Functional Outcomes of Anterior Cruciate Ligament Reconstruction Surgery

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Submitted for the higher degree of Doctor of Medicine (MD)

University College London

November 2019

Declaration

I, Ayman Gabr, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Ayman Gabr

Abstract

Anterior cruciate ligament (ACL) is one of the most common sports injuries with a reported yearly incidence rate of over two million injuries worldwide. The main aim of this thesis is to investigate various aspects related to the functional outcomes of ACLR through a series of clinical studies. Ethical approval was sought and granted by the North of Scotland Research Ethics Service.

A systematic review was conducted to investigate the outcome measures used in Level I and II clinical ACLR studies. The review showed wide variability in the outcome measures utilised with no consensus on the ideal outcome instrument or combination of instruments to report the outcome of ACLR. Five-year results from the UK National Ligament Registry (NLR) were analysed with review for limitations of registry data and future recommendations. The data analysed provided a comprehensive review for the demographics, surgical techniques and functional outcomes of ACLR surgery across the UK. NLR data is limited by multiple factors including high rate of incomplete data, duplication of data, poor patient compliance and lack of validation of the data.

A study was conducted to examine the hypothesis that patients with ACLR do not return to their pre-injury functional status at two years postoperatively. The study showed significant improvement in patient symptoms postoperatively compare to their post-injury scores, but the majority of patients failed to achieve their pre-injury functional outcome scores at 2 years postoperatively.

In a comparative study, the anteromedial portal (AM) technique in femoral tunnel drilling was compared with the trans-tibial (TT) technique with respect to radiological and functional outcomes. The hypothesis was that AM portal produces better functional outcomes compared with TT technique. We found that the AM portal achieved a more anatomical position of the graft but there was no difference between the two techniques in functional outcome at 2 years postoperatively. However, ACLR with the AM portal technique had higher graft failure rate compared with the TT technique.

The medium- term outcome of all-inside meniscal repairs was investigated in a longitudinal study. Meniscal repairs with concomitant ACLR had a lower failure rate compared with isolated meniscal repairs. This indicates that surgeons should have a low threshold for repairing meniscal tear during ACLR surgery.

The healing response technique was studied in a selected group of patients with complete proximal ACL tears. This technique yielded good functional outcome for most of the patients at 2 years postoperative follow up.

The studies included in this thesis provides substantial information for surgeons treating patients with ACL injuries. It provides a platform for further research studies investigating the outcomes of ACLR surgery.

Impact Statement

Anterior Cruciate Ligament (ACL) reconstruction surgery is one of the most commonly published topics in the orthopaedic literature. The research that was undertaken in my thesis has the potential to change the way clinician and researchers have been reporting on the outcomes of ACL reconstruction surgery. Most of ACL reconstruction studies utilise a comparison between the preoperative and postoperative patient reported outcome scores to assess the success of the surgical intervention. However, this overlooks the patients' functional status before sustaining the ACL injury. Moreover, this tends to overestimate the success of the surgical intervention when the outcome scores are compared to the post- injury pre-operative scores. In my thesis, we have compared the patient reported outcomes at different stages that are pre-injury, post-injury preoperative and 2 years postoperatively. We have found that most patients do not return to their pre-injury functional level, 2 years following ACL reconstruction surgery. This would encourage clinicians and researchers to change the methodology they use to report on ACL surgery outcomes and consider utilising pre-injury scores when reporting on their surgical outcomes.

In my thesis, we have reported on the medium-term outcomes of meniscal repairs with and without concomitant ACL reconstruction. We demonstrated better results for meniscal repairs that were carried out with concomitant ACL reconstruction. This would encourage surgeons to perform meniscal repair rather than partial meniscectomy when faced with a repairable meniscal tear during ACL reconstruction surgery.

The National Ligament Registry (NLR) has been set up to collect and store outcome data relating to ACL reconstruction surgery in the United Kingdom. The main aims of the registry are to collect essential demographic data, identify current or emerging trends, identify failing techniques or devices and provide functional outcome data. We analysed five-year results from the NLR since its launch in 2013. The results showed the epidemiology, current surgical trends and clinical outcomes of ACL reconstruction surgery. This represents a national reference for orthopaedic surgeons treating patients with ACL injuries. We also identified the current challenges facing the NLR and possible solutions that would improve data quality and enhance analysis of the information on the registry. This would ultimately raise the overall standards of care for the benefit of patients, clinicians, the National Health Service and industry.

Acknowledgement

First and foremost, I would like to thank my wife, Aisha, for her relentless support and patience during the completion of this work. I am deeply grateful for her time and efforts to support me during the journey of this thesis along with raising our son, Adam, who has been my inspiration to achieve greatness.

I would like to express my sincere gratitude and special thanks to my supervisor, Professor Haddad, for his endless support and guidance throughout my career. His encouragement and inspiration were above all a significant motivator to complete this work. I would also like to thank Mr. De Medici for his support and guidance.

I would also like to acknowledge my colleagues Miss Rosalind Tansey, Mr. Mohsin Khan, and Mr. Sunil Kini.

Finally, I am most thankful for my parents for their care, support and encouragement throughout my life.

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Abbreviations

ACL	Anterior cruciate ligament
ACLR	Anterior cruciate ligament reconstruction
AM portal	Anteromedial portal
BMI	Body mass index
CT	Computed tomography scan
EQ-5D	EuroQol 5-domain index
HRT	Healing response technique
ICF	International Classification of Functioning, Disability and Health
IKDC	International Knee Documentation Committee Subjective Knee Form
KOOS	Knee Injury and Osteoarthritis Outcome Score
LA	Lateral meniscus
LCL	Lateral collateral ligament
MCL	Medial collateral ligament
MM	Medial meniscus
MRI	Magnetic resonance imaging
NJR	National Joint registry of England, Wales and Northern Ireland
NLR	National Ligament Registry
OA	osteoarthritis
PCL	Posterior cruciate ligament
PROM	Patient reported outcome measure
ROM	Range of motion
SANE	Single Assessment Numeric Evaluation
SF-12	12-item Short Form Health Survey
SF-36	Short Form 36 health survey
TT	Trans-tibial
VAS	Visual Analog Scale for Pain
WHO	The World Health Organization
WOMAC	Western Ontario and McMaster Universities Osteoarthritis Index

Chapter 1

An Introduction to Anterior Cruciate Ligament Reconstruction Surgery

1.1 Introduction

Injuries to the anterior cruciate ligament (ACL) are common in sports with a reported incidence rate of between 36.9 and 60.9 per 100,000 persons per year (Gianotti et al., 2009; Parkkari et al., 2008). Adolescents and younger individuals are at increased risk for ACL injuries, and the incidence in males and females is highest between ages 15 and 34 (Renstrom et al., 2008). ACL tears are most commonly the result of a non-contact injury. The mechanism of injury is usually a combination of movements such as knee hyperextension and rotation or knee flexion, tibial external rotation and valgus (Brophy et al, 2010). Shimokochi and Shultz (2008) reported that there is a high risk for non-contact ACL injuries during acceleration and deceleration motions with excessive quadriceps contraction and reduced hamstrings contraction at or near full knee extension. Results from the United Kingdom National Ligament register showed that Football (soccer) was the most common sport activity associated with an ACL injury. Among men, the second most common activities associated with ACL injury were rugby followed by snow skiing. However, snow skiing was the most common activity associated with an ACL injury in women followed by netball and football (Gabr et al., 2015).

The treatment options for ACL tears include non-operative and operative management. The operative management include ACL reconstruction (ACLR) or ligament preservation surgery in the form of ACL repair. Non-operative treatment includes physiotherapy, supportive bracing and physical activity modification. In the acute phase following ACL injury, physiotherapy aims at reducing the knee swelling and restoration of knee range of movement. Cryotherapy and compression are often used to control the knee swelling. Knee hemarthrosis, following ACL injury, usually causes reflex inhibition of the quadriceps femoris muscle. If the patient's ability to actively contract the quadriceps muscle is limited, neuromuscular electric stimulation may be utilised at this phase of treatment to facilitate a normal quadriceps contraction (Hurd et al., 2009). Strengthening of both the quadriceps and the hamstring muscles is crucial to improve knee joint stability. The Quadriceps strengthening can be achieved through open kinetic chain (OKC) exercises or closed kinetic chain (CKC). In CKC, the foot is fixed to the ground while it is free in OKC. CKC exercises were often considered to be safer to utilise compared to OKC exercises as the latter produce larger anterior shear forces (Yack et al., 1993). However, Tagesson et al. (2008) demonstrated in a randomised controlled trial that OKC quadriceps exercises resulted in greater muscle strength compared to CKC exercises with no difference in static or dynamic tibial translation after rehabilitation. Therefore, both CKC and OKC exercises are often included in the rehabilitation regimen.

Conservative management of ACL injuries was often reported to be associated with relatively poor functional outcome (Hawkins et al., 1986; Kannus and Järvinen, 1987; Fithian et al., 2005). However, Frobell et al. (2010) showed in a randomized controlled trial that a strategy of rehabilitation plus early ACLR in young active adults with acute ACL tears was not superior to a strategy of rehabilitation plus optional delayed ACL reconstruction. The same authors later reported the five-year results of their study demonstrating that 50% of the patients who received rehabilitation and optional delayed ACLR did not require surgical reconstruction (Frobell et al., 2013). Mechanical knee stability was better in patients with early ACLR as measured with the Lachman and pivot shift test. However, functional results with patient reported outcome measures at five years did not differ between patients who received either early or late ACLR and those treated with rehabilitation alone. Smith et al. (2014) conducted a systematic review and metanalysis on clinical studies comparing operative versus nonoperative management of ACL injuries. They reported no significant difference in functional outcomes, including patient reported outcome measure and radiographic evidence of osteoarthritis, between the two treatment modalities.

ACL repair was historically associated with poor results (Engebretsen et al., 1988; Sherman and Bonamo, 1988). However, there is currently growing interest in re-exploring this avenue. ACL reconstruction is still considered to be the gold standard treatment for young and physically active patients with symptoms of instability attributed to the ACL injury, patients with multiple knee ligament injuries and those who remain symptomatic after a trial of non-operative treatment (Paschos and Howell, 2016). It is estimated that more than 200,000 ACL reconstructions (ACLR) are performed each year in the United States alone (Lyman et al., 2009). Abram et al.

(2018) studied the rate of ACLR procedures in the United Kingdom between 1997 and 2017. They reported an annual rate of 24.2 ACLR procedures per 100,000 population in 2016-2017 with a 12-fold increase in ACLR rate compared to 1997-1998. Advantages of surgical treatment include restoration of joint stability and minimizing the risk of joint subluxation that prevents further injuries to the menisci and articulating cartilage thus potentially delaying early onset of secondary degenerative changes in the knee joint (Moksnes and Risberg, 2009).

The ACLR surgery has significantly evolved over the last 50 years. This is mainly due to development in our understanding of the ACL anatomy and function. In this chapter, the history of ACLR is revisited with emphasis on the evolution of graft choices and surgical techniques.

1.2 Historical overview

1.2.1 Early years

The cruciate ligaments have been known about since old Egyptian times and their anatomy was described in the famous Smith Papyrus (3000 BC). Hippocrates also (460–370 BC) mentioned the subluxation of the knee joint with ligament pathology (Davarinos et al., 2014). However, the first to give a true description of the ACL was Claudius Galen; a Greek physician in the Roman Empire. Galen described ligaments as the supporting structures of diarthrodial joints and emphasized their role as joint stabilizers and their ability to restrict abnormal motion. In discussing the anatomy of the knee, he commented on the “genu cruciata” but did not describe its function (Snook, 1983). The first recorded description of rupture of the cruciate ligament in the literature was by Stark in 1850 (Stark, 1850). He treated two patients with bracing that resulted in apparent recovery but persistent slight disability. In 1875, the Greek Georgios Noulis gave a detailed description of what is now known as the Lachman test (Pawssler and Michel, 1982). In 1879, Paul Segond described an avulsion fracture of the anterolateral margin of the tibial plateau that is routinely associated with ACL tears. This fracture is now known as a Segond fracture and is considered pathognomonic for ACL tears (Davarinos et al., 2014).

1.2.2 Direct ACL repair

Although William Battle of St. Thomas in London was the first to publish the successful results of a single case of open ACL repair with a silk suture in 1900, the first repair of the ACL is attributed to Mayo Robson. in 1895, Robson performed suture repair for both the ACL and PCL in a 41-year-old miner who injured in an earthfall 36 weeks earlier. Six years later, the patient still described his knee as “perfectly strong” and he was able to walk afterwards without a limp (Robson, 1903). In 1913, Goetjes produced a detailed study of ruptures of the cruciate ligaments. He discussed ligament function and mechanisms of rupture, as determined by cadaver studies (Snook, 1983). He advocated surgical repair for the acute injury, replacement of the bony fragment rather than excision of the fragment in the avulsed tibial spine, and conservative management for the neglected cases and in elderly retired patients in whom the diagnosis was not clear. He was the first to suggest examination under anaesthesia when the clinical diagnosis was uncertain.

However, the results of direct suturing at that time remained doubtful and it was further criticized by prominent surgeons at that time. Hey Groves (1920) of Bristol disagreed with the concept of direct repair commenting that ‘‘… in all my cases the ligaments have been so destroyed … that direct suture would have been utterly impossible’’. Recognising the limitations of direct suturing, O’Donoghue (1950) reported his technique of ACL repair that consisted of a suture weave through the tibial stump and passing it up through a femoral tunnel followed by postoperative immobilization for 4 weeks with the knee held at 30°.

Surgical techniques of ACL repair continued to develop with good clinical results reported by MacIntosh and Marshall (MacIntosh and Tregonning, 1977; Marshall et al., 1979). Both devised a variation in the surgical technique of ACL repair with sutures being passed behind the lateral femoral condyle in a so-called ‘over-the top’ repair. Feagin et al. (1976) presented his 5-year results of 32 army cadets who underwent direct ACL repair. Although good functional results were observed initially, at 5 years almost all patients suffered some degree of instability with two-thirds experienced pain and 17 out of the 32 had sustained a re-injury during the follow-up period. Similarly, Engebretsen et al. (1990) reported poor long-term outcomes of ACL repair that further discouraged surgeons from routinely consider this surgical option. ACL ligament preservation surgery has come back to light over the last decade with new surgical techniques showing promising results; that will be discussed further in chapter 7 of this thesis (Perrone et al., 2017).

1.2.3 ACL reconstruction

1.2.3.1 Autologous fascia lata graft

It is believed that the first attempt of an anatomic reconstruction of the ACL was performed by Grekov in 1914. He operated on a 40-year-old man with knee dislocation following a fall from the third floor. He used a free fascia graft which passed through drill holes in the femur and stitched against the ligament remnants on the tibia with reportedly good results.

In 1917, Hey Groves published the first properly documented ACLR surgery. He detached a strip of fascia lata from its insertion in Gerdy's tubercle and directed it through a tunnel in the femur and tibia and stitched it to the periosteum of the tibia (Hey Groves, 1917). Hey Groves believed that by leaving the tendon attached to the muscle belly, blood supply and nutrition to the tendon would be preserved. Two years later, he reported on 14 additional cases where he modified his technique by leaving the graft attached to the tibia and detaching it at the upper end (Hey Groves, 1919). He also pointed out to the importance of oblique graft placement to improve rotational stability, a concept that took over 80 years to be widely recognised. Moreover, Hey-Groves described the anterolateral subluxation of the tibia, a phenomenon which was later coined by Galway et al. (1972) to devise the pivot-shift test that is widely used to assess for ACL deficiency.

1.2.3.2 Patellar tendon graft

In 1928, Ernst Gold reported a case of a 27-year-old lady hampered with knee instability, who had torn her ACL skiing 2 years earlier (Gold, 1928). He used a distally based strip of extensor retinaculum and medial border of the patellar tendon and then brought it into the joint through a tibial tunnel. This extensor retinaculum strip was then secured against the anterior–superior aspect of the PCL with interrupted locking sutures.

Campbell (1936) published the first of two articles in which he described the use of extensor retinaculum containing ‘‘very strong tendinous tissue from the medial border of the quadriceps and patellar tendons’’. This strip was threaded through tibial and femoral tunnels drilled in accordance to Hey Groves technique and sutured against the periosteum of the distal femur. Campbell suggested that this procedure was much simpler and produced less postoperative reaction than Hey-Groves’ procedure.

Jones (1963) published the first description for bone patellar tendon graft. He used a medial parapatellar incision extending from one inch distal to the patella to just distal to the tibial tubercle. After drilling of a femoral tunnel, the middle third of the patellar tendon was then incised throughout its length, with the incisions extending proximally across the patella and into the quadriceps tendon. Using a saw, a triangular block of bone was cut from the superficial cortex of the patella in line with the longitudinal incisions. The patellar articular surface was not breached. The end result was a graft that consisted of a bone block from the patella and the central one-third of the patellar tendon that was in continuity with its tibial insertion. This graft was then passed through the femoral tunnel. Although Jones reported excellent clinical outcome in 11 patients who underwent the procedure, the technique was criticised due to the short length of the graft that resulted in drilling the femoral tunnel at the anterior margin of the notch and not at the insertion of the native ACL.

Using similar technique, Brückner (1966) used the medial one-third of the patellar tendon. He left the graft attached to the tibia but passed it through a tibial tunnel. This gave the graft more working length than in Jones technique. The graft was then passed through the femoral tunnel and secured to the lateral aspect of the lateral femoral condyle with sutures passing through a button. This technique was further developed by Franke (1976). He was the first to describe using free bone-patellar tendon-bone graft consisting of one-quarter of the patellar tendon with blocks of bone derived from the patella and proximal tibia at the far ends of the graft. The graft was wedged with a piece of bone anchored in the tibial plateau and a shell-like piece of bone fixed into the femoral condyle.

1.2.3.3 Hamstring graft

The Italian orthopaedic surgeon Riccardo Galeazzi (1934) was the first ever to describe a technique for ACLR using the semitendinosus tendon. The tendon was released from its musculotendinous junction and placed intra-articularly through a 5 mm diameter bone tunnel drilled in the tibial epiphysis and a tunnel drilled through the lateral femoral condyle, where it was fixed to the periosteum. Galeazzi used three incisions: one for harvesting of the semitendinosus tendon, another for arthrotomy, and a third laterally for fixation. He used a cast for 4 weeks and partially weight bearing for 6 weeks. He reported on three cases. At 18 months follow up, the final outcome was a stable knee that achieved full extension with only a mild reduction of flexion.

Five years later, Macey (1939) reported on using the semitendinosus tendon for the reconstruction of the ACL. Only the tendinous part of the semitendinosus muscle was harvested in his technique. During harvesting, Macey stopped short of the musculo-tendinous junction and attached the graft with the knee in position of full extension.
Lindemann (1950) used the semitendinosus tendon as dynamic stabilizer for ACL deficient knees. McMaster et al. (1974) used the gracilis tendon in isolation. Its distal attachment was left intact and it was pulled through the tibial and femoral tunnels; then fixed to the lateral condyle using a staple.

1.2.3.4 Synthetic graft

Lange (1903) proposed silk sutures as prosthetic replacement for ligaments in the human body. He reported four cases of unstable knee joints that he successfully managed to stabilise using ligament made of silk. Ludloff (1927) used a broad strip of fascia lata that was wrapped around a thick silk suture. In the 1970s and 1980s, many synthetic ligaments were introduced for human clinical trials including carbon fibres. Jenkins (1978) started using flexible carbon fibres to reconstruct ACL. The carbon was hypothesised to act as a temporary scaffold that encouraged the ingrowth of the fibroblastic tissue and subsequently to produce new collagen. However, various studies reported poor clinical results. Complications associated with the use of carbon fibre graft included synovitis, staining of the articular surface and meniscus; and skin ulceration over the subcutaneous carbon-fibre knots used to secure the graft (Rushton et al.,1983).

1.2.3.4 Allograft

There was a remarkable interest developed in the use of allograft in ACLR in the 1980s. Shino et al. (1984) studied the mechanical properties of both allografts and autografts in a dog model without finding any significant differences. Two years later, his group became one of the first to publish clinical results of 31 patients who had received allogenic ACLR using mainly anterior tibial and calcaneal tendon grafts (Shino et al., 1986). After a minimum of 2 year follow up, all but one patient had been able to return to full sporting activities. Levitt et al. (1994) reported excellent results in 85% of cases at 4 years with patellar and Achilles tendon allografts. Furthermore, Defrere and Franckart (1994) demonstrated similar results in their group of 70 patients at 4.5 years follow up with patellar grafts. Advantages of the use of allograft are well recognized including decreased donor site morbidity, reduced surgical time and availability of different graft sizes. However, there are concerns with using allografts. the increased risk of viral disease transmission (e.g. HIV, Hepatitis C) associated with allografts in the 1990s discouraged surgeons from using this technology (Miller and Gladstone, 2002). Although sterilisation methods including irradiation were developed to minimise this risk, radiation affected the collagen structure and subsequently the mechanical properties of the graft (Rasmussen et al.,1994).

1.2.3.5 Arthroscopic ACL techniques

On the 24th April 1980, David Dandy performed the first arthroscopically assisted ACLR procedure at Newmarket General Hospital (Dandy et al. 1982). He used a carbon fibre ligament and augmented the repair with a Macintosh lateral extra-articular tenodesis in 8 patients with good results at 1 year. Arthroscopic ACLR was technically challenging at that time due to lack of appropriate instrumentation such as camera and monitor. Moreover, surgeons had to come very close to the lens to aid visualization which increased the risk of desterilisation (Schindler, 2012).

These procedures were performed through a two-incision approach. Besides the anterior tibial incision, another incision was made over the lateral aspect of the lateral femoral condyle (McCulloch et al., 2010). Through the lateral incision, a rear-entry guide was then placed around the posterior aspect of the condyle and allowed for outside-in drilling of the femoral tunnel. The graft was then fixed to the lateral femur with a staple, spiked washer, or interference screw placed from outside-in. Advances in arthroscopic guides to ensure proper tunnel placement alleviated the need for the second incision on the lateral femur. The single-incision or all-inside endoscopic technique became popular in the early 1990s when surgeons began to use intra-articular drilling for the femoral tunnel.

Femoral tunnel placement is one of the most researched topics in ACL studies. Various anatomical studies have investigated the detailed anatomy of the Femoral attachment of the ACL. Ivar Palmer (1938) published his thesis on “the injuries to the ligament of the knee joint”. He studied the anatomy, biomechanics, pathology and treatment of ACL injuries. He developed a femoral drill and emphasised that anatomic reconstruction is essential for the surgical outcome. He also pointed out in his thesis that ACL is made of two bundles. Palmer was the first to perform surgical repair for both bundles separately. Moreover, he published a microscopic examination of the ACL graft maturation into the bone tunnels. However, the orthopaedic community did not appreciate the significance of Palmer’s work at that time. It was not till 1982 when Mott published a description for the first double-bundle ACL reconstruction. He used semitendinosus tendon and drilled two tunnels in both the femur and tibia through an arthrotomy. However, Mott did not publish any clinical results for his technique. Zaricznyj (1987) reported his double-bundle ACLR technique as well as minimum of 2 years follow up in 14 patients. He used the semitendinosus tendon with drilling of one femoral tunnel and two tibial tunnels. He reported that 12 patients had good to excellent results whereas only two had fair results. None of his patients had a positive pivot shift test at the last follow up. Rosenberg and Graf (1994) described the first arthroscopic assisted double-bundle ACLR. The authors used the semitendinosus tendon and fixed it with Endobuttons on the femur. The tendons were pulled through one tibial into 2 femoral tunnels.

It is of interest that the principle for double-bundle ACLR was published by Palmar a few decades before it was adopted into clinical practice. Similarly, Hey Groves had emphasised the importance of graft obliquity 80 years before it became the foundation for developing the anteromedial portal for independent femoral tunnel drilling. The history of ACLR surgery demonstrates that not all what we know now is actually new knowledge. Nevertheless, we knew many facts in the past but did not appreciate their significance. Knowledge of the evolution of ACL reconstruction is invaluable for better understanding on how to improve the outcomes of the procedure, build on advances that are already made and more importantly to prevent repeating the mistakes of the past.

1.3 Aim and Objectives

The main aim of this thesis is to investigate various aspects related to the functional outcomes of ACL reconstruction surgery through a series of clinical studies. The objectives for this thesis are:

1) Identify a standard framework for assessment of functional outcome following ACLR surgery and assessment of the role of pre-injury outcome scores.
2) Study the demographics, surgical techniques and functional outcomes from a National register.
3) Investigate the influence of femoral tunnel drilling technique on the outcome of ACLR surgery.
4) Study the effect of concomitant ACLR on the outcome of all-inside meniscal repair.
5) Evaluate the functional outcomes of ligament preservation surgery in the management of complete proximal ACL tears.

Chapter 2

Variability in Outcome Measures for Anterior Cruciate Ligament Reconstruction: A Systematic Review

2.1 Introduction

The growing numbers of ACLR procedures has alerted clinicians and researchers to the need for agreed measures to assess the functional outcome following the surgical intervention. There is a plethora of objective and subjective outcome measures to assess the functional outcome following ACLR. However, there appears to be no consensus regarding which test or combination of tests are most appropriate for evaluating recovery after ACLR (Phillips et al., 2000). Moreover, no gold standard yet exists for identifying successful outcome following ACLR (Lynch et al., 2013). Many factors contribute to the confusion over defining a successful outcome. The variable patient demographics result in patients having different goals from their treatment and subsequently different perception of success. For an elite athlete with ACLR, return to sports at a pre-injury level would be perceived as success even with a painful knee. On the other hand, patients with minimal sports participation would perceive a successful ACLR as having a pain free knee that is stable during normal daily activities. Patients with ACL tears may have other associated ligamentous, meniscal or chondral injuries. They may also have an underlying patellar mal-tracking, lower limb mal-alignment, hip or ankle pathology.

Generally, outcome measures for patients with ACLR include clinical outcomes, process outcomes, patient satisfaction, and cost (Irrgang, 2008). Process outcomes include measures such as the duration of care, waiting times, length of hospital stay, number of outpatient visits, and number and type of interventions provided to the patient. Important information on clinician and organizational performance can be obtained through evaluation of process outcomes (Zelle et al., 2005). Patient satisfaction measurement can be used for a variety of purposes, such as validating quality of care, developing patient-care models, evaluating health-care delivery systems, and facilitating quality improvement (O'Holleran et al., 2005). Furthermore, development and use of a standardized patient satisfaction instrument to measure the outcomes in ACLR patients would be a valuable tool to permit benchmarking between providers and organizations (Zelle et al., 2005). Kocher et al. (2002) demonstrated that the most robust relationships of patient satisfaction with the outcome following

ACLR were subjective measures of symptoms and function; rather than objective measures. Symptoms such as pain, swelling, giving way, locking, noise, stiffness and limp had highly significant association with dissatisfaction.

In current practice, the cost of care is also an important outcome measure. The total costs to an individual with a knee injury include the direct costs for medical care as well as indirect costs. The direct costs for medical care include the expenses for diagnosis, management, and rehabilitation. The indirect costs of an injury may be related to work time lost, decreased productivity, or costs for house-hold assistance (Zelle et al., 2005). Clinical outcomes are often the area of interest when it comes to evaluate the effectiveness of the surgical intervention.

2.1.1 A framework for clinical outcome measures

In 2001, The World Health Organization (WHO) introduced the International Classification of Functioning, Disability and Health (ICF) in an attempt establish a common language for describing health and health-related states (World Health Organisation, 2001). In the ICF disability model, health domains are described in terms of: (1) body structure and function and (2) activity and participation.

