community. Along similar lines, given the relatively small number of cases examined, the 95% confidence intervals calculated for the rate of inadequate graft harvesting were broad, limiting the extent to which authoritative results can be drawn. Assessing a larger group of patients, operated upon by a larger group of surgeons, would have allowed the calculation of narrower confidence intervals. However, this article lays the foundations for a larger study involving multiple surgeons.

The definition of the term inadequate graft harvesting as it was employed in this study was not based on a validated established definition or on a predetermined agreement by a group of experts in ACL reconstruction surgery. Instead, the definition of inadequate graft harvesting was based on the personal views of the candidate who was the senior author of the article, as this was how the term was used in the candidate's clinical practice. It is possible that other surgeons might have used an alternative definition for inadequate graft harvesting by accepting the use of only a semitendinosus graft rather than a combined gracilis and semitendinosus graft, or by accepting a graft of less than 7mm in diameter. Similarly, other surgeons might have used alternative surgical techniques to deal with a short or thin graft which may avoid harvesting from a different site, such as using the semitendinosus tendon in a triple strand configuration (Drocco et al., 2018).

Furthermore, this study was retrospective and as a result certain data such as the graft diameter of 7 cases and the ethnicity of 2 cases could not be retrieved. In line with this, the radiological assessment of the MRI scan of the case of a thin semitendinosus tendon reported in the article was retrospective and not blinded as to the intra-operative appearance of the tendon, raising the possibility of assessment bias.

e. Further research

This study (Charalambous et al., 2021) may form the basis of a future prospective study involving multiple surgeons to determine the rate of inadequate graft harvesting in the general surgical population. A further study may also evaluate the impact of the learning curve on the rate of insufficient graft harvesting by comparing both within surgeon and between surgeon practices.

Furthermore, a prospective clinical study may further evaluate the role of preoperative MRI in identifying cases where graft harvesting may be technically challenging and determine factors as to the reasons for this. With improvements of MRI sensitivity and the quality of images obtained it may be possible to determine preoperatively the presence of hamstring tendon accessory bands, or hamstring tendon scarring and hence aid the harvesting process. MRI scanning may also look at the whole of the leg to capture the proximal musculotendinous junction of hamstring tendons, unlike current MRI practice where only the distal part of the thigh and knee are routinely imaged. Scanning the musculotendinous junction may identify scarring which could make the harvesting process more technically challenging.

G. **Commentary article 4 - *Hamstring tendon harvesting-Effect of harvester on tendon characteristics and soft tissue disruption; cadaver study. Charalambous CP, Alvi F, Phaltankar P, Gagey O. Knee. 2009 Jun;16(3):183-6. PMID: 1927278***

https://www.thekneejournal.com/article/S0968-0160(08)00205-6/fulltext.

DOI: 10.1016/j.knee.2008.11.010

a. Contribution by CP Charalambous

Developed the concept of the article, co-designed the methodology, collected and analysed the data, and led the writing of the article.

b. Article description -Full article

This was a cadaveric study comparing 2 types of tendon harvester in obtaining hamstring tendons for ACL reconstruction. It compared a closed stripper with a blade harvester in 18 paired knees from 9 human fresh cadavers. Use of the blade harvester gave longer lengths of usable tendon whilst minimising the stripping of muscle and of any non-usable tendon. This study showed that the type of harvester per se influenced the length of tendon as well as the extent of associated soft tissue disruption. The findings of this study supported the hypothesis that a graft blade harvester causes less soft tissue disruption as compared to a closed tendon stripper. However, the hypothesis that a graft blade harvester produces a shorter graft as compared to a tendon stripper was rejected as longer lengths were obtained with the blade harvester. A copy of the full article is presented next.

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The Knee

Hamstring tendon harvesting — Effect of harvester on tendon characteristics and soft tissue disruption; cadaver study

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ABSTRACT

The purpose of this study was to determine whether the type of hamstring tendon harvester used can influence harvested tendon characteristics and soft tissue disruption. We compared two different types of tendon harvesters with regard to the length of tendon obtained and soft tissue disruption during hamstring tendon harvesting. Thirty six semitendinosus and gracilis tendons were harvested using either a closed stripper or a blade harvester in 18 paired knees from nine human fresh cadavers. Use of the blade harvester gave longer lengths of usable tendon whilst minimising the stripping of muscle and of any non-usable tendon. Our results suggest that the type of harvester *per se* can influence the length of tendon harvested as well as soft tissue disruption. Requesting such data from the industry prior to deciding which harvester to use seems desirable.

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1. Introduction

Hamstring tendons are extensively used in arthroscopic and open ligamentous reconstruction of the knee [1–4]. Harvesting of semitendinosus and gracilis is most commonly performed via a small incision adjacent to the tibial tuberosity using a tendon harvester introduced from distal to proximal. Obtaining a long tendon harvest whilst minimising soft tissue disruption during the harvesting process is desirable. There are a wide variety of tendon harvesters available, these differ in both their size and harvesting characteristics. The aim of this study was to compare two tendon harvesters with regard to the length of tendon obtained and adjacent soft tissue disruption caused by harvesting and thus determine whether the tendon harvester *per se* can influence these parameters.

2. Methods

This study was performed at the Department of Anatomy, University Renes Descartes, Paris. Eighteen knees from nine human fresh cadavers (mean age 83 years old) were used. None had any macroscopic pathology. One knee of each cadaver was allocated to using a 6.9+/−0.125 mm inner diameter closed tendon stripper (ConMed Linvatec, Swindon, UK) with the opposite knee allocated to using a 4.55 +/− 0.125 mm inner diameter blade harvester (ConMed Linvatec, Swindon, UK), (Figs. 1 and 2). The nine cadavers were randomly assigned a number one to nine. The first four cadavers had their right knee hamstrings harvested using the blade harvester and

Fig. 1. Mouth of closed tendon stripper (Linvatec, UK).

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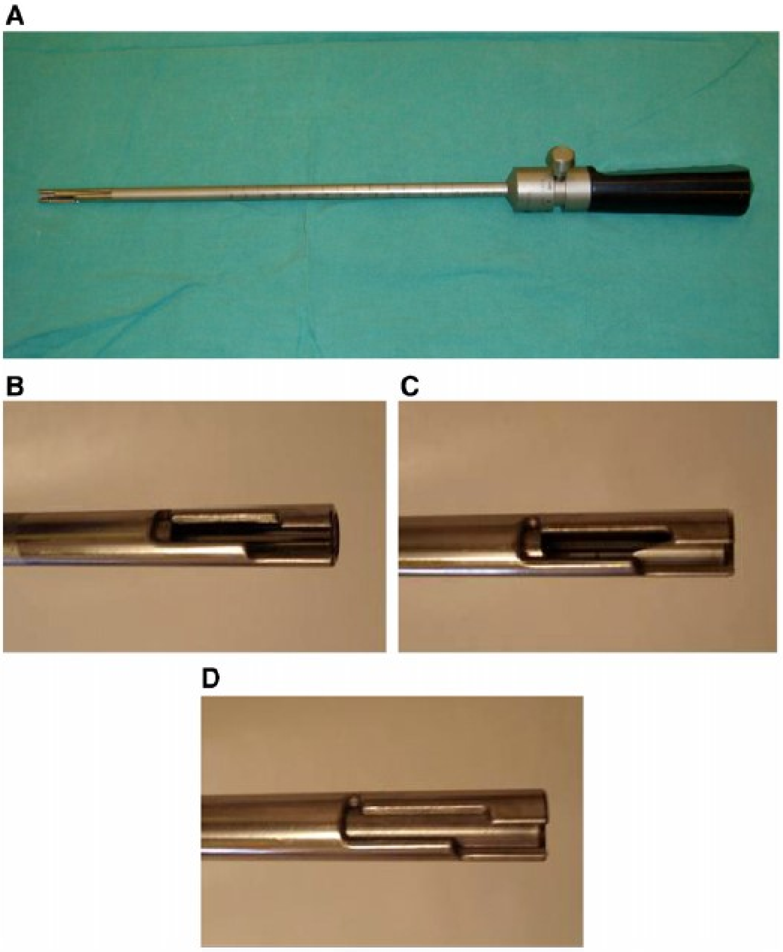

Fig. 2. A: Blade harvester (Linvatec, UK). The harvester has a proximal knob which controls its distal mouth and changes it from open (B) to closed (C) and cutting (D) positions.

the left knee hamstrings harvested using the closed tendon stripper. The order was then reversed so that the remaining five cadavers had their right knee harvested with the closed tendon stripper and the left knee with the blade harvester. Harvesting was performed in the same way as follows:

Each cadaver was positioned with the knee flexed freely at the end of an operating trolley. A 4 cm longitudinal incision was made medial to the tibial tuberosity. The sartorius fascia was incised and the tendons of gracilis and semitendinosus were identified. Using a tendon hook these were delivered out of the surgical wound sequentially. Any vincular attachments were divided. Tendons were then harvested using either the closed tendon stripper, or blade harvester.

Closed tendon stripper: the tendon was sharply divided at its insertion into the tibia and after passed through the harvester mouth its free end was held with an artery forceps. The stripper was slid along the tendon as far as possible and until there was no further resistance on pulling upon the tendon. The harvester was then withdrawn delivering the harvested tendon.

Table 1
Comparison of tendon length cm) and width (cm) harvested between the two harvesters (paired *t*-test).

	Closed tendon stripper	Blade harvester	*p* value
Usable tendon length harvested (combined gracilis + semitendinosus)	23.1 +/−2.1	26.9 +/−1.3	0.002
Usable tendon length harvested (semitendinosus)	25.3 +/−2.3	28.3 +/−2.1	0.014
Usable tendon length harvested (gracilis)	20.8 +/−3.7	25.4 +/−1.3	0.039
Maximal width of harvested tendon (combined gracilis + semitendinosus)	9.3 +/−1.2	10.9 +/−1.4	0.075

Values are given as means and confidence intervals. Where the results of semitendinosus and gracilis are combined, the overall means and confidence intervals for the gracilis and semitendinosus tendons in consideration were calculated.

Table 2
Comparison of tendon and muscle discarded between the two harvesters (paired *t*-test).

	Closed tendon stripper	Blade harvester	*p* value
Tendon length discarded (cm) (gracilis + semitendinosus)	2.3 +/−0.8	1.8 +/−0.5	0.062
Muscle mass discarded (g) (gracilis + semitendinosus)	1.0 +/−0.4	0.4 +/−0.1	0.013

Values are given as means and confidence intervals.

Fig. 3. Tendons harvested with the closed blade harvester were more clean cut as compared to those harvested using the closed stripper which had more ragged proximal ends. The four tendons above were harvested from the same cadaver, the two on the left with the closed stripper and the two on the right with the closed blade harvester.

Blade harvester: The mouth of the blade harvester has three positions, open closed and cutting, controlled by a proximal knob. With the harvester in the open position, the distal part of the tendon was inserted into the mouth of the blade harvester and the harvester's mouth was then closed locking the tendon in position. The harvester was then slid along the tendon as far as possible, and the harvester's knob was turned to the cutting position cutting the tendon. The harvester was then withdrawn bringing the harvested tendon with it. The tendon was then divided at its insertion to the tibia.

The harvested tendons were inspected and their proximal ends were classified either as clean cut or ragged. All muscle was then stripped off the harvested tendon using dissecting scissors and was weighed. The maximum length of harvested tendon was measured before and after discarding any tendon considered to be of too poor quality for use. The maximal width of the harvested tendon was measured using a digital calliper (No. 500-191, Mitutoyo, Japan). The assessment of the tendons was done by a person different to the one who performed the harvesting. The assessor of the tendons was blinded to the method of harvesting.

Statistical analysis was performed using SPSS for Windows 11.5 (SPSS Inc, Chicago, 9IL) with paired *t* and chi-square tests. Statistical significance was established at the $p<0.05$ level. Results are presented as means and confidence intervals.

3. Results

Thirty six tendons in total were harvested, 18 of semitendinosus and 18 gracilis. Eighteen tendons were harvested using the closed tendon stripper and 18 using the blade harvester.

Hamstring tendon harvesting using the blade harvester gave a significantly greater length of usable tendon, and less stripped muscle mass (Tables 1 and 2). There was a trend of more tendon being discarded in the closed stripper group although this did not reach a statistically significant difference (Table 2). There was no significant difference in the maximum width of tendon harvested between the two groups (Table 1). There were no cases of premature tendon amputation in either group. Nine of the tendons harvested with the closed stripper were described as having ragged proximal ends, whilst only three of those harvested with the blade harvester had ragged proximal ends ($p=0.037$, chi-square test) (Fig. 3).

4. Discussion

In this study we have shown that the harvester used *per se* can influence the tendon length and quality obtained as well as the amount of muscle mass stripped along with the tendon. We have shown that the blade harvester gives a longer tendon length while minimising muscle stripping as compared to a closed tendon stripper. Hamstring tendons harvesting is a procedure increasingly performed as part of arthroscopic and open ligamentous reconstructions of the knee [1–4]. Obtaining adequate length of good quality tendon whilst keeping any soft tissue disruption to the minimum is essential harvesting requirements. To our best knowledge this is the first study to compare the use of two tendon harvesters with regard to their influence on such parameters.

In this study we compared a closed tendon stripper with a blade harvester, of the same company. The mean lengths of semitendinosus and gracilis tendons obtained in this study are comparable to those reported in a recent large anatomical morphological study in human cadavers [5]. In that study [5] a significant correlation was shown between the length and cross-section of tendons harvested from opposite knees of the same cadaver, which supports the choice to use paired knees in this study. We used the weight of stripped muscle and the length of discarded poor quality tendon as a marker of soft tissue disruption.

Our results suggest that the blade harvester gives a longer tendon length whilst causing less associated soft tissue disruption. This may be attributed to the smaller diameter of the blade harvester. The blade harvester also uses a blade mechanism to cut sharply the tendon rather then relying simply on stripping, which may reduce the muscle mass and length of poor quality tendon that has to be discarded. The fact that a greater proportion of the tendons harvested with the closed stripper had ragged proximal ends as compared to those harvested with the blade harvester further suggests that tissue disruption may be greater with the former harvester.

There are certain limitations to our study. We did not dissect the track of harvesting and simply relied on the mass of muscle stripped and tendon discarded as a marker of soft tissue disruption. As the closed tendon stripper and the blade harvester we used were of different diameters we cannot determine whether their differences in tendon characteristics and soft tissue disruption are attributable to their different diameters or their different mechanism of action. In addition, we should distinguish between statistical and clinical significance. The differences observed in tendon length between the two harvesters were small and in some reconstructive procedures where the tendon length is not a limiting factor, either harvester could be successfully used.

In conclusion, within the limitations of this study our results suggest that the type of tendon harvester *per se* can influence the length and quality of tendon obtained as well as any adjacent soft tissue disruption. Future studies comparing different types of tendon harvesters available in the market as well as clinical studies comparing different harvesters with regard to patient morbidity such as thigh bruising and haematoma would be of great value. Our results suggest that it is desirable to request data from the industry with regard to the effect of tendon harvesters upon tendon characteristics and soft tissue disruption prior to deciding which harvester to use.

5. Conflict of interest

This article has not been submitted for publication anywhere else and all authors have seen and agree as to the final manuscript. No conflict of interest exists.

No funding or sponsorship was undertaken in this study.

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c. Contribution to knowledge

This article contributed to the literature in that it demonstrated a relation between the type of hamstring tendon harvester and the length as well as quality of the tendon obtained. It also suggested that the type of tendon harvester is related to the extent of disruption in the surrounding soft tissues. This article emphasized the need for tendon harvester manufacturers to gather and report such data for individual harvesters, and the need for surgeons to seek and evaluate such information when choosing a tendon harvester for their clinical practice.

d. Article limitations

In the introduction of the article, although the overall aim of the study was described specific hypotheses to be tested were not presented. The main methodological limitation of this article was the use of cadaveric specimens and specimens from individuals whose characteristics may differ from those of patients that have ACL reconstruction surgery. The properties of cadaveric tissue may differ from that of living humans in parameters such as stiffness and flexibility of the tendons or their accessory bands, as well as in the volume of the hamstring muscle tissue. Soft tissue layers in cadavers may be more adherent to each other and less mobile making the passage of a tendon harvester challenging. A living muscle may respond to stimulation, such as when coming into contact with a tendon harvester, by contracting, whereas in cadavers this cannot occur. It could be postulated that such contraction responses may influence the mass of muscle that is harvested along with the hamstring tendon.

Specimens from elderly patients with a mean age of 83 years were used for this study. The characteristics of the tendons may thus differ from those of younger patients, in whom ACL reconstruction surgery is more commonly performed. ACL reconstruction surgery is performed in knees which had previous injury causing an ACL tear, but in this study none of the included cadaveric knees had any macroscopic pathology, and it is likely that they did not have any previous substantial knee injury. These parameters may influence the harvesting process, the qualities of the harvested tendon and the soft tissue disruption, all of which may limit the applicability of the study's findings to clinical practice. However, a cadaveric study was considered an appropriate initial evaluation prior to an in-vivo clinical study as in the latter the various tendon measurements could prolong the operative time.

It is of note that harvesting was performed by a single surgeon, and the characteristics of the tendon harvested could have been influenced by the surgeon's technique rather than solely by the harvester. In addition, as only one surgeon carried out the harvesting, the effect of the surgeon on the harvesting process was not assessed. There was also no formal assessment of the intra- and inter-variability of classifying the tendon ends as clean cut or ragged, nor of carrying out the measurements of the tendon length or width. The decision as to how much of the tendon was considered of too poor quality to use and was thus discarded was based on subjective and not objective criteria. In relation to this there was no formal examination of the accuracy and repeatability of this assessment. It would have been preferable to use two or more assessors and establishing their inter- and intra- agreement in carrying out the relevant measurements. There was no prospective or retrospective power calculation for the statistical comparisons made, hence it is possible that type 2 statistical error accounted for the lack of significant differences in some of the comparisons. Similarly, there was no prospective definition as to what was considered a minimal important clinical difference with regards to the parameters examined, such as for the length of usable tendon and for the mass of stripped muscle.

The findings of this article apply only to the 2 types of tendon harvester and to the exact harvesting techniques employed. In this study, when using the tendon stripper, the distal part of the hamstring tendon was initially divided from its insertion onto the tibia and was held with an artery forceps, whilst the harvester was slid over the tendon proximally. It is possible that the properties of the tendon harvested in this way might differ had a tendon stripper been used that can slide over the tendon without having to divide the tendon's insertion. Furthermore, although a statistically significant difference was observed in the length of usable tendon obtained and the mass of discarded muscle between the tendon stripper and blade harvester, it was not possible to determine the cause of this difference and in particular whether this was due to the different diameters of the two harvesters or other reasons. The use of a blade harvester and tendon stripper of the same or similar diameter could have shed some light onto the role of the tendon diameter on these findings.

e. Relevant work since the article was published

This article was cited by a further study (Naik and Acharya, 2019) that evaluated conditions whereby the quality of the tendon harvested may not be optimal. The potential relation between the chronicity of ACL injury and the quality of harvested hamstring graft was examined in 40 consecutive patients who had ACL reconstruction. Of these 58% had a chronic injury defined as more than 3 months duration, whilst 42% had an acute injury of less than 3 months duration. In that study it was reported that the surgeon encountered more difficulty in advancing the tendon stripper beyond the musculotendinous junction in chronic as compared to acute cases. The proximal end of the harvested tendon was found to be ragged in a higher proportion of chronic as compared to acute injuries. The mean percentage of usable tendon was lower in the chronic as compared to the acute group with about 89% in the former vs. 94% in the latter. Based on the findings of this study its authors suggested that fibrosis at the musculotendinous junction secondary to injury may be more common in chronic injuries due to repeated instability episodes. The findings of this further study emphasised that the effect of the tendon harvester could vary according to the chronicity of ACL instability and should thus be evaluated in knees which had a torn ACL rather than in cadavers who may not have had a knee injury.

A further study suggested that the differences in donor site morbidity by soft tissue disruption and harvesting of non-usable tendon may have substantial clinical implications (D'Alessandro, Wake, and Annear, 2013). That was a randomised controlled trial of 34 patients allocated either to hamstring tendon harvesting using a blade harvester or a tendon stripper. Patients in the blade harvester group had less postoperative pain (10.05mm vs. 24.66mm p=0.0398 on a visual analogue score). In addition, patients in the blade harvester group had a significantly lower rate of postoperative hamstring strains as compared to those in the tendon stripper group (25% vs. 50%, p=0.045) (D'Alessandro, Wake, and Annear, 2013).

f. Further research

The article evaluated above (Charalambous et al., 2008) may form the basis of a future comparative study to explore the effects of a wider range of commonly used tendon harvesters in real surgical practice, as compared to a laboratory in vitro situation. Such a comparative study could be a pragmatic randomised trial involving multiple surgeons to provide more robust evidence as to differences that may exist between tendon harvesters.

CHAPTER 4 – INFECTION IN ACL RECONSTRUCTION

A. Background

Infection is a recognised complication in surgery and is described as the invisible enemy of the surgeon (Charalambous, 2019). Superficial infections which involve the skin and subcutaneous tissue are successfully treated with antibiotics. However, deep infections of the soft tissues or bone and septic arthritis which is infection of the knee joint can have devastating complications; septic arthritis can destroy the joint's cartilage and cause graft rupture with resultant loss of function. Deep infections are much more challenging to deal with and their management often involves both antibiotic treatment and surgery. In surgery for deep infections the infected joint and tissue are washed with normal saline and any non-viable tissue is removed.

In surgical procedures whereby a tendon graft is utilised there is concern that graft contamination with bacteria may lead to introduction of these infective organisms into the joint and cause joint infection. Contamination by bacteria may occur during graft harvesting or graft preparation. In the case of allografts whereby the graft is obtained at a longer interval prior to surgery there is also the potential of contamination occurring during graft storage. Concerns about graft related infections were initially raised for allografts by reports on patients who developed such infections (Barbour and King, 2003, CDC, 2001). The identification of organisms on culture samples in about 10% of allografts prior to their insertion into the knee led to the possibility that graft contamination could introduce bacteria into the joint and thus cause infection. Subsequent studies showed that high rates of graft contamination occurred in autografts too, both hamstring autografts as well as patellar-tendon-bone autografts (Badran and Moemen, 2016, Hantes et al., 2008). Such concerns led to studies which assessed the relation between graft type and infection risk in ACL reconstruction surgery, but these were largely small studies.

Given the risk of infection and its devastating consequences in ACL reconstruction surgery, several measures are taken to minimise the risk of infection one of which is the use of prophylactic antibiotics. Prophylactic antibiotics may be administered systemically, including oral or intravenous administration, or topically. Prior to considering the use of topical antibiotics in ACL surgery prophylactic topical antibiotics had been extensively used in orthopaedic spinal surgery (O'Neill et al., 2011, Sweet, Roh and Sliva, 2011). In spinal surgery topical administration included vancomycin powder applied to the surgical wound, bone graft containing antibiotics, or saline mixed with antibiotics for washing the surgical wound prior to stitching. Such topical administration achieved high antibiotic concentrations in the local tissues, well above the minimum inhibitory concentration for common pathogens. At the same time blood levels of vancomycin remained within a safe range (Armaghani et al., 2014). In spinal surgery the use of topical antibiotics was shown to be associated with a reduction in surgical site infections (Xiong et al., 2014). Concerns were raised that the administration of topical vancomycin could lead to bacteria becoming less sensitive to vancomycin a process referred to as the development of antibiotic resistance (Gande et al., 2019). However, an increase in infections with bacteria that would not be eliminated or supressed by vancomycin was not consistently observed in clinical studies (Khanna et al., 2019).

In ACL reconstruction surgery topical antibiotics may be administered by presoaking the ACL graft in an antibiotic solution or by mixing antibiotics in the normal saline solution used to inflate the joint during arthroscopic surgery. The use of topical vancomycin for presoaking hamstring tendon grafts was initially reported in a series of 870 cases (Vertullo, 2012). The outcomes of these cases were compared to those of 285 cases who had only intravenous prophylactic antibiotics. In that initial report it was postulated that soaking the graft in an antibiotic such as vancomycin eradicated any bacterial contamination and prevented infection. Vancomycin was chosen as the preferred antibiotic as it was active against the organisms commonly associated with infection in ACL reconstruction surgery (such as staphylococcus aureus) and it was also water soluble. Vancomycin soaking with a solution concentration of 5mg/mL for 15min was used based on an in vitro study which assessed the release of vancomycin from bovine tendons and showed that a 5 mg/mL soak solution for 15 minutes would achieve adequate vancomycin levels to decontaminate the graft without causing toxicity to cartilage and tendon cells (Grayson et al., 2011). In the initial report no infections were encountered in the group having vancomycin graft presoaking alongside prophylactic intravenous antibiotics as compared to 4 (1.4%) infections seen in the group receiving only intravenous antibiotics (Vertullo et al., 2012).