Applying the ICF model to patients with ACL injury, the impairment of body structure includes disruption of the ACL itself as well as possible injury to the meniscus, articular cartilage, and/or subchondral bone. Clinical outcome measures to assess Integrity of ACL may include magnetic resonance imaging (MRI) and arthroscopy. Impairment of body function associated with ACL injury may include laxity of the knee, a sense of instability, limited range of motion, muscle weakness or inhibition and proprioceptive deficits. Measures of clinical outcome at the level of impairment of body function for an individual with an ACL injury may include manual or instrumented testing of ligament laxity, goniometry to measure range of motion of the knee, and/or isometric or isokinetic testing to measure muscle performance.

Patients with ACL injury may experience activity limitations such as difficulty walking, climbing stairs, running, jumping and landing, or cutting and pivoting (Zelle et al., 2005). The resulting participation restrictions may include the inability to participate in sports or to work. These limitations can be expressed on a scoring scale, by a functional test, or by grading of activity (Lysholm and Tegner, 2007). Within the ICF framework, return to sports is an important participation outcome measure for athletes who are recovering from ACLR.

Generally, outcomes measures are either clinician-based or patient-reported. Clinician based outcomes are based on objective measures such as range of motion, muscle strength and knee laxity. These measures are ideal for assessment of the body structure and function counterpart of the ICF model. Patient-reported outcomes are the subjective measures to assess the activity and participation component of the ICF model. The aim of patient reported outcomes is to assess the patient's perception of her or his own functional ability, symptoms, and quality of life (Suk et al., 2008).

Patient reported outcome measures (PROMs) are classified into generic health outcomes and disease or anatomic specific outcomes. Generic health outcome measures permit comparisons among patients with the same condition and between patients with different conditions. Furthermore, they may detect unintended side effects of the treatment (Patel et al., 2007). However, they tend to be less responsive than specific measures of health-related quality of life to changes in health status; which makes them less likely to show the effects of a specific intervention (Suk et al., 2008). Examples of generic health related quality of life measures in patients with ACL injury include SF-36 and EQ-5D.

Measures of health-related quality of life specific to musculoskeletal disease are focused on aspects of health that are specific to a disease (e.g. ACL injury) and anatomic area (e.g. knee) (Wright, 2009). These instruments generally have higher sensitivity than generic quality of life instruments. Their targeted focus permits them to detect clinically important changes and this makes them more clinically relevant when assessing changes in health status over time. In contrast to the generic measures, they often lack the ability to detect unforeseen effects of a health intervention. ACL specific outcome measures commonly used are Lysholm, Tegner, the Cincinnati Knee Rating System, and the Quality of Life Outcome Measure Questionnaire for Chronic Anterior Cruciate Ligament Deficiency (Mohtadi,1998; Barber-Westin, 1999).

Commonly used Knee specific outcome measures include The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Knee Injury and Osteoarthritis Outcome Score (KOOS) and the International Knee Documentation Committee Subjective Knee Form (IKDC). Most epidemiologists believe that studies should include a general health outcomes measure in addition to disease- or anatomic-specific measures (Wright, 2009). In this study, we aim to identify the commonly used outcome measures in ACLR clinical studies. Our hypothesis is that there is high variability in the types of outcome measures used in ACLR literature.

2.2 Methods

2.2.1 Literature search

A systematic review was performed using Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). We performed an electronic search of the published literature through searching PubMed (Medline) and Embase databases. The search query terms used were (anterior AND cruciate) OR (ACL) AND (reconstruction) AND (outcome). We used broad search terms to encompass all possibilities for applicable studies. The search was limited to articles published between 2004 and 2013 and written in English language. The search was performed on February 8, 2014.

2.2.2 Study selection criteria

After exclusion of duplicates, titles and abstracts were screened according to the inclusion and exclusion criteria. Randomized clinical trial (RCT) and prospective cohort studies were included in this review (Level I and II evidence) (Centre of evidence-based medicine, 2009). Studies that were excluded include animal, cadaveric and laboratory studies. Systemic reviews, narrative literature reviews and meta-analysis studies were excluded. Clinical studies that report less than a minimum of 2 years postoperative follow up were also excluded (Table 2.1). The rationale for these exclusion criteria was to review high quality Level I and II studies.

Table 2.1: Inclusion and exclusion criteria that were used to assess abstracts from search results

Inclusion criteria	Exclusion criteria
Randomized clinical trials	Animal studies
Prospective cohort studies	Cadaveric studies
Minimum of 2 years postoperative follow up	Systematic reviews or narrative literature reviews
	Meta-analysis
	Case series, retrospective studies, case reports and editorials (Level III, IV, V evidence)
	Less than 2 years postoperative follow up

2.2.3 Data extraction and analysis

Full articles were reviewed and assessed against the inclusion and exclusion criteria. Two authors assessed the methodological quality of each study and its eligibility. Disagreement was resolved by the senior author when necessary. The following data were extracted from the remaining articles: authors, journal of publication, year of publication, type of study, level of evidence, sample size, mean follow up time, and all outcome measures that were utilised. The studies were further categorised into five main groups to facilitate analysis: graft type, surgical technique, graft fixation methods, timing of surgery and rehabilitation, and longitudinal and registry studies.

Outcome instruments that have been recorded include: range of motion (ROM), Lachman test, pivot shift test, Anterior drawer test, quadriceps muscle circumference, KT-1000 and KT-2000, jump-landing test, single-hop test, triple-hop test, IKDC objective examination, ACL quality of life (ACL-QoL), Short Form-36, EQ-5D, pain visual analogue scale, WOMAC, Single Assessment Numeric Evaluation (SANE), IKDC(Subjective), KOOS, Cincinnati knee score, Lysholm, Tegner, X-rays, Stress views, Computed tomography (CT) scan, MRI, second look arthroscopy, return to sports, and re-rupture and revision surgery. Outcome measures that were used only once were excluded. The outcome measures were further categorised according to which domain they satisfy in the ICF framework (Table 2.2).

Table 2.2: Outcome measures that are commonly used in ACLR studies and the ICF domains addressed for each outcome measure.
B= Body function and structure; A= Activity; BAP= Body function and structure + activity and participation; BA= Body function and structure + activity; AP= Activity and participation; P= participation

Measures	B	A	BAP	BA	AP	P
KT1000/KT2000	x					
Lysholm				x		
Pivot shift	x					
IKDC-objective				x		
IKDC-Subjective			x			
Tegner					x	
Lachman	x					
X-ray	x					
ROM	x					
Single-leg hop		x				
Quad strength	x					
KOOS			x			
Anterior Drawer	x					
Cincinnati knee score				x		
MRI	x					
Re-rupture/revision	x					
VAS	x					
SF-36			x			
Return to sports						x
OA	x					
Triple-hop		x				
ACL-QoL			x			
Quad Circumference	x					
Jump-landing test		x				
Stress views	x					
CT scan	x					
Marx Activity					x	
WOMAC			x			

2.3 Results

There were 1409 study that met the research key terms (Figure 1). After exclusion of duplicates, 193 abstracts satisfied the inclusion and exclusion criteria. Full text was retrieved for these studies. 94 studies were further excluded as they did not meet the eligibility criteria. Out of the remaining 99 studies, 58 were randomised clinical trials and 41 were prospective cohort studies. The average patient follow up was 4.1 years (range 2 – 15 years). The total number of studies investigated in each category were: graft type (34), surgical technique (29), graft fixation methods (15), timing of surgery and rehabilitation (6), and longitudinal and registry studies (15). Instrumented measurement of anterior knee laxity with KT-1000 and KT-2000 arthromeres was the most frequently reported outcome measure in ACLR studies (72.7%) (Table 2.3). The second most common outcome measure was the Lysholm score (56.5%).

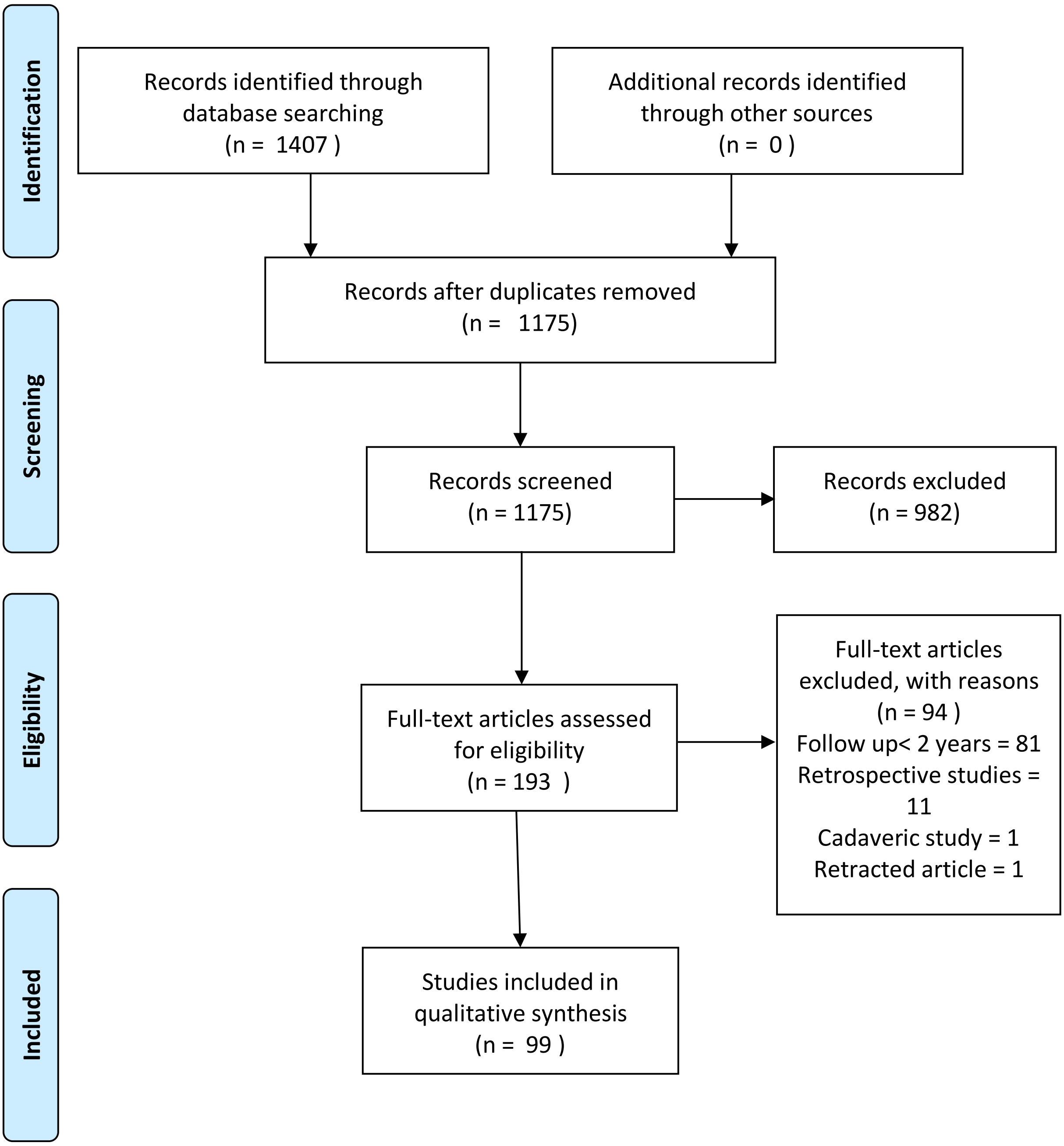


Figure 2.1: PRISMA Chart of the Study Selection Process

Table 2.3: Outcome measures that were used in all studies (n = 99)
WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index; EQ-5D index = EuroQol 5-domain index; ROM = range of motion; IKDC = International Knee Documentation Committee; KOOS = Knee injury and Osteoarthritis Outcome Score; VAS = Visual Analog Scale for Pain; SF-36 = Short Form 36 Health Survey; SANE = Single Assessment Numeric Evaluation

Measures	Graft Type (n=34) (%)	Surgical Technique (n=29) (%)	Fixation Methods (n=15) (%)	Longitudinal and Registry Studies (n=14) (%)	Timing and Rehabilitation (n=7) (%)	Totals (n=99) (%)
KT1000	26 (76.4)	20 (68.9)	10 (66.6)	6 (42.8)	5 (71.4)	67 (67.6)
Lysholm	21 (61.7)	15 (51.7)	11 (73.3)	5 (35.7)	4 (57.1)	56 (56.5)
Pivot shift	20 (58.8)	17 (58.6)	7 (46.6)	4 (28.5)	3 (42.8)	51 (51.5)
IKDC-objective	23 (67.6)	13 (44.8)	7 (46.6)	4 (28.5)	3 (42.8)	50 (50.5)
IKDC-Subjective	20 (58.8)	13 (44.8)	3 (20.0)	4 (28.5)	2 (28.5)	42 (42.4)
Tegner	16 (47.0)	15 (51.7)	7 (46.6)	2 (14.2)	2 (28.5)	42 (42.4)
Lachman	18 (52.9)	5 (17.2)	6 (40.0)	2 (14.2)	4 (57.1)	35 (35.3)
X-ray	14 (41.1)	9 (31.0)	5 (33.3)	3 (21.4)	2 (28.5)	33 (35.3)
ROM	16 (47.0)	6 (20.6)	4 (26.6)	2 (14.2)	3 (42.8)	31 (31.3)
1-leg hop	16 (47.0)	2 (6.8)	3 (20.0)	2 (14.2)	2 (28.5)	25 (25.2)
Quad strength	6 (17.6)	6 (20.6)	3 (20.0)	3 (21.4)	2 (28.5)	20 (20.2)
KOOS	7 (20.5)	4 (13.7)	2 (13.3)	5 (35.7)	0	18 (18.1)
Ant Drawer	8 (23.5)	3 (10.3)	1 (6.6)	2 (14.2)	0	14 (14.1)
Cincinnati knee score	6 (17.6)	0	1 (6.6)	4 (28.5)	1 (14.2)	12 (12.1)
MRI	2 (5.8)	4 (13.7)	5 (33.3)	0	0	11 (11)
Re-rupture/revision	6 (17.6)	3 (10.3)	1 (6.6)	0	0	10 (10)
VAS	5 (14.7)	2 (6.8)	0	1 (7.1)	1 (14.2)	9 (9.1)
SF-36	1 (2.9)	4 (13.7)	0	1 (7.1)	1 (14.2)	7 (7.1)
Return to sports	2 (5.8)	2 (6.8)	0	2 (14.2)	0	6 (6.1)
KT2000	3 (8.8)	2 (6.8)	0	0	0	5 (5.1)
triple-hop	1 (2.9)	1 (3.4)	0	2 (14.2)	0	4 (4)
ACL-QoL	1 (2.9)	0	0	1 (7.1)	1 (14.2)	3 (3)
Quad Circumference	1 (2.9)	1 (3.4)	0	0	1 (14.2)	3 (3)
Jump-landing test	2 (5.8)	0	0	1 (7.1)	0	3 (3)
Stress views	1 (2.9)	2 (6.8)	0	0	0	3 (3)
CT scan	1 (2.9)	2 (6.8)	0	0	0	3 (3)
Marx Activity	0	1 (3.4)	0	1 (7.1)	0	2 (2)
WOMAC	1 (2.9)	0	0	1 (7.1)	0	2 (2)

2.3.1 Objective outcome measures

There were 88 studies that used a combination of objective and subjective outcome measures (Figure 2.2). Seven studies used objective outcome measures only whereas four studies used subjective outcome measures only.

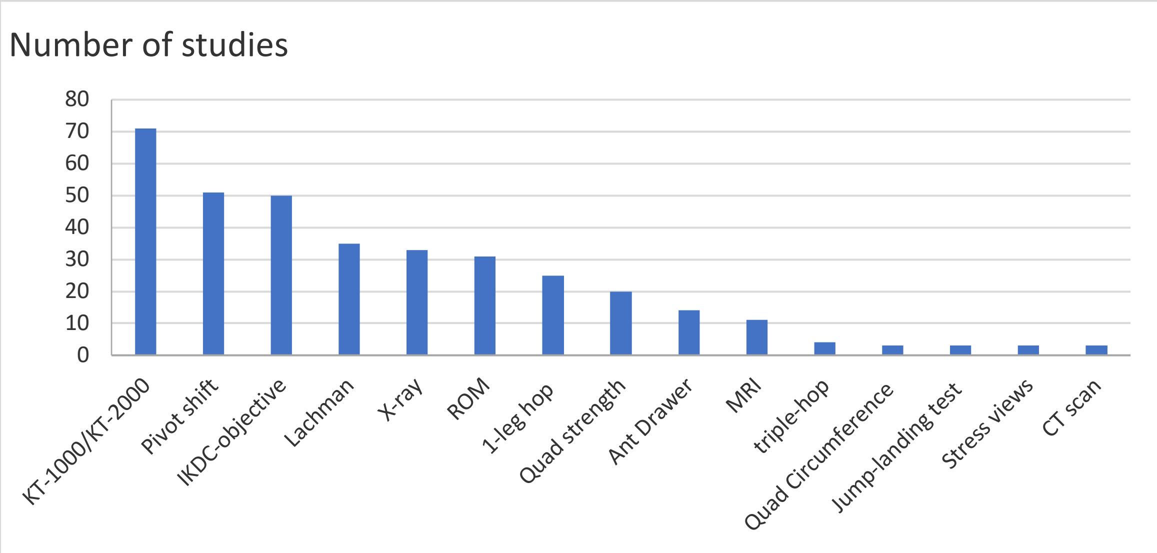


Figure 2.2: Objective outcome measures and the number of clinical studies that have used each of them

Anterior Knee Laxity: Clinical tests that examine anterior knee laxity following ACLR include Lachman test (Strobel et al., 1990), anterior drawer test (Torg et al., 1976), and pivot shift test (Galway et al., 1980). Among the three clinical tests, pivot shift was the most commonly used test (51 studies, 51.5%). 35 studies (35.3%) utilised Lachman test while 14 studies (14.1%) used anterior drawer test. 16 studies used at least one of the three clinical tests, whereas 28 studies used two of them and 10 studies used all three clinical tests.

Instrumented measurement of anterior knee laxity could be performed with the KT-1000 or KT-2000 arthromeres (MEDmetric, San Diego, CA, USA). KT-1000 and KT-2000 arthrometers were the most common used objective outcome measure. KT-1000 arthrometer was used in 67 studies whereas KT-2000 arthrometer was used in 5 studies. However, instrumented measurement was only used in 8 studies (40%) in the longitudinal and registry studies subgroup.

Range of motion: ROM examination is particularly relevant following ACLR, as an initial loss of knee range is a possible postoperative complication. The goniometer is used to objectively assess active and passive joint ROM. 31 studies (31.3%) reported ROM following ACLR.

IKDC objective score: The IKDC objective score assesses patients in 7 parameters related to the knee. The patients get graded in 4 different grades: normal, nearly normal, abnormal and severely abnormal, for each of these parameters, and the worst grading determines the final outcome (Hefti et al., 1993). 50 studies (50.5%) reported on the IKDC objective score.

Quadriceps muscle strength and circumference: The quadriceps muscle power is critical to dynamic knee stability, and weakness of this muscle group is related to poor functional outcomes following ACLR (Palmieri-Smith et al., 2008). 20 studies (20%) recorded quadriceps muscle strength while 3 studies (3%) reported on quadriceps muscle circumference.

Radiographic evaluation: This includes plain radiographs, CT and MRI scans of the knee. Plain X-rays were reported in 33 studies (33.3%). X-rays were used to investigate either tunnel placements or the incidence of osteoarthritic changes postoperatively. Knee MRI scans were utilised in 11 studies (11%) while CT scans were used in 3 studies (3%).

2.3.2 Subjective outcome measures

Figure (2.3) shows the number of studies that have used the various subjective outcome measures. Seven studies used no subjective outcome measures. 24 studies used only one subjective outcome measure, whereas 39 studies reported on two outcome measures (Figure 2.4).

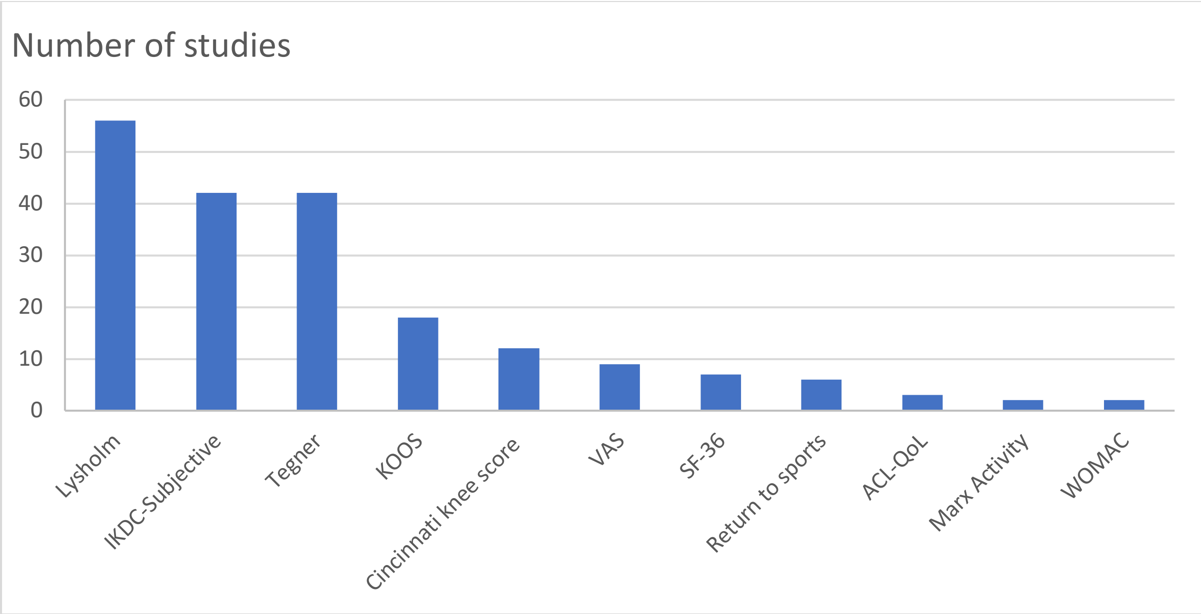


Figure 2.3: Subjective outcome measures and the number of clinical studies that have used each of them

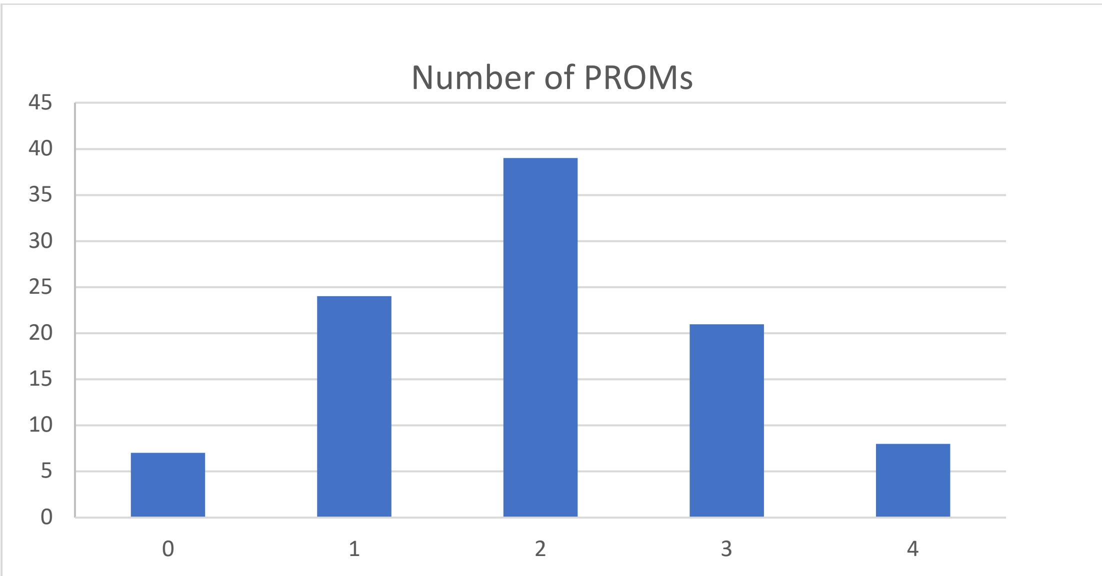


Figure 2.4: Number of PROMs utilised in each study

Tegner- Lysholm scoring system: The Lysholm consists of eight items including limp, support, stair climbing, squatting, instability, locking and catching, and pain and swelling. The total score is presented on a zero to 100 points scale (Tegner and Lysholm, 1985). The Lysholms score was the most common subjective score used (56 studies, 56.5%). Tegner score is a ten points scale. Zero represents disability secondary to knee problems, while a score of 10 is assigned to national- or international- level players (Tegner and Lysholm, 1985). Tegner score was the third common subjective outcome measure and it was utilised in 42 studies (42.4%). Although the Tegner score was designed to complement the Lysholm score, the Lysholm score was used independently in 23 studies.

IKDC subjective form: The form consists of 18 questions and evaluates symptoms, function, and sports activity. The raw scores are summed and transformed to a scale from 0 to 100, with higher scores representing better outcomes. 42 studies (42.4%) utilised the IKDC subjective scores. It was only used in 4 studies (26.6%) in the longitudinal and cohort studies subgroup.

KOOS score: The KOOS score is a 42-item self-administered questionnaire that has 5 subscales that include pain, symptoms, activities of daily living, sport and recreation function and knee-related quality of life. Scores are transformed to a 0–100 scale, with zero representing extreme knee problems and 100 representing no knee problems. The KOOS score was reported in 18 studies (18.1%). It was used in 5 studies (35.7%) in the longitudinal and registry studies subgroup.

Cincinnati knee rating score: The Cincinnati scoring system is composed of 6 subscales including symptoms, daily and sports activities, physical examination findings, stability, radiographic findings, and functional testing. The measure is scored on a 100-point scale, with higher scores indicating better outcomes (Guyatt et al., 1986). The Cincinnati score was reported in 12 studies (12.1%).

2.3.3 WHO ICF model

The majority of studies (75.7%) used outcome measures that satisfied both domains of the WHO ICF mode that are body function and structure; and activity and participation (Table 2.4). 10 studies utilised outcome instruments that only satisfied the body function and structure domain of the ICF.

Table 2.4: Domains of WHO ICF model that have been addressed in ACLR studies.
B= Body function and structure; BAP= Body function and structure + Activity and participation; BA= Body function and structure + activity

WHO ICF domain(s)	Graft Type (n=34)	Technique (n=29)	Fixation Methods (n=15)	ACL Cohort Outcomes (n=14)	Timing and Rehabilitation (n=7)	All Studies (n= 99)
B	3	3	3	1	0	10
BAP	29	23	8	9	6	75
BA	2	3	4	4	1	14

2.4 Discussion

Our hypothesis was supported in this systematic review as there was wide variability in the outcome measures used to assess the outcome of ACLR surgery. This significant variability was also observed in studies investigating the same research question such as studies reporting on ACL graft type or graft fixation methods. The inconsistency in reporting outcome measures in high quality studies hinders researches and clinician from comparing outcomes between different studies. The main question to be answered is what actually constitutes a successful ACLR surgery and how we can measure the outcome. Lynch et al. (2015) investigated criteria identifying successful ACLR through establishing a consensus based on expert opinions. The authors sent out a survey to orthopaedic surgeons, rehabilitation specialists, researchers and sports medicine specialists who are members of international sports medicine associations. 1779 responses were obtained, and a consensus was then defined as agreement of 80% or more. The consensus criteria identified were joint effusion, giving way, muscle strength (body structure and function), PROMs (activity and participation) and return to sport (participation). Although PROM was a consensus criterion, there was no consensus to which subjective outcome measure should be used.

An ideal outcome measure should be easy to administer, could be generalised to all clinical settings and targets all aspect of health condition in the ICF model (Irrgang et al., 1998). There are certain features for an outcome measurement to have in order to be considered as a good outcome measure. Suggested quality criteria are mostly opinion based because there is no empirical evidence in this field to support explicit quality criteria. These criteria include content validity, internal consistency, criterion validity, construct validity, reproducibility, responsiveness, interpretability and floor and ceiling effects (Poolman et al., 2009). Content validity is simply an assessment of whether the instrument actually measures what it is intended to measure (Marx et al., 2001). A PROM is most likely to have good content validity if patients are involved in its development, and this is an essential first step when developing new instruments (Beard et al., 2010). Internal consistency is a measure of the extent to which items in a questionnaire subscale are correlated (homogeneous), thus measuring the same concept. Internal consistency is an important measurement property for questionnaires that intend to measure a single underlying concept (construct) by using multiple items (Terwee et al., 2007).

Criterion validity refers to the extent to which scores on a particular instrument relate to a gold standard. If a gold standard is available, the outcome instrument can be compared with this standard. However, as a gold standard is frequently unavailable, construct validity has to be assessed (Poolman et al., 2009). Construct validity refers to the extent to which scores on a particular instrument relate to other measures in a manner that is consistent with theoretically derived hypotheses concerning the concepts that are being measured (Terwee et al., 2007). Reproducibility refers to the degree to which repeated measurements (test-retest) in steady populations provide similar answers. Reproducibility is built on agreement and reliability. Agreement is the extent to which the scores on repeated measures are close to each other (absolute measurement error). Reliability is the extent to which patients can be distinguished from each other, despite measurement errors (relative measurement error) (Poolman et al., 2009).

In this systematic review, the Lysholm score was the most frequently used subjective outcome measure (56.5%). The Lysholm score was first presented in 1982. It was further developed and refined to include only subjective items. An activity-grading scale was then added (Tegner and Lysholm, 1985). The main advantage of the Lysholm activity scale is not comparing different patients but identifying changes in the activity level in the same person at different times. With this scale, the pre-injury level and the present and desired activity levels can be defined (Lysholm and Tegner, 2007). Briggs et al. (2006) demonstrated that the Lysholm knee score had acceptable test-retest reliability, floor and ceiling effect, criterion validity, construct validity and responsiveness to change following ACLR surgery. A criticism to the Lysholm score is that it addresses activity related symptoms. If patients alter their activity levels or frequency of participation, they would score higher because symptoms would only be triggered by stressful activities (Sgaglione et al., 1995).

The second most frequently used subjective outcome measure was the IKDC subjective score (42.4%). The IKDC score was first published in 1993 and revised in 1994. In 1997, the board of the American Orthopaedic Society for Sports Medicine moved to revise the form in light of the progress in the evaluation of medical outcomes (Irrgang et al., 2001). The result was a joint-specific, rather than a disease- or condition-specific, instrument for evaluating symptoms, function, and sports activity applicable to a variety of knee conditions. An 11.5-point change on the 100-point scale is considered as a clinically significant improvement in patient's condition (Wright, 2009). The IKDC subjective form has been validated and shown to be reliable and responsive for a wide range of knee disorders including ACL injuries (Irrgang and Anderson, 2002; Irrgang et al., 2006). Normative data for the IKDC sores is also available which allow comparing the functional status of patients with knee injuries to their age- and gender-matched peers (Anderson et al., 2006). The main strength of the IKDC form is that it can be used as a single form to assess any condition involving the knee and thus allow comparison between groups with different diagnoses. Moreover, The IKDC score satisfies all three domains on the ICF framework. Another advantage of the IKDC subjective score is that it is the only adult PROM that has been proved to be translatable to the paediatric version in adolescent patients (Brusalis et al., 2017). Oak et al. (2015) demonstrated that the adult and paediatric forms of the IKDC were significantly different by only 1.5 points. This difference was not clinically significant. The authors concluded that the adult version of the IKDC could be used in adolescents aged 13 to 17 years. This is an important advantage especially for ligament registries where one PROM could be used for both adult and adolescent patients allowing standardisation of PROMs across the register.

The IKDC subjective score is often compared to the KOOS score due to the fact that both scores are comprehensive, knee specific and satisfy all 3 domains of the ICF model. The KOOS score was the fourth most frequently used subjective outcome measure in this study (18.1%). The KOOS score was developed to evaluate functioning in daily living, sport, and recreation, as well as the knee-related quality of life in patients with knee injuries who are at risk of OA developing. These include ACL, meniscus, or chondral injuries. The KOOS is currently available in 28 different languages and has been culturally adapted and cross-culturally validated for use in the United States, United Kingdom, Sweden, France, Germany, Iran, Singapore, and the Netherlands (Cameron et al., 2013; Roos and Toksvig-Larsen, 2003). It is the primary PROM used in the Scandinavian national ligament registries. Therefore, it is more appropriate for multicentre comparative studies on ACLR outcomes. This might explain what we observed in our study that the highest percentage of using the KOOS was in the longitudinal and registry studies subgroup (35.7%).

The KOOS score has good evidence of reliability, validity and responsiveness, and has been recommended as a good choice for long- and short-term assessment of knee OA, ACLR and meniscus injury (Beard et al., 2010). Roos and Lohmander (2003) reported that a change of 8 points or more in the KOOS score may represent a clinically significant change following ACLR. The authors recommended that 8–10 points may represent the minimal perceptible clinical improvement (MPCI) of the KOOS score. The MPCI represents the difference on the measurement scale associated with the smallest change in the health status detectable by the patient. The pain, sport and recreation, and knee-related quality-of-life subscales have been determined to be the most sensitive, with the largest effect size for active, younger patients (Wright, 2009). Only 3 studies in our review collected both KOOS and IKDC subjective scores. This is an expected finding as both scores cover similar domains. Although KOOS score is widely utilised in registry studies, it has been reported that the IKDC subjective score is more useful in assessing patients following ACLR surgery. Van Meer et al. (2013) investigated the utilisation of both the IKDC subjective form and KOOS score in patients who had ACLR surgery. The authors demonstrated that the IKDC subjective form showed superiority to the KOOS form with respect to relevance of the questions, construct validity, responsiveness, and ceiling effects. They concluded that the IKDC subjective form was more useful than the KOOS questionnaire in evaluating patients in the first year following ACLR surgery.

This review showed that instrumented measurement of anterior knee laxity with the KT-1000 and KT-2000 arthrometers was the most frequently used outcome measures in Level I and II studies concerning ACLR. Furthermore, 16 studies used at least one of the three clinical tests for anterior knee laxity while 28 studies used two of these tests. This indicates that clinicians and researchers believe that restoring anteroposteior knee stability is of utmost importance in ACLR surgery. However, some authors challenged the correlation between knee joint laxity and patients' subjective functional outcomes. Sydney-Marker et al. (1997) demonstrated no correlation between measurements of anterior ligament laxity with the KT-2000 arthrometer and the level of activity and participation in athletes with ACL deficiency. Kocher et al. (2002) studied a cohort of 201 patients who had ACLR with a minimum of 2 years follow up. The authors examined anterior laxity of the knee with the KT-1000 arthrometer, Lachman and pivot shift tests. They observed that KT-1000 arthrometer examination and the Lachman test had no significant relationships with the patient-reported symptoms and function, whereas the pivot- shift examination was correlated with some aspects of patient-reported symptoms and function. They concluded that increased knee laxity on objective physical examination does not necessarily correlate with worse symptoms and function from the patient's perspective.

Activity and participation after ACL surgery can be measured by the use of performance-based tests as well as with PROMs. Functional based tests include single and triple hop tests for distance, timed hop tests, vertical jump tests, shuttle runs, cross-over hop tests, figure eight running and the stairs hopple test. the single and triple hop tests for distance have been commonly used among these tests. Stair Hopple test was originally described by Risberg and Ekeland (1994). In this test, the patient jumps on the uninjured leg up and down 22 steps on a staircase (each step measures 17.5 cm in height). The patient then repeats the test on the injured leg and the difference in time is recorded. Studies conducted on normal and ACL reconstructed subjects have demonstrated that these tests are highly reliable. In our review, the single leg hop test was used in 25 studies (25.2%) whereas the triple hop test was only reported in 4 studies (4%).

Functional tests have shown to correlate with subjective outcome measures. Logerstedt et al. (2012) demonstrated that Single-legged hop tests that are conducted at six months after ACLR can predict the likelihood of successful and unsuccessful outcome at one year after ACLR procedure. Functional tests are essentially designed to mimic functional demands of sporting activities. Therefore, they are often used as a guide for returning an athlete with ACLR to sport. Barber-Westin et al. (2011) conducted a systematic review on objective criteria for return to sport following ACLR. Functional tests were the second most common criteria following lower extremity isokinetic muscle strength. A recent literature review demonstrated that functional tests were used in 71 of 209 studies reporting on criteria to return to sport following primary ACLR (Burgi et al., 2019). Time from ACLR surgery to return to sport was the most common criterion (85%) while subjective patient reported criteria were used in 12% only. The CR'STAL is a recent prospective single centre study that aims at identifying which criteria or combination of criteria that could allow return to sport following ACLR with the lowest possible risk of reinjury (Rambaud et al., 2017). The results of this study are due in the next 2 years and this would give a great insight into the reliability of functional tests for assessing safe return to sport following ACLR.

Assessment of patients with ACLR should include a combination of subjective and objective outcome measures to satisfy the components of the WHO ICF model (Reinke et al., 2011). There has been great emphasis in the recent literature on the relevance of the subjective outcome measures over the clinician-based instruments. Subjective outcome measures reflect more of the patient activity and participation. The lack of a direct relationship between impairment of body structure and function, and activity and participation limitations is inherent in the ICF. In this model, disability is the outcome of a complex interaction between the individual's health condition and contextual factors. This implies that objective measures such as knee laxity should not be combined with measures of disability into a single composite score (Zelle et al., 2005). Furthermore, objective outcome measures should be reported separately and not to replace any PROMs. The choice of PROM should ideally include a generic as well as knee specific instruments. An outcome measure should be appropriate to the population targeted and the question asked. In other words, it should be chosen based on evidence of its validity, reliability, context and purpose. No universal agreement has yet been achieved on a single or a combination of subjective outcome measures in the assessment of patients following ACLR. However, we recommend based on this systematic review, to use a combination of Lysholm and IKDC subjective scores for subjective assessment of patients following ACLR surgery.

2.4.1 Limitations

This study has a few limitations. We only searched 2 large databases for relevant studies and did not look into other sources. This review only included studies written in English languages, so we might have missed many trials that were published in foreign-language journals. Our literature search was limited to 10-year period only. This was intentionally chosen in order to investigate recent ACLR literature although we might have missed some relevant studies given our search timeframe. It is possible that inclusion of only Level I and II studies would actually underestimate the variability in outcome reporting. The low quality and retrospective studies often tend to show greater inconsistency in outcome measures as they rely on readily available data.

2.5 Conclusion

We found extensive variation in the types of outcome measures used in Level I and II clinical studies reporting on the outcome of ACLR surgery. We observed this variability even further within clinical study groups that investigate the same research topic in ACLR literature. Identification of this significant variability in reporting patterns is essential to assess whether or not the current state of reporting leads to challenges in comparing or pooling results from different ACLR studies. This study confirms the widespread use of PROMs in current ACLR literature. However, there is no agreement on what outcome measure or combination of outcome measures should be utilised to assess the functional outcome of ACLR. We recommend the use of combination of Lysholm and IKDC subjective scores for subjective assessment of function following ACLR surgery. Future research should determine whether consensus can be developed for a standardized set of outcome measures that are considered to be the most important predictors of success following ACL reconstruction. This is of paramount importance especially in registry-based studies and international collaborative ACL studies. Until greater consistency is achieved, it is unlikely that researchers and clinicians would be able to compare across studies to infer the effects of various surgical techniques for patients undergoing ACLR surgery.

Chapter 3

The UK National Ligament Registry: Five-year Results, Challenges and Future Direction

3.1 Introduction

National clinical registries have long been established to face evolving diversity in surgical techniques and implants in orthopaedic surgery. Although randomised controlled trials provide a higher level of evidence, they can only compare limited numbers of surgical techniques and implants. Clinical registries are population based with large number of patients that enable surgeons and researchers to compare multiple treatment modalities. New orthopaedic devices are designed and manufactured with the aim that they would be equivalent or superior to existing products. Despite going through rigorous testing prior to product release, their use in the patients represent the true and ultimate test for these implants. Revision rates for failed orthopaedic implants are typically small thus hard to pick up early in a single hospital-based patient cohort. Therefore, clinical registries enable us to identify failing devices earlier on through its large sample size.

With this in mind, the Mayo Clinic total joint registry (United States) was established in 1969 as the first institutionally based joint registry. However, the first national registry to emerge was the Swedish Knee Arthroplasty Register in 1975 (Robertsson et al., 2000). The second to follow was the joint replacement registry in Finland in 1980 then Norway in 1987. Arthroplasty registries play a fundamental role in post market implants surveillance. The recall of the ASR hip systems (Depuy Orthopaedics, Warsaw, IN, USA) in 2010, following warnings from the National Joint registry of England, Wales and Northern Ireland (NJR), represents an example of how efficient the clinical registries are in early detection of failing implants.

Inspired by the success of arthroplasty registries, the first national ligament registry was established in Norway in 2004. The rest of the Scandinavian national ligament registries were established shortly afterwards. Over the last decade, the Scandinavian registries have published extensively on demographics and outcomes for both primary and revision anterior cruciate ligament reconstruction (ACLR) procedures. They have significantly contributed to our understanding for the patients' journey through ACLR and rehabilitation.

Based on the Scandinavian models, The United Kingdom National Ligament Registry (NLR) was launched at the British Association for Surgery of the Knee (BASK) annual scientific meeting in 2013 (Gabr et al., 2015). The NLR has been set up to collect and store outcome data relating to ACLR surgery. The registry is currently focused on single procedure, ACLR, in order to be able to provide valid and robust data. When fully established, it will ease the journey to develop similar pathways for the revision of ACLR procedures, ACL ligament repair, other ligament reconstructions and non-arthroplasty knee interventions. The NLR could also be used to look at the outcome for patients who are managed non-operatively. The main aims of the registry are to collect essential demographic data, identify current or emerging trends, identify failing techniques or devices and provide functional outcome data. This would be achieved by creating one central hub of clear and concise data that will allow establishing standard of best practice. The NLR is established as a surgeon led entity without the initial involvement of governmental agencies. This approach therefore requires external financial support that is currently provided by the industry and BASK.

Registry data provides a substantial amount of information directed towards answering questions and raising overall standards of care for the benefit of patients, clinicians, the NHS and industry. The NLR continues to grow both in terms of patient numbers and in terms of its reach and popularity. There were 742 registered users by the end of 2017. These continue to increase at a rapid rate. This number should steadily increase as surgeons and orthopaedic departments see the advantage of having a readymade tool for use in governance, appraisals and revalidation.

In this chapter, we analyse the data available on the NLR from its launch in 2013 till the 31st of December 2017.

3.2 Methods

The NLR is a web-based platform that collects various outcome data from ACLR operations. The Registry platform is easily accessible via computer and tablet, simplifying the process for both clinicians and patients. Bluespier was selected as the company to collect and host the data utilising their newly developed Amplitude system.

The ‘registry route’ is simple, requiring small contributions from both surgeon and patient at different stages.

The data on the NLR is managed by the surgeons who initially input their patients on the system. Patients go on the NLR website to sign the consent for their details to be stored on the system. They then complete the registration process by entering their basic demographic details and answer injury-related questions. The crucial step in patients’ registration is to have a valid email address as this is the sole way of communication between the registry and the patients. The population undergoing ACL reconstructions are typically younger, more mobile and busy. This makes them difficult to trace and track which is why the key element of information is email address. Surgeons complete the operative details online once the surgical procedure is completed. The NLR online system then automatically prompts patients to fill in their patient reported outcome measures (PROMs) at scheduled times throughout their treatment and rehabilitation. The outcome measures chosen are the knee injury and osteoarthritis outcome score (KOOS), subjective International Knee Documentation Committee (IKDC), Euroqol (EQ5D) and the Tegner activity score. The PROMs are collected preoperatively then at 6 months, 12 months, 2 years and 5 years postoperatively. These scores allow comparison with existing Registries as well as allowing potential ‘generic health benefit’ comparisons to other non-Orthopaedic procedures.

It is important to appreciate that not all the data on the NLR have been entered online by the patients. Two main exceptions do exist on the registry. First is the data from some hospitals in the independent sector that have their own local hospital database that store information on patients undergoing ACLR procedures. This data gets collectively imported to our online system at the end of each year. The data imported is entered manually on the NLR system by administrative staff. The other exception is patients who have not filled in the online PROMs due to either not having a valid email address to receive the reminders from NLR or incompliance with using the online system. Some of these patients fill in paper PROMs forms when they attend their follow up with their surgeons. The surgeons then upload this data manually on the online system. This means that NLR has a mixture of both online completed and imported data.

We analysed all the data entered on the NLR since its launch at the beginning of 2013 till 31st of December 2018. The raw data was extracted from the online system and inputted into a Microsoft Excel 2016 data-base. We analysed all the data that might influence the outcome following ACLR procedures including patients' demographic data, injury related factors, graft choice, surgical techniques and fixation devices. We also looked at PROMs and patients' compliance with the registry.

3.3 Results from Current Data

A total of 12558 patients with ACL injury were registered in the national ligament registry between the first of December 2012 and the 31st of December 2018. Of these, 9794 patients (78%) underwent ACLR surgery. The remaining 2764 patients (22%) are either waiting for surgery or have no operative data entered on the registry (Table.1). A total of 2733 patients were added to the registry between 1st of January 2018 and 31st of December 2018. Of these, 1831 patients (67%) underwent ACLR procedure and are the main focus of this report. The remaining 902 patients (33%) are still waiting for surgery or have no operative data entered on the registry.

Table 3.1: Number of patients who had primary ACLR with completed procedure form on the NLR between 2013 and 2018

	Primary ACLR (Patients with procedure form)(%)	**Patients without procedure form (%)**	**Total (100%)**
2013	590(89%)	73(11%)	663
2014	1339 (88%)	175(12%)	1514
2015	1879(84%)	354(16%)	2233
2016	1987(78%)	566(22%)	2553
2017	2168(76%)	694(24%)	2862
2018	1831(67%)	902(33%)	2733
Total	9794(78%)	2764(22%)	12558

A total of 101 surgeons have entered patients on the NLR in 2018. There has been a gradual increase in the number of surgeons adding patients to the registry over the past 6 years (Fig 3.1).

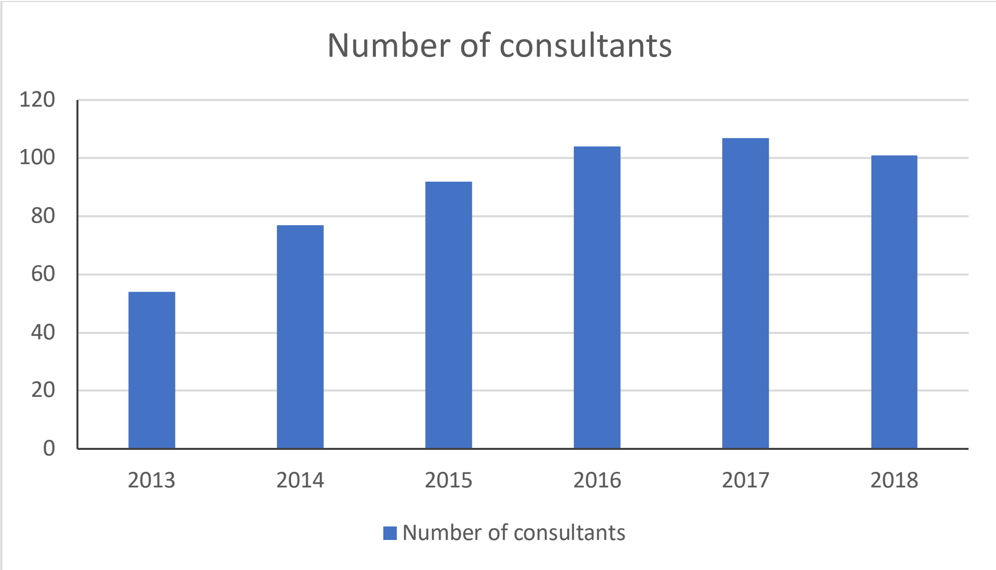


Figure 3.1: Number of surgeons who entered patients on the NLR between 2013 and 2018

3.3.1 Age at surgery

The average age for patients undergoing ACLR between 2013 and 2018 was 29. 18% of patients who underwent ACLR surgery were over the age of 40. This could be attributed to the increased sports participation in this age group with patients performing athletic activities later in life that predispose them to ACL injury. Figures (3.2 and 3.3) demonstrate the number of patients who had ACLR surgery in different age groups. Figure (3.4) demonstrates the number and percentage of patients in different age groups over the last 6 years. In 2018, there were more patients above the age of 40 and fewer patients under the age of 20 undergoing ACLR compared to 2017.

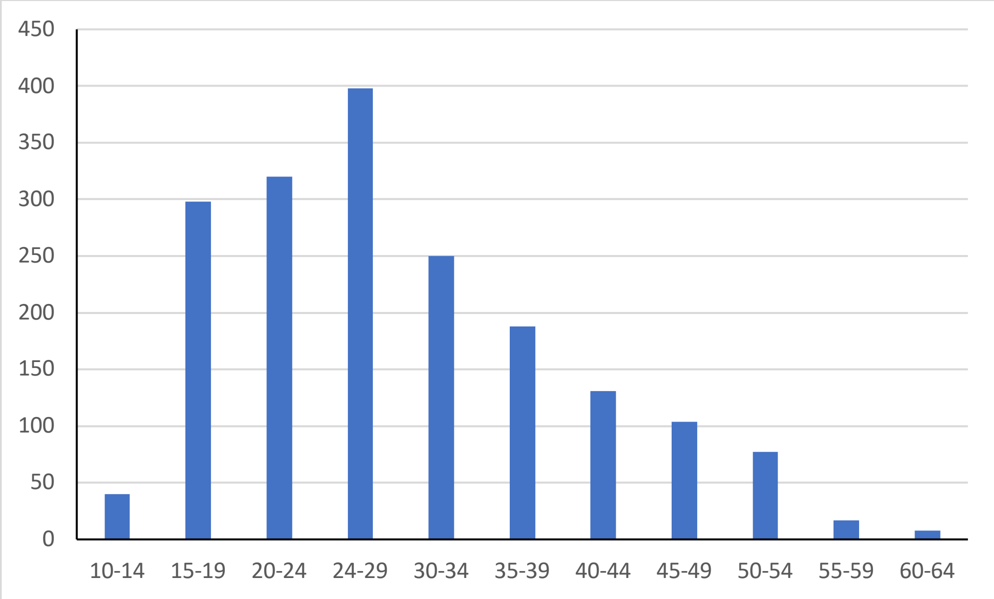


Figure 3.2: Number of patients who underwent primary ACLR in 2018 according to their age at time of surgery

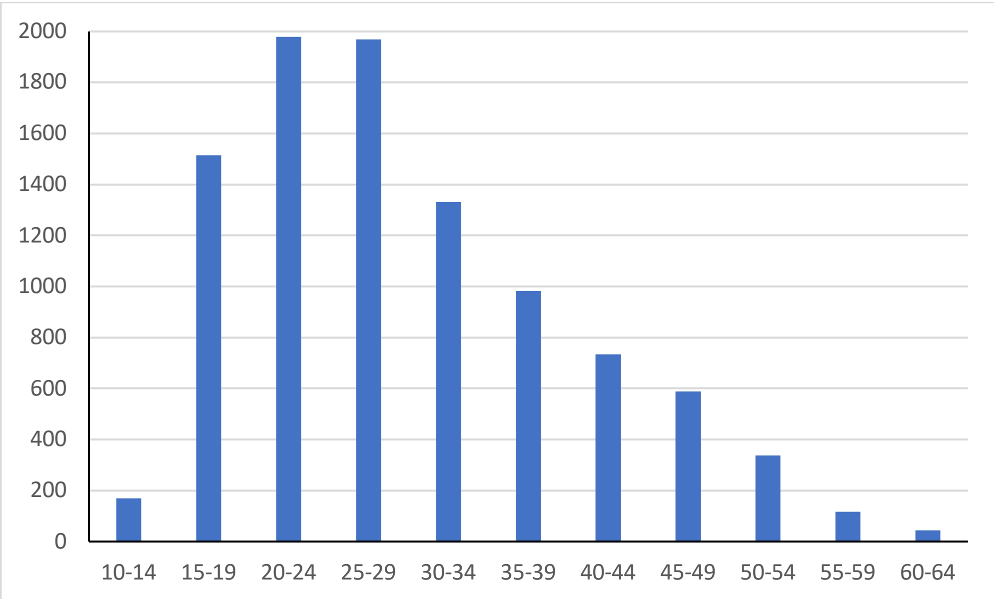


Figure 3.3: Number of patients on the NLR who underwent primary ACLR according to their age at time of surgery (2013-2018)

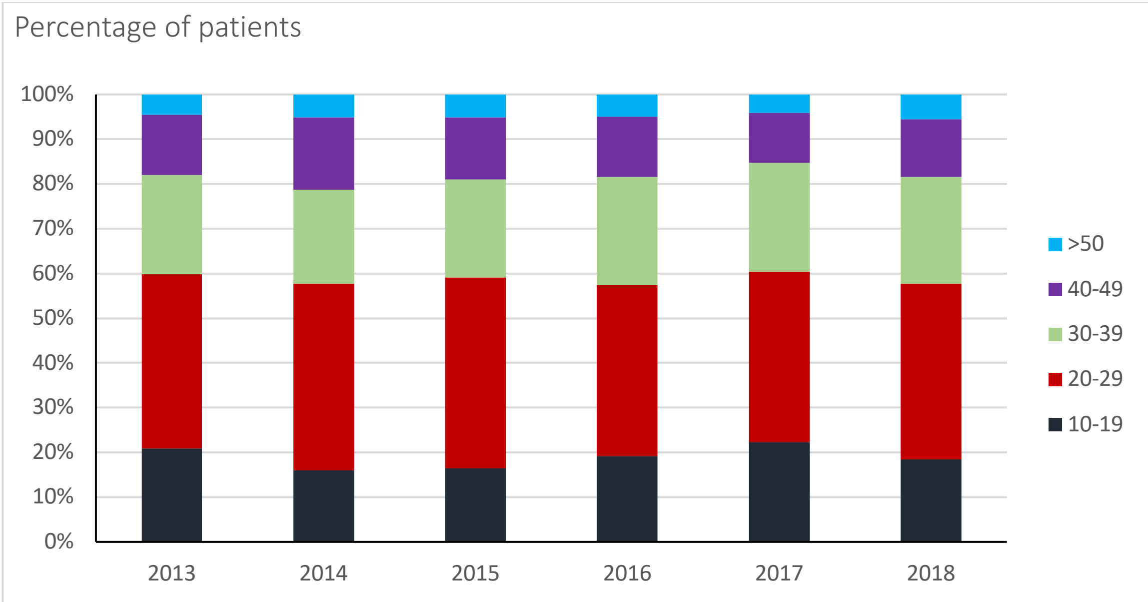


Figure 3.4: Percentage of patients who underwent primary ACLR according to their age groups at time of surgery between 2013 and 2018

3.3.2 Gender distribution

The percentage of men and women who underwent ACLR surgery in 2018 were 72% and 28% respectively (Figure 3.5). These percentages have been similar every year since 2013. The average age for women who had ACL surgery was 32 while it was 29 in men. The distribution of male and female in different age groups is shown in Figure (3.6). More women underwent ACL surgery above the age of 50.