Despite the administration of prophylactic antibiotics and other measures that aim to reduce the risk of surgery related infections, some infections still occur. Once faced with deep infection such as septic arthritis following ACL reconstruction the surgeon needs to consider how to manage this. One approach is to try and treat the infection with the use of systemically administered antibiotics along with surgical washout of the joint whilst preserving the reconstructed graft. An alternative approach is to use antibiotics, wash the knee, but also remove the reconstructed graft and all fixation devices. The rational for the latter approach is that the graft and fixation devices may be seeded with infecting organisms and hence their removal may aid the eradication of infection. However, with this approach the reconstructed graft is sacrificed, potentially leading to knee instability and need for revision reconstruction surgery. Hence, developing evidence to guide the clinical management of such infections would be of high value.

B. **Knowledge gap**

At the time the included studies were carried out, there was no substantial systematic evidence assessing the rate of infection in ACL reconstruction surgery, its relation to graft type as well as its relation to vancomycin presoaking. Similarly, there was no systematic evidence determining the effectiveness of arthroscopic washout and antibiotic treatment with graft salvage in tackling bacterial infection post ACL reconstruction.

C. **Objectives**

Given the knowledge gap, the objectives of the studies included in this chapter were to determine the relationship between infection rates and type of graft utilised in ACL reconstruction surgery and explore whether presoaking the graft with vancomycin is associated with a reduction in infection rate. A further objective was to determine whether arthroscopic washout with graft salvage is an effective measure in managing such infections. Given the rarity of infection post ACL reconstruction surgery individual studies may lack the power to demonstrate differences in infection rates according to graft type, to fully evaluate the effect of antibiotic presoaking, and to determine the effectiveness of arthroscopic washout with antibiotic treatment and graft salvage in tackling bacterial infection. Pooling the results of individual studies through a systematic review and meta-analysis may allow more meaningful conclusions.

D. **Hypotheses**

To meet the objectives described above the studies presented in this chapter explored the hypotheses that:

1) Hamstring tendon grafts are associated with a higher infection rate than bone-patellar tendon-bone autografts in ACL reconstruction surgery.
2) Allografts are associated with a higher infection rate as compared to autografts in ACL reconstruction surgery.
3) Vancomycin presoaking of hamstring grafts is associated with a lower infection rate as compared to no graft presoaking in ACL reconstruction surgery.
4) Arthroscopic washout along with antibiotic treatment and graft salvage is an effective way of managing septic arthritis following ACL reconstruction surgery in the majority of cases.

These hypotheses were examined by 2 articles as described next.

E. **Commentary article 5 - *Relationship of Graft Type and Vancomycin Presoaking to Rate of Infection in Anterior Cruciate Ligament Reconstruction: A Meta-Analysis of 198 Studies with 68,453 Grafts. Kuršumović K, Charalambous CP. JBJS Rev. 2020 Jul;8(7):e1900156. PMID: 32759615***

https://journals.lww.com/jbjsreviews/Abstract/2020/07000/Relationship_of_Graft_Type_and_Vancomycin.13.aspx. *doi: 10.2106/JBJS.RVW.19.00156.*

a. Contribution by CP Charalambous

Developed the concept of the article, co-designed the methodology, contributed to data collection, carried out the data analysis (meta-analysis) and co-wrote the article

b. Article description - Full article

This article presented a meta-analysis of the relationship between graft type and risk of infection following ACL reconstruction surgery. In addition, it assessed the relationship between presoaking the hamstring tendon graft with vancomycin on infection rate. It demonstrated that hamstring tendons were associated with a higher infection rate as compared to bone-patellar tendon-bone grafts as well as compared to allografts. Furthermore, it showed that vancomycin presoaking was associated with about 10-fold reduction in infection rate as compared to no antibiotic presoaking.

The study identified 306 bacterial infections in 68,453 grafts across 198 studies. The overall estimated ACL graft infection rate was 0.9% (95% CI: 0.8% to 1.0%). Hamstring autografts were associated with a higher infection rate (1.1%, 95% CI: 0.9% to 1.2%) as compared to bone-patellar tendon-bone autografts (0.7%, 95% CI: 0.6% to 0.9%) and allografts (0.5%, 95% CI: 0.4% to 0.8%) ($p<0.001$). Presoaking hamstring autografts in vancomycin reduced the infection rate to 0.1% (95% CI: 0.0% to 0.4%) and this reduction was statistically significant ($p=0.001$). The concentration of the vancomycin solution utilised in the included studies was 5mg/ml. The findings of this study thus supported the hypothesis that hamstring tendon grafts are associated with a higher infection rate than bone-patellar tendon-bone autografts but rejected the hypothesis that allografts are associated with a higher infection rate as compared to autografts. Furthermore, based on the findings of this study the hypothesis that vancomycin presoaking of hamstring grafts is associated with a lower infection rate as compared to no graft presoaking in ACL reconstruction surgery was also accepted. A copy of the full article is presented next.

JB&JS REVIEWS

Relationship of Graft Type and Vancomycin Presoaking to Rate of Infection in Anterior Cruciate Ligament Reconstruction

A Meta-Analysis of 198 Studies with 68,453 Grafts

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Abstract

Background: Infection is a devastating complication in anterior cruciate ligament reconstruction (ACLR) surgery. Given the rarity of infection, pooling individual studies via meta-analysis can allow more meaningful evaluation of factors influencing infection rates. We aimed to determine the relationship of graft type and vancomycin graft presoaking to bacterial infection rates following ACLR.

Methods: A systematic literature search was conducted on PubMed, Ovid MEDLINE, Embase, and CENTRAL (Cochrane Register of Controlled Trials). Included articles were those reporting on primary arthroscopic or open ACLR procedures, using hamstring (HT) or bone-patellar tendon-bone (BPTB) autografts or allografts of any type, with regard to the outcome of infection (deep infection or septic arthritis). Meta-analyses were performed to estimate the overall infection rates in ACLR surgery according to graft type and to examine the effect of presoaking grafts in vancomycin on infection rates.

Results: We identified 306 bacterial infections in 68,453 grafts across 198 studies. The overall estimated ACL graft infection rate in our meta-analysis was 0.9% (95% confidence interval [CI] = 0.8% to 1.0%). HT autografts were associated with a higher infection rate (1.1%, CI = 0.9% to 1.2%) than BPTB autografts (0.7%, CI = 0.6% to 0.9%) and allografts (0.5%, CI = 0.4% to 0.8%) ($Q = 15.58$, $p < 0.001$). Presoaking HT autografts in vancomycin reduced infection rates to 0.1% (CI = 0.0% to 0.4%) ($Q = 10.62$, $p = 0.001$).

Conclusions: Infection following ACLR remains a rare but serious complication. HT autografts are associated with higher infection rates than other graft types. Presoaking HT autografts in vancomycin reduces infection rates by an estimated tenfold.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

The anterior cruciate ligament (ACL) is one of the main structures contributing to knee stability. Tears of the ACL are common, with an estimated incidence of >200,000 per year in the United States[1,2]. A large proportion of ACL tears are treated surgically by ACL

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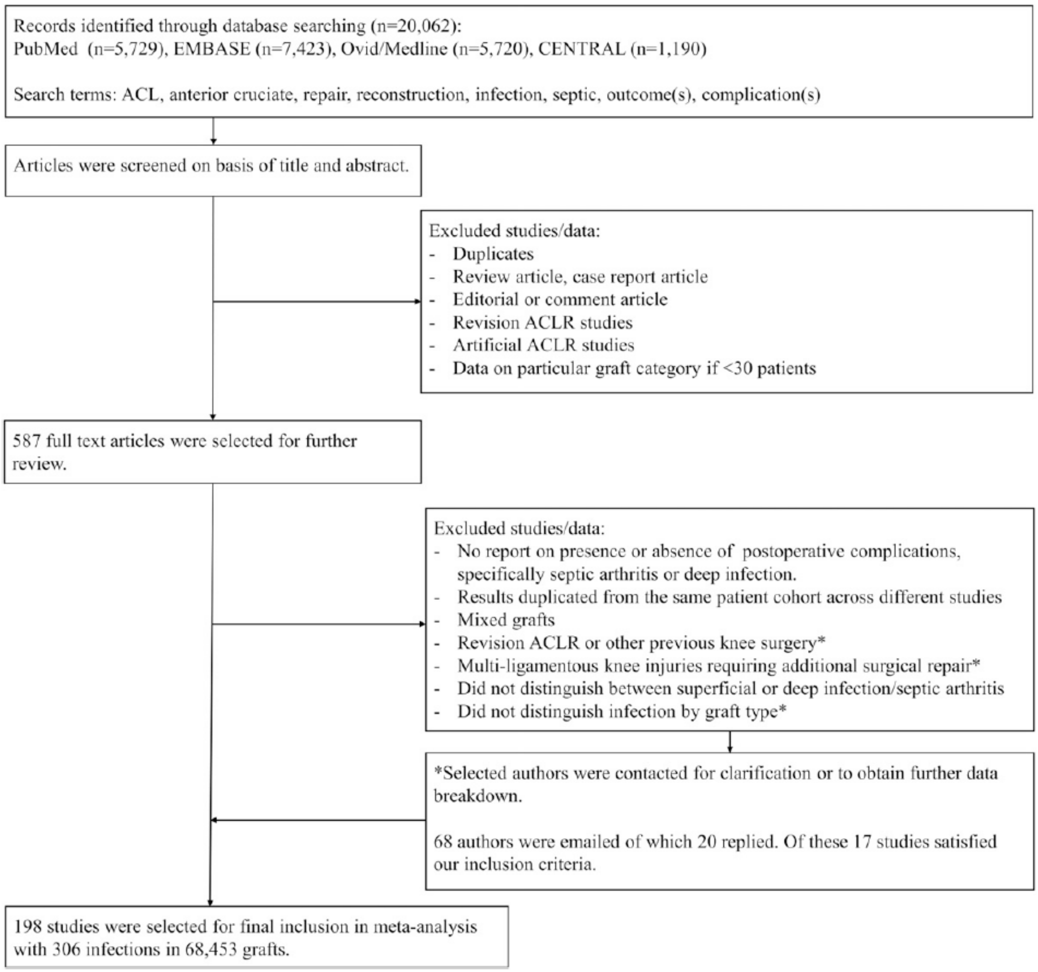

Fig. 1
Literature search strategy flowchart.

reconstruction (ACLR) using autograft or allograft tendons. Allograft sources are typically tibialis (anterior or posterior) tendon, bone-patellar tendon-bone (BPTB), Achilles tendon, or hamstring tendon (HT), and more rarely other soft tissues such as fascia lata or peroneal tendon. It is estimated that >130,000 reconstructions are performed per year in the United States[3,4].

Infection (deep infection or septic arthritis) is a devastating complication in ACLR surgery that may lead to graft failure, loss of function, and the need for further extensive and costly surgery[5]. Initial reports suggesting that allograft tendons are associated with a higher infection risk led to the introduction of robust donor selection and graft sterilization techniques[6]. However, more recent reports have suggested a higher infection rate with autografts, especially HT autografts, than with allografts[7-12]. In addition, there have been reports suggesting that presoaking grafts in antibiotics prior to implantation may reduce infection rates[13-17].

Given the rarity of infection following ACLR, individual studies may lack the power to demonstrate differences in infection rates among grafts and to fully evaluate the effect of antibiotic presoaking. Pooling of the results of individual studies through a meta-analysis, as in the current study, may allow more meaningful conclusions.

The aim of this study was to compare the rate of deep infection or septic arthritis following ACLR reconstruction using HT and BPTB autografts and allografts, and to determine the effect of presoaking HT autografts in vancomycin on infection rates.

Materials and Methods

A systematic literature search was conducted on PubMed, Ovid MEDLINE, Embase, and CENTRAL (Cochrane Register of Controlled Trials) databases for English-language studies from

TABLE I Included Studies with HT Autograft in Primary ACLRs (N = 133)

Study	Year	Country	Study Type	No. of Grafts	No. Infected
Su[87]	2019	People's Rep. of China	Cohort	67	0
Bohu[47]	2019	France	Cohort	1,079	2
Desai[48]	2019	U.S.A.	Cohort	136	1
Figueroa[17]	2019	Chile	Cohort	230	4
Offerhaus[16]	2019	Germany	Cohort	167	7
Sonnery-Cottet[49]	2019	France	Cohort	3,337	10
Todor[50]	2019	Romania	Cohort	33	0
Alomar[37]	2018	Saudi Arabia	Case series	50	0
Kim JG[51]	2018	South Korea	RCT	111	1
Stańczak[52]	2018	Poland	RCT	48	0
Zhu[53]	2018	People's Rep. of China	RCT	78	0
Adravanti[54]	2017	Italy	RCT	60	0
Hantes[55]	2017	Greece	Cohort	931	7
Ibrahim[56]	2017	Kuwait	RCT	50	0
Järvelä[57]	2017	Finland	RCT	90	0
Kim HJ[58]	2017	South Korea	Case series	98	7
Krutsch[59]	2017	Germany	Case series	1,809	17
MacDonald[60]	2018	Canada	RCT	96	0
Nakayama[61]	2017	Japan	RCT	125	0
Parkinson[62]	2017	U.K.	Case series	124	1
Singh[63]	2017	India	Case series	44	0
Badran[38]	2016	Egypt	Cohort	60	0
Björnsson[64]	2016	Sweden	RCT	86	1
Carulli[65]	2017	Italy	RCT	90	0
Ebert[66]	2016	Germany	Cohort	50	0
Franz[67]	2016	Germany	RCT	100	0
Ha[68]	2016	South Korea	Cohort	239	0
Leo[69]	2016	U.S.A.	Cohort	71	0
Mayr[70]	2016	Germany	RCT	62	0
Mohtadi[20]	2016	Canada	RCT	220	1
Phegan[14]	2016	Australia	Cohort	285	4
Pérez-Prieto[15]	2016	Spain	Cohort	591	13
Schurz[71]	2016	Austria	Case series	79	2
Tian[72]	2016	People's Rep. of China	RCT	40	0
Tian[73]	2016	People's Rep. of China	RCT	62	0
Wierer[74]	2017	Austria	Case series	59	0
Yasen[75]	2017	U.K.	Case series	108	0
Zhang[76]	2016	People's Rep. of China	Cohort	40	1
Amano[77]	2015	Japan	Case series	121	0
Andrés-Cano[78]	2015	Spain	Case series	315	1
Arama[79]	2015	Australia	RCT	40	0
Baverel[80]	2015	France	Case series	77	0
Brophy[21]	2015	U.S.A.	Cohort	639	8
Devgan[81]	2015	India	Case series	30	0
Ibrahim[82]	2015	Kuwait	RCT	66	0

continued

TABLE I (continued)

Study	Year	Country	Study Type	No. of Grafts	No. Infected
Jia[83]	2015	People's Rep. of China	RCT	53	0
Karaaslan[84]	2015	Turkey	RCT	105	0
Karimi-Mobarakeh[85]	2015	Iran	RCT	119	0
Kautzner[86]	2015	Czech Republic	RCT	73	0
Li[89]	2015	People's Rep. of China	RCT	32	0
Morey[90]	2015	U.S.A.	Cohort	40	0
Ruffilli[91]	2015	Italy	Case series	51	0
Schuster[92]	2015	Germany	Case series	5,848	24
Yoo[93]	2017	South Korea	RCT	68	0
Zekcer[94]	2015	Brazil	Case series	30	0
Aldrian[95]	2014	Austria	Cohort	55	0
Azboy[96]	2014	Turkey	Cohort	64	2
Boström Windhamre[97]	2014	Sweden	Case series	4,384	43
Calvo[98]	2014	Chile	Case series	1,564	7
Engelman[99]	2014	U.S.A.	Cohort	35	0
Ho[100]	2014	Taiwan	Cohort	73	0
Razi[101]	2014	Iran	RCT	34	2
Taketomi[102]	2014	Japan	Case series	34	0
Xu[103]	2014	People's Rep. of China	Cohort	64	0
Yazdi[104]	2014	Iran	RCT	177	4
Ahldén[105]	2013	Sweden	RCT	98	0
Ballal[106]	2013	U.K.	Case series	92	2
Bourke[107]	2013	Australia	RCT	60	0
Eajazi[108]	2013	Iran	Cohort	96	0
Janssen[109]	2013	Netherlands	Case series	84	0
Kumar[110]	2013	U.K.	Case series	32	0
Maletis[12]	2013	U.S.A.	Cohort	3,257	20
Streich[111]	2013	Germany	Case series	40	0
Ahldén[112]	2012	Sweden	Cohort	244	3
Frosch[113]	2012	Germany	Cohort	59	0
Gobbi[114]	2012	Italy	Cohort	60	0
Ventura[115]	2012	Italy	Cohort	50	0
Courvoisier[116]	2011	France	Case series	37	0
Muneta[117]	2011	Japan	Cohort	196	1
Niki[118]	2011	Japan	Cohort	89	0
Noh[119]	2011	South Korea	Cohort	70	1
Sadoghi[120]	2011	Austria	Cohort	51	0
Sonnery-Cottet[121]	2011	France	Cohort	700	4
Sun[122]	2011	People's Rep. of China	RCT	91	0
Aglietti[123]	2010	Italy	RCT	70	0
Greenberg[22]	2010	U.S.A.	Cohort	46	0
Liu[124]	2010	People's Rep. of China	Cohort	32	0
Monaco[125]	2010	Italy	Case series	1,432	14
Park[126]	2010	South Korea	Cohort	113	4
Raviraj[127]	2010	India	Cohort	99	0

continued

TABLE I (*continued*)

Study	Year	Country	Study Type	No. of Grafts	No. Infected
Stener[128]	2010	Sweden	RCT	64	4
Gavriilidis[39]	2009	Germany	Case series	89	0
Harilainen[129]	2009	Finland	RCT	110	1
Plaweski[130]	2009	France	Case series	105	0
Stengel[131]	2009	Germany	RCT	30	0
Taylor[132]	2009	U.S.A.	RCT	32	1
Toritsuka[133]	2009	Japan	Case series	78	0
Capuano[134]	2008	U.K.	RCT	30	0
Edgar[135]	2008	U.S.A.	Cohort	37	0
Katz[11]	2008	U.S.A.	Cohort	114	4
Papachristou[137]	2008	Greece	RCT	41	0
Siebold[138]	2008	Germany	RCT	70	2
Binnet[8]	2007	Turkey	Cohort	312	2
Buchner[139]	2007	Germany	Case series	70	0
Kocher[140]	2007	U.S.A.	Case series	61	0
Maletis[141]	2007	U.S.A.	RCT	53	2
Almazán[142]	2006	Mexico	Cohort	96	0
Colombet[143]	2006	France	Case series	33	0
McCormack[144]	2006	Canada	RCT	78	0
Plaweski[145]	2006	France	RCT	60	0
Rose[146]	2006	Germany	RCT	68	0
Salmon[147]	2006	Australia	Cohort	200	0
Siebold[148]	2006	Australia	Cohort	43	0
Giron[150]	2005	Italy	Case series	43	0
Prodromos[151]	2005	U.S.A.	Case series	133	0
Talwalkar[153]	2005	U.K.	Case series	38	0
Aglietti[154]	2004	Italy	RCT	60	0
Arneja[155]	2004	Canada	RCT	35	0
Boonriong[156]	2004	Thailand	Cohort	30	0
Gobbi[157]	2004	Italy	Cohort	40	0
Soon[158]	2004	Singapore	Case series	76	0
Williams[159]	2004	U.S.A.	Case series	85	2
Feller[160]	2003	Australia	RCT	34	0
Jansson[161]	2003	Finland	RCT	45	0
Colombet[162]	2002	France	Case series	200	1
Scranton[163]	2002	U.S.A.	Case series	120	0
Shaieb[164]	2002	U.S.A.	RCT	37	0
Eriksson[165]	2001	Sweden	RCT	80	2
Goradia[166]	2001	U.S.A.	Cohort	120	0
Buelow[167]	2000	Germany	Case series	100	1
Noojin[168]	2000	U.S.A.	Cohort	65	0
Howell[169]	1999	U.S.A.	Cohort	108	0
Otero[170]	1993	U.S.A.	Cohort	36	0
Total				35,753	241

TABLE II Included Studies with BPTB Autograft in Primary ACLRs (N = 67)

Study	Year	Country	Study Type	No. of Grafts	No. Infected
Bohu[47]	2019	France	Cohort	36	0
Sonnery-Cottet[49]	2019	France	Cohort	549	1
Stańczak[52]	2018	Poland	RCT	48	0
Hantes[55]	2017	Greece	Case series	311	0
Björnsson[64]	2016	Sweden	RCT	61	1
Mohtadi[20]	2016	Canada	RCT	110	0
Pérez-Prieto[15]	2016	Spain	Cohort	219	2
Shakked[171]	2017	U.S.A.	Cohort	37	0
Witoński[172]	2016	Poland	Case series	101	0
Brophy[21]	2015	U.S.A.	Cohort	931	3
Kautzner[86]	2015	Czech Republic	RCT	74	0
Ali[88]	2014	Pakistan	Case series	36	0
Razi[101]	2014	Iran	RCT	37	1
Sarzaeem[173]	2014	Iran	RCT	158	3
Maletis[12]	2013	U.S.A.	Cohort	2,965	2
Pan[174]	2013	People's Rep. of China	Cohort	30	0
Benner[175]	2011	U.S.A.	Cohort	4,927	12
Sadoghi[120]	2011	Austria	Cohort	41	0
Sonnery-Cottet[121]	2011	France	Cohort	655	5
Greenberg[22]	2010	U.S.A.	Cohort	171	0
Sutherland[136]	2010	U.K.	Case series	128	2
Kim SJ[176]	2009	South Korea	Cohort	32	0
Stengel[177]	2009	Germany	Case series	100	0
Sun[178]	2009	People's Rep. of China	RCT	33	0
Taylor[132]	2009	U.S.A.	RCT	32	0
Ververidis[179]	2009	Greece	Case series	54	0
Han[180]	2008	South Korea	Cohort	72	0
Hart[181]	2008	Czech Republic	RCT	80	0
Katz[11]	2008	U.S.A.	Cohort	45	0
Barber[182]	2007	U.S.A.	Case series	40	0
Binnet[8]	2007	Turkey	Cohort	919	4
Maletis[141]	2007	U.S.A.	RCT	46	0
Almazán[142]	2006	Mexico	Cohort	330	0
Mahirogullari[183]	2006	Turkey	Cohort	30	0
McCormack[144]	2006	Canada	RCT	40	0
Pavlik[184]	2006	Hungary	Case series	285	0
Rihn[185]	2006	U.S.A.	Cohort	63	0
Salmon[186]	2006	Australia	Case series	67	0
Krywulak[187]	2005	Canada	RCT	35	0
Mastrokalos[188]	2005	Germany	Cohort	100	0
Roe[152]	2005	Australia	Cohort	90	0
Aglietti[154]	2004	Italy	RCT	60	0
Boonriong[156]	2004	Thailand	Cohort	45	1
Gobbi[157]	2004	Italy	Cohort	40	0
Feller[160]	2003	Australia	RCT	31	0

continued

TABLE II (continued)

Study	Year	Country	Study Type	No. of Grafts	No. Infected
Jansson[161]	2003	Finland	RCT	42	1
Halder[189]	2002	Germany	Case series	40	0
Shaieb[164]	2002	U.S.A.	RCT	33	1
Brandsson[190]	2001	Sweden	Case series	99	0
Curran[191]	2001	U.S.A.	Case series	284	0
Eriksson[165]	2001	Sweden	RCT	84	0
Järvelä[149]	2001	Finland	Cohort	34	0
Benedetto[192]	2000	Austria/Netherlands	RCT	113	4
Bach[193]	1998	U.S.A.	Case series	103	0
Bach[194]	1998	U.S.A.	Case series	97	0
Aglietti[195]	1997	Italy	Case series	89	0
Boszotta[196]	1997	Austria	Case series	114	0
Heier[197]	1997	U.S.A.	Case series	45	0
Gerich[229]	1997	Germany	RCT	40	0
Marti[198]	1997	Switzerland	Case series	69	0
Noyes[199]	1997	U.S.A.	Cohort	79	0
Victor[200]	1997	Belgium	Cohort	48	0
Cameron[230]	1995	U.S.A.	RCT	45	0
Daniel[201]	1995	U.S.A.	Cohort	140	0
Buss[202]	1993	U.S.A.	Case series	59	0
Otero[170]	1993	U.S.A.	Cohort	55	0
Raab[203]	1993	U.S.A.	RCT	100	0
Total				16,106	43

database inception to November 2019, using the search terms ("ACL" or "anterior cruciate") AND ("repair" or "reconstruction") AND ("infection" OR "septic" OR "outcome" OR "outcomes" OR "complication" or "complications") (Fig. 1).

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology guidance was used[18]. We included randomized controlled trials (RCTs), cohort studies, and case series reporting on primary arthroscopic or open ACLR procedures using HT autografts, BPTB autografts, or allografts of any type. We also included such studies that involved a combination of procedures but reported only pooled results, if it was possible to extract the raw data for the primary ACLR procedures. Authors were contacted for clarification if the article did not specify that revision cases had been excluded. Both prospective and retrospective study types were included, as were all arthroscopic or open techniques and patients of any age, irrespective of comorbidities.

Studies were included if they reported the presence or absence of complications in the specific categories "deep infection" or "septic arthritis." "Superficial" wound infections were excluded. Only bacterial infections were included. We used the conceptualization method of Mathes and Pieper to distinguish between cohort studies and case series[19].

Duplicated results were excluded, as were results involving hybrid grafts. Similarly, cases of multiligamentous knee injuries requiring additional surgical repair where also excluded. Data about a particular graft type within a study were excluded if <30 patients were reported on. Review articles and case studies were excluded.

Meta-analyses were performed to estimate the overall bacterial infection rates in ACLR surgery and those for 3 types of grafts (HT and BPTB autografts and allografts of any type), and to examine the effect of antibiotic presoaking of HT autografts on infection rates.

Summary event rates, risk ratios, and 95% confidence intervals (CIs) were calculated using a random-effect model. Heterogeneity was assessed using tau^2, I^2, and Q values. Small-study effect bias was assessed using visual analysis of funnel plots and the Egger intercept test. A sensitivity analysis was performed by performing a fixed-effect analysis and comparing the results with those of the primary random-effect analysis, and also by separately analyzing the studies that were designed specifically to compare

TABLE III Included Studies with Allograft in Primary ACLRs (N = 39)

Study	Year	Country	Study Type	No. of Grafts	No. Infected
Su[87]	2019	People's Rep. of China	Cohort	47	0
Yu[204]	2018	U.S.A.	Cohort	10,190	15
Tian[205]	2017	People's Rep. of China	RCT	83	0
Carter[206]	2016	U.S.A.	Case series	42	0
Dai[207]	2016	People's Rep. of China	RCT	113	0
Niu[208]	2016	People's Rep. of China	RCT	96	0
Tian[72]	2016	People's Rep. of China	RCT	43	0
Tian[73]	2016	People's Rep. of China	RCT	59	0
Jia[83]	2015	People's Rep. of China	RCT	53	0
Kang[209]	2015	People's Rep. of China	RCT	84	0
Lenehan[210]	2015	U.S.A.	Cohort	99	3
Li[89]	2015	People's Rep. of China	RCT	32	0
Lubowitz[211]	2015	U.S.A.	RCT	58	0
Niu[212]	2017	People's Rep. of China	Cohort	88	0
Yoo[93]	2017	South Korea	RCT	64	0
Engelman[99]	2014	U.S.A.	Cohort	38	0
Kim SJ[213]	2014	South Korea	Cohort	131	0
Indelicato[214]	2013	U.S.A.	RCT	67	0
Kang[215]	2013	People's Rep. of China	Cohort	56	0
Lubowitz[216]	2013	U.S.A.	RCT	120	0
Sun[217]	2012	People's Rep. of China	RCT	69	0
Sun[122]	2011	People's Rep. of China	RCT	95	0
Barber[218]	2010	U.S.A.	Case series	32	0
Greenberg[22]	2010	U.S.A.	Cohort	640	0
Snow[219]	2010	Canada	Case series	64	0
Almqvist[220]	2009	Belgium	Cohort	55	1
Song[221]	2009	South Korea	Cohort	40	0
Sun[178]	2009	People's Rep. of China	RCT	66	0
Edgar[135]	2008	U.S.A.	Cohort	47	0
Katz[11]	2008	U.S.A.	Cohort	535	2
Centeno[40]	2007	U.S.A.	Case series	210	1
Rihn[185]	2006	U.S.A.	Cohort	39	0
Bach[222]	2005	U.S.A.	Case series	59	0
Barrett[223]	2005	U.S.A.	Cohort	38	0
Indelli[224]	2004	U.S.A.	Case series	50	0
Siebold[225]	2003	Germany	Cohort	225	0
Kuechle[226]	2002	U.S.A.	Case series	47	0
Valenti[227]	1994	Spain	Cohort	30	0
Levitt[228]	1994	U.S.A.	Cohort	167	0
Total				14,071	22

infection rates in different graft types. $P < 0.05$ was considered significant. Data were analyzed with Comprehensive Meta-Analysis software (version 2; Biostat).

Results

Our search strategy revealed 20,062 titles, of which 5,729 were on PubMed; 5,720, on Ovid MEDLINE; 7,423, on Embase; and 1,190, on CENTRAL databases.

From a total of 587 titles identified after removing noncorresponding studies, duplications, and studies that were ineligible according to the exclusion criteria outlined above, 198 studies met

TABLE IV Included Studies with Vancomycin-Presoaked HT Autografts in Primary ACLRs (N = 4)

Study	Year	Country	Study type	No. of Grafts	No. Infected
Figueroa[17]	2019	Chile	Cohort	260	0
Offerhaus[16]	2019	Germany	Cohort	257	0
Phegan[14]	2016	Australia	Cohort	1,300	0
Pérez-Prieto[15]	2016	Spain	Cohort	706	0
Total				2,523	0

the inclusion criteria and were analyzed (Fig. 1).

Included articles were published between 1993 and November 2019. Their demographics, split according to graft type (HT, BPTB, allograft, and vancomycin-soaked HT), are shown in Tables I, II, III, and IV, respectively.

We identified 306 bacterial infections in 68,453 grafts. The overall estimated ACL graft infection rate in our meta-analysis was 0.9% (CI = 0.8% to 1.0%). HT autografts were associated with a higher infection rate (1.1%, CI = 0.9% to 1.2%) than BPTB autografts (0.7%, CI = 0.6% to 0.9%) and allografts of any type (0.5%, CI = 0.4% to 0.8%) (Q = 15.58, $p < 0.001$) (Fig. 2) (heterogeneity assessment: $tau^2 = 0.14$, $I^2 = 17.41$, Q = 288.153, degrees of freedom [df] = 238, p = 0.014). Funnel plot visual analysis did not show a small-study effect (Fig. 3), which was confirmed with the Egger intercept test (intercept = 0.10, CI = −0.13 to 0.33, t = 0.85, 2-tailed p = 0.40).

Four studies satisfying our inclusion criteria examining the effect of vancomycin presoaking of HT autografts on infection rates were included[14-17]. The exact protocol for presoaking varied among the studies but all involved the "vancomycin wrap." The graft was wrapped in gauze soaked in a 5 mg/mL vancomycin solution (made by dissolving 500 mg of vancomycin in 100 mL of normal saline solution or Ringer's solution) for several minutes prior to implantation in addition to the administration of perioperative intravenous (IV) antibiotic prophylaxis (Table V). The estimated infection rate with HT autografts presoaked in vancomycin was 0.1% (CI = 0% to 0.4%), much lower than the rate with unsoaked HT autografts (Fig. 4) (Q = 10.62, p = 0.001) (heterogeneity assessment: $tau^2 = 0.12$, $I^2 = 19.05$, Q = 166.78, df = 135, p = 0.033). Funnel plot visual analysis did not show a small-study effect (Fig. 5), which was confirmed with the Egger intercept test (intercept = −0.04, CI = −0.34 to 0.26, t = 0.27, 2-tailed p = 0.80).

In the sensitivity analysis, using a fixed-effect rather than a random-effect analysis yielded no substantial change in the results. In addition, the analysis including only the studies that were specifically designed to compare infection rates between different graft types[8,11,12,20-22] showed results similar to those of the overall analysis, with HT autografts again associated with a higher infection rate (1.0%, CI = 0.6% to 1.8%) than BPTB autografts (0.3%, CI = 0.1% to 0.6%) and allografts of any type (0.3%, CI = 0.1% to 0.6%) (Q = 1.41, p = 0.005).

Discussion

Deep infection or septic arthritis after ACLR is a devastating complication that usually requires further surgery and may lead to graft dysfunction. Our meta-analysis study confirmed that the deep infection rate following ACLR is low, on the order of 1% or less. However, higher infection rates were associated with HT autografts compared with either BPTB autografts or allografts of any type.

This has important implications, given that HT autografts may be the most common graft type in primary

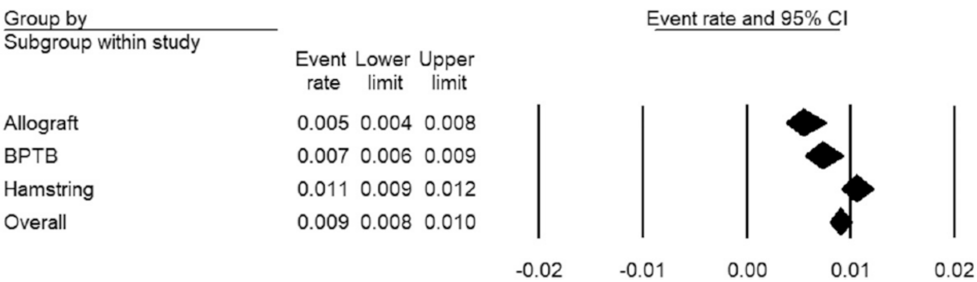

Fig. 2
Meta-analysis of infection rates among different graft types.

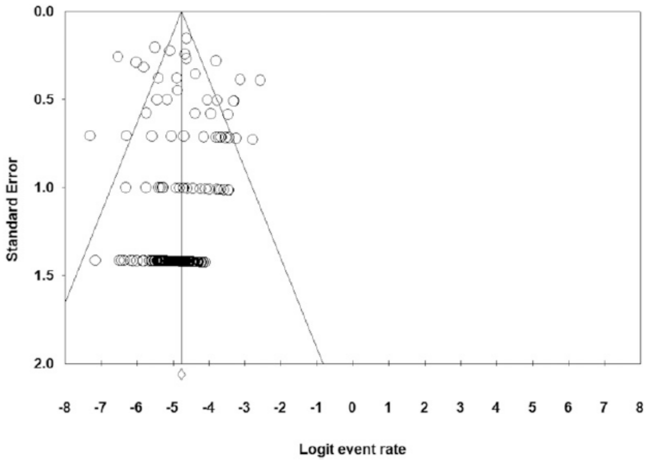

Fig. 3

Funnel plot analysis of standard error by logit event rate for the meta-analysis of infection rates among different graft types.

TABLE V Vancomycin Presoaking Protocols for HT Autografts in ACLR

	Vancomycin Concentration	Full Harvesting and Vancomycin Soaking Technique	Direct "Dipping" of Graft in Vancomycin on Harvesting	"Vancomycin Wrap"	Rinsing of Graft Prior to Implantation	Soaking Duration	IV Antibiotic Prior to Tourniquet Inflation
Phegan[14]	5 mg/mL	Original technique described by Vertullo[13]. During tunnel creation, the harvested HT graft, still attached to the tibia, was w rapped in a presoaked swab ("vancomycin wrap"), then placed back into the harvest site deep to skin and subcutaneous fat. Before transplantation, the graft was rinsed with normal saline solution	No	Yes	Yes	Not stated	Cephalothin 2 g (or alternative antibiotic if known allergy)
Perez-Prieto[15]	5 mg/mL	On harvesting, the graft was briefly directly immersed in the vancomycin solution (" dipping"), then wrapped in presoaked gauze on the side table	Yes	Yes	No	10-15 min	Cefazolin 2 g (or vancomycin 1 g if penicillin allergy)
Figueroa[17]	5 mg/mL	The graft was wrapped in presoaked gauze only on the side table; no direct immersion of the graft in the solution. Before transplantation, the graft was rinsed with Ringer's solution	No	Yes	Yes	≥15 min	Cefazolin 2 g (or vancomycin 1 g if penicillin allergy)
Offerhaus[16]	5 mg/mL	On harvesting, the graft was dipped in vancomycin solution, then wrapped in presoaked gauze on the side table. Before transplantation, the graft was rinsed with normal saline solution	Yes	Yes	Yes	Not stated	Cefazolin 2 g

Group by / Subgroup within study	Event rate	Lower limit	Upper limit
Hamstring	0.011	0.009	0.012
Hamstringsoaked	0.001	0.000	0.004
Overall	0.010	0.009	0.012

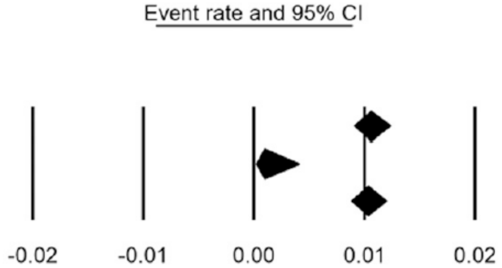

Fig. 4
Meta-analysis of infection rates of HT autografts presoaked or not presoaked in vancomycin.

ACLR, followed by BPTB autografts, according to data from Scandinavian national registries (Denmark, Sweden, and Norway)[23] as well as surveys of orthopaedic clinics in Germany[24] and surgeons from the United States[25] and other countries[26]. Allografts are the third most common graft choice in primary ACLR in the United States[25] and other countries[26], although their use in Europe remains low[23,24].

Early reports of allograft use indicated the possibility of not only viral but also bacterial transmission. The U.S. Centers for Disease Control and Prevention investigated musculoskeletal allograft infections between 1998 and 2002; of the 26 cases of bacterial infection reported[27-29], 12 involved Clostridium species, and 9 of those involved ACLR surgery[27-29]. These findings led to stringent controls of allograft sterilization, with methods including irradiation or chemical processing[6,22,30,31]. Our results suggest that, overall, allografts are not associated with an increased risk of infection compared with autografts, thus confirming the safety of such grafts in this respect.

The predominant organisms implicated in infection after ACLR are coagulase-negative staphylococci (mainly *Staphylococcus epidermidis*), followed by *S. aureus* and *Propionibacterium* (now *Cutibacterium*) *acnes*[5,32]. The most likely source is graft contamination from the patient's skin commensal organisms[32-34]. Potential differences in harvesting and preparation have been proposed to explain the increased risk of infection with HT autografts compared with BPTB autografts[9-12,35].

Harvest-site factors have also been implicated in reports in which organisms isolated at infected harvest sites matched those isolated on intra-articular cultures in patients with infection[9]. Unlike the BPTB harvest site, the HT harvest site is directly adjacent to the outer aperture of the tibial tunnel, and there is more extensive tissue dissection and morbidity at the HT autograft harvest site compared with the BPTB autograft harvest site[10-12]. During harvesting, the HT autograft may be left resting on the front of the leg, in direct contact with skin, thus possibly leading to contamination. HT autografts may require longer preparation times, which could also increase the opportunity for contamination[9-12,35]. Finally, multifilament sutures used to prepare the HT autograft may harbor bacteria[12], and improper sterilization of HT harvesting

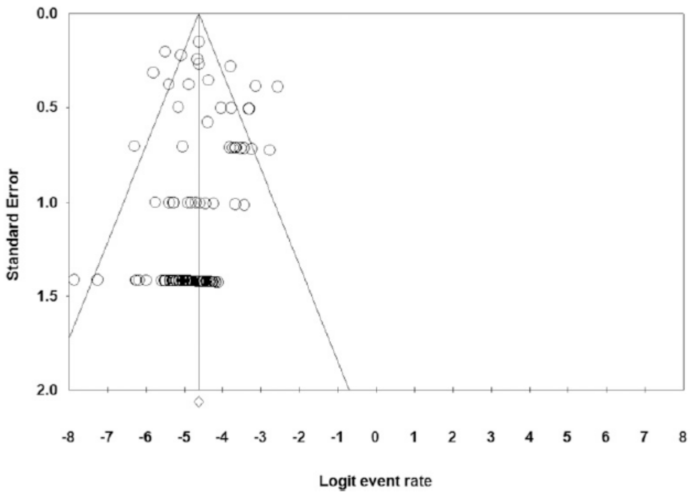

Fig. 5
Funnel plot analysis of standard error by logit event rate for the meta-analysis of infection rates of HT autografts presoaked or not presoaked in vancomycin.

instruments may provide an exogenous source of infection; Tuman et al.[36] reported 3 cases of HT autograft infection attributed to failure to fully disassemble the HT harvester before sterilization.

The inadvertent contamination rate of HT autografts may be as high as 10% to 23% according to studies in which grafts were cultured prior to implantation[33,35,37-43]. In a study by Hantes et al.[35], the overall rate of contamination of autografts was 12%, with rates that were similar between BPTB and HT autografts. Similar allograft studies[40,42,43] that cultured allografts during ACLR reported contamination rates of 4.8% to 13.3%. However, in none of these studies did positive culture results correspond to infection.

Wrapping of HT autografts in gauze soaked with 5 mg/mL vancomycin has been shown to fully eradicate inadvertent contamination of the autograft prior to implantation in actual ACLR procedures[33] and after deliberate *S. epidermidis* contamination of porcine tendon grafts[44].

Four separate author groups[14-17] examined the effect of vancomycin presoaking of HT autografts, in combination with routine prophylactic IV antibiotics, on infection rates in ACLR (Table IV). Our meta-analysis comparing the infection rates in these studies with those in studies utilizing unsoaked HT grafts suggests that presoaking HT autografts significantly reduces the infection risk, by about tenfold.

In vitro elution studies suggest that vancomycin-soaked tendon grafts can act as reservoirs for vancomycin for >24 hours after implantation[45]. The amount released and the elution profile depended on rinsing, tendon volume, and soak solution concentration[45]. The prophylactic effect of vancomycin eluted from a presoaked graft into the synovial fluid of the knee may defend against not only contamination of the tendon but also any organisms subsequently entering the joint space directly or through hematogenous spread[45]. This may account for the success of the presoaking method amid the likely multifactorial causes of infection. Given the substantial estimated reduction in infection rates associated with vancomycin presoaking, we recommend this as routine practice in ACLR.

There are little data on the effect on vancomycin presoaking on the functional integrity of tendon grafts in ACLR. However, Schüttler et al.[44] found no biomechanical impairment, in terms of maximum load to rupture and Young's modulus, in porcine tendons wrapped in gauze soaked in vancomycin at concentrations ranging from 1 to 10 mg/mL for 10 or 20 minutes.

In their retrospective analyses, 2 separate author groups have reported that vancomycin presoaking does not lead to higher rates of arthrofibrosis, rerupture, or revision or to lower functional outcomes compared with unsoaked HT autografts[14,16]. Furthermore, Antoci et al.[46] suggested that vancomycin is less toxic than alternative antibiotics such as tobramycin, cefazolin, and gentamicin, with levels of >125 mg/mL required before osteoblastic toxicity occurs and bone regeneration is inhibited. Similarly, Grayson et al.[45] demonstrated that, in vitro, elution from bovine tendons soaked in vancomycin at concentrations up to 5 mg/mL is below the concentration considered toxic to osteoblasts. This is the concentration used in the studies evaluating the role of vancomycin presoaking (Table V).

In a basic cost-benefit analysis that evaluated only direct medical costs, Offerhaus et al.[16] reported a 0.27% reduction in the infection rate after ACLR to be cost-effective in the German health-care system. This calculation was based on the added €27 cost of 500 mg of vancomycin (plus 2 syringes or 2 cannulas) compared with €10,160 for 3 arthroscopic irrigation and debridement procedures per case of deep infection after ACLR[16]. Similarly, in the French health-care system, Bohu et al.[47] reported direct medical costs of up to nearly €10,000 for ACLR complicated by deep infection that could require 1 or more arthroscopic irrigation and debridement procedures.

Limitations of our study include possible variations in surgical site infection risk factors across ACLR cases, including the specific surgical technique, the type of prophylactic IV antibiotics utilized, and the patient's general state of health. However, we feel that the pooling of a large number of cases allows us to reliably estimate infection rates for different graft types and to thoroughly assess the impact of presoaking in vancomycin.

In conclusion, deep infection or septic arthritis in ACLR remains a rare but serious complication. HT autografts are associated with a higher infection rate compared with both allografts and BPTB autografts. Vancomycin presoaking is a cost-effective method to reduce this rate by about tenfold, and we recommend this as routine practice in ACLR.

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c. Contribution to knowledge

This publication contributed to knowledge in that it provided evidence regarding the relation between graft type and vancomycin presoaking with infection in ACL reconstruction surgery. It was based on large number of studies and grafts aiming to give confidence to the clinician that its findings could be relied upon. This study aimed to raise awareness amongst surgeons of the higher risk of infection associated with hamstring graft and provided robust evidence that vancomycin presoaking may be related to a reduced infection rate. There was inconsistency in the literature with regards to these parameters, hence a meta-analysis allowed multiple studies to be pooled together and gave a more convincing message to guide clinical practice. Hamstring tendon grafts are the graft of choice of most surgeons in ACL reconstruction surgery (Grassi et al., 2018) due to their potential advantages of lower donor site morbidity, lower resultant anterior knee pain and extensor strength deficit, as compared to patellar tendon grafts. Hence, the recommendation of routine use of vancomycin presoaking could guide a substantial proportion of ACL reconstruction procedures.

The potential impact of this study on orthopaedic practice was assessed by a written survey administered to attendees of a podium presentation of its findings at the 2017 annual congress of the European Federation of National Associations of Orthopaedics and Traumatology (EFORT). In that survey, 29 attendees performing a median of 40 ACLs per year responded. Of these 24% had encountered an ACL infection in the previous 2 years and 48% in the previous 5 years. Only 10% presoaked the ACL graft with an antibiotic. About a quarter of those not presoaking the graft would consider changing their practice to presoaking with vancomycin with similar findings seen in those that used a hamstring graft as their first choice. The results of that survey suggested that the findings of this meta-analysis can have a substantial impact on the clinical practice of orthopaedic surgeons (Kuršumović and Charalambous, 2022).

d. Article limitations

The protocol of this study was not prospectively registered or published. There was no formal assessment of bias using a validated bias assessment tool, nor a formal assessment of the quality level of evidence presented. Similarly, the data was not extracted by two independent reviewers.

The findings apply to bacterial infections and not infections with other organisms such as fungal organisms which may also be encountered in clinical practice (Costa-Paz et al., 2021). There was no assessment of infection in other commonly used grafts such as quadriceps tendons hence the findings are directly applicable only to the types of grafts examined.

There was variability in the infection rates reported by individual studies but reasons for such variability were not explored. Several factors other than graft type and vancomycin graft pre-soaking may influence infection rates but these were not considered and could have acted as confounders in the analysis. As most studies were observational a causal relationship was not established between graft type and infection rates. Analysis in isolation of randomised trials comparing different graft types could have provided more definitive information. Similarly, as all studies looking at vancomycin graft presoaking were observational a causal relationship between vancomycin graft presoaking and infection rates could not be established.

Only a small proportion of the included studies were specifically designed to compare infection rates between different graft types, raising the possibility of underreporting infection rates by the remaining studies. However, the large number of studies considered and patients, allowed this rare complication to be examined with a greater degree of confidence as to the findings. Furthermore, the inclusion of observational studies, as well as different study designs, allowed a more pragmatic assessment of the available evidence.

e. Relevant work since the article was published

Since the article was published multiple subsequent studies have looked at risks of infection in ACL reconstruction surgery. Of these one is of particular note as in addition to graft type it assessed various patient and surgery factors with regards to their influence on infection risk, hence building on the evidence provided by the above article (Kuršumović and Charalambous, 2020). This further systematic review and meta-analysis examined 23 studies reporting on 3,871 infections amongst 469,441 ACL reconstructions (Zhao et al., 2022). It indicated that the use of hamstring autografts was related to infection risk but not the use of bone-patellar tendon-bone autografts or allografts. It also showed than in addition to graft type other patient and surgical technique factors increased the risk of surgical site infection (superficial and deep). These factors included male sex, obesity, smoking, diabetes, steroid use, being a professional athlete, previous knee surgery, revision ACL reconstruction surgery, concomitant lateral extra-articular tenodesis, and prolonged operating time. In contrast, patient's age, surgery performed as outpatient or inpatient basis, and concomitant meniscal tear repair did not increase the risk of surgical site infection. The findings of this meta-analysis confirm the findings of the article described above (Kuršumović and Charalambous, 2020) with regards to higher infection rates seen with hamstring grafts, but also emphasise that not just graft type but also other factors may influence infection risk, and this must be considered in clinical practice.