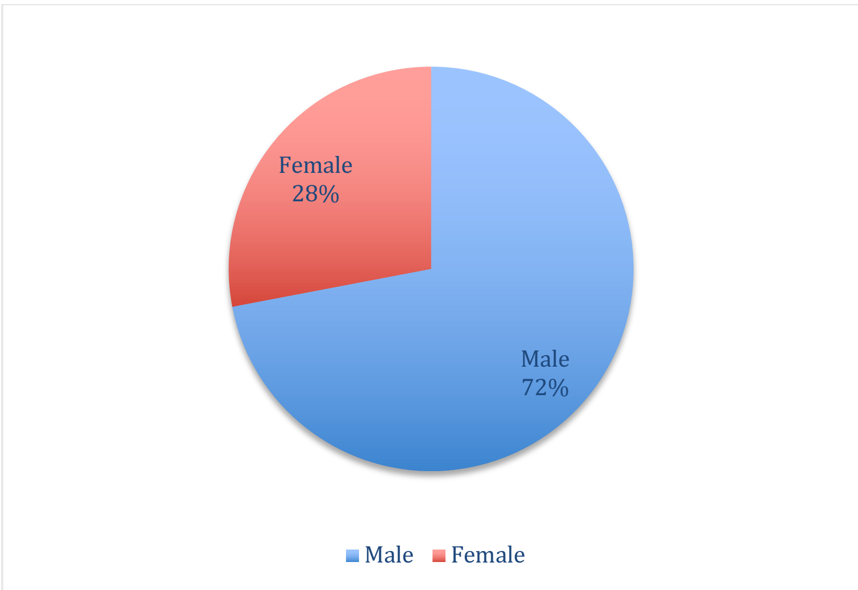


Figure 3.5: Percentage of male and female patients who underwent ACLR surgery

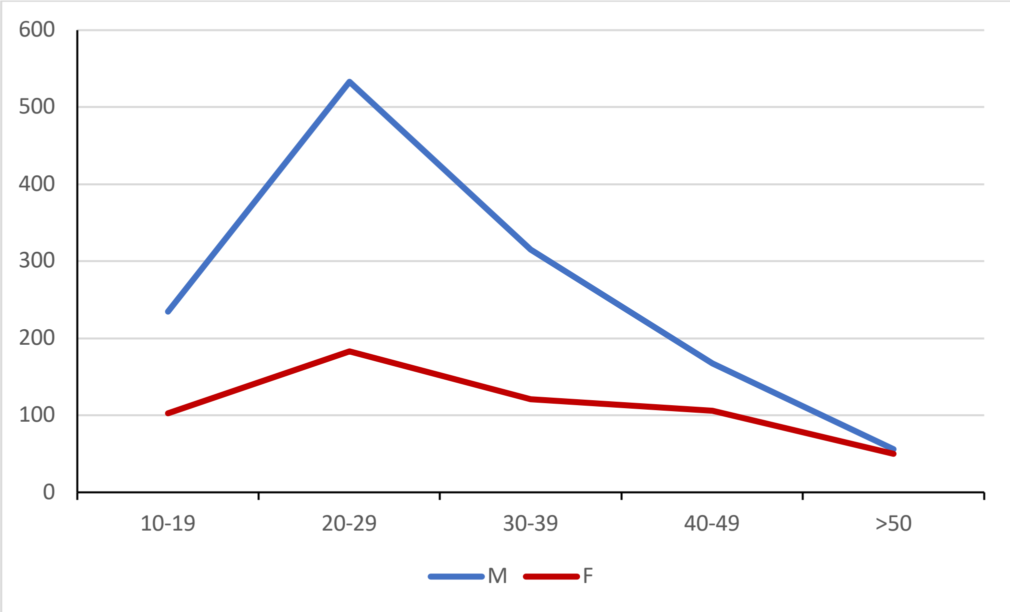


Figure 3.6: Distribution of male and female patients who underwent ACLR surgery in different age groups in 2017

3.3.3 Operated side

In 2018, the right knee was operated upon in 53% of patients who underwent ACLR surgery while it was the left knee in 47% of patients (Figure 3.7). This percentage has been persistent since the launch of the registry in 2013.

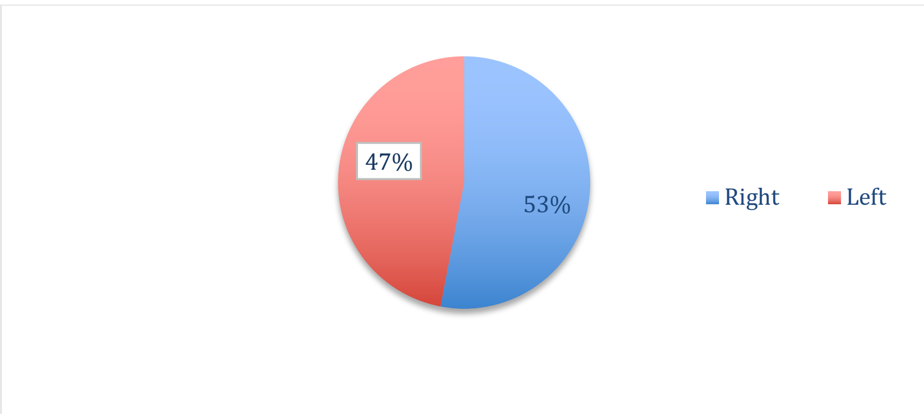


Figure 3.7: Operated Side

3.3.4 BMI distribution

Figure (3.8) describes the body mass index (BMI) ranges for patients who underwent ACLR procedures in 2018. The BMI was recorded in 1617 patients (76%). Of these, approximately 44% had BMI values between 18.5 and 25 while 3% were over 35. Figure (3.9) demonstrates the percentage of patients in different BMI groups over the last 6 years.

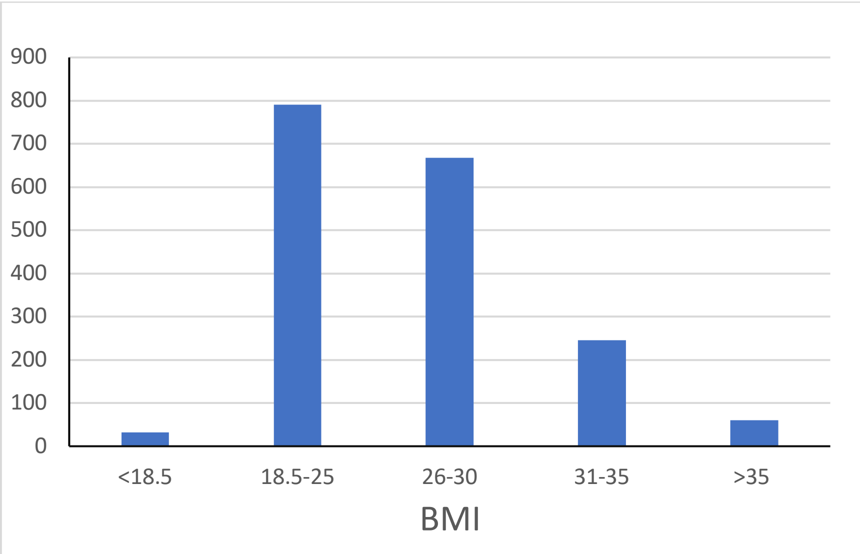


Figure 3.8: BMI ranges for patients who underwent ACLR procedures in 2018.

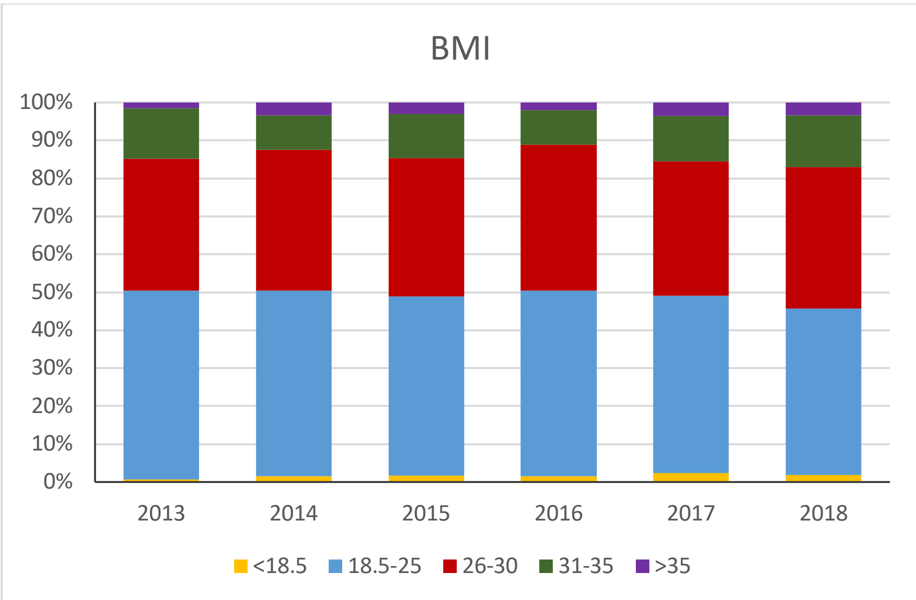


Figure 3.9: Percentage of patients who underwent primary ACLR according to their BMI at time of surgery between 2013 and 2018.

3.3.5 Activity in association with the ACL injury

Sport injuries are the leading cause for ACL tears. This is particularly common in pivoting and cutting sports. Out of 9794 patients with ACLR on the registry, 4299 (44%) have answered the question on the activity leading to their ACL injury. 87% of those that answered sustained their ACL injury while engaged in sports activities while 13% sustained their ACL injury due to non-sport activities. Football (soccer) was the most common activity associated with an ACL injury. Among men, the second most common activity associated with ACL injury was rugby followed by snow skiing. However, snow skiing was the most common activity associated with an ACL injury in women, followed by netball. Table (3.2) shows the sport activities in relation to the ACL injuries in men and women. Table (3.3) shows the various non-sport activities that lead to ACL injury. Over one third of these patients reported having a fall as the cause for their ACL injuries.

Table 3.2: Distribution of sport activities as the cause for ACL injuries in men and women

	M	F	Total	(%)
Football (Soccer)	1651	117	1768	47.4%
Rugby(Union)	434	56	490	13.1%
Snow Skiing	145	320	465	12.5%
Netball	0	184	184	4.9%
Other	118	83	201	5.4%
Rugby(League)	74	13	87	2.3%
Hockey (Field Hockey)	15	36	51	1.4%
Martial Arts	30	18	48	1.3%
Trampolining	12	41	53	1.4%
Basketball	43	11	54	1.4%
American Football	30	1	31	0.8%
Cycling (Mountain Bike)	25	5	30	0.8%
Running	18	7	25	0.7%
Horse riding	1	30	31	0.8%
Gaelic Games	22	4	26	0.7%
Badminton	15	9	24	4.9%
Squash	12	3	15	0.4%
Tennis	6	15	21	0.6%

Cricket	19	1	20	0.5%
Skate Boarding	16	0	16	0.4%
Gymnastics	5	11	16	0.4%
Volley Ball	11	5	16	0.4%
Boxing	6	4	10	0.3%
Cycling (Road bike)	7	3	10	0.3%
Athletics – Field	3	4	7	0.2%
Wrestling	6	0	6	0.2%
Judo	6	3	9	0.2%
Snow Boarding	3	2	5	0.1%
Hockey (Ice Hockey)	4	0	4	0.1%
Handball	1	2	3	0.1%
Roller Blading	3	0	3	0.1%
TOTAL	2741	988	3729	

Table 3.3: Distribution of non-sport activities as the cause for ACL injuries in men and women

	Male	Female	Total	(%)
Assault	12	4	16	3%
Dance	13	34	47	8%
Fall	124	104	228	40%
Motor Bike(Off road)	15	2	17	3%
Motor Bike(Traffic accident)	23	5	28	5%
Motor vehicle(Traffic accident)	8	6	14	2%
Other	72	72	144	25%
Work Related Injury	63	13	76	13%
Total	330	240	570	

3.3.6 Associated knee injuries with ACL tears

Of the 9794 patients who had ACLR surgery on the NLR, 50% had associated knee injuries that required surgical treatment. Medial meniscal surgery including partial meniscectomy and meniscal repair were the commonest associated surgery (21%). The second most common associated procedure was lateral meniscal surgery (14%). Combined medial and lateral meniscal surgeries were undertaken in 6.7% of the patients. Table (3.4) shows a breakdown of patients who had knee surgery associated with ACLR procedures.

Table 3.4: Total number of ACLR and associated surgery
MM= Medial Meniscus, LM= Lateral Meniscus, CL= Collateral Ligament, AC= Articular Cartilage, ALL= Anterolateral Ligament, PLC= Posterolateral Corner, PCL= Posterior cruciate Ligament

Number	2013	2014	2015	2016	2017	2018	Total
ACL	342	704	922	941	949	807	4665
ACL+ MM	82	267	385	457	515	406	2112
ACL+ LM	86	164	268	280	348	303	1449
ACL+ MM+ LM	34	68	129	126	169	137	663
ACL+ AC	12	30	32	30	36	34	174
ACL+ Other	0	10	15	21	18	18	82
ACL + CL	5	9	14	13	12	12	65
ACL+ Lateral tenodesis	1	3	12	24	17	17	74
ACL+ AC+ MM	5	16	7	17	15	21	81
ACL + PLC	1	13	11	4	9	4	42
ACL+ MM+ LM+ AC	5	10	7	4	12	11	49
ACL + LM+ AC	3	0	10	10	13	8	44
ACL+ LM+ lateral tenodesis	0	1	10	6	4	5	26
ACL+ MM+ lateral tenodesis	0	6	4	8	2	4	24
ACL+ MM+ other	1	3	6	6	3	2	21
ACL + ALL	0	6	4	3	5	2	20
ACL+ MM+ LM+ lateral tenodesis	0	2	6	6	3	0	17
ACL+ LM + CL	2	4	6	2	3	12	29
ACL + LM+ Other	1	1	2	7	3	3	17
ACL+ loose bodies	1	3	1	4	0	2	11
ACL+ MM+ CL	1	2	4	1	0	7	15
ACL+ MM+ Loose bodies	3	0	0	1	3	3	10
ACL+ MM+ LM+ PLC	0	1	1	0	5	0	7
ACL+ MM+ ALL	0	0	1	1	4	2	8
ACL + PLC+ CL	0	0	4	1	1	1	7
ACL+ MM+ LM+ CL	0	2	2	1	0	2	7
ACL+ PCL+ CL	1	1	2	0	1	1	6
ACL+ PCL	1	1	2	0	1	0	5
ACL+ LM+ ALL	0	0	1	1	2	1	5
ACL+ MM+ LM+ loose bodies	0	1	1	1	1	1	5
ACL+ LM+ PLC	0	1	1	1	1	0	4
ACL+ MM+ PLC	0	0	0	1	3	0	4
ACL+ AC+ Others	1	0	0	1	1	0	3
ACL+ MM+ AC+ other	0	1	1	0	1	1	4
ACL + PLC+ Lateral tenodesis	0	1	1	1	0	0	3
ACL+ MM+ LM+ ALL	0	0	0	1	2	0	3
ACL + CL+ Other	1	0	0	0	1	2	4
ACL+ AC+ PCL+ PLC	0	1	1	0	0	0	2
ACL+ LM+ Loose bodies	0	1	0	0	1	0	2
ACL+ MM+ LM+ AC+ loose bodies	0	1	0	0	1	0	2

ACL+ MM+ PCL	0	0	0	0	2	0	2
ACL+ Lateral tenodesis+ Other	0	2	0	0	0	0	2
ACL+ LM+ PCL+ Lateral tenodesis	0	1	1	0	0	0	2
ACL+ AC+ loose bodies	0	0	1	1	0	1	3
ACL+ AC+ CL + Loose bodies	1	0	0	0	0	0	1
ACL+ MM+ LM+ CL+ ALL	0	0	0	1	0	0	1
ACL + LM+ AC+ Other	0	1	0	0	0	0	1
ACL+ MM+ AC+ ALL	0	1	0	0	0	0	1
ACL+ AC+ CL	0	0	1	0	0	0	1
ACL+ AC+ MM+ lateral tenodesis	0	0	1	0	0	0	1
ACL+ MM+ PCL+ CL	0	0	1	0	0	0	1
ACL+ MM+ PCL+ PLC	0	0	1	0	0	0	1
ACL+ MM+ PLC+ ALL	0	0	0	1	0	0	1
ACL + PLC+ PCL	0	0	0	1	0	1	2
ACL+ LM+ PCL+ PLC	0	0	0	1	0	0	1
ACL + PLC+ PCL+ Lateral tenodesis	0	0	0	1	0	0	1
ACL+ PCL+ ALL	0	0	0	0	1	0	1
Total	590	1339	1879	1987	2168	1831	9794

3.3.7 Funding sources

The source of funding was recorded in 2264 patients (23%) out 9794 patients who had ACLR between 2013 and 2018. The NHS funded 80% of these patients while 20% were independently funded. Figure (3.10) shows the breakdown for funding sources over the last 6 years.

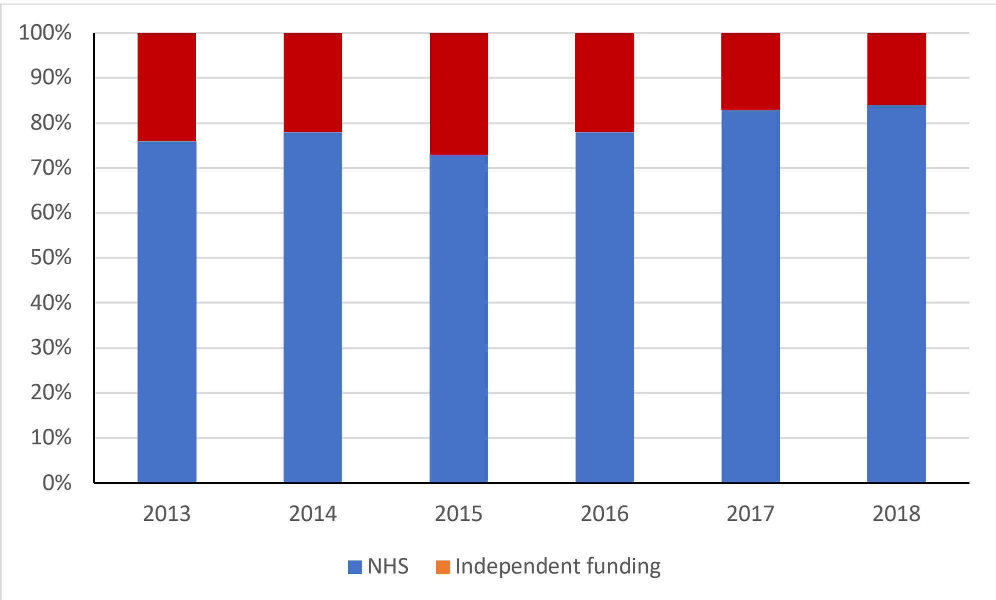


Figure 3.10: Funding sources for ACLR procedures (A total of 2264 patients were available for analysis)

3.3.8 Time to surgery

In 2018, the average time between ACL injury and surgical reconstruction was 164 days (Figure 3.11). Although this might appear as a long period between injury and surgery, it is similar to what has been reported by the Scandinavian registries. The reason for such a long period is unknown. Possible explanations include delayed diagnosis, long surgical waiting lists, prehabilitation and lengthy rehabilitation programs for patients who were initially managed non-operatively.

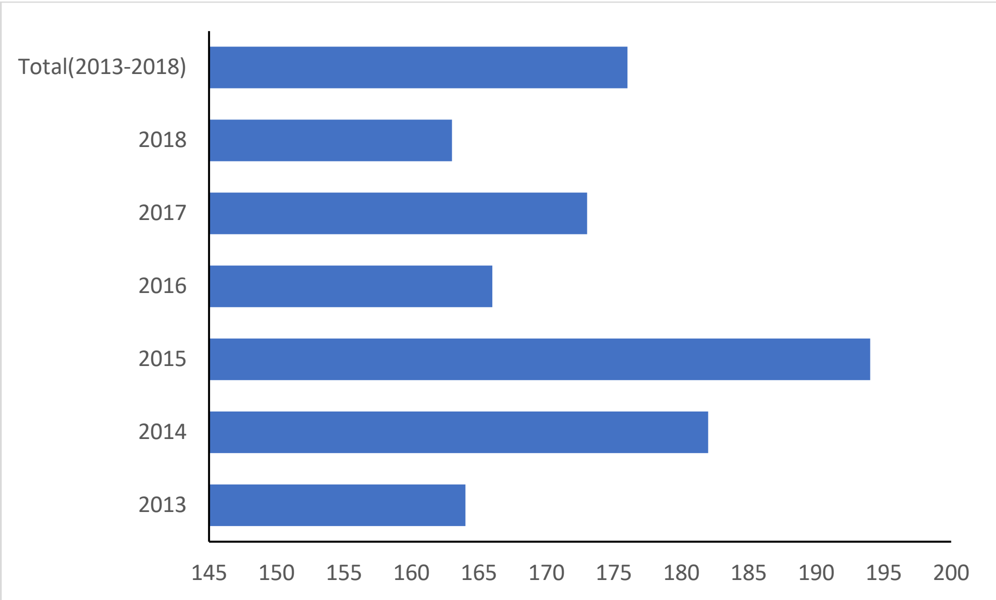


Figure 3.11: Average time from injury to ACLR surgery (days) over the last 6 years

3.3.9 Surgeons' profile

In 2018, 101 surgeons have registered their patients on the NLR. Forty-one surgeons performed 10 or less ACLR surgery while only one surgeon performed over 90 ACLR procedures. Figure (3.12) demonstrates the number of surgeons in relation to the total ACLRs procedure they have performed between 2013 and 2018. Figure (3.13) shows the grade of operating surgeons who performed the ACLR surgery. In 2018, there was a noticeable increase in ACL procedure performed by trainees and fellows compared to previous years. Approximately 90% of ACLR procedures on the registry have been performed by consultant grade surgeons.

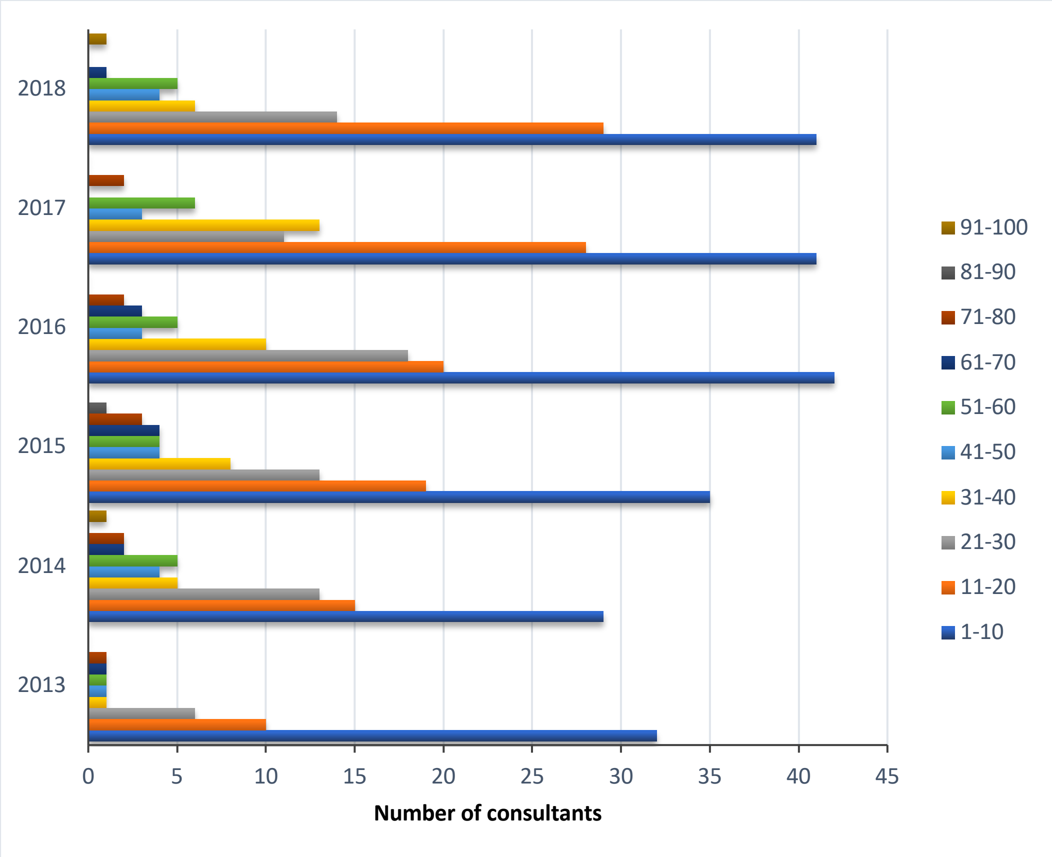


Figure 3.12: Number of surgeons in relation to the total ACLRs procedures they performed between 2013 and 2018

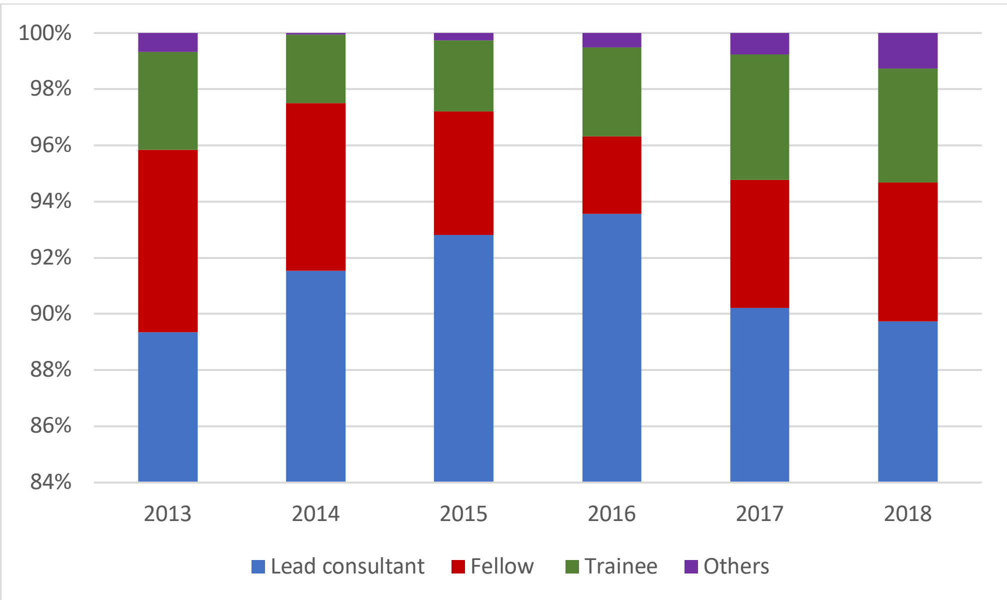


Figure 3.13: Grade of operating surgeons

3.3.10 Thromboprophylaxis

Perioperative thromboprophylaxis strategies were recorded in 2120 patients who underwent ACLR procedure between 2013 and 2018. Of these, 38% had no thromboprophylaxis given and 30% had mechanical methods of thromboprophylaxis (Figure 3.14). There were no details on type of mechanical or chemical prophylaxis that were used. The indications for specific thromboprophylaxis strategy were not recorded either.