Since this article (Kuršumović and Charalambous, 2020) was published several other studies examined the role of graft antibiotic presoaking in minimising infection risk in ACL reconstruction. The results of the article reported above (Kuršumović and Charalambous, 2020) were replicated by a recent metanalysis of comparative studies that evaluated the role of vancomycin presoaking (Xiao et al., 2021). In that study 10 articles reported on 7,507 cases where vancomycin was used and 13,861 cases with no vancomycin. Eight of the 10 studies included only autografts with about 95% of grafts being hamstring autografts. Soaking grafts in vancomycin resulted in significantly fewer infections (0.013% versus 0.77%; OR 0.07; 95% CI 0.03, 0.18; $P < 0.001$). There was no difference in re-rupture rates between the groups. Two of the studies analysed assessed patient-reported outcomes and both showed no difference in this parameter at 1 year post surgery (Xiao et al., 2021). Furthermore, the cost-effectiveness of vancomycin presoaking was recently assessed in a modelling economic analysis (Ruelos et al., 2021). Assuming costs of US$24,178 for revision ACL reconstruction versus US$44/1,000 mg of vancomycin, it was shown that vancomycin presoaking was cost-effective if it prevented 1 infection in 550 cases. It was also shown that if the ACL graft was salvaged following infection (with arthroscopic washouts), vancomycin presoaking was cost-effective if it prevented 1 infection in 146 cases.

The findings of studies supporting the effectiveness of the use of vancomycin in reducing the risk of infection have led to calls for this to become the recommended practice in ACL reconstruction surgery (Vertullo et al., 2021, Pfeiffer, 2021). However, a recent study showed that although the routine presoaking of grafts with vancomycin in ACL reconstruction surgery was taken up by a substantial proportion of surgeons the majority still did not presoak the graft and concerns about the safety of graft presoaking remained. In a survey members of the ACL study group were enquired about their practice with regards to presoaking ACL grafts in vancomycin (Xiao et al., 2021). It was reported that about one-third (38%) of respondents presoaked their ACL grafts in vancomycin, with most (76%) having adopted this practice within the past 5 years. It was reported that most respondents wrapped the graft in a vancomycin-soaked gauze (56%), soaked for a variable amount of time (56%) and used a concentration of 5 mg/mL (68%). Their concerns with regards to vancomycin presoaking included its potential detrimental effects on the mechanical properties of the graft (35%), cost of vancomycin (23%), availability (12%), and development of antibiotic resistance (9%).

As shown by the survey from the ACL study group (Xiao et al., 2021) and discussed in the examined article (Kuršumović and Charalambous, 2020), one of the concerns of vancomycin presoaking of ACL grafts is whether this could lead to graft cell (tenocyte) toxicity and thus impairment of the biomechanical properties of the graft. This could lead to early graft stretching or graft failure compromising the functional outcomes of ACL reconstruction. Since this article (Kuršumović and Charalambous, 2020) was published, 2 further studies were reported which examined whether there is any evidence of such a potential detrimental effect of antibiotic presoaking. The tenocyte toxicity caused by vancomycin soaking of grafts was evaluated in an in vitro laboratory study (Xiao et al., 2020). Human tenocytes derived from human patellar tendons were exposed to 5 different vancomycin concentrations at 3-time intervals. Vancomycin exposure of tenocytes was compared to sole culture medium exposure applied for the same length of time. It was shown that vancomycin exposure did not cause significant changes in tenocyte viability after 2 and 6 hours of incubation at any concentration up to about 13mg/mL. Incubation with vancomycin for 24 hours led to a significant decrease in cultured cell viability at higher concentrations. Based on these findings it was concluded that exposing tendons to vancomycin for a short period of time by graft soaking during ACL reconstruction is unlikely to cause tenocyte toxicity. Along similar lines, the effect of soaking ACL grafts in vancomycin solution on the biomechanical properties of the graft at the time of implantation was evaluated in bovine patellar tendons (Lamplot et al., 2021). These tendons were wrapped in normal saline soaked gauze and then in vancomycin-soaked gauze for 30 minutes and were subsequently subjected to tensile testing. No difference in Young's modulus, which is a measure of stiffness, between saline and vancomycin soaking was demonstrated. It was thus concluded that vancomycin soaking of patellar tendon grafts does not adversely affect their material properties at the time of implantation into the knee. Similarly, the biomechanical properties of grafts subjected to tensile loading were assessed in 30 semitendinosus tendons harvested during ACL reconstruction (Jacquet et al., 2020). Tendons were randomly allocated to a vancomycin presoaking or a control group. The vancomycin group tendons were presoaked in 5 mg/mL vancomycin and the control group in physiological serum for 10 minutes prior to mechanical testing. No significant difference was seen between the 2 groups with regards to several biomechanical properties such as the Young's Modulus, ultimate tensile strength, and elasticity limit. On the basis of this it was concluded that presoaking of human semitendinosus grafts with vancomycin does not alter its biomechanical properties. The ability of these in-vitro findings to translate to real life was explored in a retrospective cohort study that examined the re-rupture risk and functional outcomes of ACL reconstruction using the vancomycin soaking technique as compared to unsoaked grafts at a minimum 5 year follow up (Pérez-Prieto et al., 2021). The authors of that study showed that 17 (5%) of unsoaked graft cases suffered a re-rupture as compared to 15 (4%) of cases who had their graft presoaked in vancomycin, statistically a non-significant difference. Clinical outcomes were also assessed using the IKDC, Tegner system, and Lysholm knee scores. In the IKDC system scores range from 0 (indicative of lowest function or highest symptoms) to 100 points (highest function and lowest symptoms). The mean IKDC score was 82/100 in the unsoaked and 83.9/100 in the vancomycin-soaked group (P=0.049). The Tegner activity scale grades activity based on work and sports activities from 0 to 10 (0 being disability and 10 participation at national or international level soccer). The Tegner system score was 4 in both groups. The Lysholm Scale score ranges from 0-100 with higher scores indicating less disability. The Lysholm Knee score was 90.3 in the unsoaked and 92 in the vancomycin-soaked group (P=0.015). It was concluded that vancomycin presoaking of ACL grafts is a safe clinical practice, is not associated with an increased risk of graft re-rupture and does not impair the clinical functional outcomes of arthroscopic ACL reconstruction.

f. Further research

Future work may aim to determine a direct causal relation between vancomycin graft presoaking and reduced infection rates through randomised controlled trials. The estimated effect and confidence intervals reported in this meta-analysis can inform the calculation of the number of participants required in such a study. However, given the magnitude of the difference in infection rates reported in the article presented here (Kuršumović and Charalambous, 2020), as well as in a subsequent meta-analysis by a different group (Xiao et al., 2021) the possibility of a causal-effect relation is highly suggestive, which may limit the need for such a randomised trial. Furthermore, given the overall low rate of infection following ACL reconstruction surgery, such a trial will be challenging to design and complete, as a large number of participants would be needed to demonstrate a difference between groups. It is equally important to gather high quality evidence to conclusively support the safety of vancomycin graft pre-soaking in ACL reconstruction. This may be of particular importance given that concerns with regards to detrimental effects of vancomycin on the mechanical properties of the graft were amongst the barriers cited by surgeons in adopting vancomycin graft presoaking in clinical practice (Kuršumović and Charalambous, 2022, Xiao et al., 2021). A randomised trial comparing the clinical and functional outcomes as well as graft re-rupture rates between grafts presoaked in vancomycin vs. those presoaked in saline may give definitive high-quality evidence to allow vancomycin graft presoaking to become universal practice. Such a randomised trial is likely to require a smaller group of participants, as compared to a trial to assess infection rates, and hence be more feasible to carry out.

Having demonstrated that vancomycin graft presoaking along with systemic antibiotics administration is associated with reduced infection rates as compared to systemic antibiotics given in isolation, a next step would also be to assess whether vancomycin presoaking alone is also sufficient. This could initially be evaluated in line with the IDEAL framework (McCulloch et al., 2009) by looking at infection rates in a case series of patients having vancomycin graft presoaking without concomitant systemic antibiotics.

Further work may also be in the form of basic science studies to explore the cause of higher risk of infection associated with hamstring grafts and to guide the implementation of alternative preventive measures for minimising the risk of infection. Emerging technologies that may be further evaluated include the surface modification of graft fixation devices to make them more resistant to bacterial colonisation and graft soaking with anti-microbial non-antibiotic peptides.

F. **Commentary article 6 -** ***Graft salvage following infected anterior cruciate ligament reconstruction: a systematic review and meta-analysis. Kuršumović K, Charalambous CP. Bone Joint J. 2016 May;98-B(5):608-15 PMID: 27143730. Errata. Bone Joint J. 2016 Aug;98-B(8):1151-2. doi: 10.1302/0301-620X.98B8.38074c. Erratum for: Bone Joint J. 2016 May;98-B(5):608-15. PMID: 27482032.***

https://online.boneandjoint.org.uk/doi/full/10.1302/0301-620X.98B5.35990?rfr_dat=cr_pub++0pubmed&url_ver=Z39.88-2003&rfr_id=ori%3Arid%3Acrossref.org. *. doi: 10.1302/0301-620X.98B5.35990.*

a. Contribution by CP Charalambous

Developed the concept of the article, co-designed the methodology, contributed to data collection, carried out the data analysis (meta-analysis) and co-wrote the article.

b. Article description - Full article

This article presented a meta-analysis which examined the ability of arthroscopic washout to treat septic arthritis in primary ACL reconstruction surgery. Such a treatment approach helps to preserve the reconstructed graft and avoid further extensive revision surgery. This study identified 147 infected hamstring grafts across 16 included studies. The graft salvage rate was 86% (95%CI 73% to 93%) when excluding ACL re-ruptures. When re-ruptures were included as failures, the graft salvage rate was 85% (95% CI 76% to 91%). These findings supported the hypothesis that arthroscopic washout along with antibiotic treatment and graft salvage is an effective way of managing septic arthritis following ACL reconstruction surgery in most cases. A copy of the full article is presented next.

■ KNEE

Graft salvage following infected anterior cruciate ligament reconstruction

A SYSTEMATIC REVIEW AND META-ANALYSIS

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Aims

To examine the rates of hamstring graft salvage with arthroscopic debridement of infected anterior cruciate ligament (ACL) reconstruction as reported in the literature and discuss functional outcomes.

Materials and Methods

A search was performed without language restriction on PubMed, EMBASE, Ovid, CINAHL and Cochrane Register of Controlled Trials (CENTRAL) databases from their inception to April 2015. We identified 147 infected hamstring grafts across 16 included studies. Meta-analysis was performed using a random-effects model to estimate the overall graft salvage rate, incorporating two different definitions of graft salvage.

Results

The graft salvage rate was 86% (95% confidence intervals (CI) 73% to 93%; heterogeneity: $tau^2 = 1.047$, $I^2 = 40.51\%$, $Q = 25.2$, $df = 15$, $p < 0.001$), excluding ACL re-ruptures. Including re-ruptures as failures, the graft salvage rate was 85% (95% CI 76% to 91%; heterogeneity: $tau^2 = 0.099$, $I^2 = 8.15\%$, $Q = 14.15$, $df = 13$, $p = 0.36$).

Conclusions

Arthroscopic debridement combined with antibiotic treatment can lead to successful eradication of infection and graft salvage, with satisfactory functional outcomes in many cases of septic arthritis following ACL reconstruction. Persistent infection despite repeat arthroscopic debridements requires graft removal with the intention of revision ACL surgery at a later stage.

Take home message: Arthroscopic debridement combined with antibiotic therapy is an appropriate initial approach in most cases of septic arthritis following ACL reconstruction, achieving graft salvage rates of about 85%.

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Septic arthritis following anterior cruciate ligament (ACL) reconstruction is a rare but serious complication with a reported incidence of 0.14% to 2.25%.[1] It can lead to graft failure, cartilage destruction and arthrofibrosis. There is a lack of best practice guidance concerning the specific management of septic arthritis following ACL reconstruction, and little evidence on the functional outcomes of patients who develop this complication.

Previous authors have recommended arthroscopic lavage and arthroscopic debridement with prolonged empirical and culture specific antibiotic therapy.[1-5] Controversy exists regarding graft salvage or primary graft removal. Radical debridement with graft and hardware removal facilitates treatment. It eliminates a potential nidus of persistent infection with ongoing intra-articular inflammation and chondrolysis.[6,7] However, graft removal may destabilise the knee, necessitating a repeat reconstructive procedure.[2,3,8] A survey conducted in the United States showed that 85% of orthopaedic fellowship programme directors preferred to attempt graft salvage and repeat arthroscopic debridements as many times as necessary.[2]

Several studies have reported promising success rates of graft salvage of up to 100%[9-16], while others have presented high graft removal rates in the range of 27.8% to 87.5%.[6,7,17-19] This wide variation in graft salvage rates may be partly attributable to the paucity of cases in some reports and inclusion of different graft types. Pooling such studies with a meta-analysis including only infected

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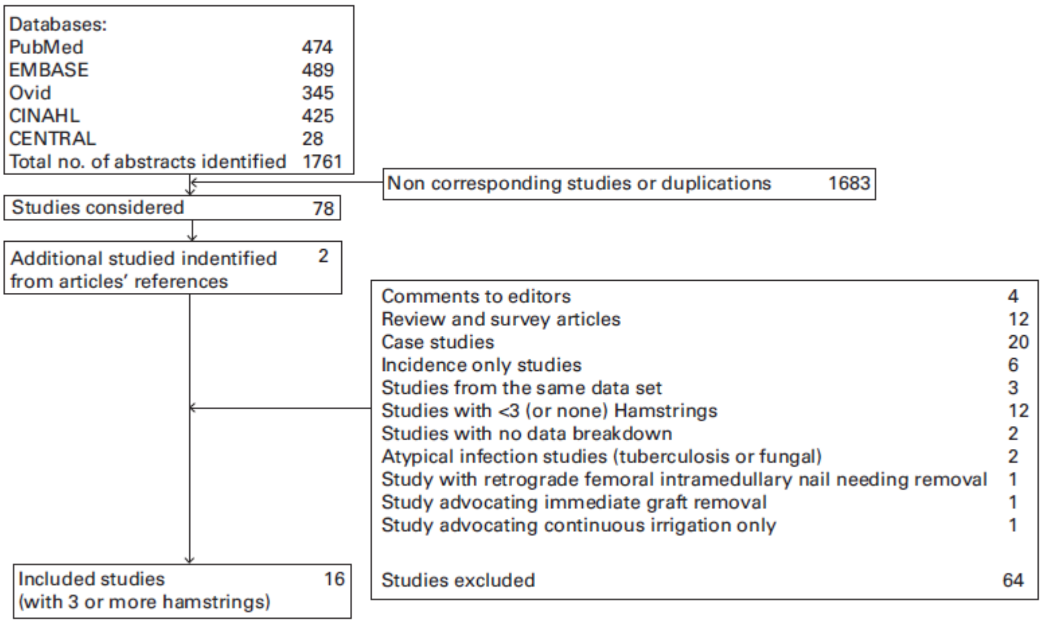


Fig. 1

Study selection algorithm. Search terms: ("anterior cruciate" OR "ACL") AND ("septic" OR "infection").

autologous hamstring grafts may provide more robust evidence to guide practice.

Our primary aim was to undertake a systematic review and meta-analysis of studies examining rates of hamstring graft salvage with arthroscopic debridement of infected ACL reconstructions.

Materials and Methods

A literature search was performed without language restriction using the combinations ("anterior cruciate" OR "ACL") AND ("septic" OR "infection") on PubMed, EMBASE, Ovid, CINAHL and Cochrane Register of Controlled Trials (CENTRAL) databases from their inception to April 2015.

The Preferred Reporting items for Systematic Review and Meta-Analyses (PRISMA) methodology guidance was used.[20] Full texts were reviewed for relevant articles, and where a decision regarding inclusion could not be made from the title and abstract. References within selected articles were reviewed for any additional relevant studies.

The inclusion criteria were studies with three or more reported cases of bacterial septic arthritis with a hamstring graft and treated with arthroscopic debridements with the primary intention of graft salvage. Where several ACL graft types were described, data extrapolation was conducted to obtain values for hamstring grafts only. Authors of included studies were contacted if further information was needed. Case reports, technical notes, comments to editors, review articles and abstract only publications were excluded. Our literature search strategy is summarised in Figure 1.

Extrapolated data from the included studies was extracted in a standardised manner. Collected data included study characteristics, patient demographic details, the nature of the presentation of the infection, treatment, follow-up information and functional outcomes. The functional outcomes included: range of movement, Lachman test[21], pivot shift test,[22] KT-1000 arthrometer (MEDmetric Corporation, San Diego, California) side to side difference,[23] Lysholm knee score[24] and Tegner activity score.[25]

Statistical analysis. Summary statistics were expressed as means and ranges or numbers and percentages, calculated from the available individual patient data reported in the studies or, where possible, provided by authors upon request. Meta-analysis was performed using a random-effects model to estimate the overall graft salvage rate, incorporating two different definitions of graft salvage. In the first analysis, the endpoint was defined as graft salvage taking into account the need for graft removal during surgical treatment for infection. In the second analysis the endpoint was defined as graft salvage taking into account either a graft removal during surgical treatment of infection, or a later graft re-rupture on follow-up. Summary risk ratios with 95% confidence intervals (CI) were calculated for each outcome. Heterogeneity was assessed using tau^2, I^2, Q and p-values. All data were analysed with

Table I. Summary data of the included studies

	Authors	Hams. grafts	Age (y)	% male	Presentation (days)	Follow up (mths)	% +ve culture	Abx regimen	n AD procedures	n grafts rem.	ACL re-ruptures
1	Boström Windhamre et al[10]	27	27	48	8	60	100	10 (2to5)d IV + 7.6 (4to18)w PO	3.7	0	3
			(16 to 43)		(1 to 22)	(13 to 108)			(1 to 11)		
2	Calvo et al[17]	7	28	100	11	*	100	4w IV + 2w PO	1.6	2	0
			(14 to 51)		(4 to 30)	(18 to 108)			(1 to 3)		
3	Abdel-Aziz et al[9]	24	26	100	12	59	87.5	4 (3to7)w IV	2.8	0	3
			(21 to 31)		(5 to 45)	(18 to 96)			(1 to 6)		
4	Torres-Claramunt et al[26]	13	34	*	26	36	92.3	6 (4to8)w IV + PO	1.3	1	0
			(*)		(7 to 50)	(15 to 58)			(1 to 3)		
5	Demira? et al[11]	5	31	80	35	57	100	3to 4w IV + 2to 3 PO	1.1	0	0
			(21 to 40)		(*)	(33 to 72)			(1 to 2)		
6	Sonnery-Cottet et al[12]	4	41	100	22	12	100	3d IV + 6w PO	1.25	0	0
			(32 to 49)		(15 to 37)	(*)			(1 to 2)		
7	Barker et al[18]	5	33	60	17	*	40.0	6w IV	1.6	3	*
			(16 to 52)		(11 to 22)	(*)			(1 to 2)		
8	Wang et al[13]	14	27	90	14	*	75.0	19.4 (13 to 28)d Iv + 2 to3w PO	1	0	*
			(16 to 51)		(3 to 29)	(*)			(all 1)		
9	Sajovic et al[14]	3	32	100	8	33	66.6	2w IV + 4w PO	1	0	0
			(23 to 48)		(2 to 14)	(4 to 61)			(all 1)		
10	Parada et al[15]	5	26	60	27	12	40.0	4.8 (2to 8) IV + PO	2.4	0	0
			(16 to 47)		(7 to 42)	(all 12)			(1 to 4)		
11	Van Tongel et al[27]	11	33	*	11	57	100	24.6 (12 to 46)d IV + 3.2 (2 to 5)m PO	1.8	0	0
			(17 to 50)		(2-455)	(9 to 99)			(1 to 4)		
12	Schulz et al[19]	4	33	50	9	35	100	25.5 (5 to 60)d intraarticular beads + PO	3.3	3	0
			(17 to 49)		(6 to 13)	(15 to 63)			(2 to 5)		
13	Judd et al[8]	11	28	73	15	22	100	4 (2 to 7)w IV ± PO	2.4	1	0
			(22 to 35)		(8 to 45)	(10 to 48)			(1 to 4)		
14	Fong et al[16]	7	23	100	25	12	100	17.3 (8 to 31)d IV + 4 to 6w PO	1.4	0	0
			(19 to 30)		(7 to 56)	(5 to 26)			(1 to 3)		
15	Schollin-Borg et al[28]	4	27	75	11	40	50.0	4 to 12w IV + PO	1	0	0
			(26 to 29)		(6 to 13)	(24 to 56)			(all 1)		
16	Williams et al[6]	3	31	100	9	56	100	4 to 6w IV + PO	1.3	2	0
			(24 to 45)		(7 to 12)	(35 to 71)			(1 to 2)		
	Total or mean	147	28.5	81.3	17.6	45.2	89.1		2.2	12	6
	(range)		(14 to 52)		(1 to 455)	(4 to 108)			(1 to 11)		

* Missing data

Comprehensive Meta-analysis version two (Biostat, Englewood, New Jersey) and Microsoft Excel 2007 (Microsoft, Redmond, Washington).

Results

From 1761 abstracts identified, after removing non-corresponding studies (that did not specifically report on a series of patients treated for infected ACL grafts), duplications and others according to the exclusion criteria, 16 studies were finally included (Fig. 1). All were retrospective, except for one prospective case control study,[9] and were published between 1997 and 2014.

Five studies with three or more hamstring grafts were excluded. These included one study advocating immediate graft removal and another which required open removal of a retrograde intramedullary femoral nail (for a previous fracture) in one of its three infected hamstring graft patients. The third excluded study used only continuous irrigation without a formal arthroscopic debridement procedure. The fourth described tuberculosis infections and the fifth described fungal infections and were excluded due to their special features.

A total of 147 infected ACL reconstructions that were identified from the 16 studies identified.

Table I displays demographics of the included studies.[6,8-19,26-28] Summary values are expressed as means (ranges) or percentages. The mean patient age was 28.5 years (14 to 52). Gender was recorded in 123 cases, of which 100 (81.3%) were male. Presentation time with infective symptoms from the index procedure was at a mean of 17.6 days (1 to 455).

The definition of infection varied amongst studies. In all, nine studies accepted a positive synovial fluid culture. The other seven studies included negative cultures but raised inflammatory serum markers or white cells in the synovial fluid (white cells > 100 000/ml) in the context of symptoms

Table II. Organisms cultured. The percentages are non additive due to inclusion of polymicrobial cultures

Organism	n (%)
Coagulase Negative *Staphylococcus*	76 (*51.7*)
Staphylococcus aureus	34 (*23.1*)
Other (*Propionibacterium Acnes, Klebsiella, Enterococcus faecalis, Enterobacter cloacae, Enterobacter aerogenes, Escherichia coli, Peptostreptococcus, Corynebacterium, Streptococcus Group C* and *Propionibacteriae)*	27 (*18.4*)
Polymicrobial	8 (*5.4*)

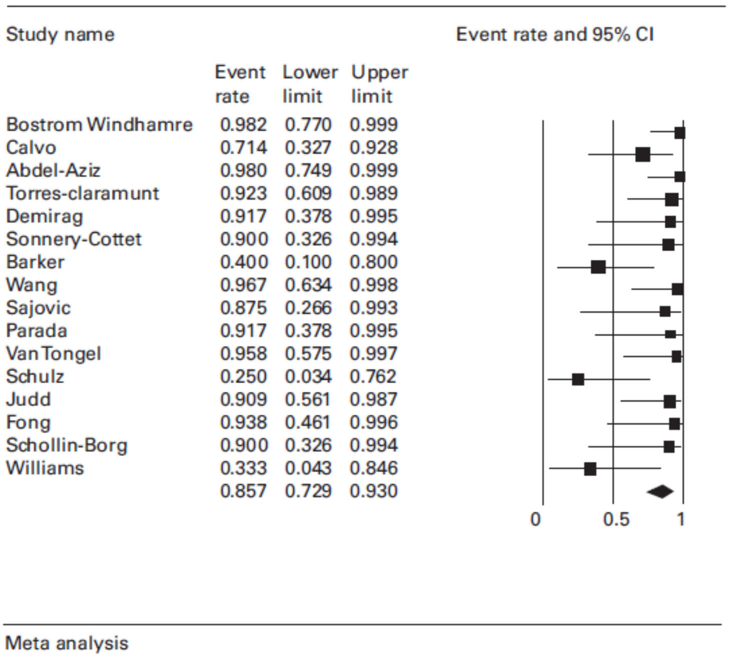


Fig. 2

Graft salvage rate excluding anterior cruciate ligament re-ruptures (heterogeneity: tau^2 = 1.047, I^2 = 40.51%, Q = 25.2, df = 15, p < 0.001).

consistent with septic arthritis. The rate of positive cultures ranged between 40% and 100% between studies, with a total of 129 (88%) positive cultures and 18 (12%) negative cultures in the pooled data. Coagulase negative *staphylococcus* (CNS) was the most common bacterial group, isolated in 76 (51.7%) cultures, followed by *Staphylococcus aureus* (SA) in 34 cultures (23.1%) (Table II).

Laboratory markers on admission were not consistently reported. Where data were available, in 74 infected ACL reconstructions, the mean white cell count was 10.1 x 109/L(5 to 17) (n = 91), CRP 119.7 mg/L (10 to 497) (n = 101) and erythrocyte sedimentation rate was 62.4 mm/hr (9 to 124).

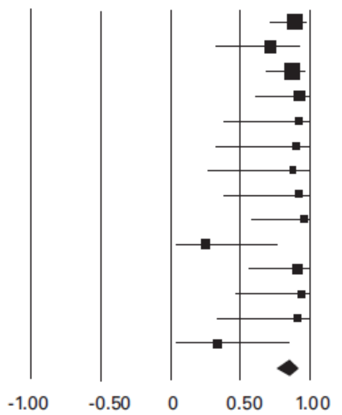
The first arthroscopic debridement occurred at a mean of 2.0 days (zero to 34) delay from initial presentation with symptoms of infection. A median of 2.0 (one to 11) arthroscopic debridements were required. In all, 68 (46.3%) had a single procedure, 35 (23.8%) required two procedures and 44 (29.9%) needed three or more. The reason and timing for a repeat procedure was not always clear (ranging between three days to a week) but was generally at the surgeon's discretion considering persistent symptoms of infection and raised inflammatory markers. Six patients in two studies had continuous irrigation on the ward in addition to arthroscopic debridements.[12,14]

Antibiotic regimens varied widely. Most involved intravenous antibiotics with conversion to oral antibiotics for a total duration of four to six weeks or longer. The exceptions were Van Tongel et al[27] whose patients received a mean of 3.2 months (two to five) of oral antibiotics after a mean of 24.6 days (12 to 46) of intravenous therapy[27] and Schulz et al,[19] who used intra-articular gentamicin-polymethyl methacrylate beads for a mean of 25.5 days (five to 60) alongside oral antibiotics.

A total of 12 grafts were removed as they were insufficient on probing, covered with purulent exudate, or had persisting infection.[6,8,17-19,26] Five were removed during the first procedure, one during the second, four on the third and one on the fourth procedure. For one graft it is unclear when it was removed during the three procedures undertaken.[7] Two grafts were removed as part of conversion to

Study name — Event rate and 95% CI

Study name	Event rate	Lower limit	Upper limit
Bostrom wind.	0.889	0.707	0.964
Calvo	0.714	0.327	0.928
Abdel-Aziz	0.875	0.676	0.959
Torres-clar	0.923	0.609	0.989
Demirag	0.917	0.378	0.995
Sonnery-Cottet	0.900	0.326	0.994
Sajovic	0.875	0.266	0.993
Parada	0.917	0.378	0.995
Van Tongel	0.958	0.575	0.997
Schulz	0.250	0.034	0.762
Judd	0.909	0.561	0.987
Fong	0.938	0.461	0.996
Schollin-Borg	0.900	0.326	0.994
Williams	0.333	0.043	0.846
	0.849	0.759	0.909



Meta analysis

Fig. 3

Graft salvage rate including anterior cruciate ligament re-ruptures (heterogeneity: tau^2 = 0.099, I^2= 8.15%, Q = 14.15, df = 13, p = 0.36).

open irrigation and debridement due to persisting infection.[6,19] Metalwork was extracted and tunnels were debrided in all cases where grafts were removed.

Sole exchange of tibial screws with graft preservation was undertaken due to persisting infection in two patients in two studies.[10,12] A revision ACL reconstruction was performed at a later stage in three of 12 (25%) patients in whom grafts had been removed. In total, six of the remaining 135 grafts had ruptured on follow-up in two studies (three re-ruptures each).[9,10] The authors did not specifically relate this to the infection or a further injury.

Meta-analyses showed a graft salvage rate of 86% (95% CI 73 to 93; heterogeneity: tau^2 = 1.047, I^2 = 40.51%, Q = 25.2, df = 15, $p \leq 0.001$), when ACL graft ruptures were excluded (Fig. 2). Including graft ruptures as failures, the graft salvage rate was 85% (95% CI 76 to 91; heterogeneity: tau^2 = 0.099, I^2 = 8.15%, Q = 14.15, df = 13, p = 0.36) (Fig. 3).

There was an increasing incidence of graft removal and graft rupture as the time to presentation from the primary ACL reconstruction reached five or more days, or the first arthroscopic debridement was delayed for six or more days from the index reconstruction procedure (Table III). Similarly, rates of graft removal and graft rupture increased as the number of required arthroscopic debridements increased (Table III).

Excluding polymicrobial infections, there were 72 positive synovial fluid cultures for CNS and 29 for SA. Although the mean time to presentation and the first arthroscopic debridement from the index procedure were similar across both groups, the graft removal and graft rupture rate in SA infection was higher than in the CNS group (Table IV).

A total of 128 patients were followed up for a mean of 45.2 months (four to 108). There were 19 patients across two studies with no follow-up.[15,18] Functional outcomes were not consistently reported. The following functional data were available for patients in whom the grafts were preserved. Range of movement was reported for 107 patients with a mean loss of extension of 1.1° (0° to 11°) and loss of flexion of 5.4° (0° to 50°). Lachman and/or pivot shift test for knee laxity were positive in 26 of 69 patients (37.7%).Side-to-side difference measured using the KT-1000 arthrometer of affected and contralateral knee was recorded in 81 patients. In 65.4%, the knee was 'tight' (difference of < 3 mm), 27.2% showed 'moderate' laxity and 7.4% were deemed 'loose' (> 5 mm). In 100 patients the mean Lysholm knee score was 80.2 (14 to 100). Of these 56 (56%) were rated good to excellent, 24 (24%) fair and 20 (20%) poor. The post-operative mean Tegner activity score was 5.4 (1 to 9) in 103 patients for whom this was recorded.

Discussion

Arthroscopic debridement combined with antibiotic therapy can reliably eradicate hamstring graft infections after ACL reconstructions in most cases. Some evidence suggests that hamstring autografts are associated with higher infection rates than bone-patella-tendon-bone (BPTB)

Table III. Relationship of the time of presentation or first arthroscopic debridement from the index anterio cruciate reconstruction reconstruction and the number of arthroscopic debridements to the hamstring graft salvage rate

	Patients in the group (n)	Grafts removed n (%)	Grafts re-ruptured n (%)
Presentation post index procedure			
≤ 5 days	19	-	-
≤ 6 days	28	1 (*3.6*)	-
≤ 7 days	43	3 (*7.0*)	-
> 7 days	104	9 (*8.7*)	6 (*5.8*)
First arthroscopic debridement post index procedure			
≤ 6 days	13	-	-
≤ 7 days	24	2 (*8.3*)	-
> 7 days	123	10 (*8.1*)	6 (*4.9*)
Arthroscopic debridements (n)			
1	68	2 (*2.9*)	1 (*1.5*)
2	35	4 (*11.4*)	-
≥ 3	44	6 (*13.6*)	5 (*11.4*)

autografts and allogenic grafts.[8,18,29-31] In a registry study with over 10 000 ACL reconstruction procedures, Maletis et al[29] found a risk of infection with hamstring autografts 8.2 times that of BPTB grafts. The reason for the seemingly higher infection rate with hamstring autografts is unclear and warrants further investigation.[30,31]

Our meta-analysis shows a success rate of 86% (CI 73% to 93%) in salvaging the graft where this was the primary intention. Graft preservation is important as it avoids further complex reconstructive procedures, with their associated morbidity and potential complications.[32-34]

The need for multiple arthroscopic debridements carries a decreasing graft salvage rate. Three of the 68 (4.4%) patients requiring a single arthroscopic debridement required graft removal or suffered a graft rupture on follow-up, compared with four out of 35 (11.4%) and 11 out of 44 (25.0%) patients undergoing two and three or more arthroscopic debridements, respectively. This however may reflect that more severe infections necessitate repeat arthroscopic debridements as they are threatening a graft's survival. We therefore advocate performing repeat arthroscopic debridements in unresponsive infections.

The infecting organism may influence the success of graft salvage. Other authors have suggested that less virulent bacteria such as CNS may allow for greater graft salvage rates than more virulent organisms such as SA.[1,5,35] Our pooled data support this. The most common infecting bacterial group was CNS, followed by SA. However, only three of 72 (4.2%) hamstring grafts infected with CNS required removal or re-ruptured on follow-up compared with eight of 29 (27.6%) hamstring grafts infected with SA. We strongly support aggressive therapy both operative and antimicrobial aiming to preserve the graft whenever possible, regardless of the bacterial organism.

Graft salvage is achievable in acute presentations but less so in those presenting late.[13,17,19,35] In a systematic review considering all types of infected graft, Wang, Lee and Siebold[1] found that retention was more successful where septic arthritis was diagnosed within seven days post ACL reconstruction compared with those diagnosed later. Saper, Stephenson and Heisey[5] did not find such a difference at a two-week cut off. Our findings suggest that this crucial cut off may be sooner at five to six days, highlighting the urgency of arthroscopic debridement and antibiotic therapy where an infected graft is suspected.

Even though arthroscopic debridement can successfully eradicate infection in most cases, graft retention and eradication of infection are not the only measures of successful treatment.[4,8] The overall goal in managing septic arthritis is to preserve the graft and avoid knee instability whilst protecting the articular cartilage and preserving joint function.[8,11] There seems to be a lack of consensus about functional outcomes in cases treated for septic arthritis post ACL reconstruction. This could be due to inconsistent outcome reporting and variation in measures used to capture the data, in addition to small case series data. Some authors have suggested that good to excellent functional results can be achieved with graft retention, arthroscopic debridement(s) and antibiotics.[9,10,12,14,15,17] Others have shown a more mixed result with this approach.[6-8,19,26,27,36] In Calvo et al's series[17] of seven infected hamstring grafts, the combined mean post-operative Lysholm score was 95 (89 to 100). The Lysholm scores were significantly better in the five patients for whom retention of the graft was possible, compared with the two for whom the grafts were removed. However, only one of the latter two patients had revision surgery introducing a confounding factor.[17] All five patients with preserved grafts returned to pre-injury sporting levels.[17] Other case series claimed satisfactory outcomes with graft salvage with arthroscopic debridements at 12 months follow-up,[12,15] but do not objectively quantify this with the findings from clinical examination or functional outcome scores. Five case control studies compared functional outcomes in infected patients with matched controls of uncomplicated ACL reconstruction.[9,10,26-28] When compared with controls, most of these studies reported no difference between infected and non-infected groups in range of movement,[9,10] knee stability[9,10,26,27] and other formal functional outcome scoring such as the Lysholm score.[9,10,27,28] One study reported that functional outcomes

Table IV. Relationship of infecting organism (coagulase negative*staphylococcus* (CNS) and *staphylococcus aureus* (SA)) to the time of presentation or first arthroscopic debridement from the index anterior cruciate ligament reconstruction, the number of arthroscopic debridements and the hamstring graft removal or graft rupture on follow-up

	CNS (n = 72)	SA (n = 29)
Presentation post index procedure (days)	13.7 (1 to 50)	13.0 (5 to 42)
First arthroscopic debridement post index procedure (days)	16.3 (1 to 50)	16.0 (5 to 42)
Number of grafts removed	2 (*2.8*)	4 (*13.8*)
Number of grafts re-ruptured on follow up	1 (*1.4*)	4 (*13.8*)

Values are expressed as mean (range) in days or n (%). Polymicrobial infections are excluded

in the infected group were inferior to those in patients without infection with mean Lysholm scores of 37.7 and 90.7, respectively.[26]

Where outcomes were less favourable, the main complaints were pain and stiffness.[8] Pain may be related to chondrolysis. Some authors have expressed concern about the retained ACL graft as a potential nidus for persistent infection, as well as sterile microbial fragments and inflammatory mediators that might pose the risk of persistent chondrolysis.[6,7] McAllister et al[36] presented four patients with post-operative infections for whom the graft was retained (three BPTB and one hamstring graft) and observed full thickness cartilage lesions and diffuse chondral thinning on post-operative magnetic resonance imaging. They believed these articular cartilage changes were the most likely cause of patients' inferior functional assessment scores compared with those with an uncomplicated ACL reconstruction.[36] Demira?, Unal and Ozakin[11] argued that shaving off the fibrinous layer from the ACL graft during arthroscopic debridement can affect the structural integrity and mechanical properties of the graft causing it to stretch. This could explain the instability and knee laxity at follow-up in some cases. Considering that the primary goal of ACL reconstructive surgery is to treat knee instability and restore patient confidence, Demirağ et al[11] suggested that this treatment may be suitable for patients engaging in light to moderate activities, but not those seeking to resume high demand activities. We feel that as some high-demand patients, such as athletes and heavy workers, may benefit from graft salvage, this approach is initially adopted, with revision surgery being performed in those with persistent instability.

This review is limited by the heterogeneity amongst studies in the definition of infection, the criteria for diagnosing septic arthritis and the criteria for resolution of infection. The definitions of infection in some studies were vague, and thus some infections were potentially overlooked. In addition, the number of arthroscopic debridements varied amongst cases as did the rational for their use. Our study did not control for additional interventions such as drains or continuous irrigation. Moreover, the wide variation in antibiotic treatment protocols across studies has prevented analysis of the effect of any particular protocol on graft preservation. Variation in outcome reporting, especially functional outcomes at follow- up has limited our analysis in determining the relationship between graft survival and post infective graft function. Hence, based on the available evidence we cannot reliably conclude that graft salvage truly equates to long term graft survival and good graft function. Also, infection may not have been completely eradicated in all cases of graft salvage, as low grade infection may remain dormant without clinical symptoms.[37] Furthermore, some infected grafts may have failed but this may have been missed if the knee settled clinically, required no further debridement, and remained mechanically stable. Therefore the true salvage rate may be lower than our estimation.

Although these limitations require caution when interpreting our results, they are also understandable due to the nature of the condition, and the fact that decisions are usually based on clinical grounds and clinical progress. We feel that the pooling of a large number of cases, of an unusual complication, allows us to conclude on a pragmatic approach, despite the limitations encountered.

In conclusion, arthroscopic debridements combined with antibiotic treatment can lead to successful eradication of infection and graft salvage in about 85% of cases of septic arthritis following ACL reconstruction. Where functional outcomes have been measured following graft salvage, more than two thirds have stable knees and more than half have 'good' to 'excellent' Lysholm scores. A single arthroscopic debridement may suffice, but in resistant cases further arthroscopies may be needed, guided by clinical grounds and laboratory investigations. A minimum period of antibiotic treatment of four weeks is recommended, but longer duration may be necessary in more severe cases. Persistent infection despite repeat arthroscopic debridements requires graft removal with the intention of revision ACL surgery at a later stage.

Author contributions:
K. Kursumovic: Data collection, Analysis and writing article.
C. P. Charalambous: Data collection, Analysis and writing article.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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Errata

F. S. Haddad

From The British Editorial Society of Bone & Joint Surgery, London, United Kingdom

K. Kuršumović, C. P. Charalambous. Graft salvage following infected anterior cruciate ligament reconstruction.

Bone Joint J 2018;97-B:608–615.

We regret that the data for figure 3 were published incorrectly. The correct figure is published below:

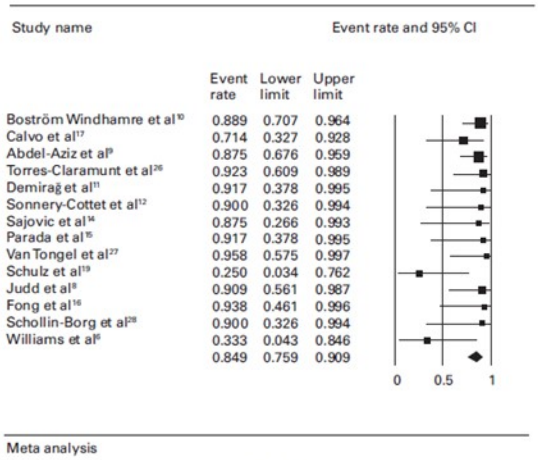

Fig. 3

Graft salvage rate including anterior cruciate ligament re-ruptures (heterogeneity: $tau^2 = 0.099$, $I^2 = 8.15\%$, Q = 14.15, df = 13, p = 0.36). (CI, confidence interval).

E. N. Hanley, G. Ode, J. B. Jackson III, R. Seymour. Coccygectomy for patients with chronic *coccydynia*.

Bone Joint J 2016;98-B:526–533.

We regret that the name of one of the authors was published incorrectly. The correct version is printed above.

M. P. Abdel, M. T. Houdek, C. D. Watts, D. G. Lewallen, D. J. Berry. Epidemiology of periprosthetic femoral fractures in 5417 revision total hip arthroplasties.

Bone Joint J 2016;98-B:468–474.

We regret that the data in Table I were published incorrectly. The correct table is printed below:

Table I. Risk of intra-operative periprosthetic fracture of the femur by cement status and type of uncemented stem

Variables	No. of fractures/No. of revision THAs (%)
Intra-operative (all)	668 / 5417 (*12.3*)
Uncemented	516 / 2781 (*18.6*)
Proximally coated	161 / 848 (*19.0*)
Fully coated	242 / 1213 (*20.0*)
Modular fluted tapered	113 / 720 (*15.7*)
Cemented	152 / 2636 (*5.8*)

THA, total hip arthroplasty

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Bone Joint J 2016;98-B:1151–1152.

c. Contribution to knowledge

This article contributed to the literature in that it provided robust evidence as to the effectiveness of antibiotic treatment and arthroscopic washout/debridement with graft salvage in dealing with this complication. This was unique in that it provided evidence based on a substantial number of studies and ACL reconstruction procedures, giving the clinician confidence when relying upon the results.

d. Article limitations

The aim of the article was stated in the introduction but specific hypotheses to be tested were not presented. There was a description of the design of the articles included in the analysis, and a discussion as to the limitations of their design, especially when considering retrospective observational studies. However, a formal bias assessment or quality evaluation was not performed.

The generalisability of the study's findings are limited as this meta-analysis looked at graft salvage in the management of only bacterial septic arthritis after ACL reconstruction using a hamstring tendon graft. Hence, its findings may only directly apply to bacterial infections of hamstring grafts and not to infections due to other microorganisms, such as fungal organisms which may also be encountered in clinical practice or infections of other graft types. However, as bacterial septic arthritis is the most common type of septic arthritis encountered after ACL reconstruction, and as hamstring tendon grafts are commonly used grafts, the findings of this study are still relevant to a large part of the orthopaedic surgical community.

Although the effectiveness of arthroscopic debridement, antibiotic treatment and graft salvage with regards to eradicating infections was determined, there was sparse data as to the clinical outcomes of patients treated in that way. The quality of such data was also limited as most of the included studies were retrospective and of low-level evidence. Although data on knee function and stability were presented, this was done in a descriptive way, and they were not statistically pooled, although a meta-analysis could have been conducted allowing greater confidence in the conclusions drawn.

e. Relevant work since the article was published

Since the publication of this article 3 further studies evaluated the outcomes of graft preservation in managing septic arthritis post ACL reconstruction and their findings were in line with the results of the examined article (Kuršumović and Charalambous, 2016). These studies also provided information on the clinical outcomes of such patients which can further improve our understanding as to functional status of patients who have graft salvage.

The first of these assessed a standardised protocol of graft salvage for the management of knee joint infection after ACL reconstruction (Otchwemah, 2019). The protocol involved arthroscopic lavage and debridement of the knee along with 6 weeks of antibiotic treatment. Arthroscopic washout was performed at least twice and repeated every 2 days until clinical signs of infection resolved. Forty-one patients were admitted with infection at a mean of about 14 (±8) days post ACL reconstruction and were assessed for up to about 10 months. Microorganisms causing the infection were identified in 34 (83%) cases, with coagulase-negative staphylococci seen in 28 (82%) of these. Patients had an average of 3.8 (± 1.4) washouts. The authors showed that by repeated arthroscopic washout and antibiotic treatment it was possible to treat the infection and preserve the graft in 37 of 41 (90%) of cases with no infection relapse. The authors referred to a minor limitation of knee function observed in one of their cases and instability in four cases, but a high-quality objective clinical functional assessment was not presented.

The second study explored the clinical outcomes of military personnel in the USA treated for septic arthritis after ACL reconstruction with or without graft retention (Waterman et al., 2018). The authors of that study looked at 31 cases of septic arthritis that had urgent arthroscopic washout at a median of about 5 weeks post ACL reconstruction. ACL reconstruction had been performed in 17 cases with a hamstring autograft, in 11 with an allograft, and in 3 with a patellar tendon autograft. The graft was salvaged in 22 cases (71%), whilst 9 cases (29%) had early graft resection. The mean follow up was 26.9 months. Three patients with salvaged grafts had laxity and opted for revision ACL reconstruction. However, only twelve of 22 (55%) of patients with graft salvage returned to military function mainly due to continued pain or instability. The development of symptomatic post-infection arthritis and arthrofibrosis were associated with inability to return to active military duty. These findings suggested that at least when it comes to high demand activities, such as those in military duty, graft salvage may not equate to acceptable knee function.

The third study looked at subjective and objective clinical outcomes of patients treated with arthroscopic washout for septic arthritis following isolated ACL reconstruction at a single institution in Germany (Pogorzelski et al., 2018). According to the authors' protocol when dealing with septic arthritis following ACL reconstruction the graft was retained wherever possible, but graft removal was done in high stage infections and when the graft integrity was compromised by the infection. Patients were categorized into 2 groups, one group of 21 cases with graft retention and a second group of 12 cases with initial graft removal. At an average follow up of about 55 months patients who had graft retention reported better subjective and objective outcome measures including the Lysholm and IKDC knee scores as compared to those who had graft removal. Magnetic resonance imaging showed lower rates of cartilage damage and meniscal tears among patients with graft retention versus graft resection. The authors of that study concluded that graft-retaining should be the aim in the management of septic arthritis following ACL reconstruction.

f. Further research

Given the limitations described above, further work to systemically analyse the clinical outcomes of graft salvage may help shed further light as to the effectiveness of this approach in restoring knee function when dealing with septic arthritis following ACL reconstruction. In addition, although the above study assessed the clinical effectiveness of antibiotic treatment along with arthroscopic washout and graft salvage, there is limited evidence as to its cost implications, an area that future research may address.

CHAPTER 5 - COMPLICATIONS OF SUTURE BUTTON FEMORAL GRAFT FIXATION IN ACL RECONSTRUCTION

A. Background

In ACL reconstruction surgery the graft may be secured to the distal femur and to the proximal tibia in bone tunnels. There are several ways of holding the graft in the femoral tunnel. One of these is suspending the graft from the outer femoral cortex round a suspensory device known as a suture button. Although various versions of suture buttons are commercially available, they essentially involve a metal plate to which a closed loop is attached. The graft is passed around the loop and the plate suspends this construct from the outer cortex of the femur in the bone tunnel. The length of the loop may be non-adjustable and come in predetermined lengths, referred to as fixed length loop, or adjustable during surgery and referred to as variable length loop.

One of the pitfalls of suture button fixation is that the button may be misplaced in relation to the outer femoral cortex. The button may not be adequately seated on the outer femoral cortex with soft tissue interposed between the two. Alternatively, the button may not to be pulled completely out of the femoral tunnel and thus remain within the bone a position referred to as intraosseous. If the button is misplaced away from the femoral cortex the interposed soft tissue may necrose and break down which could then lead to movement of the button closer to the cortex. Such movement of the button is referred to as button migration and could cause graft laxity and knee instability. Similarly, an intraosseous located button may migrate into the knee joint and cause symptoms such as knee catching or locking.

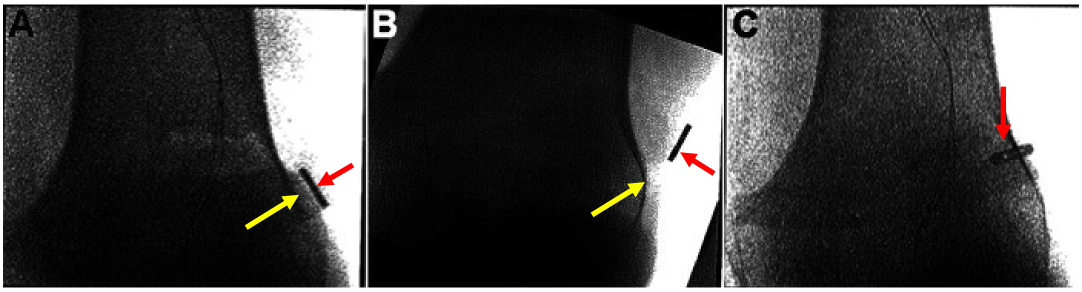

Figure 5.1 Intraoperative radiographs of the knee in ACL reconstruction. A – suture button (red arrow) appropriately seated on the lateral femoral cortex (yellow arrow). B- suture button (red arrow) misplaced away from the lateral cortex. C- suture button (red arrow) partially located in the femoral tunnel (intraosseous) (adapted from O'Brien et al., 2021).