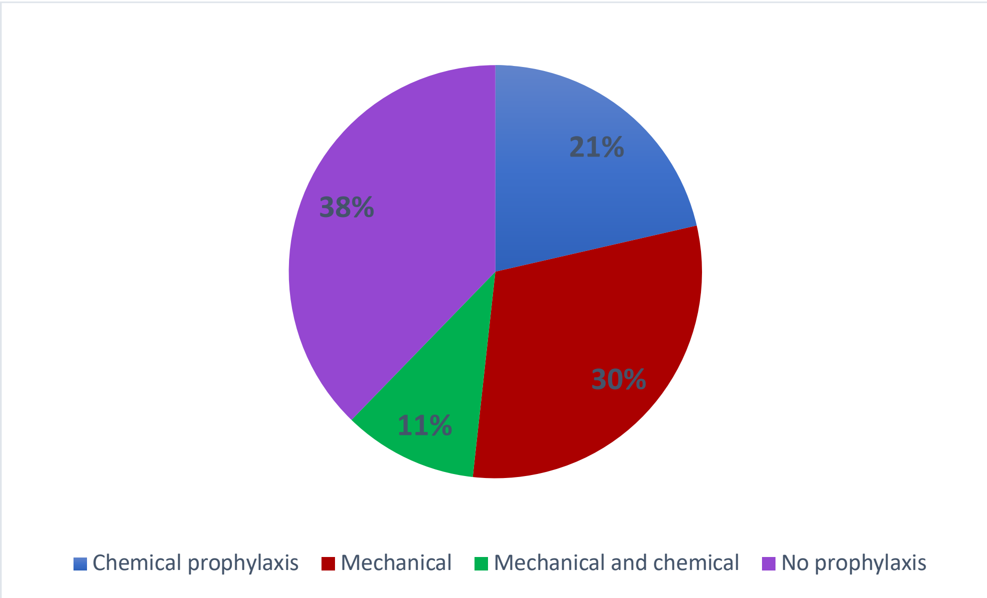


Figure 3.14: Percentage of different thromboprophylaxis strategies used in patients who underwent ACLR procedure

3.3.11 Graft type

The type of ACL graft used was recorded in 9261 out of 9794 patients who had primary ACLR between 2013 and 2018. Autograft was the most common graft choice in ACLR procedures (98%). Allograft was used in primary ACLR surgery in 1% of the patients. A synthetic graft was used in 32 patients only. Seventeen patients underwent direct suture repair for the ACL tear instead of reconstruction procedure (Figure 3.15). The outcome has only been captured for two of these patients so far.

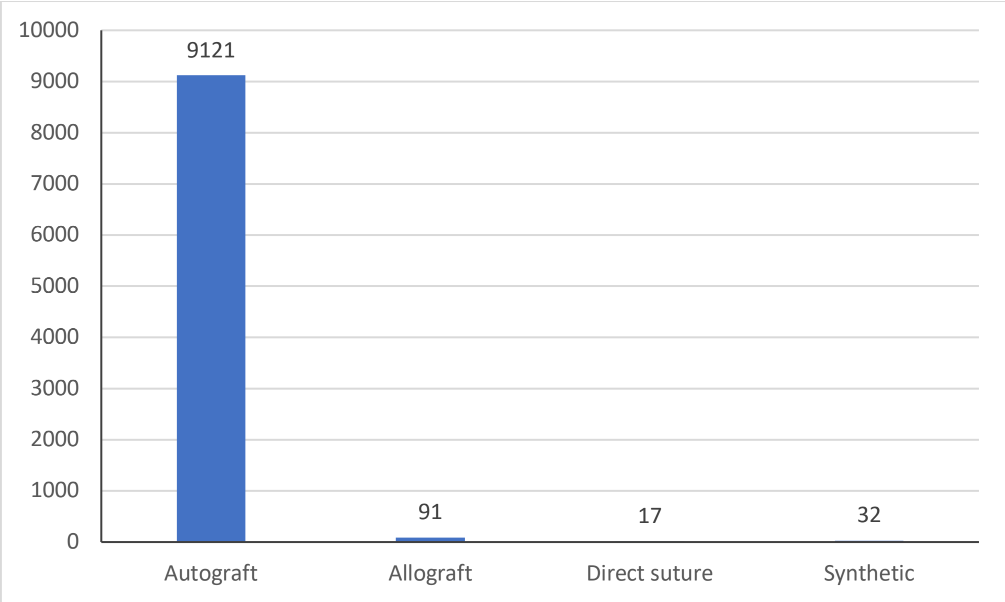


Figure 3.15: Type of ACL Graft. Data from 1867 patients were available for analysis

Hamstring tendon autograft was the graft of choice in the majority of patients who underwent ACLR procedures. A doubled semitendinosus and gracilis graft was the most commonly used autograft (79%) followed by semitendinosus alone (12%) and patellar tendon (9%). Quadriceps tendon autograft was used in 26 patients only (Figure 3.16).

The hamstring tendon autograft can be used in a single- or multi-strand configuration. Four-strand configuration was the most common (81%) followed by five-strand configuration (9.5%). Single-strand configuration was used in 40 patients only (Figure 3.17).

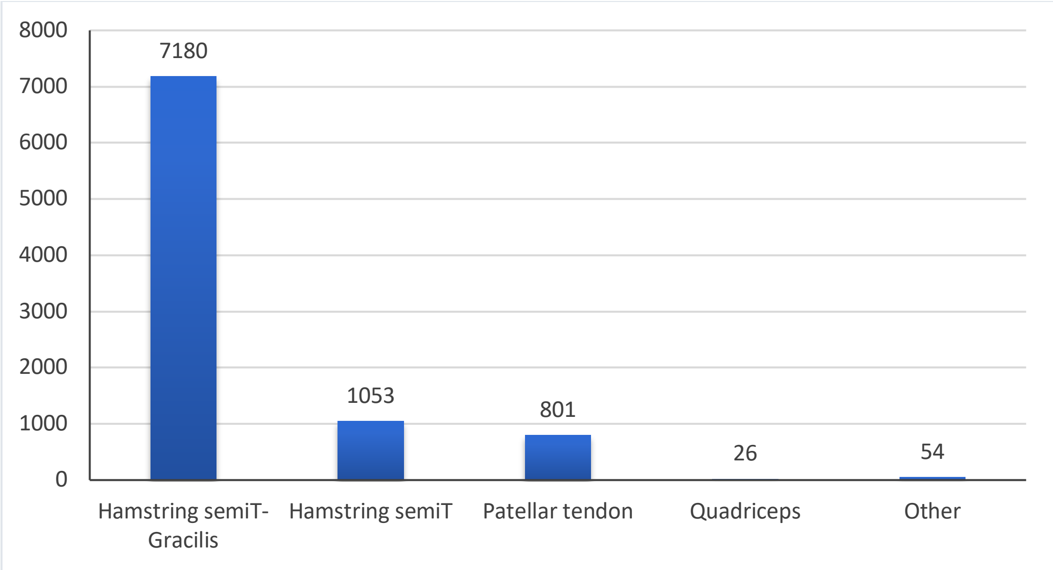


Figure 3.16: Types of ACL autograft

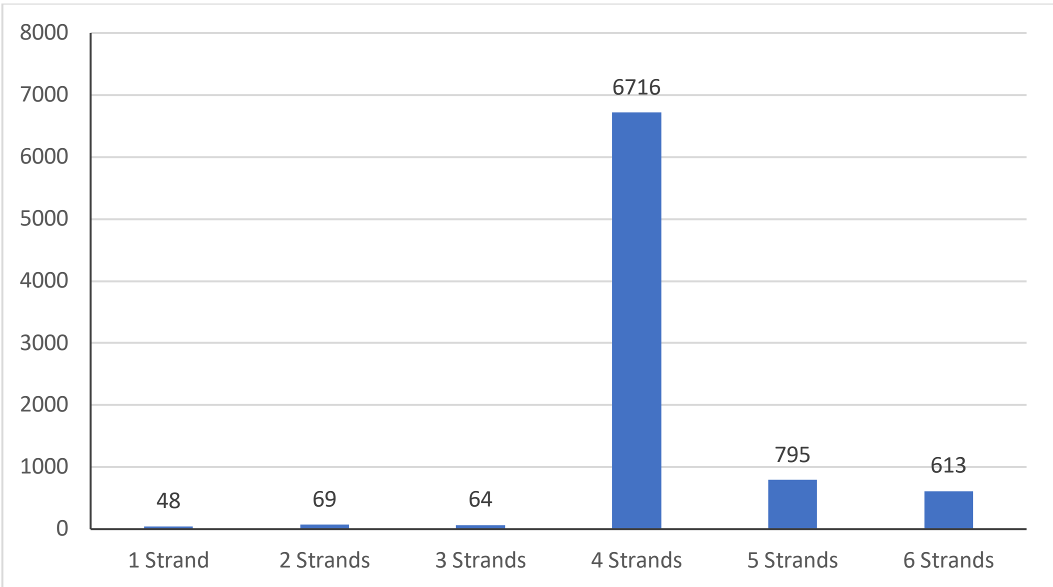


Figure 3.17: Hamstring tendon autograft doubling configurations.

3.3.12 Graft diameter

The most common hamstring autograft diameter was 8 mm (36%). 21 patients had a graft diameter of 6 mm (Figure 3.18). Figure (3.19) shows the graft diameters among men and women in different age groups. We studied the correlation between the patients' BMI and their graft diameter utilizing correlation coefficients (Pearson *r*). Figure (3.20) demonstrates that hamstring graft diameter was proportionately related to BMI (r = 0.25, P = 0.013). This suggests that patients with higher BMI will have a bigger graft diameter.

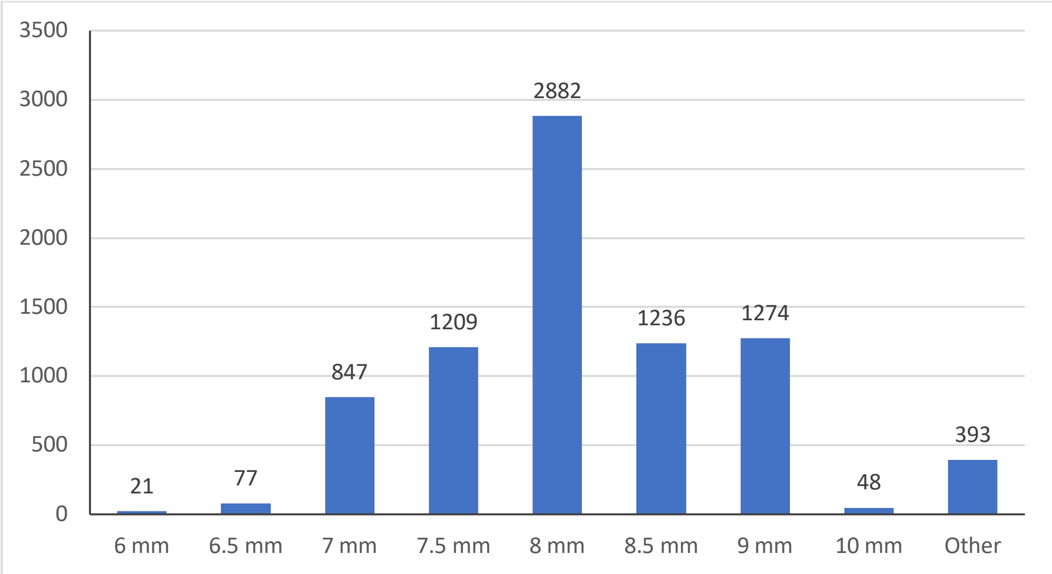


Figure 3.18: Graft diameter. Data from a total of 1838 patients were available for analysis.

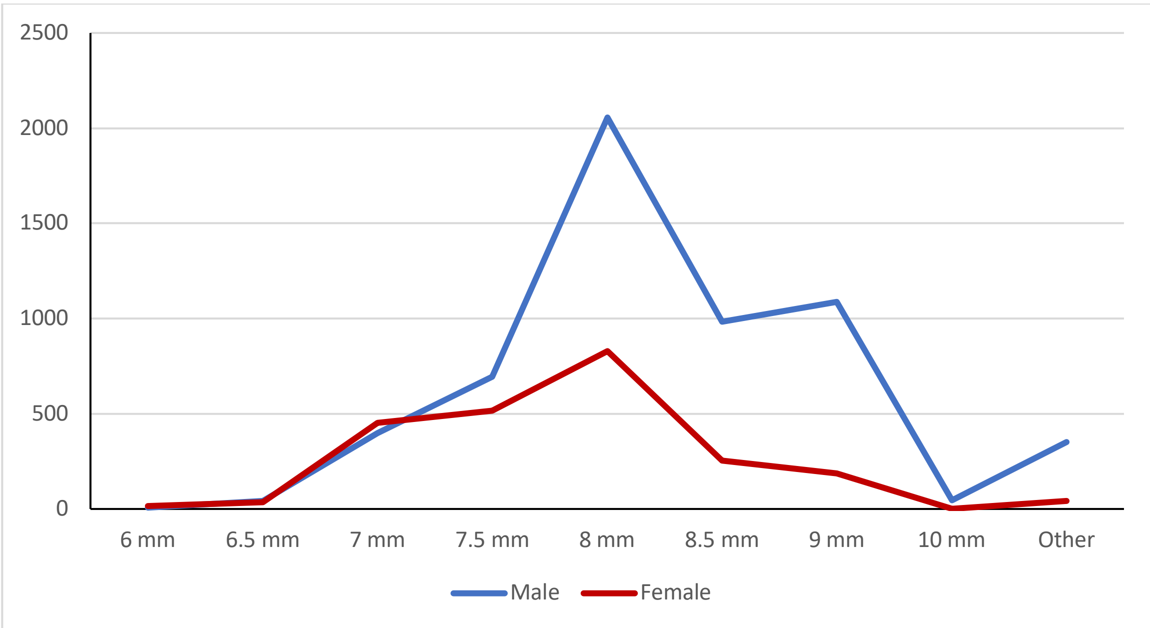


Figure 3.19: Graft diameter among men and women in different age groups.

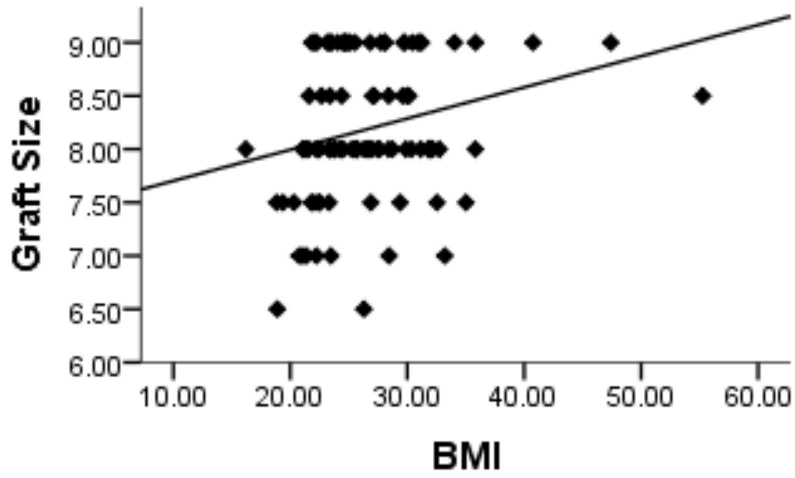


Figure 3.20: Correlation between BMI and graft diameter

3.3.13 Femoral and tibial tunnels drilling

Anteromedial portal (AM) was the most common portal for femoral tunnel drilling (Figure 3.21). The second common portal was through the all-inside technique. The transtibial technique was least common technique for femoral tunnel drilling. Figure (3.22) shows the percentages for different femoral tunnel drilling technique over the last 6 years. This shows a change in the trends in femoral tunnel drilling with the transtibial technique seems to be falling out of favour while there is growing increase in the use of all-inside technique. The outside-in technique was the predominant technique for tibial tunnels drilling (Figure 3.23). Figure (3.24) shows gradual increase in the use of the all-inside technique for tibial tunnel drilling over the last 6 years.

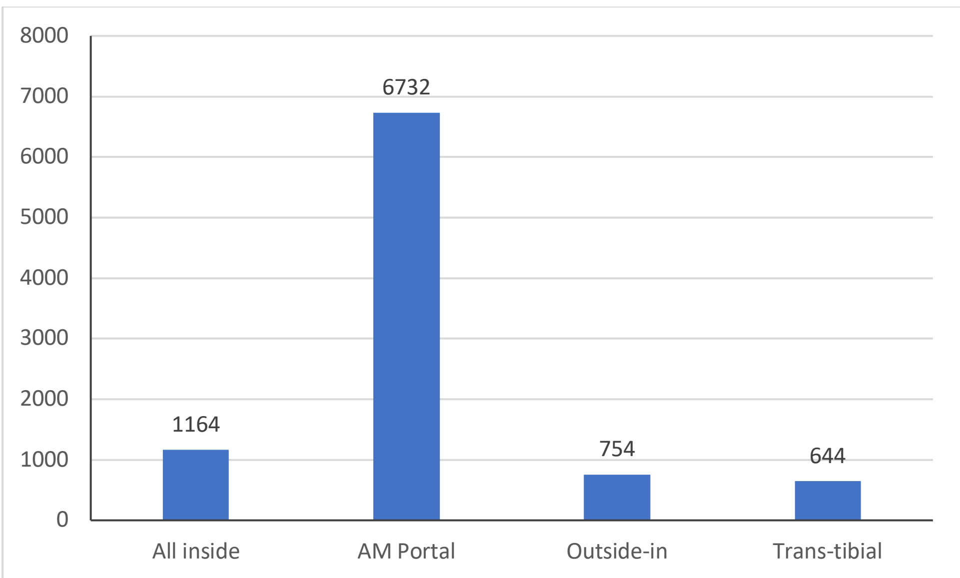


Figure 3.21: Femoral Tunnel Drilling Techniques between 2013 and 2018

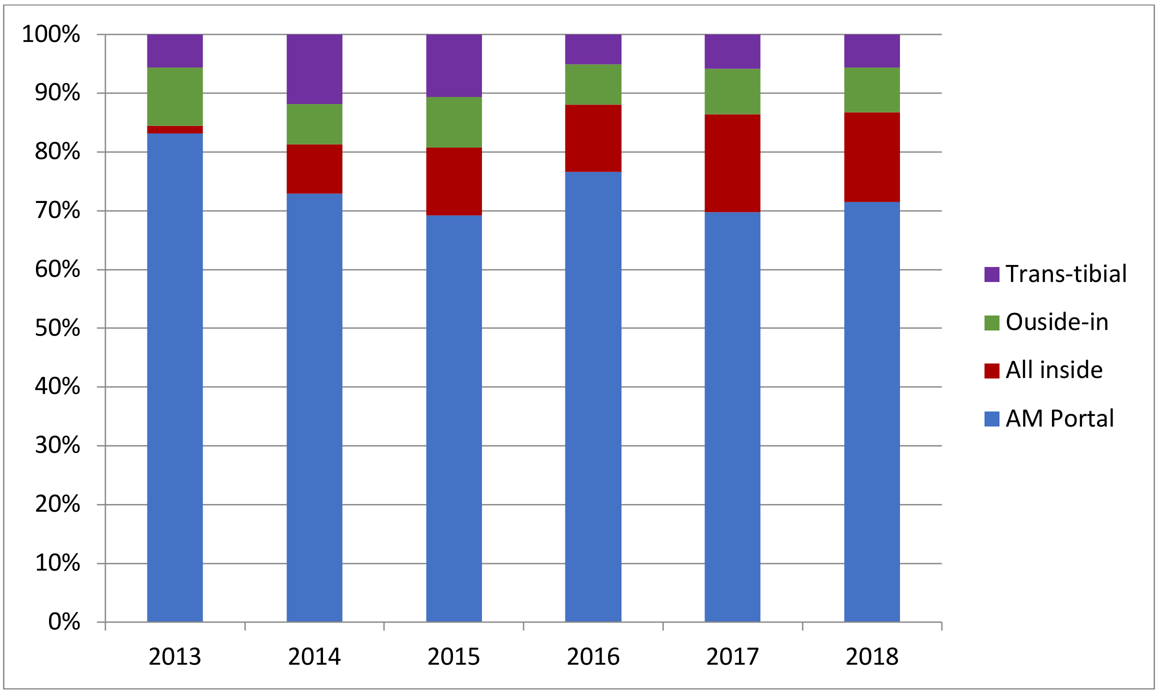


Figure 3.22: Percentages of different femoral tunnel drilling techniques between 2013 and 2018

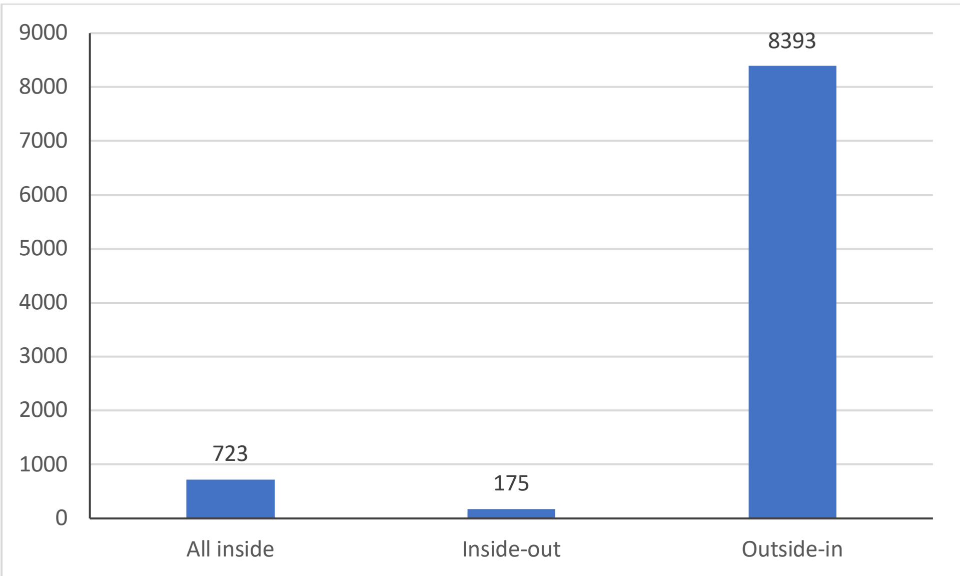


Figure 3.23: Tibial Tunnel Drilling Techniques

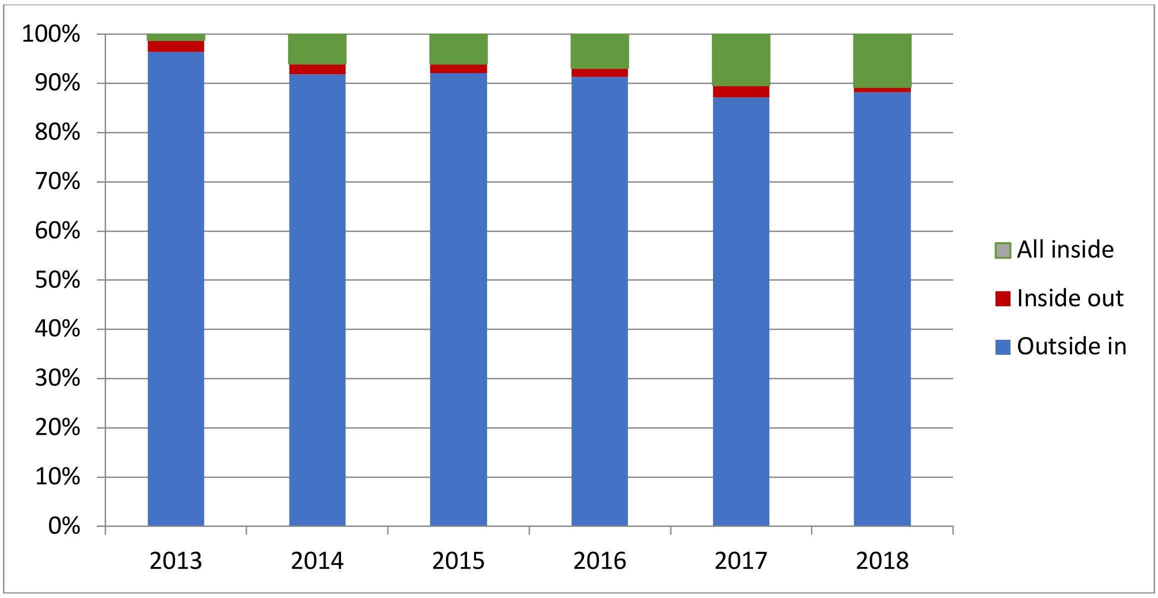


Figure 3.24: Percentages of different tibial tunnel drilling techniques between 2013 and 2018

3.3.14 Femoral and tibial tunnels fixation

Figure (3.25) shows the percentage of different fixation devices for the ACL graft in the femoral tunnel. Endobutton suspensory mechanism was the most common fixation method followed by interference screw fixation.

For tibial tunnel fixation, interference screws were used in 87% of all ACLR procedures on the NLR (Figure 3.26). Metal was the most common material used for femoral and tibial tunnels interference screws, although there growing increase in the use of PEEK screws over the last 6 years for tibial tunnel fixation (Figure 3.27 and 3.28).