Correct seating of the button on the femoral cortex may be determined during surgery by several methods of which two involve manual manoeuvres. The first of these manoeuvres is the alternate suture pull test which involves pulling alternatively on each of the passing sutures of the button whilst palpating for each end of the suture button pressing on the outer femoral cortex in an alternating fashion. The other is the pull-back test which involves pulling on the sutures of the distal part of the graft whilst visualising the graft in the knee to ensure it does not pull back out of the femoral tunnel. Alternatively, rather than using manual tests, the position of the button may be checked by direct visualisation using the arthroscopic camera or by intraoperative radiographic screening.

B. **Knowledge gap**

At the time of performing the study presented in this chapter there was a lack of systematic evaluation of reported complications related to the use of suture buttons for the femoral fixation of the ACL graft.

C. **Objective**

Given the knowledge gap, the objective of the study presented in this chapter was to determine the complications related to the use of femoral suture button graft fixation in ACL reconstruction surgery.

D. **Hypothesis**

To meet the objective described above the study presented in this chapter explored the hypothesis that suture button misplacement is one of the most frequently reported complications when using a suture button to fix the graft onto the femur in ACL reconstruction surgery.

E. **Commentary article 7 - *Complications following Suture Button Use for Femoral Graft Fixation in Arthroscopic Anterior Cruciate Ligament Reconstruction: A Systematic Review. Yassa R, Adam JR, Charalambous CP. J Knee Surg. 2021 Jun;34(7):755-763. PMID: 31905415.***

https://www.thieme-connect.com/products/ejournals/abstract/10.1055/s-0039-3400753. *doi: 10.1055/s-0039-3400753.*

a. Contribution by CP Charalambous

Developed the concept of the article, co-designed the methodology, contributed to data collection and analysis, and co-wrote the article

b. Article description - Full article

This study systematically assessed the spectrum of complications related to the fixation of the ACL graft onto the distal femur when using a suture button, as well as the consequences of such complications. The potential clinical importance of such complications and ways in which they may be avoided were discussed.

This study reported that suture button misplacement was the most frequently encountered complication. In most cases button misplacement was minimal and did not adversely affect clinical outcomes. However, in some cases suture button misplacement led to graft failure, irritation of the surrounding soft tissues, or mechanical knee symptoms such as instability and locking, and required further surgery. It was recommended that intraoperative screening or arthroscopic evaluation of the deployed suture button may reduce these complications. This study's findings supported the hypothesis that suture button misplacement is one of the most frequently reported complications when using a suture button to fix the graft onto the femur in ACL reconstruction surgery. A copy of the full article is presented next.

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Complications following Suture Button Use for Femoral Graft Fixation in Arthroscopic Anterior Cruciate Ligament Reconstruction: A Systematic Review

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J Knee Surg

Abstract

Understanding any potential complications that may occur in relation to the use of a suture button for femoral graft fixation in arthroscopic anterior cruciate ligament reconstruction can help raise awareness among surgeons and improve safety when using such implants. This is a systematic review of suture button related complications. A literature search was conducted using the PubMed, Embase, and CINAHL (Cumulative Index to Nursing and Allied Health Literature) databases from their year of inception until January 3, 2019. We included studies reporting on suture button related complications in their outcomes of femoral graft suture button fixation in anterior cruciate ligament reconstruction. Our search identified 479 articles, of which 19 met our inclusion criteria. Suture button misplacement (initial or subsequent migration) was the most commonly reported complication. Although, in most cases, button misplacement is minimal and does not adversely affect clinical outcomes, in some cases it may lead to graft failure or local soft tissue irritation and require further surgery. Intraoperative screening or arthroscopic evaluation of the deployed suture button may reduce this complication.

Keywords
- suture
- button
- anterior
- cruciate
- complication

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Anterior cruciate ligament (ACL) reconstruction surgery involves securing a graft to the distal femur and the proximal tibia through bone tunnels replicating the native ACL. This procedure can be associated with a broad range of intra-operative complications[1] depending on the exact technique used and the grafts fixation implants employed. There are several types of femoral graft fixation, one of which is suspension from the outer femoral cortex by means of a suture button. Various versions of suture buttons exist, produced by different manufacturers, but essentially they involve a metal plate to which a closed loop is attached. The graft is looped around the loop, and the plate is used to suspend this construct from the outer femoral cortex in the femoral graft tunnel. The loop may be of fixed length or variable length.

Understanding any potential complications that may occur intra- or postoperatively in relation to the use of a suture button for femoral graft fixation can help raise awareness among surgeons and improve safety when using such implants, inform patients as part of the consent process, and instate measures to minimize the risk of such complications occurring. The aim of this study was to carry out a systematic review of the described complications related to femoral suture button use in ACL reconstruction surgery reported in the literature and to recommend ways of avoiding them or dealing with them if encountered.

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Methods

Search Strategy

A literature search was conducted using the PubMed, Embase, and CINAHL (Cumulative Index to Nursing and Allied Health Literature) databases from their year of inception until January 3, 2019. Broad search terms were used and included combinations of the following keywords: "knee" and "endobutton" and "cruciate" and "knee" and "suspensory" and "cruciate." Language limits were not applied to the search. Article references were reviewed for any additional studies. The references of all included articles were also searched for any further relevant articles. The corresponding authors of selected articles were contacted for further clarification when deemed necessary.

Inclusion Criteria

We included original full articles, meeting proceedings, case reports, and case series reporting on complications in their outcomes of femoral graft suture button fixation in ACL reconstruction. Complication was defined as any complication related specifically to the suture button use. This covered technical complications and failures purely related to the suture button implants. Femoral tunnel widening was not considered a complication. In addition, general surgical complications and complications related specifically to tunnel placement were excluded. Failures of suture buttons due to further injury were also excluded.

Exclusion Criteria

Cadaveric studies and review articles were excluded.

Article Quality Evaluation

A critical appraisal of the included articles was undertaken using the MINORS (Methodological Index for Nonrandomized Studies). The tool evaluates 12 baseline criteria that define thorough and accurate reporting of noncontrolled studies.

Data Synthesis

Data were extracted using a standardized, predefined proforma. Details extracted included sample size, patient demographic data, type of suture button, surgical technique, follow-up period, time when complications were noted, knee stability, graft integrity, functional status, graft type, and procedural complications.

Results

Our search identified 479 articles, of which 19 met our inclusion criteria and were analyzed (►**Fig. 1**). Demographics of the cases are given in ►**Table 1**, and a summary of the complications identified are given in ►**Tables 2** and **3**. A cumulative list of all the complications encountered is shown in ►**Table 4**. Suture button misplacement (initial or subsequent migration) was the most commonly reported complication. Quality evaluation of the included studies showed that most were noncontrolled case series (►**Table 5**).

Discussion

Suture buttons are commonly used for femoral graft fixation during ACL reconstruction. Although multiple manufacturers have slight variations in their instrumentation and techniques, on the whole the surgical technique for femoral suture button fixation of the ACL graft has standard steps. It involves passing a guidewire through the knee into the lateral femoral condyle at a preselected point considered to be the center of the ACL femoral origin (inside-out technique), with the guidewire exiting the outer femoral cortex. The wire is overdrilled with a small diameter drill, and the length of the resultant tunnel (from the outer cortex to the inner cortex of the lateral femoral condyle) is measured. The guidewire is overreamed to create a femoral tunnel as per the size of the proposed reconstruction graft. It is advisable to leave at least 5 mm of the outer cortex unreamed to facilitate fixation of the suture button onto the outer cortex. Alternatively, the guidewire may be inserted from the lateral femoral cortex to the inner cortex exiting at the ACL femoral origin (outside-in technique), overdrilled, and then overreamed with a flip reamer in a retrograde manner.

There are two types of suture buttons commonly used to secure the graft onto the lateral femoral outer cortex. These are either fixed length or flexible length, which refers to whether the length of the loop attaching the suture button to the graft is of fixed or modifiable length. In the fixed-length type, the loop length dictates the tunnel length needed to accommodate the loop and graft, whereas in the flexible type, the loop length can be adjusted based on the achievable tunnel length. Various systems have different techniques for seating the suture button onto the outer cortex, but this usually involves a leading thread pulling the button through the tunnel followed by pulling a second thread to allow horizontal flipping (deployment) and seating of the suture button onto the lateral femoral cortex outside the femoral tunnel. When using the flexible length suture button, the leading thread is pulled first, and once the button is passed outside the cortex, the second string is pulled to shorten the loop and seat the suture button down against the lateral cortex of the femur. Confirmation of apposition of the suture button onto the outer cortex may be achieved by longitudinal traction on the graft, by pulling alternatively the passing and deployment sutures, radiologically by intraoperative X-ray screening, or by direct arthroscopic inspection.

Our systematic review has identified several complications related to suture button use in femoral graft fixation during ACL reconstruction, some occurring intraoperatively and some postoperatively. Among the intraoperative complications, breakage of the guidewire has been reported, the cause of which may be multifactorial, including wire bending by the surrounding soft tissues, drill or tunnel reamer, or movement at the knee. The wire may deform because of multiple attempts of passage, leading to the development of stress risers that predispose to breakage. The risk of breakage may be minimized by avoiding knee movement while the guidewire is placed across the knee and by ensuring that the cannulated drill and reamer slide easily over the guidewire without

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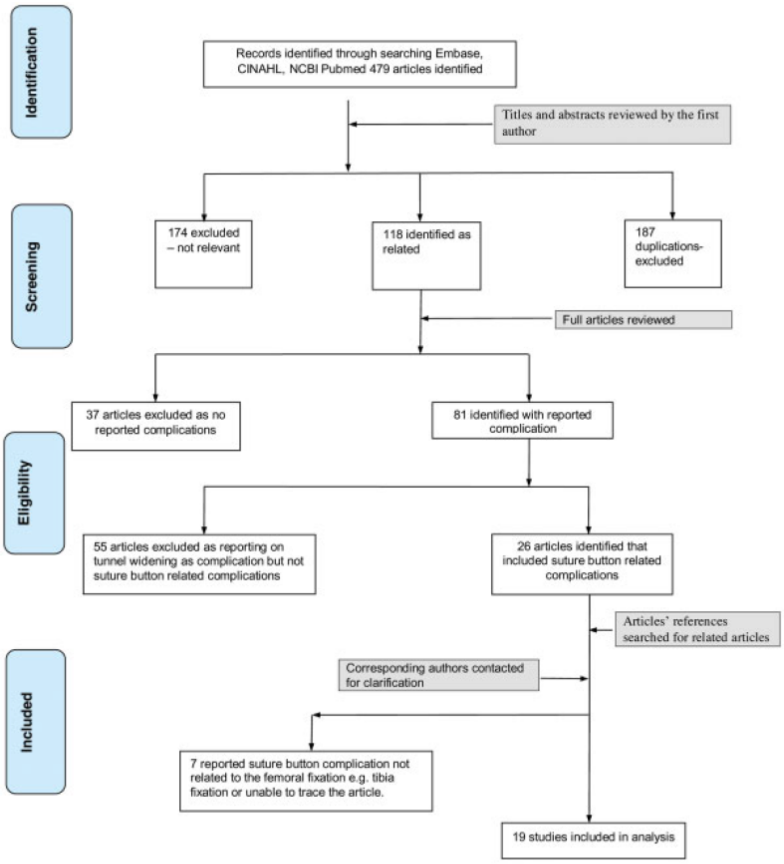

Fig. 1 Literature search results (PRISMA [Preferred Reporting Items for Systematic Reviews and Meta-Analyses] flowchart 2009). CINAHL, Cumulative Index to Nursing and Allied Health Literature.

bending or distorting it. Wire bending or partial disruption may necessitate its replacement before full breakage occurs. If such a wire breakage is encountered, the broken part is removed using arthroscopic or open means, with direct visualization or radiological guidance. A residual guidewire in the bone may be removed by overdrilling or overreaming.

Another widely reported complication of suture buttons is misplacement of the suture button in relation to the outer femoral cortex. This may occur at the time of surgery or because of migration at a later stage. As our results show, misplacement may be intra- or extra-articular, the latter being in the soft tissues away from the outer cortex or within the femoral tunnel.

Misplacement of the button away from the outer cortex may be due to intraoperative entrapment of soft tissue between the button and the bone surface. This may be more likely when using a flexible length suture button compared with a fixed-length suture button as the latter, if measured correctly, has enough length only to come out of the femoral tunnel. Such misplacement may be minimal with the button close to but not apposed to the outer cortex or may be substantial with the intramuscular location of the button. Postoperative migration may occur due to necrosis of tissue interposed between the button and the cortex or due to the graft stretching out, getting slacker, thus reducing the tension on the suture button, and allowing it to migrate. Some studies have reported migration of the suture button closer to the femoral cortex and some further away. Misplacement of the button in the soft tissues around the femur may cause local irritation or foreign bodylike reactions and necessitate implant removal. Apposition of the suture button on the outer cortex may be achieved by applying longitudinal traction on the graft while cycling the knee following suture deployment and may be confirmed by alternatively pulling the pull-through and deployment sutures, direct arthroscopic visualization (such as through a superolateral accessory arthroscopic portal), or intraoperative radiological screening.

Kim et al[8] reported five cases with inadequate seating of the suture button on the lateral cortex. These cases were discovered intraoperatively as skin retraction was observed when pulling the graft following button deployment. This complication was dealt with by intraoperative release of the

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Table 1 Demographics of the cases reported

Author	Study type	Exclusion	No of cases	Mean age, years	Sex	Type of SB	Mean FU	Technique
Yanmiş et al[2]	CR	NA	1	28	M	Not stated	2 y	Single bundle
Price et al[3]	RCT	Revision surgery Additional ligamentous injuries Degenerative changes/ chondral injury	13	26.4 (16–48)	NS	EB (S&N)	24 mo	Single bundle
Taketomi et al[4]	CS	Not stated	2	53 35	F: 1 M: 1	EB (S&N)	24 mo (F) 12 mo (M)	Double bundle
Kondo et al[5]	Cohort	Additional ligamentous injuries or bony/meniscal injury (concomitant or previous) Severe degenerative changes/chondral injury	46	24.5 (15–45)	F: 25 M: 21	EB CL (S&N) CL BTB (S&N)	24 mo	Double bundle
Brucker et al[6]	CR	Not stated	1	24	F	EB CL (S&N)	1 wk	Double bundle
Crawford et al[7]	CC	Previous surgery Missing information on graft type used in ACL reconstruction Older than 60 y	413	33 (13–60)	F: 268 M: 145	Not stated	6 mo	Single bundle
Kim et al[8]	CS	Additional ligamentous injuries or meniscal injury (concomitant or previous) Revision surgery	47	23.8 (19–38)	F: 46 M: 1	Not stated	18.7 mo	Double bundle
Karaoglu et al[9]	CR	NA	1	30	M	EB (Acufex)	22 mo	Single bundle
Mae et al[10]	CS	Additional ligamentous or chondral injury	101	30.2 (14–71)	F: 59 M: 42	EB (S&N)	12 mo	Double bundle
Muneta et al[11]	CS	Additional ligamentous injury	54	24 ± 7	F: 21 M: 33	Not stated	24 mo	Double bundle
Muneta et al[12]	CR	NA	1	25	M	EB (Acufex, S&N)	25 mo	Double bundle
Uchida et al[13]	CS	Additional ligamentous or chondral injury	77	31.2 (14–65)	F: 42 M: 35	EB (S&N)	12 mo	Double bundle
Lee et al[14]	TN	Not stated	23	Not stated	Not stated	EB (S&N)	9 mo	Double bundle
Ibrahim et al[15]	RCT	Not stated	98	28 (21–33)	Not stated	EB (S&N)	29 mo	Double bundle group: 50 Single bundle group: 48
Nag and Gupta[16]	TN	NA	NA	NA	NA	TightRope RT (Arthrex, Naples, FL)	NA	NS
Gelber et al[17]	CR	NA	1	16	M	XO Button (ConMed Linvatec, Largo, FL)	6 mo	Single bundle
Petit and Millett[18]	CR	NA	1	20	F	EB (S&N)	6 mo	Single bundle
Ho and Lee[19]	CR	NA	1	26	M	EB (S&N)	36 mo	Single bundle
Sargın et al[20]	CR	NA	1	22	M	Not stated	19 mo	Not stated

Abbreviations: CC, case–control; CR, case report; CS, case series; EB, EndoButton; F, female; FU, follow-up period; HT, hamstring tendons; M, male; NA, not applicable; NS, not specified; RCT, randomized controlled trial; S&N, Smith & Nephew (Andover, MA); SB, suture button; TN, technical note.

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Table 2 SB-related complications identified

Author	No of cases with complications	Complications	Time to complication recognition	Management	Graft integrity	Knee stability	Functional status	FU since injury
Yanmiş et al[2]	1	SB located intra-articularly	2 y	Nil	Minimal graft elongation	Lachman test positive Pivot shift test positive KT-1000 3 mm greater than the contralateral side	No subjective complaints	4 y
Price et al[3]	1	Broken SB guidewire	Intraoperative	Intraoperative wire retrieval	Not stated	Stable	Not stated	2 y
Taketomi et al[4]	2	ITB irritation In two cases (well-positioned SB)	1 y	SB removal at 2 y in both cases	Intact	Stable	Moderate pain in the lateral aspect of the knee	2 y
Kondo et al[5]	3	SB of the PL bundle graft flipped within the lateral vastus muscle	Intraoperative	Corrected intraoperatively by further dissection	Intact	Stable	No reported deficits	2 y
Brucker et al[6]	1	SB of the PL bundle located intra-articularly	1 wk	Removal of SB and PL bundle	Deficient PL bundle AM bundle intact	Stable	Not stated	Not stated
Crawford et al[7]	7 1	Painful SB site Painful SB site + arthrofibrosis	26 wk 26 wk	Hardware removal Hardware removal and manipulation under anesthesia	Not stated Not stated	Not stated Not stated	Complete resolution Complete resolution	Not stated Not stated
Kim et al[8]	5	SB seated off the lateral cortex	Intraoperative	Intraoperative release of the impinged muscle	Intact	Stable	No reported problems	1 y
Karaoglu et al[9]	1	SB seated in the femoral tunnel	1 d	Observation	Intact	Stable	Pain at the distal fixation site at 14 mo postoperative	14 mo
Mae et al[10]	51 71	SB seated off the lateral femoral cortex, i.e., >1 mm from the lateral femoral cortex SB migration (closer to the lateral femoral cortex)	Immediately postoperatively 1 y postoperatively	Observation	Not stated	Stable	No reported problems	1 y
Muneta et al[11]	54	Breaking of the posterior cortex of the lateral femoral condyle in two cases SB seated off the lateral cortex (some cases, number not stated)	Intraoperative Postoperative, timing not stated	Pullout fixation at the femoral site SB removal at 29 mo	Not stated Not stated	Not stated Not stated	Not stated Knee pain in one case (location not stated)	2 y
Muneta et al[12]	1	SB located intra-articularly	25 mo	Arthroscopic removal of SB	Intact	KT-1000 4 mm difference at 20 lb	Fear of turning while playing football	27 mo
Uchida et al[13]	37 SBs in 34 cases	SB migration	1 y	Observation	Not stated	Stable	No reported deficits	1 y

(*Continued*)

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Table 2 (*Continued*)

Author	No of cases with complications	Complications	Time to complication recognition	Management	Graft integrity	Knee stability	Functional status	FU since injury
Lee et al[14]	2	SB seating off the lateral femoral cortex	Not stated	Not stated	Not stated	Not stated	Not stated	Range: 4–18 mo
Ibrahim et al[15]	2	SB migration further away from the lateral femoral cortex	20–22 mo	Removal of SB	Not stated	Stable	Pain on flexion	Range: 25–38 mo
Nag and Gupta[16]	Not stated	SB in the tunnel SB seated off the outer cortex	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated
Gelber et al[17]	1	SB migration proximally and laterally, myxoid tumor development	6 mo	Resection of the myxoid tumor and removal of SB	Intact	Stable	PL knee mass and tenderness	2 mo postexcision
Petit and Millett[18]	1	Localized SB pain	6 mo	Removal of SB	Partial ACL graft tear	Stable	Pain in the superolateral aspect of the knee	Minimum 2 wk
Ho and Lee[19]	1	Intra-articular placement of SB	Immediate postoperative	Removal of SB and revision ACL reconstruction	Complete tear	Positive Lachman test and anterior drawer test	Instability and effusion	36 mo
Sargın et al[20]	1	Intra-articular placement of SB	19 mo	Removal of SB	Not stated	Positive Lachman test and anterior drawer test	Friction and pain	19 mo

Abbreviations: ACL, anterior cruciate ligament; FU, follow-up period; ITB, iliotibial band; PL, posterolateral; SB, suture button.

impinging muscle/soft tissue. The final position of the suture button on the lateral femoral cortex was confirmed by intraoperative radiographs.

The clinical significance of postoperative migration of the suture button in the surrounding tissues has been extensively investigated. Mae et al[10] examined whether tissue interposition had an effect on the migration of suture buttons and also whether button migration influenced clinical outcomes. They looked at cases of double-bundle ACL reconstruction, with femoral tunnels drilled using the outside-in technique. They defined soft tissue interposition as a distance of over 1 mm between the button and lateral femoral cortex on an anteroposterior radiograph obtained immediately after surgery. Migration was defined as movement of the button more than 1 mm along the femoral tunnel axis or rotation of more than 5 degrees at radiological examination 1 year postsurgery compared with immediately after surgery. They identified soft tissue interposition in 51 EndoButtons (~25%) of those examined, being more frequent in posterolateral bundle grafts, and described as being 1 to 2 mm in most cases. Migration was seen in 71 EndoButtons (~35% of those evaluated), being more frequent in those with initial soft tissue interposition. Neither soft tissue interposition nor migration was related to Lysholm score at 1 year or KT side-to-side difference. There were no cases of positive Lachman test, and the presence of a pivot shift glide was not related to interposition or migration. Uchida et al[13] studied the initial location and 1-year migration of EndoButtons used in double-bundle ACL reconstruction with femoral tunnels drilled using the outside-in technique. They used both anteroposterior and lateral knee radiographs and defined migration as in the study by Mae et al[10] The average distance from the center of the cortical button to the posterior wall of the femur on the lateral radiograph immediate postoperatively was 11.8 ± 12.7 mm. Of the EndoButtons examined, 37 (24%) migrated. Migration was seen more frequently in buttons of the posterolateral bundle that were seated posterior to the lateral supracondylar line, which may be related to multiple layers of soft tissue encountered in that area. Although migration was not related to clinical outcomes including Lysholm score, KT side-to-side difference, and Lachman or pivot shift tests, the authors recommended that femoral tunnels are drilled anterior to the lateral supracondylar line of the femur, especially if outside-in drilling technique is used. Hence, it may be concluded that small degrees of tissue interposition and button migration do occur in routine ACL reconstruction but do not adversely affect the clinical outcome in a substantial manner.

Misplacement of the suture button may also occur in the femoral tunnel or the knee joint. Intratunnel misplacement may be due to premature horizontal deployment of the button before it emerges from the outer cortex. Alternatively, it may be due to blowout of the outer cortex at tunnel reaming, which can, thus, not support the button, allowing its migration back into the femoral tunnel or knee joint. Such misplacement may affect the integrity of graft fixation, leading to instability symptoms, and, if migrated into the joint, may cause intra-articular pain or mechanical symptoms such as locking.

Karaoglu et al[9] presented a case of misplaced suture button into the femoral tunnel, which was discovered

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Table 3 Summary of the reported SB complications

Types of complications	Number	Authors
SB misplacement (initial or migration)	278	Yanmiş et al,[2] Kondo et al,[5] Brucker et al,[6] Kim et al,[8] Karaoglu et al,[9] Mae et al,[10] Muneta et al,[11] Muneta et al,[12] Uchida et al,[13] Lee et al,[14] Ibrahim et al,[15] Nag and Gupta,[16] Gelber et al,[17] Ho and Lee,[19] Sargın et al[20]
Intraoperative instrument breakage	2	Price et al,[3] Lee et al[14]
Breaking of the posterior cortex of the femoral tunnel in the posterolateral bundle	2	Muneta et al[11]
Pain and soft tissue irritation	12	Taketomi et al,[4] Crawford et al,[7] Petit and Millett,[18] Muneta et al[12]
Myxoid tumor (reactive)	1	Gelber et al[17]

Abbreviation: SB, suture button.