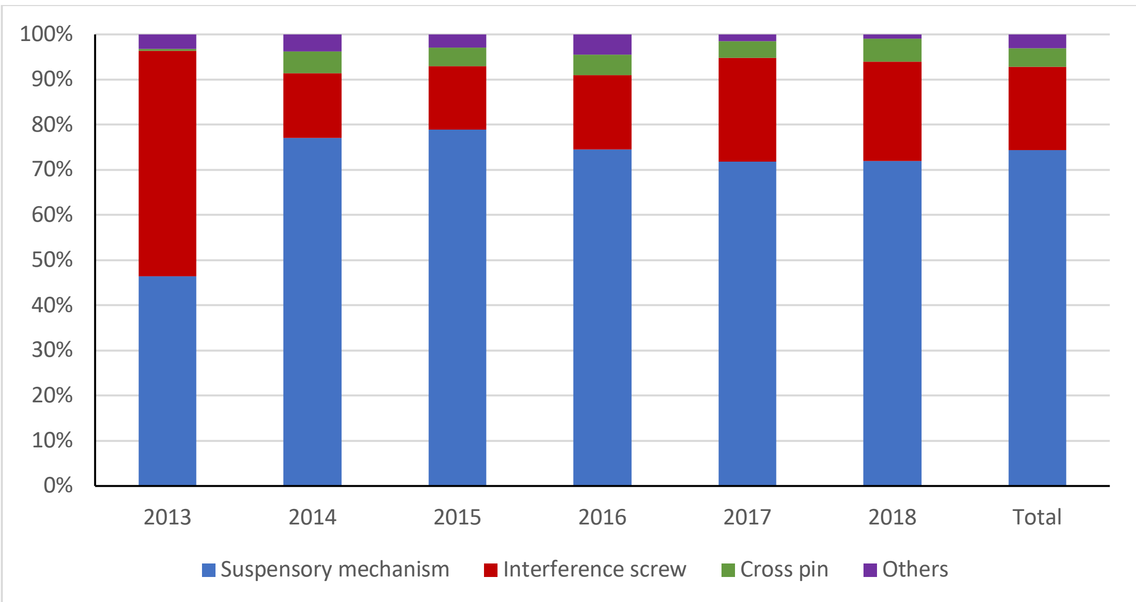


Figure 3.25: Femoral fixation devices

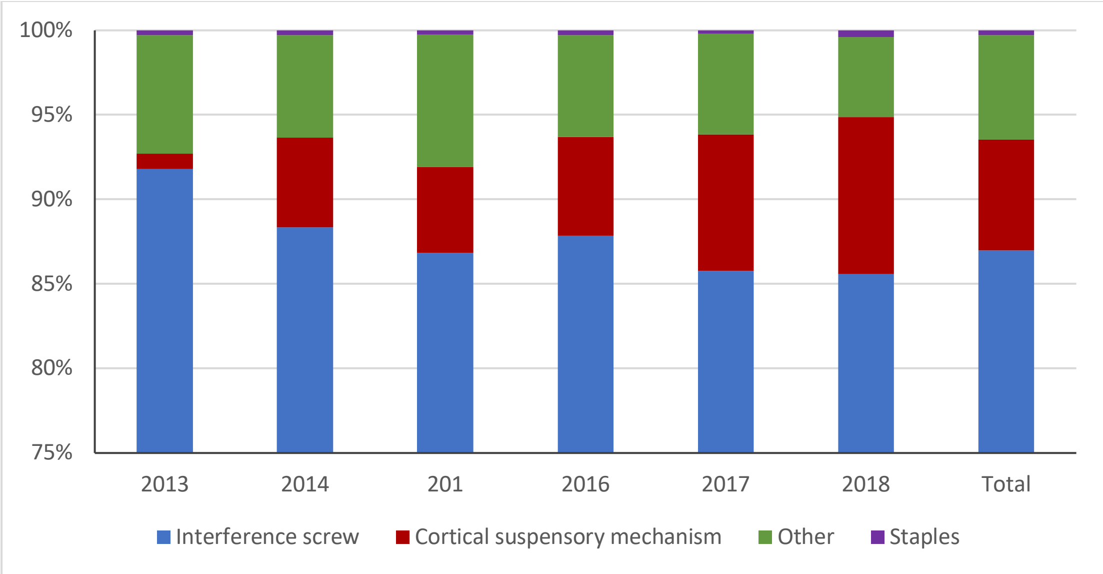


Figure 3.26: Tibial tunnel fixation devices

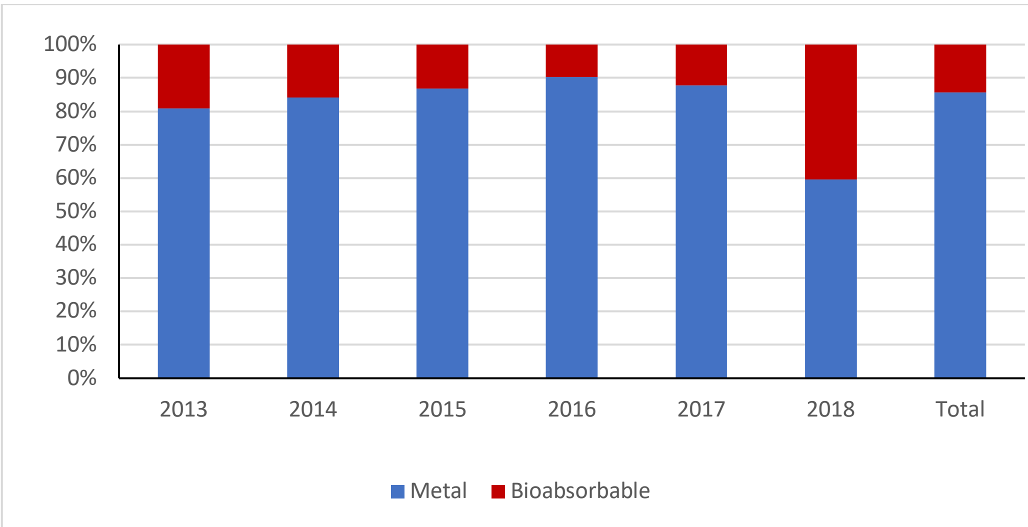


Figure 3.27: Materials used for femoral tunnel interference screws

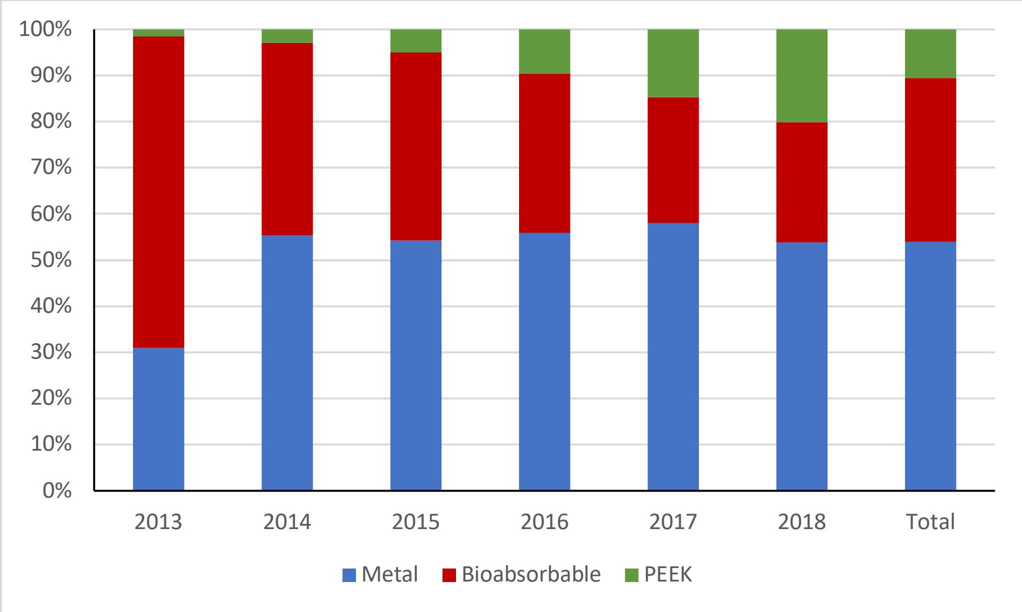


Figure 3.28: Materials used for tibial tunnel interference screws

3.3.15 Patient reported outcome measures (PROMS)

PROMs have become an integral part for assessment of any surgical intervention. A combination of generic and disease specific outcome measure is commonly used to assess treatment outcome. The NLR collect PROMS from patients preoperatively then at 6 months, 1 year, 2 years and 5 years postoperatively. The collected PROMs are EQ-5D, IKDC subjective, Tegner and KOOS scores. The results below are for all the patients registered on the NLR between 1st of December 2012 and 31st of December 2018.

3.3.16 EQ-5D

The EQ-5D is a simple generic measure of health for clinical and economic appraisal. It allows description of general health status along five domains. The results are presented as an index, a quality of life weighting between 0 (death) and 1 (complete health). The EQ VAS records the respondent’s self-rated health on a 0 to 100 visual analogue scale with endpoints labelled ‘the best health you can imagine’ and ‘the worst health you can imagine’. Figure (3.29 and 3.30) show improvements in postoperative EQ5D-index and EQ5D-VAS scores at 1 year and 2 years compared to preoperative scores.

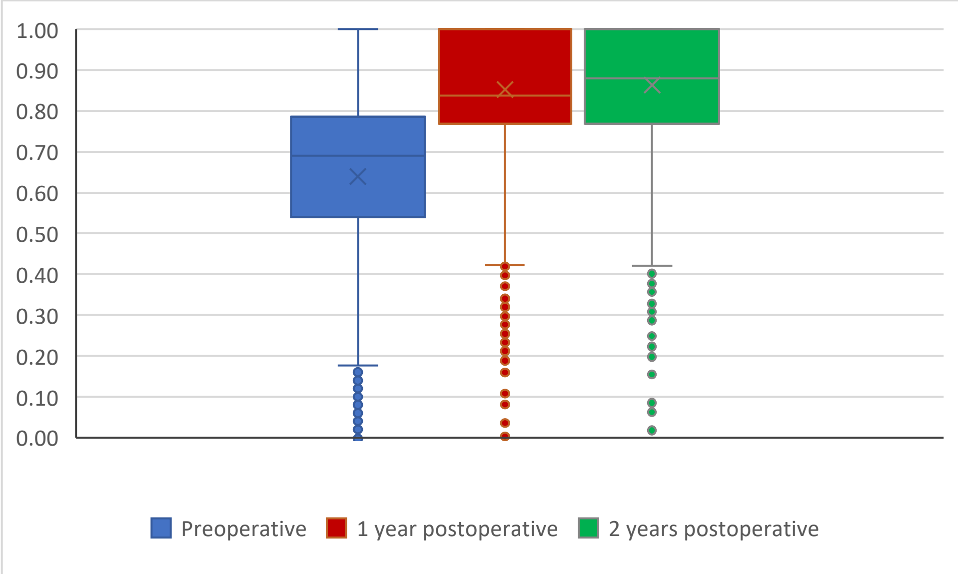


Figure 3.29: Preoperative, 6 months, 1 year and 2 years postoperative EQ5D-index scores for ACLR procedures

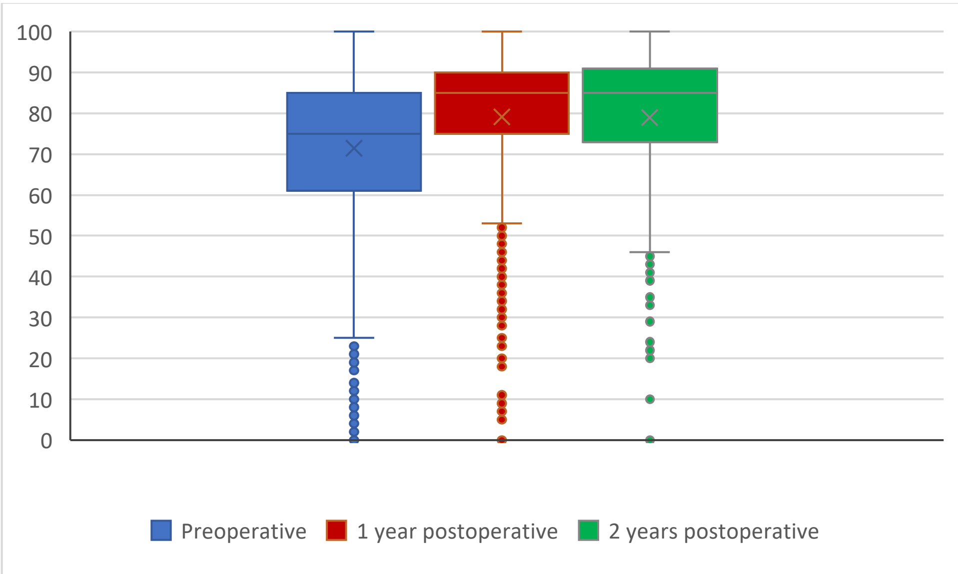


Figure 3.30: Preoperative, 1 year and 2 years postoperative EQ5D-VAS scores ACLR procedures.

3.3.17 The International Knee Documentation Committee Subjective score (IKDC)

The IKDC subjective knee questionnaire consists of 18 questions and evaluates symptoms, function, and sports activity (Irrgang et al., 2001). The raw scores are summated and transformed to a scale from 0 to 100. Figure (3.31) shows improvement in IKDC subjective scores at 2 years postoperatively.

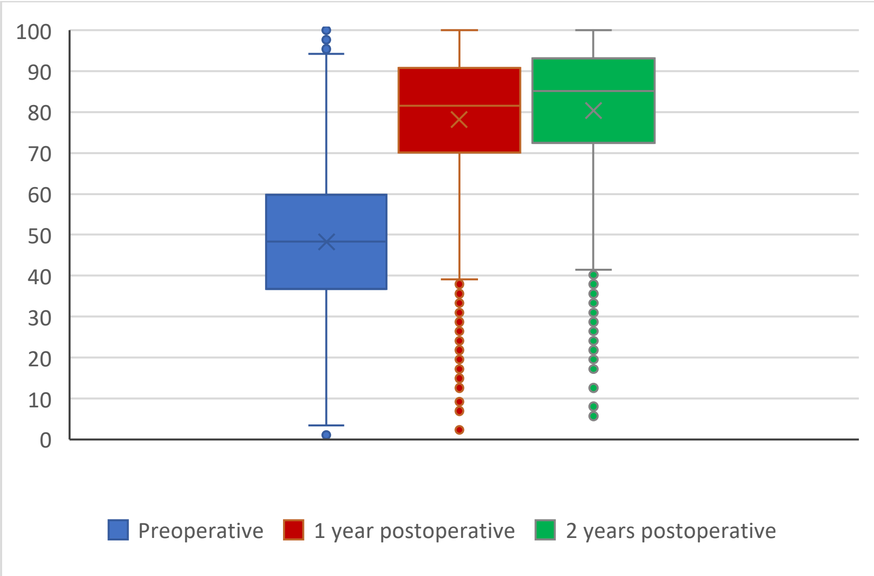


Figure 3.31: Preoperative, 6 months, 1 year and 2 years postoperative IKDC subjective scores for ACLR procedures.

3.3.18 Tegner score

The Tegner activity scale was designed as a score of activity level for patients with ligamentous injuries (Tegner and Lysholm, 1985). The instrument scores a person's activity level between 0 and 10 where 0 is defined as 'on sick leave/disability' and 10 is defined as 'participation in competitive sports'. Figure (3.32) shows improvement in Tegner scores at 2 years postoperatively.

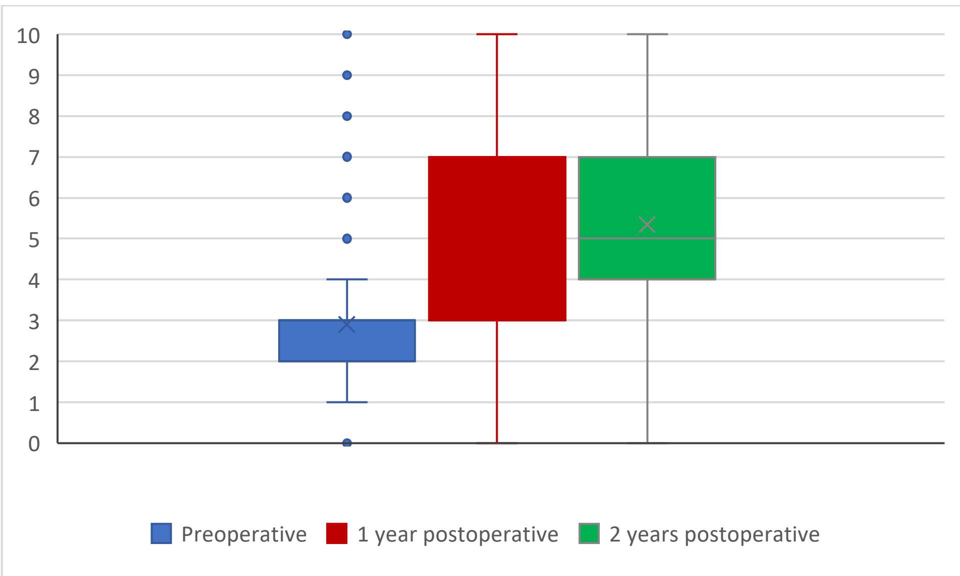


Figure 3.32: Preoperative, 6 months, 1 year and 2 years postoperative Tegner scores for ACLR procedures

3.3.19 Knee Injury and Osteoarthritis Outcome Score (KOOS)

The KOOS is a knee-specific patient-reported instrument (Roos et al., 1998). It is used to evaluate five domains: pain, symptoms, activity of daily living, sport and recreation, as well as the knee-related quality of life in patients with knee injuries who are at risk of OA developing (ACL, meniscus, or chondral) injury. It consists of 42-item self-administered self-explanatory questionnaire. It is intended to monitor the short- and long-term consequences (i.e., OA) of these injuries. Figure (3.33) demonstrates the improvement in the average KOOS scores at 6 months, 1 year and 2 years postoperatively across the 5 subscales. The quality of life subscale showed the highest increase in scores postoperative and was the most sensitive to change in the patient general health.

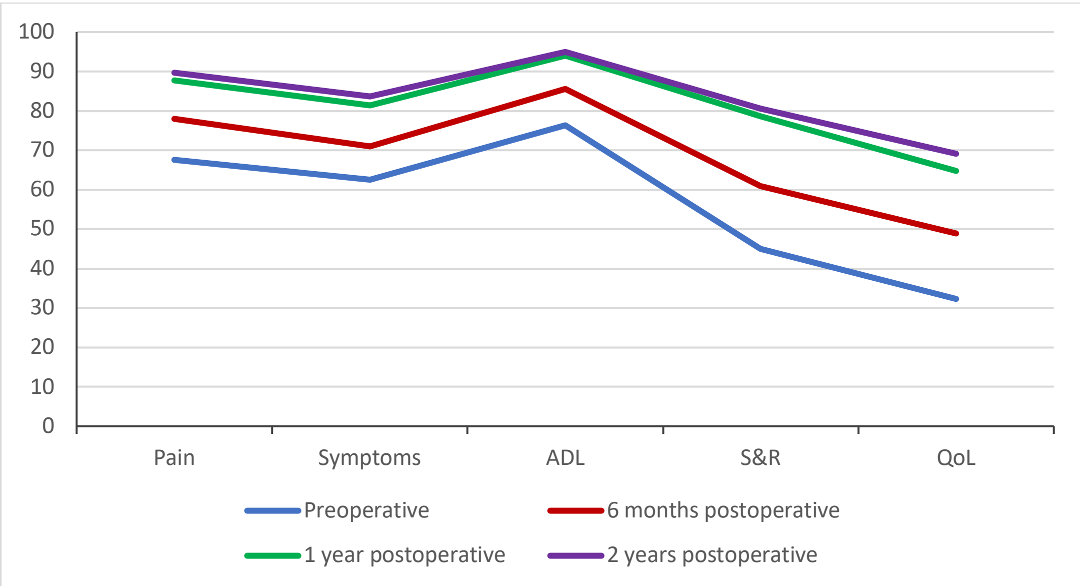


Figure 3.33: Preoperative, 6 months, 1 year and 2 year postoperative KOOS scores for ACLR procedures

3.3.20 Compliance: compliance with personal data and compliance with PROMS

The NLR is web-based register that relies on data entered by patients and surgeons. Figure (3.34) demonstrates the compliance rate for filling in the basic information entered for each patient. The email address is fundamental in registering patients on the NLR as it the main contact tool with the patient. Email address was recorded for 77% of patients in 2013; that has significantly increased to approximately 100% in 2018. All the patients included in this data analysis have given consent to store their information on the registry. It is reassuring to see a gradual increase in compliance with basic patient information over the last 6 years.

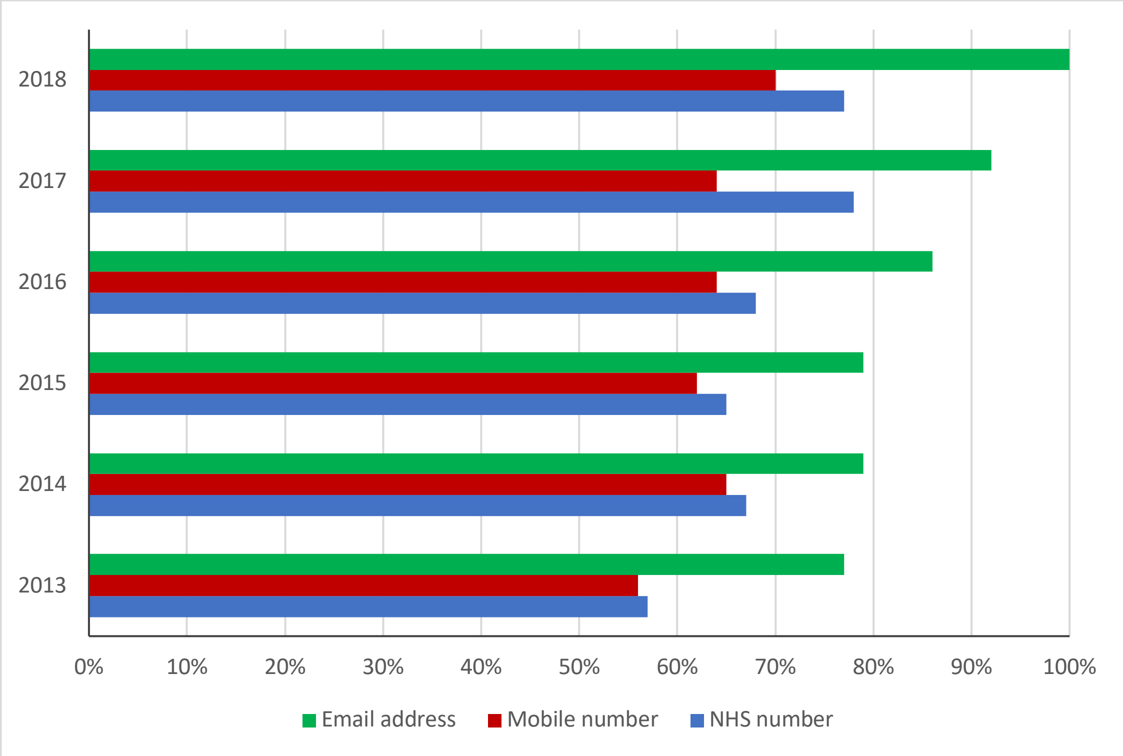


Figure 3.34: Compliance with basic patients' information between 2013 and 2018

Figure (3.35-3.38) shows compliance with filling in the different preoperative and postoperative PROMS questionnaires for patients who have been added between 2013 and 2017. We included all the completed PROMs for the patients on the registry who had a completed procedure form. The charts below show patients' compliance according to the year they had their operations in. The average response rate preoperatively was up to 58%. However, this drops down to approximately 37% at one year postoperatively and further down to approximately 32% at 2 years postoperatively. Interestingly, compliance rates are not the same across the various PROMs for the same time points. This indicates that patients sometimes complete some PROMs but not all four sets of PROMs.

It is important to appreciate that the aforementioned compliance rates are for all the patients on the NLR who had ACLR procedures. These include patients who had their dataset imported to the registry, and patients who had completed paper forms of

PROMs uploaded on the system. To analyse this further, we looked at patient compliance with online collection of data. This was for patients who had a valid email address on the system for communication. We measured compliance for KOOS score only. The results showed a significant increase in compliance by using the online system only (Figure 3.38). The response rate preoperatively was 76% then 46% and 38% at one-and two years postoperatively, respectively.

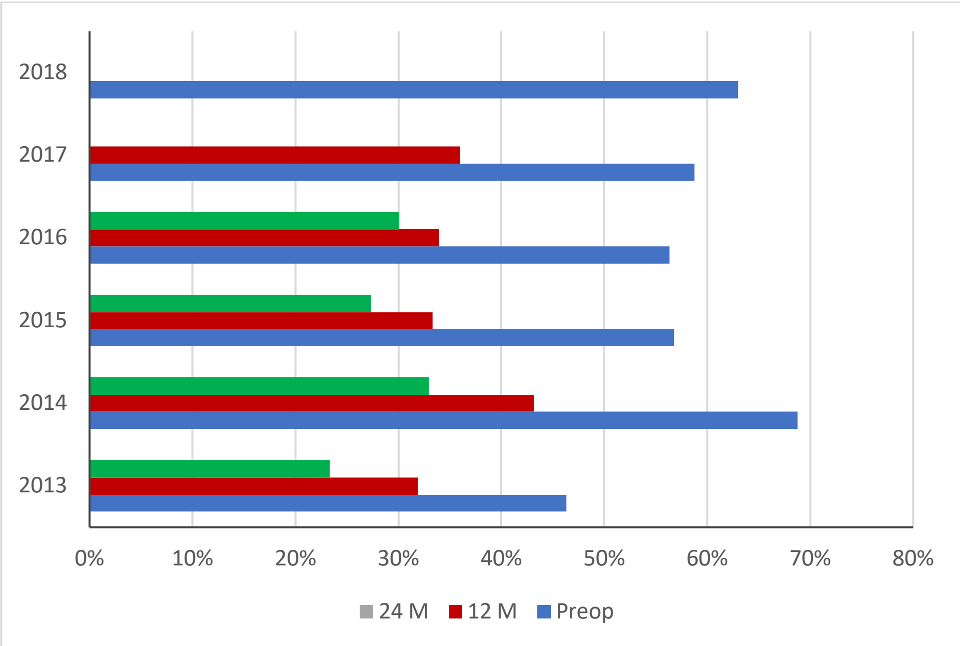


Figure 3.35: Response rate for preoperative and postoperative EQ5D VAS/Index scores between 2013 and 2018

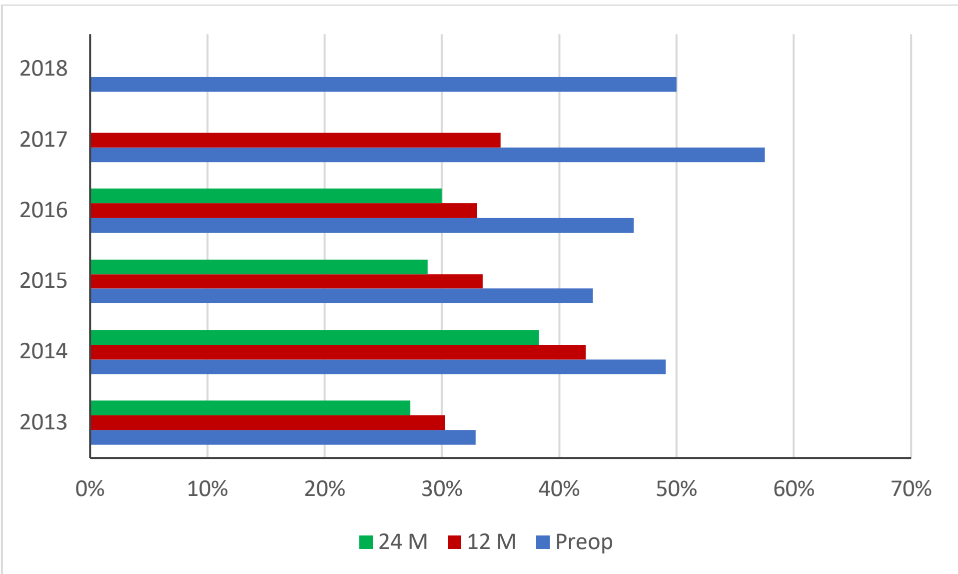


Figure 3.36: Response rate for preoperative and postoperative Tegner scores between 2013 and 2018

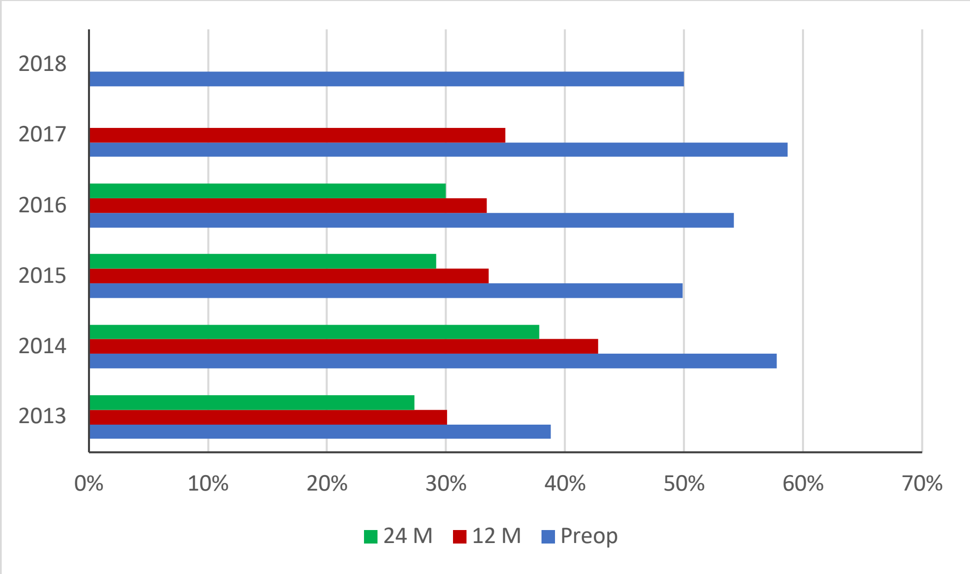


Figure 3.37: Response rate for preoperative and postoperative IKDC scores between 2013 and 2018

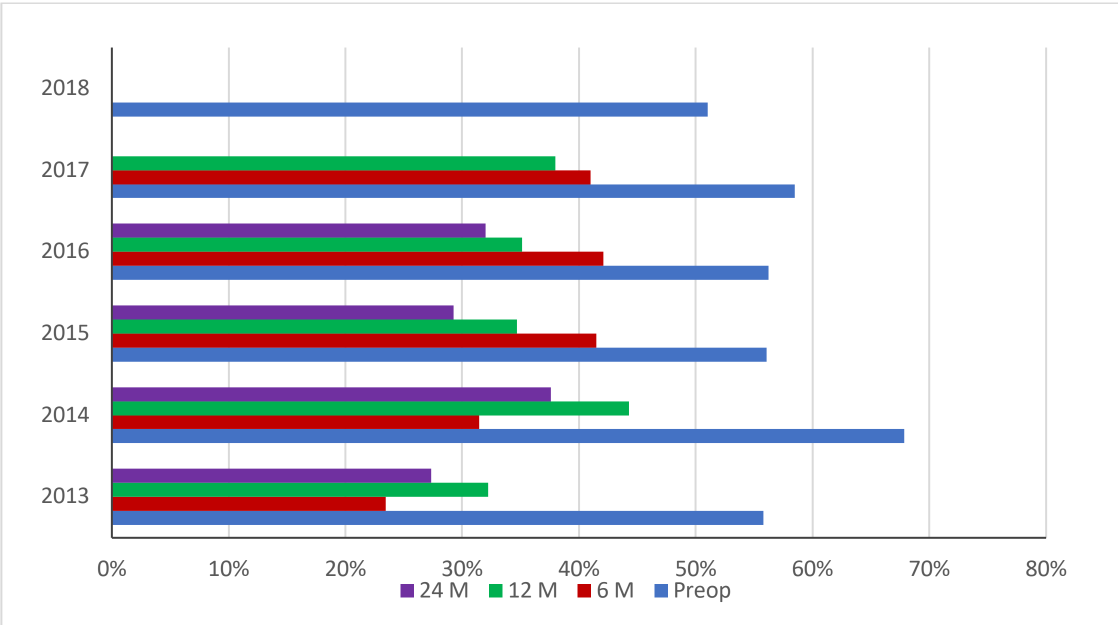


Figure 3.38: Response rate for preoperative and postoperative KOOS scores for all patients on NLR between 2013 and 2018

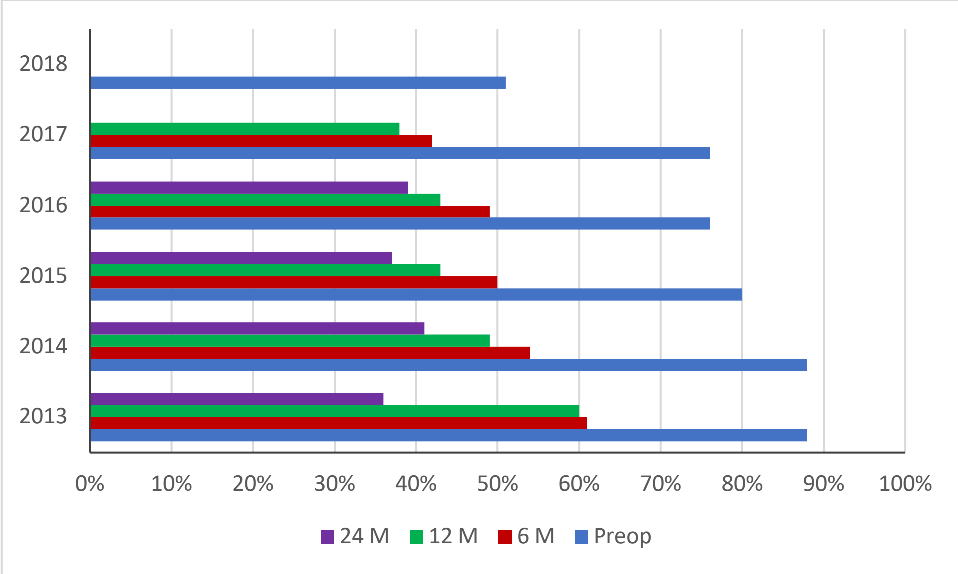


Figure 3.39: Compliance rate for online collection of KOOS score through email communication only between 2013 and 2018

3.3.21 Complications

We are aware that not all complications have been recorded on the NLR online database (Table 3.5, 3.6). The commonest Intraoperative complication was implant malfunction. Blown out femoral tunnel was reported in 15 cases. Graft failure was the most common postoperative complication (18 cases). The second most common complication was wound infection (15 cases). All cases of wound infection required further surgical debridement, wound wash out and IV antibiotics except for two cases of superficial wound infections that were treated with oral antibiotics. One case had a broken guide wire in the knee joint intraoperatively that required further surgery for arthroscopic removal of the broken wire.