Table 4 Location of SB misplacement

Location	Number	Author
Intra-articular	5	Yanmiş et al,[2] Brucker et al,[6] Muneta et al,[11] Ho and Lee,[19] Sargın et al[20]
In femoral tunnel	1	Karaoglu et al[9]
Displacement outside the femoral tunnel		
SB within the lateral vastus muscle	3	Kondo et al[5]
SB not seated on the outer cortex	58	Kim et al,[8] Mae et al[10] Lee et al[14]
SB migration from the initial location	111	Mae et al,[10] Uchida et al,[13] Ibrahim et al,[15] Gelber et al[17]

Abbreviation: SB, suture button.

radiologically at 1 day postsurgery. At follow-up, no adverse outcome was reported and the integrity of the graft was maintained. Yanmiş et al[2] described a case in which the suture button was in the correct position, as confirmed by the postoperative radiographs. However, at 2-year follow-up, the suture button was radiologically found to be in the knee joint but without causing any symptoms. In contrast, Muneta et al[11] reported a case of intra-articular location associated with symptoms of instability. Along similar lines, Ho and Lee reported a case of intra-articular placement of the suture button associated with graft tear and instability. Sargin et al[20] reported a case presenting with knee pain, crepitus, and laxity and found to have a misplaced suture button on the femoral trochlear groove, which was then removed.

We recommend inspecting the femoral tunnel, by placing the arthroscopic scope close to its articular aperture before the graft is pulled through, to check that there is no bony debris that may hinder the passage of the graft or cause premature deployment of the suture button in the tunnel. Such visualization may also confirm that the outer cortex has not been reamed (blowout). If blowout of the outer femoral cortex is encountered, use of a longer suture button (extended suture button) may allow its secure fixation over a larger outer aperture. Alternatively, supplementary aperture fixation with an interference screw may be employed. As described previously, emergence of the suture button out of the femoral tunnel may be confirmed by pulling alternatively the pull-through and deployment sutures, direct arthroscopic visualization, or intraoperative radiological screening. If the suture button is found intraoperatively to de deployed within the femoral tunnel, every attempt should be made to retrieve it, but if that is not possible and it is felt that there is adequate graft in the tunnel, supplementary fixation with an interference aperture screw is recommended.

The main limitation of this systematic study is the design of the included studies, most of which were case series or case reports; hence, the rate of suture button related complications cannot be determined. Although it is highly likely that the published reports reflect only a small proportion of those complications encountered in clinical practice, we feel that it serves its aim of describing the spectrum of potential complications and providing guidance on how to minimize their occurrence and how to deal with them. Future evaluations of the effectiveness of some of the recommended preventive measures would be of great value.

In summary, this systematic review has identified the spectrum of suture button related complications that are described in the literature for ACL reconstruction. Awareness of such potential complications may allow planning to help reduce their occurrence and correct them or minimize their effects when encountered. Our findings suggest that although in many cases suture button related complications do not adversely affect the outcome of ACL reconstruction, in some cases they may confer substantial morbidity to the patient and require further surgery. Button misplacement is

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Table 5 MINORS

Author criteria	Yanmiş et al[2]	Price et al[3]	Taketomi et al[4]	Kondo et al[5]	Brucker et al[6]	Crawford et al[7]	Kim et al[8]	Karaoglu et al[9]	Mae et al[10]	Muneta et al[11]	Muneta et al[12]	Uchida et al[13]	Lee et al[14]	Ibrahim et al[15]	Nag and Gupta[16]	Gelber et al[17]	Petit and Millett[18]	Ho and [19]	Sargın et al[20]
Clearly stated aim	NA	2	NA	2	NA	2	1	NA	2	1	NA	2	NA	2	NA	NA	NA	NA	NA
Inclusion of consecutive patients	NA	0	NA	2	NA	2	1	NA	1	2	NA	2	NA	0	NA	NA	NA	NA	NA
Prospective collection of data	NA	2	NA	2	NA	0	1	NA	1	2	NA	1	NA	2	NA	NA	NA	NA	NA
End points appropriate to the aim of the study	NA	2	NA	2	NA	1	2	NA	2	2	NA	2	NA	2	NA	NA	NA	NA	NA
Unbiased assessment of study end points	NA	0	NA	0	NA	0	0	NA	0	0	NA	0	NA	1	NA	NA	NA	NA	NA
FU period appropriate to the aim of the study	NA	2	NA	2	NA	2	2	NA	2	2	NA	2	NA	2	NA	NA	NA	NA	NA
Lost to FU < 5%	NA	0	NA	0	NA	2	2	NA	0	0	NA	2	NA	0	NA	NA	NA	NA	NA
Prospective calculation of study size	NA	2	NA	0	NA	0	0	NA	0	0	NA	0	NA	0	NA	NA	NA	NA	NA
Adequate control group	NA	2	NA	2	NA	2	0	NA	0	0	NA	1	NA	2	NA	NA	NA	NA	NA
Contemporary group	NA	2	NA	1	NA	1	0	NA	0	0	NA	2	NA	2	NA	NA	NA	NA	NA
Baseline equivalence of groups	NA	2	NA	2	NA	2	0	NA	0	0	NA	2	NA	2	NA	NA	NA	NA	NA
Adequate statistical analysis	NA	2	NA	2	NA	2	2	NA	2	2	NA	2	NA	2	NA	NA	NA	NA	NA
Total	NA	18	NA	17	NA	16	11	NA	10	11	NA	18	NA	17	NA	NA	NA	NA	NA
	Case report		Case report		Case report			Case report			Case report		Technical note		Case report	Case report	Case report	Case report	Case report

Abbreviation: FU, follow-up period; MINORS, Methodological Index for Nonrandomized Studies; NA, not applicable.

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the most common reported complication, and intraoperative screening or direct arthroscopic visualization may help reduce its occurrence; we would recommend these in routine clinical practice.

Conflict of Interest
None declared.

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c. Contribution to knowledge

This article contributed to the literature as it provided a systematic rather than an anecdotal assessment of complications related to femoral suture button fixation of the ACL graft and the potential clinical consequences of such complications. It aimed to inform surgeons that suture button related complications, and in particular misplacement of the suture button, need to be considered in preoperative planning and as part of the intraoperative technique. The article also provided guidance about how to minimise suture button complications and how to deal with them, such as with intraoperative radiological screening or arthroscopic confirmation of button placement. The information gathered also aimed to inform physiotherapists and other allied health professionals that suture button misplacement may be a cause of ongoing symptoms during rehabilitation of the ACL reconstructed knee. Its strength originates in that it combined the surgical experience of practising surgeons with an up-to date evidence base review.

d. Article limitations

There are certain weaknesses of this study. The background, clinical problem and overall aim were well described, but specific hypotheses to be tested were not presented. In addition, there are several methodological limitations. The study's protocol was not prospectively published and data was not extracted by two independent reviewers. Although a bias assessment tool was applied to the studies considered, there was no formal assessment of the quality level of evidence presented. In line with this most of the included studies were of low-level evidence being case series and case reports. The generalizability of the findings of this study are also limited as this review looked only at complications of suture buttons used for the fixation of the ACL graft to the distal femur and not to the proximal tibia.

e. Relevant work since the publication of this article

Since this article's study was carried out, several other studies have looked at suture button related complications. These studies build further on the evidence provided in the above article (Yassa, Adam and Charalambous, 2021) by describing the rate of button misplacement and assessing the potential relation between button misplacement with subsequent button migration and clinical outcomes. Furthermore, they evaluated the role of various techniques to minimise button misplacement. As elaborated below these studies demonstrated that button misplacement is commonly encountered and in many cases is substantial, with the suture button located more than 2 mm away from the femoral cortex or located in the femoral tunnel. However, as discussed below, there is still controversy as to the effects of such button misplacement and subsequent migration on clinical outcomes.

In one of these studies 361 primary ACL reconstructions were assessed for suture button misplacement (Toftoy et al., 2019). The postoperative button position was described on plain radiographs as reduced and congruent with the entirety of the button located at <2 mm from the femoral cortex, reduced and incongruent with part of the button located at <2 mm from the cortex but part of the button being at >2 mm from the cortex, displaced with the entirety of the button located at >2 mm from the femoral cortex, intraosseous whereby all or part of the button remained within the bone tunnel, or ungradable. A total of 312 buttons (86%) were found to be reduced and congruent, 18 (5%) reduced and incongruent, 10 (3%) displaced, 13 (4%) intraosseous, and 8 (2%) were classed as ungradable.

In another series of 156 ACL reconstructions the distance between the centre of the suture button and the lateral femoral cortex was measured on the first postoperative day using plain radiographs (Gürpınar et al., 2020). Cases with less than 1 mm distance were classed as Group 1 (118 cases), those with 1-2 mm as Group 2 (30 cases) and those with more than 2 mm as Group 3 (8 cases). Migration was considered as movement of the suture button of more than 1 mm along the femoral tunnel axis on anterior-posterior radiographs or as rotation on lateral radiographs. At follow up, 11 suture buttons (9%) in Group 1, 26 (87%) in Group 2 and all 8 (100%) in Group 3 were shown to have migrated. Clinical evaluation showed no significant difference between Groups 1 and 2 but clinical outcomes were significantly worse in Group 3 compared to Groups 1 and 2 ($P < 0.05$). Based on these findings it was concluded that soft tissue interposition is a major cause of suture button migration and soft tissue interposition greater than 2 mm can negatively affect ACL reconstruction clinical outcomes.

Along similar lines the effect of soft tissue interposition on button migration and clinical outcomes was assessed in 84 patients who had anatomical single-bundle ACL reconstruction with quadruple hamstring autograft (Buyukkuscu et al., 2020). These were divided into 2 groups according to the presence or absence of soft tissue interposition and hence button misplacement between the suture button and femoral cortex. At one-year post-surgery button migration was observed in 12 patients with soft tissue interposition (38%) and in 2 patients (4%) with no soft tissue interposition which showed a statistically significant difference ($P < 0.001$). However, in this study (Buyukkuscu et al., 2020), unlike in the one above (Gürpınar et al., 2020), no significant difference was observed between patients with and without tissue interposition or between those with and without button migration regarding knee stability parameters and clinical outcomes. The study's authors concluded that postoperative tissue interposition is associated with post-surgical button migration, but this is often minimal and does not compromise clinical outcomes.

Several studies have also looked at the effectiveness of intraoperative means of assessing the correct seating of the suture button in relation to the outer femoral cortex. The reliability of the manual resistance manoeuvre when applying distal tension to deploy the suspensory button along the lateral cortex of the femur was assessed in 51 ACL reconstructions carried out by 3 sports medicine fellowship–trained orthopaedic surgeons at a single centre (O'Brien et al., 2021). In using the manual resistance manoeuvre the graft was pulled distally with a strong force to deploy the button and secure it against the outer femoral cortex. Suture button positioning was then assessed by intraoperative radiographic screening. In that series 38 (74%) of the cases had correct suture button positioning as determined by intraoperative screening but 8 (16%) had interposed soft tissue and 5 (10%) had an incompletely flipped button. In all cases where button misplacement was identified it was rectified intraoperatively. Based on the observed high rate of inadequate suture button deployment the authors recommended that the position of the button should be routinely checked intraoperatively to minimise the risk of misplacement.

Two studies looked at the role of arthroscopic confirmation of the positioning of a suture button. The first of these was a retrospective clinical study which examined whether confirmation of deployment of an adjustable-loop femoral button by direct arthroscopic visualization increased the rate of contact between the button and outer femoral cortex, and then whether this influenced clinical outcomes (Sohn et al., 2020). In that study 32 cases had a blind button deployment technique in which button deployment was not directly visualised. These were compared to a group of 33 cases in whom the button was arthroscopically visualised. Cortical contact was defined as either contact of both ends of the button with the femoral cortex or contact of the central area with the femoral cortex, or a gap between the button and the cortex of 1 mm or less at more than two-thirds of the length of the button. Cortical non-contact was defined as a gap of more than 1 mm at more than two-thirds of the button. The shortest distance from the centre of the button to the femoral cortex was described as the gap distance. No significant difference was observed in the rate of femoral cortical contact between the 2 groups immediately post-surgery, with 56% of cases showing contact in the blind technique group versus 55% in the direct visualization group. Similarly, no significant difference was observed in the rate of femoral cortical contact between the 2 groups at 2 years post-surgery, with 78% of cases showing contact in the blind technique group versus 82% in the direct visualization group. At 2 years post-ACL reconstruction there was no statistical difference between the 2 groups with regards to knee stability and functional outcomes. On the basis of these findings, it was concluded that confirmation of femoral button deployment by arthroscopic visualisation is not beneficial. However, this study (Sohn et al., 2020) showed that in both groups up to 45% of cases were misplaced and did not have the desired button contact with the femoral cortex. Furthermore, the gap distance was greater than 2mm in 29% of the blind technique group and in 20% of the direct visualization group. The higher rate of cortical contact observed at 2 years post-surgery as compared to that seen immediately after surgery suggested that button migration occurred in a large proportion of cases.

The second study which looked at the role of the direct visualisation technique in confirming correct button seating was a randomised trial (Matassi et al., 2021). In that trial patients were allocated into two groups one of which had postoperative radiographs to assess button position and another which had arthroscopic exploration and visualisation of the button intraoperatively followed by postoperative radiographs. On the postoperative radiographs soft tissue interposition between the button and femoral cortex was seen in 9 of 112 cases (8%) of the first group but in none of 81 cases of the direct visualisation group. In 8 of the 9 cases with soft tissue interposition in the non-visualisation group the button was misplaced more than 2mm from the outer cortex, and in one case the button was intraosseous. In 6 cases (7%) of the visualisation group soft tissue interposition between the button and femoral cortex was identified during surgery and removed arthroscopically, hence the button was in close contact with the cortex in all radiographs.

It is of interest that the two studies evaluating the role of arthroscopic confirmation of the positioning of a suture button gave conflicting results, with the first (Sohn et al., 2020) suggesting no substantial benefit and the second (Matassi et al., 2021) suggesting that arthroscopic visualisation of the button is a clinically important assessment. The exact way that the 2 studies carried out the arthroscopic assessment of the suture button positioning may explain the discrepancy in their findings. In the first study (Sohn et al., 2020) the button position was simply visualised to see if it was deployed and whether it was positioned away from the bone, with no dissection performed to identify the surface of the femoral cortex and ensure the button was in contact with that. In contrast, soft tissue dissection was performed in the second study (Matassi et al., 2021) which could have allowed more consistent apposition of the button onto the bone surface. It is thus possible that in the first study (Sohn et al., 2020) only large degrees of button misplacement could be detected, whilst in the latter study (Matassi et al., 2021) smaller degrees of misplacement could be identified and corrected. The observed differences may also have been due to the definitions used to evaluate button misplacement, with distances more than 1mm considered in the first study (Sohn et al., 2020) but more than 2mm in the second (Matassi et al., 2021).

f. Further research

There is a need to further assess systematically the rate of button misplacement and also its clinical relation, in particular the relation between the degree of misplacement and clinical outcomes. Building on the article presented (Yassa, Adam and Charalambous, 2021) future clinical studies may evaluate the clinical effectiveness and cost-effectiveness of various methods used by ACL reconstruction surgeons to assess button positioning. Methods to be assessed and compared include manual maneuverers like the suture pull test and the pull-back test, as well as intraoperative radiological imaging and intraoperative direct arthroscopic visualisation of the suture button.

CHAPTER 6 – COMPLICATIONS OF TIBIAL TUNNEL REAMING IN ACL RECONSTRUCTION

A. Background

In ACL reconstruction surgery a graft is often secured to the distal femur and the proximal tibia through bone tunnels. The tibial tunnel may be created using a reamer which is a power tool that has a round tip at the end of a shaft which rotates and removes the surrounding bone. Creation of the bone tunnel is often performed by starting the reaming on the outer cortex of the tibia and progressing into the knee joint. The graft is then pulled into the tunnel and secured in place. The graft may be held in place using an interference screw, that is a screw inserted in the tibial tunnel adjacent to the graft. The screw holds the graft in place by compressing it against the tunnel wall. In interference screw fixation a cylindrical tunnel is preferred so the screw can compress the graft against an intact tunnel wall. If the wall of the tunnel is deficient the compression of the graft by the screw may be compromised and lead to graft slippage whereby the graft slips past the screw. Graft slippage leads to loss of graft tension which can impair knee stability and function. Another related complication is screw migration whereby the screw moves in relation to its initial position in the tunnel. Screw migration usually occurs towards the outer cortex of the tibia leading to screw prominence and irritation of the surrounding soft tissues and skin.

The process of reaming the tibial tunnel usually involves the insertion of a thin wire referred to as guidewire into the bone. The guidewire is inserted in line with the desired position of the bone tunnel. A cannulated reamer, which is a reamer that has a central hole so the guidewire can pass through it, is then inserted over the wire. This arrangement aims to direct the reamer, so it reams the tunnel in line with the guidewire. However, during reaming it is possible to inadvertently bend the wire and thus deviate from the desired tunnel position.

There are various designs of ACL reamer commercially available which include the acorn and fluted reamers. The acorn reamer has a reaming head the size of which is equivalent to the tunnel diameter. Below the reaming head is a narrower smooth shaft. On the other hand, the fluted reamer has a reaming component which extends along a greater length. As the length of the reaming component varies between the two reamers, angulation of the reamer may affect the morphology of the outer aperture of the tibial tunnel in different ways.

It was previously shown (Goble, Downey and Wilcox, 1995) that a reamer with a short reaming head attached to a shaft of smaller diameter could be displaced anteriorly as it encountered dense tibial bone close to the knee joint surface. This is because the shaft had a smaller diameter than the reaming head and hence it could be displaced in the bone tunnel that had been created by the reaming head. Such displacement of the reamer may result in the articular surface aperture of the tibial tunnel being located more anteriorly than its optimal position. This places the ACL graft more anteriorly in the knee than its desired position which can lead to graft impingement on the femoral notch, graft stretching and poorer outcomes. It was proposed that a drill-head length of 25 mm was most effective at reducing such anterior displacement of the tibial tunnel aperture as this avoided a shaft which had a smaller diameter than the tunnel and thus could not be easily displaced. This led to the recommendation in surgical technique manuals to use a fluted reamer when reaming the tibial tunnel.

B. **Knowledge gap**

Prior to the study presented in this chapter there was a lack of knowledge as to the relation between the type of tunnel reamer and the resultant morphology of the tibial tunnel aperture in ACL reconstruction surgery.

C. **Objective**

Given the knowledge gap the objective of the study presented in this chapter was to determine whether the morphology of the tibial tunnel used in graft fixation in ACL reconstruction is influenced by the type of reamer utilised.

D. **Hypothesis**

To meet the objective described above the study presented explored the hypothesis that the morphology of the outer tibial tunnel aperture would change less when using an acorn reamer compared to a fluted reamer in creating the tibial tunnel, and in particular that the morphology of the outer tibial aperture would change less with the acorn reamer as compared with the fluted reamer if deviation between the reamer and guidewire were to occur.

E. **Commentary article 8 - *Comparison of Acorn and Fluted Reamers on Tibial Tunnel Outer Aperture Dimensions in ACL Reconstruction. Gerrard AD, Jump CM, Sutton P, Charalambous CP. J Knee Surg. 2022 Apr;35(5):534-538. PMID: 32898901.***

https://www.thieme-connect.com/products/ejournals/abstract/10.1055/s-0040-1716372. *doi: 10.1055/s-0040-1716372.*

a. Contribution by CP Charalambous

Developed the concept of the article, co-designed the methodology, contributed to data collection, guided on data analysis and co-wrote the article

b. Article description - Full article

This article presented a study that examined whether the type of reamer used in tibial tunnel creation during ACL reconstruction influences the dimensions of the tunnel's outer aperture. It assessed 2 commonly employed reamers used in antegrade tibial tunnel drilling, the acorn, and fluted reamers. Tunnels were created in artificial tibial bones by antegrade reaming over a guidewire using an 8 mm acorn or fluted reamer. Reaming was either in line with the guidewire or with an intentionally applied 10 degree deviation relative to the wire. The characteristics of the outer aperture of the tibial tunnel were compared between the 2 reamers. It was shown that the use of a fluted reamer created a distal aperture which was inconsistently sized, larger, and of oblong shape compared with an acorn reamer. These findings supported the hypothesis that the morphology of the outer tibial tunnel aperture would change less when using an acorn reamer compared to a fluted reamer in creating the tibial tunnel. In particular, the hypothesis that the morphology of the outer tibial aperture would change less with the acorn reamer as compared with the fluted reamer if deviation between the reamer and guidewire occurred was accepted. A copy of the full article is presented next.

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Original Article

Comparison of Acorn and Fluted Reamers on Tibial Tunnel Outer Aperture Dimensions in Anterior Cruciate Ligament Reconstruction

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J Knee Surg

Abstract

The aim of this study was to determine if the type of reamer used in tibial tunnel creation during anterior cruciate ligament (ACL) reconstruction influences the dimensions of the tunnel's outer aperture. Tibial tunnels were created in tibial saw bones by reaming over a guidewire using an 8 mm acorn or fluted reamer in an antegrade manner. Reaming was aimed either in line with the guidewire, or with 10-degree inferior/superior deviation in relation to the wire. The shape and size of the outer aperture of the tibial tunnel were compared between the two reamers. When using the acorn reamer, a 10-degree deviation in relation to the guidewire resulted in minimal change in outer aperture length (mean 13.6 vs. 15.6 mm, $p = 0.11$) and width (11.6 vs. 11.1 mm, $p = 0.51$). However, when using the fluted reamer, although the aperture width showed no substantial change with reamer/guidewire deviation (11.4 vs. 11.2 mm, $p = 0.71$), the mean length almost doubled (14.7 vs. 28.1 mm, $p = 0.002$). The use of a fluted reamer when reaming the tibial tunnel creates a distal aperture which is inconsistently sized, larger, and of oblong shape compared with an acorn-shaped reamer. This should be taken in consideration when using a fluted reamer for creating the tibial tunnel in ACL reconstruction.

Keywords

- anterior cruciate ligament
- surgical technique
- knee
- surgery

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Anterior cruciate ligament (ACL) reconstruction involves the creation of a tibial tunnel into which a tissue graft is placed and secured. The tibial tunnel is often created by reaming from the outer tibial cortex into the knee joint. A frequent method of tibial graft fixation uses an interference screw, inserted in the tibial tunnel adjacent to the graft, holding it in place by compression.[1] Interference screws may aim to fix the graft close to the proximal (intra-articular) aperture of the tibial tunnel or the distal (metaphyseal) aperture of the tunnel.

Complications of interference screw fixation include graft slip, screw migration, screw prominence, and local irritation, infection, or pretibial cyst formation. Ideal interference screw fixation involves creating a cylindrical tunnel that is symmetrical in its dimensions to aid interference screw fixation.

Reaming the tibial tunnel usually involves a guide to direct a guidewire over which a cannulated reamer is then passed. The insertion guide and guidewire are used to aim the reamer at a precise point within the joint. Changing the angle of the guide changes the length of the tunnel and the reamer diameter changes the tunnel diameter.

For accurate tunnel positioning, the aim is to ream in line with the initial guidewire orientation; however, during reaming, it is possible to bend the wire and deviate from the desired tunnel position. This can be caused by the surgeon's hand inadvertently moving or a deflection of the reamer due to soft

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tissue at the outer aperture of the tunnel or dense subchondral bone at the inner aperture.[2]

Differing designs of ACL tunnel reamers are commercially produced, these include the short block acorn reamer and the fluted reamer. The acorn reamer has a reaming head equivalent to the tunnel diameter and a narrower smooth shaft below this. In contrast, the fluted reamer has a consistent reaming component (equivalent to the tunnel diameter) which extends along a greater length. Some of the effects of these design differences have been previously reported, but additionally, we note that as the working length varies between the two reamers, angulation of these may effect on the outer aperture of the tibial tunnel in different ways.[3,4]

To the best of our knowledge, the effect of reamer design on the size and shape of the distal tibial aperture has not been previously reported and the aim of our study was to assess this.

Our hypothesis was that the morphology of the outer tibial aperture would change less with the acorn reamer compared with the fluted reamer when deviations between reamer and guidewire line occur. We designed a Sawbones model study to assess this.

Methods

Tibial Sawbones models were mounted in a reproducible position using a custom jig. The jig was made for the purposes of this study, and it provided a fixed guide for drilling the wires at a precise angle and an adjustable guide arm that supported the drilling of the guidewire and subsequent reaming at the predetermined angle (►**Fig. 1**).