Table 3.5: Recorded Intraoperative complication during ACLR procedures

Complications	Numbers of patients
Implant malfunction/breakage	24
Femoral Tunnel blown out	15
Bleeding	2
Ligamentous injury	2
Patella fracture	1

Table 3.6: Recorded Postoperative complications following ACLR surgery

Complications	Number of cases	Time after ACLR
Superficial infection (Total=4)	2	< 6 weeks
	2	> 6 weeks
Deep infection (Total=10)	7	< 6 weeks
	4	> 6 weeks
Graft failure (Total=18)	2	3-6 months
	4	6-12 months
	18	>12 months
Broken guide wire	1	< 6 weeks
Wound dehiscence and serous leak	1	< 6 weeks
Peripheral neuropraxia	1	< 6 weeks
Ongoing knee pain	3	>6 weeks
Cyclops	4	> 6 weeks
Post-meniscectomy syndrome	1	> 6 weeks
Pulmonary Embolism	1	< 6 weeks

3.4 Discussion

Over the last 5 years, The NLR has provided invaluable information on the epidemiology, operative techniques and functional outcomes for patients with ACL injuries. Many observations can be drawn from the data presented above. There was a total of 9002 ACLR patients between December 2012 and December 2018. Men in their 20s were the predominant group of patients who underwent ACLR surgery. Sports injuries and specifically football injuries were the most common cause for ACL injury. Medial meniscus surgery was the most common associated procedure with ACLR surgery. Allograft was used in only 1% of patients who had ACLR procedures in the NLR. Four-strand hamstring tendon was the most frequently used autograft. AM portal drilling was the most common technique for femoral tunnel drilling while it was the outside-in technique for the tibial tunnel drilling. The Endobutton suspensory mechanism was the most common method for graft fixation in the femoral tunnel while interference screws predominated for tibial tunnel fixation. Patients who underwent ACLR surgery showed steady progress of their functional outcome score at six months, 1 year and 2 years postoperatively compared to their preoperative scores. Complications are not well recorded on the registry, but implant malfunction was the most common intraoperative complication while graft failure was the most common postoperatively.

3.4.1 Comparing the NLR results to other registries

In contrast to the NJR, contribution to the NLR is yet entirely voluntary for the surgeons. This subsequently affects the quality and the quantity of the data available on NLR. The estimated rate of ACLR procedures in the UK is approximately 7000 procedures per year (Jameson et al., 2012). This indicates that the compliance rate with registering patients on the NLR is approximately 26% with just over 9700 patients registered between 2013 and 2018.

A recent collaborative study investigated similarities and differences in patients' demographics and surgical techniques among six national ligament registries (Prentice et al., 2018). This included the Danish, Norwegian, Swedish, Luxemburg and Kaiser Permanente (KP) registries in addition to the NLR. Demographic data was similar across the six registries although the most common age group at the time of surgery was 15-19 years in all registries apart from the NLR.

Interference screw fixation was the most commonly used method for tibial tunnel fixation in all registries. There were differences in the material used for tibial tunnel interference screws among registries. Metal was the most common choice in Norway, Sweden and the NLR while bioabsorbable was the primary tibial fixation material used in KP, Denmark and Luxembourg. This study has demonstrated that the NLR has got higher percentage of missing data compared to other registries. However, it is important to appreciate that the NLR was the most recently established registry among the six cohorts. Inconsistency in data collected among different registries was also observed in this descriptive study. Ligament registries will need to standardise data collection in order to facilitate future collaborative multi-register studies.

3.4.2 Value of registries

There has been a widespread of patient registries worldwide over the last two decades. In the UK, they have shown noticeable successes in various medical specialties. This includes improvements in management of stroke, cancer and cardiovascular diseases (Nelson et al., 2016). Patient registries are magnificent source of big data that is available for both clinicians and researches.

The real question is whether registry studies can effectively replace randomized controlled trails (RCT) specifically when long term follow up is required. RCT's are considered to be the gold standard for clinical research (Akobeng et al., 2005). However, conducting a large scale, high quality RCT's is often difficult due to ethical, financial and logistical challenges (Dy et al., 2016). A RCT typically compares only two or three treatment modalities due to the difficulty in recruiting and randomizing patients to multiple arms. Moreover, the rate of patient agreement to be enrolled in a surgical RCT is often less than 50% (Abraham et al., 2006). One of the main reasons for such a low patient participation in RCT's is that patients may have preference to a specific treatment thus declining randomization. RCT's often struggle to early pick up failing treatment modalities that have relatively low complication rates. Prosthetic joint infection is a typical example with an incidence rate of 0.5 -2% (Lenguerrand et al., 2017). Another example is revision surgery for primary knee arthroplasty (TKA) that has an approximate cumulative revision rate of 5 % at ten years follow up. A RCT would need to recruit a very large number of patients to prove that there is a significant difference between two prostheses. In order to get an 80% chance of detecting a significant difference for an implant with a 30% worse revision rate (6.5% versus 5%) almost 4000 patients would need to be randomized and followed for ten years (Robertsson et al., 2007). It is practically very difficult to maintain a trial with such a large number of patients for such a long period.

Another limitation for RCT's in orthopaedic surgery is time constraints and the evolvement of implant designs. A great deal of effort and cost could be invested in a RCT comparing the outcome of two femoral stem implants over 10 years. However, either one or both of these implants could undergo design modification by the manufacturer during this time period. The outcome of this RCT would then be practically of very limited value, as the results cannot be applied to the new implant design that would be in use in the market and replacing the old design that was examined. Registry data provides an easy and pragmatic solution to overcome these limitations. Its large data set enables researchers to conduct effective comparative studies. The registry data also eliminates the concerns over publication bias in clinical trials. Researchers tend to submit studies for publication with positive or significant results over studies with negative results. Similarly, studies with positive results stand better chances of selection for publication (Joober et al., 2012).

Registry data is essentially a large prospective longitudinal study but without a predetermined specific research question. There is a plethora of prospective longitudinal studies with long term outcomes in the orthopaedic literature. However, the results of these studies are often difficult to be freely generalized for various reasons. They are often conducted in large centers with surgeons who are experienced with the procedure and implants. Moreover, Patients are usually recruited through specific inclusion criteria that might make the results only applicable to a certain group of patients. Many of these studies are often driven by implant designers, which creates a substantial source of bias. Labek et al. (2011) reported that implant revision rates reported by implant designer studies were significantly very low compared to registry data for the same implants. Conversely, registries provide cross-sectional population based data denoting all patient groups and surgeons at different level of experience. The results from registry studies represent both the "typical" patient and the "average" surgeon thus could be easily generalized.

The main strength of the registry data remains its role in post market surveillance for new implants. The large cohort of patients on registries allow early identification of failing medical devices (Maloney et al., 2001). National joint registries have had a good track record for identifying implants with high complications or revisions rate. A good illustrative example is the poor performance of Boneloc® cement that was detected by the Arthroplasty register in Norway. Furnes et al. (1997) reported 14 and 7 times higher risk of revisions associated with Boneloc cemented Charnley and Exeter femoral stems respectively, compared to other high viscosity cement. These poor results of Boneloc® were identified within 3 years of its use and it was then permanently removed from the market (Delaunay, 2015).

Clinical registries are population based thus providing a unique opportunity for demographic and epidemiological studies. Registry data is also agile so has the capability of being linked to other large data sets enhancing their role in investigating rare diseases (Pietrzak and Haddad, 2017). Smith et al. (2012) investigated the risk of developing cancer following metal on metal hip arthroplasties using data from the NJR of England, Wales and Northern Ireland. This data was linked to the National Health System (NHS) hospital episode statistics data. After examining data from over 40,000 metal on metal bearings, they concluded no increased risk of cancer compared to alternative bearing surfaces or age and sex matched normal population. Using similar methodology, Visuri et al. (2006) examined the risk of developing cancer following total hip arthroplasty (THA) using data from the four Nordic arthroplasty registers. With up to 28 years follow up, they found no increased risk of developing cancer following THA procedures, including metal on metal bearing surfaces, compared to general population.

There is also a great potential for developing outcome predictive tools based on registry data (Schneeweiss, 2014). The large cohort of patients on clinical registries allows identifying preoperative patient factors that independently influence the postoperative functional outcome. Based on data from the NJR, Arden et al. (2017) designed a statistical tool to predict the postoperative functional outcome following total hip and knee arthroplasties. Preoperative patient factors including age, BMI and mental health are entered on a web-based tool that calculate the predicted postoperative Oxford hip and knee scores. Patients can then be informed with the likely postoperative outcome when counselled for the surgical procedure. Further studies are needed to externally validate these tools and assess their reliability.

3.4.3 Pitfalls with registries and big data

Registries provide a wealth of information on epidemiology of diseases and outcomes; but data should be analysed with caution in order to achieve a valid conclusion. Multiple factors undermine the analysis of registry data and the validity of its results.

Lack of unified definitions – Small data sets allow clear definitions for data collected with strict inclusion and exclusion criteria. Conversely, there is lack of clarity on common data definitions in registry studies. A typical example would be Prosthetic joint infection (PJI). There is no consensus on internationally agreed criteria for diagnosis of PJI. The diagnosis of PJI varies between different surgeons, units and countries. Therefore, the reported incidence of such a complication to the registry would be inaccurate. Furthermore, Joint registries across the world collect different data on PJI (Springer et al., 2017). As an example, the NJR collect data on PJI only as an indication for revision procedure. These only include single, two-stage, and excision arthroplasty for hips and knees. However, this does not include other infection related procedures such as wound washout, debridement and implant retention. This would eventually result in underreporting of the incidence of PJI's if we solely relied on the information from the NJR (Haddad and George, 2016). Registries need to enlist a clear definition for the collected data on their websites, so users can input data correctly.

Unstructured data fields - High quality data requires structuring and organisation of the data in order to enable swift searching and analysis process. This is of particular importance in registries and big data sets. The ideal data base is the one where each field is discrete, and its information can be retrieved either separately or with data from other fields in a variety of relationships. The advances in software technology has made this target relatively achievable. However, there is still a great deal of unstructured data on the registries which hinders an easy analysis for the data. Unstructured data are free text information that vary in amount, accuracy and significance. Example of unstructured data include operation notes, intraoperative and postoperative complications. Analysis of unstructured data is a difficult task as it lacks standardised comparison and validation. The accuracy of this information depends mainly on the user entering the data and their experience level. Structuring of unstructured data is practically a difficult and time-consuming process that possess a high margin of errors. The ability for searching unstructured data is evolving with new technology (Jacofsky, 2017). However, the ultimate solution would be to move forward to structured data that is built in the electronic platforms of the registries.

Confounders - Confounding remains one of the major drawbacks of clinical registries and big data. It is defined as "a systematic difference between a group of patients exposed to an intervention and a chosen comparator group" (Brookhart et al., 2010). As an example, patients who are on antiepileptic drugs are 50 times more likely to have epileptic fits than normal population. This is not, of course, directly related to the antiepileptic intake but rather related to their risk factors for developing epilepsy (Stammers et al., 2017). This is regarded as confounding by indication (Brookhart et al., 2010). Similarly, you are 30 times more likely to die if you have seen a doctor within the last two weeks compared to general population (Stammers et al., 2017). If any confounding factors are identified and measured on a database, then it would be feasible to control these confounders by applying appropriate statistical methods such as stratification and multivariate modelling (Schneeweiss and Avorn, 2005). However, most of clinical registries often do not collect sufficient data on potential confounders thus cannot be measured and accounted for (Brookhart et al., 2010). Therefore, registry data and observational studies cannot infer causality, but they can rather demonstrate trends and correlations (Konan and Haddad, 2013).

Lumping - Sub-groups of patients are often lumped together in order to facilitate the process of coding or billing (Perry et al., 2014). This might result in invalid results and misleading conclusions. If we were to analyse hip and knee arthroplasty revisions using only hospital episode statistics, we would then be unable to identify the differences between various implants and their relationship with the indication for revision surgery.

Over reporting - Sometimes, registry studies are inadvertently “over-powered” owing to its large sample size (Perry et al., 2014). This could result in a statistically significant finding though clinically of less relevance. As an example, a study comparing two different surgical procedures may find a one-minute reduction in surgical time as a statistically significant result. However, it is unlikely that finding would be of significant clinical relevance in surgical practice.

Incomplete data - Missing data remains to be a major challenge for even well-established clinical registries. The reasons for the inconsistency in submitting the data to registries are not entirely clear. This raises concerns regarding the validity of the results from registry studies. Moreover, National registries do not seem to be capturing all the patients undergoing the surgical procedure. Rahr-Wagner et al. (2013) reported that only 60% of patients who underwent ACLR procedures in Denmark were registered on the Danish national ligament registry in 2005. This has reassuringly increased up to 86% in 2011 although still not ideal. Similarly, a study from the Norwegian Arthroplasty Registry reported that only 76% of revision hip replacement were entered on the registry while it was 62% for revision knee arthroplasties (Espehaug et al., 2006). Revision surgery was defined as removal of one or more prosthetic parts. In the UK, Sabah et al. (2015) compared the revision data on the NJR with records from the London Implant Retrieval Centre, reporting that 39.1% of retrieved implants were not correctly registered in the NJR over a ten-year period. The missing data among patient records on registries seems to be a common finding worldwide (Prentice et al., 2018). Achieving a complete dataset appears to be a very ambitious goal yet not possible to achieve.

Data cleaning - In clinical research, errors occur albeit careful study design, conduct, and implementation of error-prevention strategies. Data cleaning is a process that aims at identifying and correcting these errors or at least reducing their impact on study results (Van den Broeck et al., 2005). The data cleaning process can be divided into three stages, involving repeated cycles of screening, diagnosing, and editing of suspected data abnormalities (Van den Broeck et al., 2005).

Data cleaning should focus mainly on the errors which constitute a major drift in or beyond the population distribution. Prior knowledge of expected ranges of normal values is required for data cleaning. In most clinical epidemiological studies, errors that should be cleaned include missing gender, errors with date of birth or date of procedure, duplications and/or merging of records. Errors of gender and birth date are of particular importance as they contaminate many derived variables (Van den Broeck et al., 2005).

In the screening phase, it is important to identify four basic types of oddities: lack or excess of data; outliers, including inconsistencies; strange patterns of distribution; and unexpected results. In the diagnostic phase, the aim is to clarify the true nature of the worrisome data points, patterns and statistics. This phase is labour-intensive; the logistical and personnel requirements are typically underestimated or neglected at the design phase of the study. In the treatment stage, identified errors and missing values must be dealt with. Furthermore, steps should be undertaken to address problematic observations. The options are limited to rectifying, deleting or leaving the observations unchanged (Jacofsky, 2017).

Some registries do not have a clear strategy for data cleaning. The lack of such a strategy for data cleaning should be viewed as a warning sign that the system is inherently prone to errors. Furthermore, this might indicate that the design of the system itself may have been developed by individuals who do not have the necessary knowledge of creating a data management system (Jacofsky, 2017). This would lead to inaccurate study results and misleading conclusions drawn from these registries. It can be deduced as such, in view of the foregoing, that registries should have a clear and transparent process for data cleaning. Published studies, that are based on registries data, should ideally have a clear statement detailing their data cleaning process.

3.4.4 Specific challenges for the NLR

The NLR suffers from all the aforementioned limitations; as do other registries. However, there are specific problems that face the NLR. Some of these problems are attributed to the fact that the NLR is still in its infancy. We highlight problems that were encountered during this data analysis.

High rate of incomplete data - It is noted that there is a high rate of missing data in the NLR. The percentage of missing data is much higher than other ligament registries (Prentice eta al., 2018). Table (3.7) demonstrated the percentages of missing data on the NLR between 2013 and 2017. It is reassuring to see that the rate of missing data is receding as the registry matures. The highest percentage of incomplete data fields was thromboprophylaxis data (80%). The second most missing data were the funding source as well as the date of injury (78%). Date of birth was incomplete in approximately 4% of the patients. Data on patient gender was the most complete data.

Table 3.7: Numbers and percentages of missing data on the NLR between 2013 and 2017

	2013	2014	2015	2016	2017	Total
Date of birth	205 (25%)	37 (2%)	35 (2%)	45 (2%)	0	322 (4%)
Gender	0	2	3	0	0	5
Operated side	76 (9%)	104 (6%)	9	9	5	203 (2%)
Smoking	603 (75%)	1137 (66%)	1386 (64%)	1407 (65%)	1196 (56%)	5729 (64%)
Activity associated with injury	625 (77%)	1137 (66%)	1377 (63%)	1405 (65%)	1655 (78%)	6199 (69%)
Associated injury	224 (28%)	283 (16%)	276 (13%)	174 (8%)	26 (1%)	983 (11%)
Funding source	709 (88%)	1450 (84%)	1657 (76%)	1661 (77%)	1562 (74%)	7039 (78%)
Date of injury	671 (83%)	1337 (77%)	1640 (76%)	1686 (78%)	1684 (79%)	7018 (78%)
Surgeon's profile	206 (25%)	319 (18%)	373 (17%)	243 (11%)	18 (1%)	1159 (13%)
Thromboprophylaxis	723 (89%)	1472 (85%)	1671 (77%)	1688 (7%)	1624 (77%)	7178 (80%)
Graft type	217 (27%)	225 (13%)	202 (9%)	82 (4%)	33 (2%)	759 (8%)
Graft diameter(Hamstring)	269 (33%)	462 (27%)	612 (28%)	927 (43%)	290 (13.6%)	2560 (28%)
Femoral tunnels drilling	222 (27%)	230 (13%)	200 (9%)	81 (4%)	20 (1%)	753 (8%)
Tibial tunnels drilling	222 (27%)	228 (13%)	200 (9%)	83 (4%)	21 (1%)	754 (8%)

Femoral tunnels fixation	530 (66%)	236 (14%)	201 (9%)	90 (4%)	35 (2%)	1092 (12%)
Tibial tunnels fixation	465 (58%)	234 (13%)	204 (9%)	91 (4%)	35 (2%)	1029 (11%)
Total	808	1735	2169	2168	2122	9002

Improvement in the data collection tools would minimise the rate of missing data. As an example, there is an option of "unknown" when a surgeon is entering the side of ACLR surgery. Limiting the answers to choose from the drop list to either "right" or "left" would prevent the surgeons from choosing the "unknown" option. There is also the problem of trying to collect too many data which makes completing the surgical form rather time consuming. This subsequently leads to surgeons opting out from completing a lot of the non-mandatory fields. The end result is "patchy" data collection with important information missing that compromises data analysis and interpretation. It is important that the NLR focuses on quality of data rather than the quantity at this stage. The NLR needs to identify what the fundamental questions are which would then guide the appropriate mandatory data fields to be completed. The data pyramid should start with a strong base that has the necessary information at this early stage of the registry. Once this is established and users become familiar with the online system, then more information could be collected to answer more difficult questions.

Duplication of data - There is a high rate of duplicated data on the NLR that represents approximately 8% of the recorded pathways on the online system. This is mainly because of the imported data that had been manually entered on the live system. This is particularly notable for patient who had their ACLR surgery in the independent sector. Their data was collected at the source where they had their surgery. It was then manually imported to the NLR electronic platform by administrative staff. During this process, many patients have been entered twice with duplication of the data or often splitting the data between the two records. This means that simple deletion of one record is not enough to clean the data as merging the duplicated records would be more appropriate. The merge function has not yet been developed on the electronic NLR system. A manual merging has been performed for the analysis that has been undertaken for this study. The data was extracted from the live system on the NLR and an offline cleaning process was undertaken. This process is obviously labour-intensive and time-consuming as well. This means that the aforementioned data analysis and results cannot be reproduced instantly from the live system as the data was not cleaned on the live system. The electronic merge function needs to be developed and utilised in future data management in order to produce accurate and reproducible results.

Surgeons engagement - It is estimated that only one fourth of the patients undergoing ACLR surgery in the UK are registered on the NLR. Registering patients on the NLR is entirely voluntary. This is partly due to the fact that the registry was established as an initiative by a small group of surgeons with no substantial involvement from government bodies. There is no doubt that the registry is a helpful tool to individual surgeons as well as orthopaedics units. However, many surgeons might find the process time consuming and administrative heavy. Conversely, registering patients on the NJR, as an example, is compulsory. Registering patients on the NJR is completed on a paper form rather than electronically with fewer surgical details required to be completed compared to the NLR. These factors would explain why there is more compliance with registering patient on the NJR compared to the NLR.

Surgeons' experience with the NJR might be in itself one of the reasons for low levels of surgeons' engagement with the NLR. The NJR was initially set up to compare the outcome of different orthopaedic prostheses and identify failing implants. However, it has recently moved on to start publishing individual surgeon outcomes data. This was an initiative to enhance transparency and provide patients with information to choose their surgeons. The concept of releasing an individual surgeons outcomes has caused a stir among orthopaedic surgeons in the UK (BOA website - Publication of surgeon outcomes, 2015). There were reservations regarding the validity and completion of NJR data which would consequently affect the accuracy of individual surgeon's data on a bigger scale (Sabah et al., 2015). This has caused concerns regarding the potential clinical and legal issues in releasing this data to the public and the lay press (Haddad et al., 2016). With this in mind, surgeons might be apprehensive from the possibility that the NLR would follow the NJR path and start publishing surgeons' level data later on. The way forward would be for the NLR to declare its position on publishing individual surgeon outcomes in order to reassure surgeons on future directions of the registry.

Compliance - Patient compliance with completing PROMs on the NLR is significantly low compared to published results from the Scandinavian ligament registries (Granan et al., 2009). The reasons for that are not fully understood. The NLR relies on electronic collection of PROMs through prompting the patients by emails to go online and fill the forms. Patients must have valid email addresses entered on the registry in order to receive an automated prompting emails to complete the forms. This is not the only source of PROMs data on the registry. Patients who do not have email addresses or do not prefer the online system can fill in paper PROMs forms and then get this data uploaded on the online system by their surgeons. In this study, we have observed better compliance for patients who have completed their PROMs online compared to the compliance of the whole cohort of patients on the NLR. This indicates that patients seem to prefer completing PROMs electronically rather than filling in paper forms. Bojcic et al. (2014) demonstrated similar results when they studied 1486 patients who had ACLR procedures on the KP registry. They reported a compliance rate of 35% and 25% for electronically completed PROMs and paper forms respectively; at 1 year follow up. At 2 years follow up, the electronic response rate and the paper response rate were 38% and 20% respectively.

Another important factor that might be contributing to the low compliance rate is that patients are required to fill in four types of PROMs. The average time required to fill in all four questionnaires is between 15 and 20 minutes. This could be regarded as time consuming by many patients specifically that ACLR patients are typically young and busy. Moreover, the NLR collects IKDC and KOOS scores which both cover similar domains. The inconsistency in compliance rates between KOOS and IKDC demonstrated in our study suggests that patients often do not tend to fill in both questionnaires together. It seems logical to think that patients might abandon filling in the questionnaires when they are faced with similar questions asked in different questionnaires. It also seems logical to think that patients would not be keen on completing future follow up questionnaires if they experienced repetitive questions and lengthy time spent to complete the PROMs. It is important to note that none of the Scandinavian registries collect IKDC subjective scores but they all collect KOOS scores (Granan et al., 2009). Ideally either of the IKDC or KOOS score should be used in order to cut down the time undertaken by the patients to fill in the questionnaires. Collecting both scores does not add any additional meaningful information though eventually compromises the quality of data on the registry.

Lack of recording complication - The NLR is not currently linked to Hospital Episode Statistics Data. If patients were admitted with ACLR related complications to a hospital that is different from where they had the index procedure, there would not be a direct method for adding this complication to their existing record on the NLR. Therefore, there is no accurate record for complications on the NLR. Complications can be added to the registry by the patients or the surgeons. It is logical to think that some surgeons might not want to report their own complications on the system if they are not obliged to do so. Also, there is currently no revision pathway on the registry which means that revision ACLR procedures cannot be added or even linked to the index procedure.