The guidewire was inserted into the tibia using the guide, and either the 8 mm acorn or fluted reamer (►**Fig. 2**) was

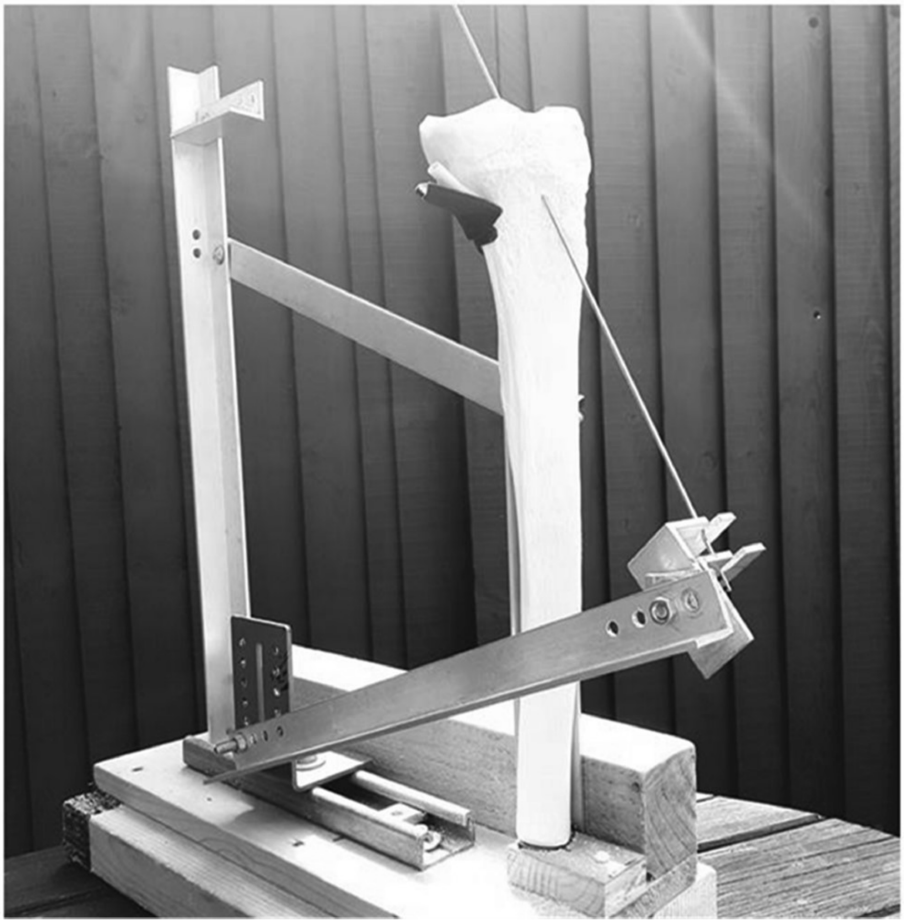

Fig. 1 Tibia Sawbones model on custom-made jig with guidewire in situ at the preset angle.

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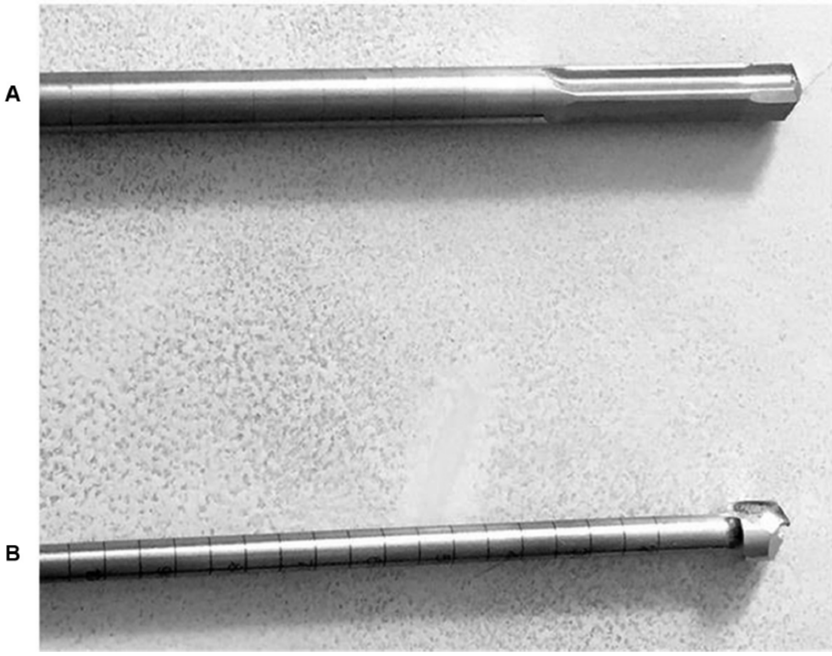

Fig. 2 (A) Fluted reamer featuring a wide reaming component that extends along its entire reaming length. (B) Acorn reamer with a narrower smooth shaft with wider reaming tip.

used to overream the wire to create the tibial tunnel using an antegrade (extra-articular to intra-articular) technique.

Twenty knee Sawbones were used. In the first 10, the angle of both the guide wire and reamers was set at 50 degrees. Five knees were randomly allocated to reaming using the acorn reamer and five to reaming using the fluted reamer.

For the second group of 10 knees, the guidewire was inserted into the tibia at 50 degrees but the reamer angle was set at 60 degrees, to replicate the surgeon dropping their hand while holding the reamer's driver. This reaming angle was measured using an electronic Digi-Pas angle measuring device. Five knees were again randomly allocated to reaming using the acorn reamer and five the fluted reamer.

After reaming, both reamer and guidewire were removed and the dimensions of the outer tibial aperture were measured, including length (caudal/cranial) and width (medial/lateral) using electronic measuring software (ImageMeter, https://imagemeter.com).

Mean and ranges for aperture width and length values were calculated for both reamers. Comparison of aperture length and width between the "in-line" and 10-degree offset reaming was made using nonpaired *t*-test with statistical significance assumed at the $p < 0.05$.

Results

There was no significant difference in aperture size when using the acorn reamer in line with the guidewire compared with 10 degrees of deviation of the reamer relative to the guidewire. Using the fluted reamer resulted in minimal change in the width of the tibial aperture but in contrast, a deviation of 10 degrees between reamer and guidewire resulted in almost double the length of the tibial aperture ($p = 0.002$) (►**Table 1**). The different shapes of the tunnel apertures are shown in ►**Fig. 3**.

Discussion

Good surgical technique is imperative for successful ACL reconstruction and to minimize the risk of revision surgery.[5] It is recognized that a crucial factor in successful ACL surgery is formation of an optimal tibial tunnel[6] and studies suggest that the majority of fixation failures occur at the tibial tunnel interface.[7] This is of particular relevance during the first 4 weeks after surgery when graft fixation has been demonstrated to be the weak component of the reconstruction.[8–10] When an interference screw is used to achieve fixation, it must be maintained in the correct position with minimal screw slippage until the graft has adhered into the bone to prevent graft failure.[11]

Several factors have been shown to affect the fixation strength of an interference screw including patient bone density, excessive early rehabilitation, screw material, use of a bone plug, and screw diameter and length. In addition to these factors, the difference between tunnel and screw diameters as well as tunnel shape influences graft fixation strength.[8,12–18]

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Table 1 Dimensions of the distal tibial aperture when using an acorn and fluted-shaped reamers at a standard 50-degree angle and with 10-degree deviation between reamer and guidewire

							Mean	*p*-Value
Length of aperture (mm)								
Acorn reamer	Standard 50-deg angle	13.0	14.7	13.4	13.1	13.7	13.6	0.11
	10-deg offset	19.3	13.7	14.5	16.5	13.8	15.6	
Fluted reamer	Standard 50-deg angle	13.6	12.6	16.5	16.0	14.6	14.7	0.002
	10-deg offset	22.2	18.1	27.7	22.9	21.5	28.1	
Width of aperture (mm)								
Acorn reamer	Standard 50-deg angle	12.4	11.2	11.5	11.0	11.9	11.6	0.51
	10-deg offset	11.7	9.8	11.0	13.2	10.0	11.1	
Fluted reamer	Standard 50-deg angle	11.6	10.7	12.0	10.9	11.8	11.4	0.71
	10-deg offset	11.4	10.5	10.5	11.7	12.1	11.2	

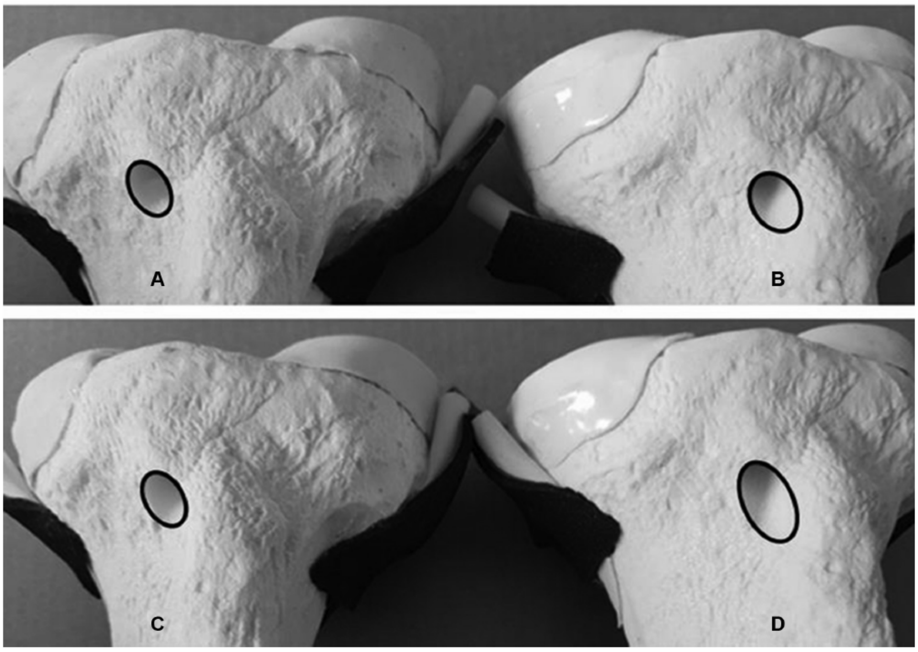

Fig. 3 Proximal tibia Sawbones demonstrating the differences in distal aperture size between use of the acorn reamer (A) and fluted reamer (B) at an angle of 50 degrees and the acorn reamer at 10-degree deviation (C) and fluted reamer at 10-degree deviation (D). Note the slight increased cranial–caudal length between the apertures of (A) and (B) but dramatic increase in length between (D) and all other apertures.

As tibial tunnel shape and diameter have been shown to affect graft fixation, it is important to understand how this is influenced by reamer design. It is known that the use of an acorn reamer can result in an inadvertent anterior displacement of the proximal tibial aperture thought due to the high cortical bone density between the spinous processes of the tibial eminence.[2] This may occur with the acorn reamer due the difference in diameter between its reaming tip and shaft allowing the narrower shaft to toggle in the tunnel reamed by tip. A fluted reamer which has a uniform reaming diameter along a much greater length may prevent this.

By contrast, tunnel aperture rim fractures have been reported as a complication of fluted reamers but not acorn reamers.[3] A study comparing five reamer models in porcine tibias reported that using an antegrade technique, a fluted reamer resulted in a 12.5% rate of proximal aperture rim

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fracture and 37.5% distal aperture rim fractures, an effect not seen with other reamer designs.[3] Fractures of the apertures may result in tunnel widening and subsequent graft failure. A further study demonstrated differences in tibial tunnel deformation between reamer designs when reaming the femoral tunnel if a transtibial technique is used.[4]

In our study, we noted that the dimensions of the tibial tunnel's outer aperture vary relative to the reamer's diameter, even when reaming was performed in line with the guidewire. We believe the likely explanation is that the reamer penetrates the outer cortical surface at an angle rather than perpendicular to it. This is supported by a previous study of the relationship between the tibial drill angle and the intra-articular bone tunnel aperture during ACL reconstruction. In this study, an 8-mm drill bit applied at a 55-degree angle to the tibial cortex created a 61.4-mm^2 aperture area and a 9.8-mm aperture length, whereas a 45-degree angle created a 71.1-mm^2 aperture area and an 11.3-mm aperture length.[19]

Our study adds to the literature as it shows that the type of reamer also influences the tibial tunnel's outer aperture shape and size. Specifically, we have demonstrated that when using a fluted reamer, relatively small deviations in angle have large effects on the size and shape of the outer tibial aperture. The consistency of the tunnels was also more erratic in the fluted reamer group compared with the acorn reamer.

During ACL surgery, the surgeon should be aware that the choice of reamer can have an adverse influence on the preparation of the tibial tunnel. There are potential disadvantages to both the fluted reamer and acorn reamer; however, we have shown that a further and previously unrecognized consideration is that the fluted reamer is more likely to lead to larger and more erratic tibial tunnel apertures. We believe this effect may have an influence on tibial graft fixation and advise surgeons using these reamers to carefully assess the tibial aperture intraoperatively and if necessary, modify tibial fixation of the graft.

We recognize the limitations of our study. We used Sawbones rather than human or animal tibiae; however, we feel this is unlikely to have had a material influence on our findings. We recognize that we only measured deviation from the guidewire at 10 degrees but think it unlikely that the tunnel aperture changes are only brought about by a 10-degree deviation and believe it is possible that greater deviations increase tibial aperture size and inconsistency. Finally, the effect of the changes in tibial tunnel aperture diameter is unclear and need further evaluation.

Conclusion

The use of a fluted reamer when reaming the tibial tunnel for ACL surgery creates an inconsistently sized and large outer tunnel aperture in comparison to an acorn reamer and this should be taken into consideration.

Conflict of Interest
None declared.

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c. Contribution to knowledge

This recent article contributed to literature in that it demonstrated that the type of reamer influences the morphology and dimensions of the outer aperture of the tunnel. It provided new evidence to challenge the usual recommendation of using the fluted reamer in creating the tibial tunnel and emphasised the need to exert caution if a fluted reamer is used. This could have important implications on interference screw fixation as it could weaken the fixation of the ACL graft on the tibial side leading to graft slippage or graft failure. Furthermore, it could predispose to backing out of the interference screw leading to local irritation of the soft tissues, cyst formation, and need for further surgery.

d. Article limitations

The main limitation was the use of artificial bones rather than cadaveric bones as the biomechanical properties of the 2 differ, including their hardness and strength. It is possible that the reamers were deflected more easily in the softer, weaker artificial bones, as compared to normal human bones of young patients undergoing ACL reconstruction. In addition, there was no formal assessment of the intra-and inter-variability with regards to confirmation of the drilling and reaming angles applied, as well as to the method used to measure the dimensions of the tibial outer aperture.

With regards to the analysis and presentation of results, the dimensions of the aperture between the in-line and 10 degrees offset reaming groups were statistically compared using non-paired t test. However, the number of artificial bones tested was small with only 5 in each group. In addition, no power calculation was performed. Hence, the lack of a statistically significant difference observed in some of the comparisons could have been due to type 2 statistical error, that is the inability to demonstrate a statistically significant difference when one exists. Similarly, there was no definition as to what was considered minimal important clinical difference in the dimensions of the outer tibial tunnel aperture. Given these limitations it might have been more appropriate to simply present the measurements without carrying out a statistical analysis, to acknowledge the uncertainty that exists in the findings.

The generalisability of the findings of this study is limited to the specific conditions applied in this study. The findings apply directly only to a 10-degree deviation between the guidewire and reamer, and the effect of other degrees of deviation have not been determined. The findings of this study also apply only to the 2 types of tunnel reamer used, with regards to the morphology and length of the reaming head. Similarly, the observed difference in aperture dimensions between the two reamer types apply to the 8mm diameter reamer and may differ with other reamer diameters.

The interpretation of the findings is limited by the methodology of the study. Although it was shown that the type of reamer influences the morphology and dimensions of the outer aperture of the tunnel, the mechanism by which this is achieved could not be established.

Although the length of the reaming component is considered to account for the observed differences, it is possible that differences in the shape of the reamer's head, which varies between the acorn and fluted reamers, may have contributed to the differences in aperture morphology. However, this parameter was not tested.

This study examined only the morphology of the outer aperture of the tibial tunnel rather than assessing the 3-dimensional construct of the tunnel created, and the effect on the location and morphology of the tunnel's intraarticular aperture. Such information would have allowed a more informed decision to guide the choice of the reamer type used in ACL reconstruction.

e. Further research

Although this article showed that the type of reamer is related to the morphology and dimensions of the outer aperture of the tibial tunnel in ACL reconstruction, several important questions remain unanswered.

There is a need to test the clinical implications of the variations observed in the examined study. Initially the relationship between the tibial tunnel's aperture morphology and the pull-out strength of the graft or interference screw used to fix the graft needs to be determined. This will allow an assessment of the minimum clinically important difference in aperture dimensions. The values of the aperture measurements obtained in this article, along with the minimum clinically important difference may then allow a power calculation to guide a further study comparing a wider variety of tibial tunnel reamers.

Further in-vivo clinical studies may also determine the relation between tunnel aperture morphology and the rate of postoperative tibial screw complications.

CHAPTER 7 – CONCLUSIONS

This commentary presented eight articles that explored the nature of complications seen in ACL reconstruction surgery, considered how such complications may be avoided through preventive measures, and how they can be managed once they occur. The evidence provided may enhance the ability of the surgeon to obtain a graft of adequate dimensions, minimise the risk of infection, and improve the graft fixation to the femur and tibia. This evidence may also guide the surgeon in how to manage postoperative infection. The studies of this commentary emphasise the need to recognise that surgical complications occur and that by discussing these and sharing experiences surgeons can learn from each other. To paraphrase a well-known saying, "A smart man or woman learns from their own pitfalls. A wise one learns from the pitfalls of others."

Based on the findings of the commentary's articles it is concluded that there are several anatomical variations of hamstring tendons to be considered during their harvesting (Charalambous and Kwaees, 2013) and that inadequate hamstring tendon harvesting is an unusual but recognised complication for which the surgeon needs to make alternative plans (Charalambous et al., 2021). The type of harvester used to obtain the graft may influence the harvested tendon's characteristics with a blade harvester giving a longer tendon and causing less soft tissue disruption as compared to a tendon stripper (Charalambous et al., 2009).

In relation to infection in ACL reconstruction it is concluded that hamstring tendons are associated with a higher infection rate as compared to patellar tendon grafts and allografts, but vancomycin graft presoaking of hamstring tendons is associated with a 10-fold reduction in this infection rate (Kuršumović and Charalambous, 2020). In dealing with bacterial septic arthritis following ACL reconstruction with a hamstring tendon graft, arthroscopic debridement along with systemic antibiotics and graft salvage is successful in eradicating infection in the vast majority (86%) of cases (Kuršumović and Charalambous, 2016).

It is also concluded that misplacement of the suture button is the commonest complication encountered when this type of device is used to fix the graft to the distal femur (Yassa et al., 2021). In addition, it is concluded that the type of reamer used to create the tibial tunnel for graft fixation may influence the morphology and dimensions of the tunnel's outer aperture with a fluted reamer creating a distal aperture which is inconsistently sized, larger, and of oblong shape compared with an acorn reamer (Gerrard et al., 2020).

These conclusions must be considered in the context of the methodological weaknesses of the commentary's articles as discussed in the individual chapters. Methodological weaknesses may limit the extent to which authoritative statements and recommendations are made based on the articles' findings. With hindsight, certain methodological limitations could have been addressed at the time of study design, but this must also be considered in the context of resource availability at the time the studies were carried out. Furthermore, even when the articles examined do not provide the definitive, authoritative answer, they provide original evidence which may be the foundation upon which, further, higher quality investigations may be performed. Despite the methodological limitations, the articles created new knowledge and presented original data which, with additional further work, could lead to improvements in clinical care.

The candidate maintains a high research activity alongside his clinical practice. The candidate currently leads multiple clinical studies both at the local level but also through national and international collaborations in his areas of clinical interest. The articles presented in this commentary identified several areas whereby further research is needed to provide evidence to fill current knowledge gaps, and the candidate is leading several projects to answer some of these questions. In particular, the candidate is leading a systematic review assessing the current evidence on the relation between vancomycin graft presoaking and graft re-rupture rates as well as clinical outcomes. In relation to this, the candidate is also leading a study to assess the feasibility of conducting a multicentre pragmatic randomised controlled trial comparing the clinical and functional outcomes between grafts presoaked in vancomycin vs. those presoaked in saline. If feasibility is established the candidate aims to apply for funding to the National Institute for Health and Care Research (NIHR) in the UK for such a trial. The candidate is also leading a systematic review and metanalysis to determine the relation between the degree of suture button misplacement and clinical outcomes, as well as a cost effectiveness study to assess the role of intraoperative radiological imaging in identifying suture button misplacement.

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Appendix 1 - List of all publications by CP Charalambous

Articles

1. Charalambous CP. Editorial Commentary: Double-Pulley Remplissage Using Transtendon Anchors: Keep It Simple. Arthroscopy. 2022 Mar;38(3):750-751. doi: 10.1016/j.arthro.2021.10.018. PMID: 35248228.

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Books - author

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Appendix 2: Confirmation statements of contribution by CP Charalambous to included studies.

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To Whom It May Concern

Re: Management of intraoperative complications in arthroscopic primary anterior cruciate ligament reconstruction. Charalambous CP, Alvi F, Sutton PM. J Knee Surg. 2015 Apr;28(2):165-74. doi: 10.1055/s-0034-1373739.

This is to confirm that Dr Charalambos P. Charalambous developed the concept of the above article, carried out the literature search, and led the writing of the article.

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<u>To Whom It May Concern</u>

Anatomical considerations in hamstring tendon harvesting for anterior cruciate ligament reconstruction. Charalambous CP, Kwaees TA. Muscles Ligaments Tendons J. 2013 Jan 21;2(4):253-7. PMID: 23738306

This is to confirm that Dr Charalambos P. Charalambous developed the concept of the above article, carried out the literature search, and led the writing of the article.

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To Whom It May Concern

Rate of insufficient ipsilateral hamstring graft harvesting in primary anterior cruciate ligament reconstruction. Charalambous CP, Kwaees TA, Lane S, Blundell C Mati W. J Knee Surg. 2021

This is to confirm that Dr Charalambos P. Charalambous developed the concept of the above article, designed the methodology, collected, analysed the data, and led the writing of the article.

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To Whom It May Concern

Hamstring tendon harvesting--Effect of harvester on tendon characteristics and soft tissue disruption; cadaver study. Charalambous CP, Alvi F, Phaltankar P, Gagey O. Knee. 2009 Jun;16(3):183-6. DOI: 10.1016/j.knee.2008.11.010. PMID: 1927278

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To Whom It May Concern

Relationship of Graft Type and Vancomycin Presoaking to Rate of Infection in Anterior Cruciate Ligament Reconstruction: A Meta-Analysis of 198 Studies with 68,453 Grafts. Kuršumović K, Charalambous CP. JBJS Rev. 2020 Jul;8(7):e1900156. DOI: 10.2106/JBJS.RVW.19.00156. PMID: 32759615

This is to confirm that Dr Charalambos P. Charalambous developed the concept of the above article, co-designed the methodology, contributed to data collection, carried out the data analysis (meta-analysis) and co-wrote the article.

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To Whom It May Concern

Graft salvage following infected anterior cruciate ligament reconstruction: a systematic review and meta-analysis. Kuršumović K, Charalambous CP. Bone Joint J. 2016 May;98-B(5):608-15. doi: 10.1302/0301-620X.98BS.35990. PMID: 27143730

This is to confirm that Dr Charalambos P. Charalambous developed the concept of the above article, co-designed the methodology, contributed to data collection, carried out the data analysis (meta-analysis) and co-wrote the article.

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To Whom It May Concern

Complications following Suture Button Use for Femoral Graft Fixation in Arthroscopic Anterior Cruciate Ligament Reconstruction: A Systematic Review. Yassa R, Adam JR, Charalambous CP. J Knee Surg. 2021 Jun;34(7):755-763. doi: 10.1055/s-0039-3400753. PMID: 31905415.

This is to confirm that Dr Charalambos P. Charalambous developed the concept of the above article, co-designed the methodology, contributed to data collection and analysis, and co-wrote the article.

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To Whom It May Concern

Comparison of Acorn and Fluted Reamers on Tibial Tunnel Outer Aperture Dimensions in Anterior Cruciate Ligament Reconstruction. Gerrard AD, Jump CM, Sutton P, Charalambous CP. J Knee Surg. 2020 Sep 8. DOI: 10.1055/s-0040-1716372

This is to confirm that Dr Charalambos P. Charalambous developed the concept of the above article, co-designed the methodology, contributed to data collection, guided on data analysis and co-wrote the article.

Kind Regards,

Mr Adam Gerrard

MBChB, MRCS

Date: 17.02.2022