Data cleaning - There is currently no established data cleaning process in the NLR electronic data management system. This means that any data analysis has to go first through a data cleaning process. It essential to establish a data cleaning process in the current system that would allow easier data analysis. One of the simple steps to be undertaken is to limit the errors in the data collection at the source. As an example, when entering the patient date of birth or age on the system there should be years limit on the electronic form that would prevent users from mistakenly entering patients with age above hundred years. It is unlikely in current clinical practice that an ACLR procedure would be undertaken for patients over that age yet there are still patients with that age recorded on the NLR. A data cleaning process would rectify this error but ensuring that the correct data is entered at the source would be a more efficient way of managing the data. Another example, would be the record of date of injury. There are a lot of patients on the NLR with a date of injury that is after the date of ACLR surgery; which is intuitively incorrect. This problem could be tackled by ensuring that the electronic form will automatically not allow users to mistakenly entering a future date when recording the date of injury. Similarly, an automated warning message should appear to the surgeons if they are entering an operation date that is before the injury date. This would warn the surgeons that they are either entering the wrong date of surgery or the date of injury was incorrectly entered and so would need rectifying.

Validation of data - The data on the NLR has not yet been validated. Data is entered by surgeons, patients and administrative staff. Therefore, the data needs to undergo a validation process to ascertain the accuracy of the data on the NLR in comparison to the original data from the hospitals. Quite simply, if the data is incomplete or incorrect, then false conclusions may be drawn from any analysis.

3.4.5 Future Plans

Increase number of registered consultants - The aim of the NLR is to develop a safe and user-friendly system to record the extent and outcomes of knee ligament surgery in the UK. Smart phone and tablet apps can be developed to improve data collection by the clinical team. This enhances not only the ease of data input but creates a more systematic approach and could allow information to be inputted at the time of surgery or clinical review, reducing error and increasing registry compliance. There are ongoing discussions towards mandating the use of the registry in both NHS and private sectors. The plan for accrediting the NLR as a 'National clinical audit' will have significant benefits with regard to consent and data issues.

Improve data capture - The population undergoing ACL reconstructions are typically young, geographically mobile and busy. This makes them difficult to trace and track which is why two of the key elements of information are the NHS number and an email address. This is the electronic age and email and text communication is the norm and must be acknowledged. It is very reassuring to observe a surge in the number of patients entering a valid email address in 2017 compared to when the NLR started in 2013. Moreover, there has been a significant increase in the percentage of patients consenting to add their details to the NLR over the last 2 years. More work is needed to ensure that all patients are consented to allow us to store their details legally and usefully on the registry.

Demographic data - Further analysis of the patients' profile including ethnicity and social area deprivation will be conducted. The UK has the advantage of multi-ethnicity among its population, which will enable a better understanding for the epidemiology and outcome of ACL injuries. As an example, there is very little known about ACL injuries in the peripartum period. It would be interesting to collect data on the incidence and functional outcome for subject who had ACL injuries during peripartum period.

Developing new pathways - To date, the NLR has concentrated on a single procedure; primary ACLR. When the primary pathway is well established, it will ease the journey to develop similar pathways for the revision of ACL procedures, other ligament reconstructions and conservative management of ACL tears.

Improve intra-operative data - The current operative form on NLR website does not have a differentiation between single and double bundle ACLR. The form also identifies collateral ligament surgery without identification whether medial or lateral. These two important surgical details need to be added to the operative form.

PROMs **-** Patient compliance with completing PROMs is still a major challenge for the registry. The figures from this study showed marginal improvement over the last 3 years but they are still less than 40% overall compliance with one- and two years postoperative scores. Online collection of PROMs seems to result in better compliance rates. However, this necessitates entering a valid email address for patients in order for them to respond to PROMs requests. Surgeons need to ensure patients have a valid email address when first adding them to the system. Encouragingly there has been a gradual increase in compliance with entering patients email address and hopefully this will improve compliance in the coming years. The inconsistency in the compliance among the different PROMs suggest that patients might find it time consuming to fill in all 4 scores. One option would be to consider collecting either the

KOOS or IKDC score to minimise the time required to complete the questionnaires and subsequently improve compliance. Both scores cover relatively similar domains and various research studies have argued the feasibility of using one over the other. Apps could also be developed for patient data collection – allowing subjects to collect their own data at home (e.g. video capture and sensor data). While these are likely to be more subjective they would provide invaluable insight to the patient experience opening up a whole new avenue of research work.

Post-operative data - Granting access to physiotherapists to input data online during rehabilitation will enrich the NLR with objective assessments for ACLR patients during the rehabilitation period. Objective measures such as Lachman test and KT-1000 could be recorded online by the physiotherapists on follow up assessment.

Improve surgeons Gains - Clinicians now have a framework to collect outcome data regarding their own ACLR practice, benchmarking it against practice across the NHS. The data can also be a valuable contribution towards each surgeon's annual appraisal and revalidation.

3.5 Conclusion

The NLR has strived to provide comprehensive data on ACLR procedures in the UK since its launch in 2013. It has offered a great insight into the demographics, surgical techniques and functional outcomes of ACLR surgery across the country. Demographics of patients undergoing ACLR surgery in the UK is quite similar to other registries worldwide although the average patient age is higher in the UK compared to other countries. Despite being a great data collection tool, the NLR suffers from the common shortfalls that affect most of clinical registries. However, as a growing registry, there are specific challenges that currently face the NLR. These include high rate of incomplete data, duplication of data, poor patient compliance and lack of validation of the data. It is crucial to tackle these issues at this stage; before embarking on any new pathways in order to ensure that the data collected on the registry is accurate and any conclusions drawn are valid and meaningful.

Chapter 4

A Comparison of Preoperative Scores Prior to ACL Reconstruction with Pre-injury Scores: What they did at their Best, Expectations and Final Scores at 2 Year Follow-up

4.1 Introduction

There is a plethora of published studies in the literature reporting improvement in the functional outcome scores following ACLR surgery. Outcome studies enable clinicians to better understand the prognosis and the likely outcome of their treatment choice. Moreover, it enables surgeons to counsel patients undergoing ACLR surgery about expected outcomes of the surgery and set realistic treatment goals. This is of paramount importance in the current era of evidence-based medicine and patient choice to decide treatment.

However, most of clinical studies reporting on ACLR outcomes rely on the preoperative post-injury functional outcome score as a baseline measurement of knee function. Understandably, the post-injury preoperative sores are often poor when compared to the postoperative scores. Therefore, most of ACLR outcome studies have shown significant improvements following surgery when compared to the preoperative post-injury scores. However, this overlooks the patients' pre-injury functional status when evaluating the outcome of the surgical intervention. Patient often expect to return back to their pre-injury functional status when they consent for ACLR surgery. The aim of this study was to compare the pre-injury functional scores for patients undergoing ACLR procedures with the post-injury preoperative score and postoperative outcome scores. Our hypothesis was that patients do not usually return to their pre-injury functional level at 2 years following ACLR surgery.

4.2 Patients and Methods

We performed a prospective study on patients who underwent primary ACLR surgery at the University College of London Hospital between October 2010 and January 2016.

4.2.1 Patient selection criteria

Patients were included in this study according to strict inclusion and exclusion criteria.

a) Inclusion criteria:

1. Adult patients aged between 18 and 45 years old.

2. ACL tears confirmed clinically and radiologically with an MRI scan.

3. The above diagnosis was made within 3 months from knee injury.

4. Patients undergoing primary ACLR surgery.

b) Exclusion criteria:

1. Associated other knee ligamentous injuries e.g. posterior cruciate ligament that would require surgical reconstruction at the same time of ACL reconstruction surgery.
2. Revision ACLR surgery.
3. Patients presented more than 3 months from the index injury.
4. Concomitant acute knee injury on the contralateral side.

4.2.2 Patient recruitment

Patients were assessed in our outpatient clinic for their knee injury. Patient with ACL tears that fulfilled the above inclusion and exclusion criteria were invited to participate in this study at the end of their first clinic appointment after the index injury. The patients were given full explanation of the scope of the study and were informed that participation was voluntary. Patients were reassured that their participation or withdrawal from this study would not influence their continued medical care in any way.

4.2.3 Surgical technique

All patients underwent arthroscopic single bundle ACLR. Professor Haddad performed all the procedures either as a first surgeon or supervising a senior clinical fellow surgeon. All patients received a quadrupled hamstring tendon autograft. Femoral tunnel drilling was through an anteromedial portal technique. All tendon grafts were fixed with Endobutton suspensory mechanism on the femoral side and interference screws on the tibial side. All patients had the same rehabilitation protocol. Patients were allowed to start weight bearing with crutches from day one postoperatively. No splint or brace were used. Patients were discharged on the day of surgery or the following day. Closed kinetic chain quadriceps strengthening exercises were allowed for the first 3 postoperative months. Isometric and open chain proprioceptive exercises were performed. Emphasis was placed on the restoration of full knee range of movement especially knee extension.

4.2.4 Outcome measures

Functional outcomes were assessed using patient reported outcome measures (PROMs). These were Knee Injury and Osteoarthritis Outcome score (KOOS) (Roos et al., 1998), Lysholm and Tegner scores (Tegner and Lysholm, 1985).

Patients who agreed to participate in the study were given two copies of these questionnaires during their first clinic appointment. Both of these copies reflect their pre-operative functional status. On the first copy, we asked patients to fill in the questionnaires recording their pre-injury functional status. On the second copy, we asked patients to record their post-injury functional level.

Patients were then given another copy of the questionnaires to complete at one year and 2 years following their ACLR procedure.

4.2.5 Statistical analysis

The data obtained from recording the outcome measures are ordinal data so non-parametric statistics were used. Kolmogorov-Smirnov testing revealed that the data were not normally distributed. Friedman's test (one-way repeated measures analysis of variance for non-parametric data) was performed with the independent variable being the time of assessment (preinjury, postinjury preoperative, one year and two years following ACL), to identify a significant improvement in each of the PROMs. A P value < 0.05 was considered statistically significant. Data were analysed using the Statistical package for Social Sciences 16.0 for Windows (SPSS Inc., Chicago, IL, USA).

4.3 Results

A total of 626 patients (338 males and 288 females) were eligible for this study according to our inclusion and exclusion criteria. Among these patients 571 patients (91%) agreed to participate in this study. There were 308 males (54%) and 263 females (46%). The mean age was 27 years old (range 19 to 46 years). 493 patients (86%) completed the questionnaires at one year following the index procedure. At 2 years postoperative follow up, 434 patients (76%) were available to complete the final questionnaires.

The mean pre-injury and preoperative post-injury Lysholm scores were 94(range 73 -

100) and 63 (range 25- 85) respectively. The respective mean Lysholm scores at one and 2 years postoperatively were 84 (range 71- 100) and 89 (range 71- 100) (*p*-value < .00001)(Figure 4.1). The mean Tegner pre-injury and preoperative post-injury scores were 7 (range 3-9) and 3 (range 0-6) respectively. The mean Tegner score at one and two years postoperatively were 6 (range 1- 8) and 6 (range 1- 9) respectively (*p*-value < .00001) (Figure 4.2). The mean KOOS scores at pre-injury, preoperative post-injury, one-and two years postoperatively were: Symptoms (96, 71, 81, 84); Pain (94, 72, 84, 87); ADLs (97, 80, 87, 91), sports and recreation function (84, 39, 66, 71), QoL (82, 37, 64, 69) respectively (*p*-value < .001) (Figure 4.3).

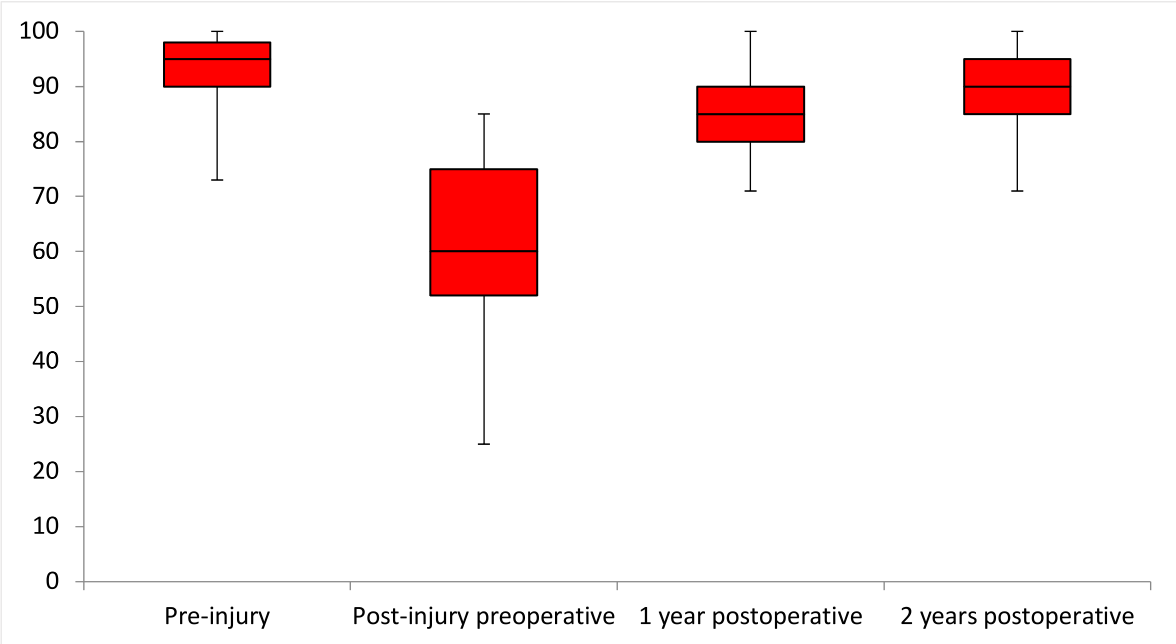


Figure 4.1: Box and Whisker plot representing the Lysholm scores at pre-injury preoperative, post-injury pre-operative, one year and 2 years postoperatively.

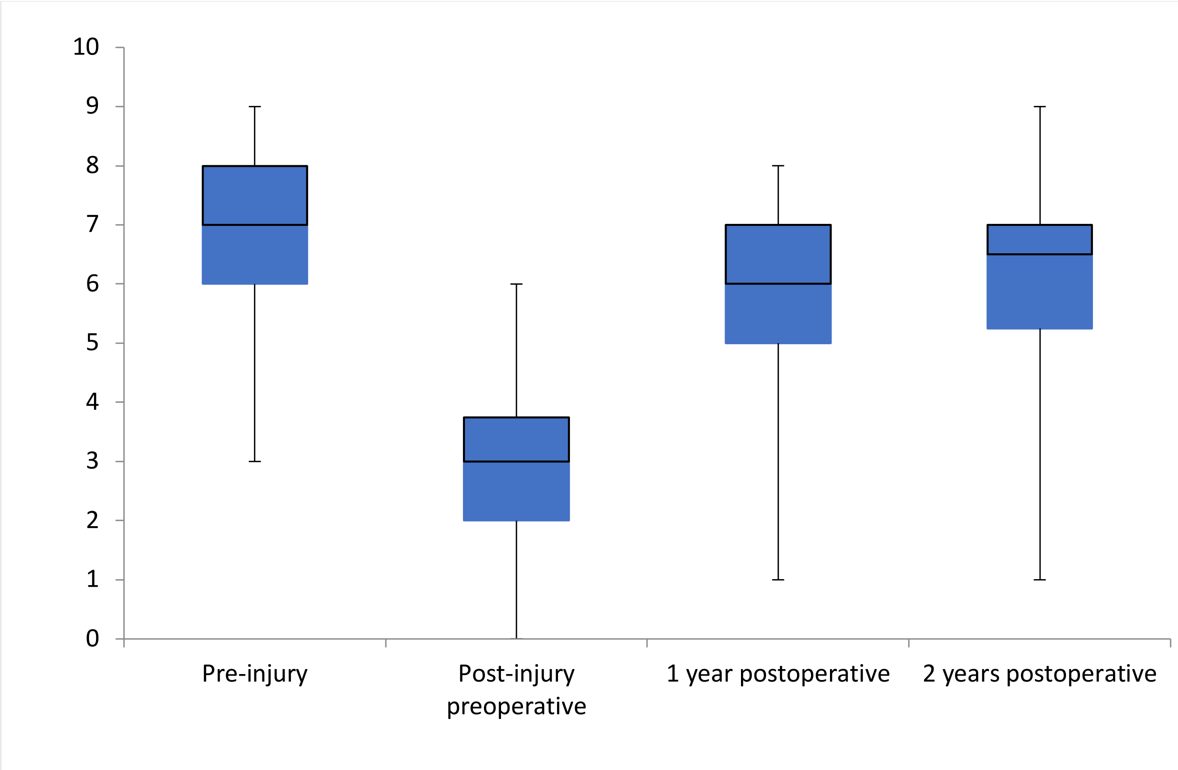


Figure 4.2: Box and Whisker plot representing the Tegner scores at pre-injury preoperative, post-injury pre-operative, one year and 2 years postoperatively

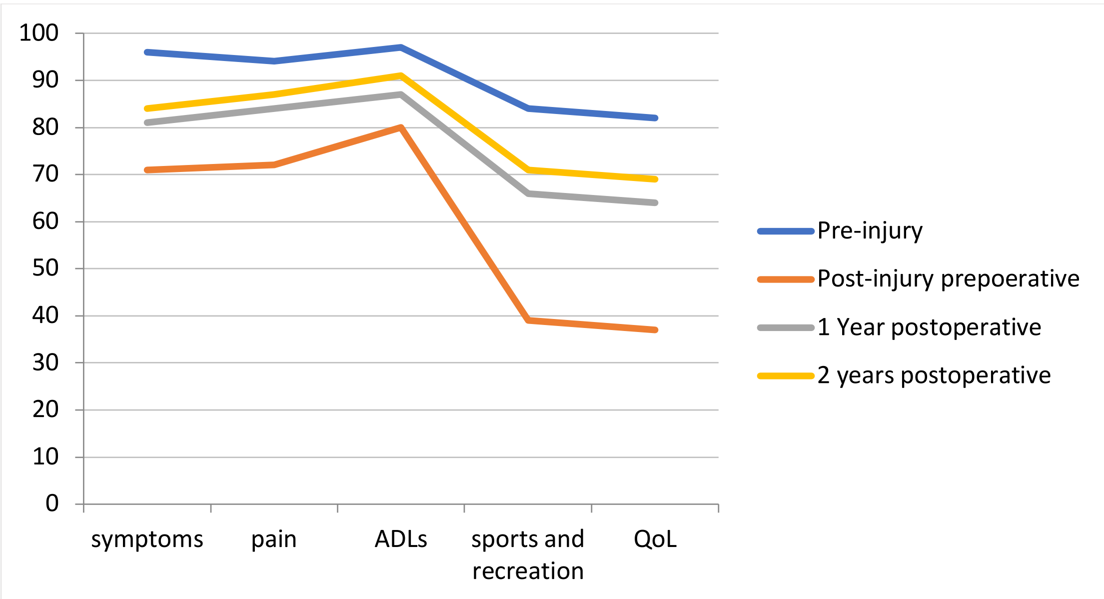


Figure 4.3: Mean KOOS score: pre-injury preoperative, post-injury pre-operative and 2 years postoperatively.

4.4 Discussion

Clinical studies have often reported improvement in patients' functional outcome following ACLR procedures (Spindler et al., 2013; Sajovic et al., 2011; Hill and O'Leary, 2013). This view is also supported by recent reports from the Scandinavians and UK national ligament registries (Desai et al., 2014; Lind et al., 2009; Gabr et al., 2015). However, this conclusion is based on comparing the preoperative post-injury PROMs to the postoperative outcome scores. Although this comparison proves the success of the surgical intervention in improving patient's symptoms, it completely overlooks the patient's functional status prior to the ACL injury. Patients usually expect to eventually return to pre-injury functional level following ACLR procedure (Feucht et al., 2016). Therefore, Comparing the pre-injury functional level to the postoperative functional status would represent a true reflection on the efficiency of the surgical intervention.

Our study has shown improvement in the mean postoperative Tegner, Lysholm and KOOS scores compared to the preoperative post-injury scores. There was a significant improvement at one year postoperatively and this continued to progress slightly at 2 years follow up. However, most of the patients have not managed to return back to their pre-injury functional level. The mean postoperative outcome scores at 2 years were lower than the mean pre-injury scores across the three PROMs in our study. The results from this study supports our hypothesis that majority of patients do not return to pre-injury level at 2 years postoperatively.

Roos and Lohmander (2003) suggested that the minimal perceptible clinical improvement (MPCI) for the KOOS score is 8-10 points. MPCI represents the difference on the outcome measurement scale associated with the smallest change in the health status that could be detected by the patient. All the five subscales of the KOOS have shown improvement by at least 10 points at 2 years postoperatively compared to the post injury pre-operative scores in our cohort. The Sport and QoL subscales were the most sensitive subscales pre-operatively and most sensitive to change post-operatively. This finding is similar to what have been reported previously by Roos et al. (1998). However, there was a clinically significant difference between the preinjury and 2 years postoperative scores in 3 subscales of the KOOS score. These are the Symptoms, Sport and QoL subscales.

The answer to what constitutes a successful ACLR outcome remains unknown. The orthopaedic surgeons usually over-estimate the postoperative knee functional level, following ACLR procedures, by 40-60 % compared to patient's own reports (Renstrom, 2012). PROMs have been utilized to represent patient's perspectives and eliminate clinician's bias in reporting ACLR functional outcome (Lynch et al. 2015). The UK National Health Service (NHS) has been collecting PROMs on all patients undergoing elective hip and knee arthroplasty surgeries since 2009 (Timmins, 2008). This was aimed at assessing the efficiency of the elective surgical intervention by comparing the patients' pre- and post-operative functional outcome scores. This is usually applicable for most of the elective orthopaedic procedures as they usually address a chronic pathology. Although ACLR surgery is usually an elective procedure, the ACL injury is usually a result of an acute event. The majority of patients undergoing ACLR procedures are young or middle aged (Barenius et al., 2013). This group of patients does usually have an active life style and so would expect a return to their pre-injury functional level postoperatively.

4.4.1 Return to sports at a pre-injury level

To our knowledge this is the first study to examine the PROMs for ACLR procedures from pre-injury stage to two years postoperative follow up. Several studies have examined return to sports at a pre-injury level in athletes who have had ACLR surgery. McCullough et al. (2012) studied 147 high school and collegiate football players who underwent ACLR in a multicentre cohort study. The percentage of return to play was reported to be between 63% and 69% at 2 years postoperative follow up. However, only 45% of high school players and 38% of college school players were able to return to play at the same pre-injury level. They also reported lower KOOS- QOL subscores in high school and college athletes who did not return to sport compared to those who returned to their pre-injury level of sport two years after ACLR. In their study, high-school athletes who returned to sport had a median KOOS-QOL subscore of 90 compared to 75 for those who did not return. College athletes who returned to sport had a median KOOS-QOL subscore of 94 compared to 72 for those who did not return.

In a similar study, Arden et al. (2014) noted that only 140(45%) out of 314 patients, who had ACLR surgery, had returned to playing sport at their preinjury level or returned to participating in competitive sport when surveyed at 2 to 7 years postoperatively. It is still unclear to why there is such a low rate of return to sports at a pre-injury level after ACLR surgery. Ardern et al. (2011) noted in a systematic review that common reasons for failure to return to sports at pre-injury level include: Fear of re-injury (19%), problems with the function of the reconstructed knee (13%), reasons other than the reconstructed knee function (18%) such as lifestyle change and fear of job loss with re-injury (11%).

4.4.2 Normative data versus pre-injury scores

Obtaining pre-injury outcome scores after the injury is a big challenge for researches and healthcare professionals. The pre-injury functional status for patients presenting with ACL tears could be assessed through two methods (Wilson et al., 2012). The first option would be to collect PROMs retrospectively as we did in our study. The second option would be to utilize the normative data available for the PROMs that are used for patient's assessment. Paradowski et al. (2006) reported the normative KOOS score in a random sample drawn from a population register in Sweden. They reported the normative KOOS score in adults between the age of 18 and 34 to be: Pain (90-95), Symptoms (84-91), ADL (92-98), Sports and recreation (80-91) and QoL (80-90). Cameron et al. (2013) reported on the normative KOOS scores for young physically active population with an average age of 19 years old. The normative KOOS score in their study was Pain 100, Symptoms 96.4, ADL 100, Sports and recreation 100 and QoL 100. However, majority of ACLR studies have reported postoperative outcome scores at two to 7 years follow up that are below the aforementioned normative KOOS scores (Herrington, 2013).

The use of normative data as a base line comparator for patients with an acute injury or trauma has been challenged by a few studies. Gabbe et al. (2007) compared the preinjury health-related quality of life (HRQL) of patients admitted with orthopaedic trauma compared to normal population. They used the 12-item Short Form Health Survey (SF-12) as measurement for HRQL. The trauma patients showed higher physical and mental SF-12 scores compared to general population between the age of 18 and 54 years. Similarly, a recent systematic review showed that pre-injury EQ-5D, SF-36, and SF-12 score exceeded the age- and gender-adjusted norms from population data (Scholten et al., 2017). Wilson et al. (2012) concluded that retrospective PROMs are more appropriate than the application of population norms to estimate health status prior to an acute-onset injury. A possible explanation to this finding is that patients with trauma or acute injury such as ACL tears have better, pre-injury, health status and function better than their age and gender peers from the general population. Patients with ACL tears are usually physically active thus represent a specific subgroup rather than a true resemblance of the general population.

However, there are concerns with retrospective collection of PROMs. Patients' perception of their health might change following the acute injury. As patients might experience poor health function after ACL injury, they might tend to overestimate their pre-injury health status. This theory is referred to as the "response shift" (Schwartz et al., 2007). Another important factor to consider when assessing retrospective PROMs is recall bias (Scholten et al, 2017). Reliability of retrospective PROMs depends on how patients have remembered their pre-injury health status, which might be different to what they actually were. This would be influenced by patients' memory and the time lag between the injury and obtaining the retrospective PROMs. Widnall et al. (2014) studied the accuracy of retrospective collection of outcome score in 36 patients undergoing elective foot and ankle surgery. They concluded that retrospective collection of scores lacks accuracy when compared to prospective collection of scores. Further studies are needed to quantify the effect of response shift and recall bias when assessing retrospective PROMs in patients with knee injuries.

4.4.3 Implications

Our study provides a platform for further work on ACLR outcome measures. Future studies reporting on ACLR outcomes need to consider using pre-injury PROMs when comparing the efficiency of the surgical procedure. Pre-injury PROMs provide a more accurate assessment of patients' base line functional status thus should be the benchmark to gauge against the success of ACLR surgery. Further studies are needed to examine the influence of recall bias on retrospective PROMs in patients with ACL injuries.

The findings of our study are of paramount importance when counselling patients for ACLR surgery. It provides patients and surgeon with a better understanding of patient's functional outcome following ACLR surgery. It is important to manage patients' expectations when obtaining consent for ACLR surgery. This study provides guidance for the patients on recovery to their pre-injury health level. This could help patients to decide whether to opt for conservative or surgical management for ACL tears.

4.4.4 Limitations

Our study has its own limitations. The patient cohort was a mixed group of recreational athletes, elite athletes and non-athletes. In a systemic review, Ardern et al. (2014) concluded that athletes have a higher rate of return to sports at pre-injury level following ACLR surgery. Reasons to explain this finding include higher levels of physical fitness and knee proprioception, different psychological profiles, access to high-quality healthcare and greater financial incentives in athletes compared to non-athletes population (Lai et al., 2018).

Another limitation is that we collected PROMs retrospectively which possess the risks of recall bias and response shift as explained above. However, all patients included in this study have completed the pre-injury PROMs scores within three months from the index injury to minimize the effect of recall bias. We also have not collected any objective outcome measures for the patients in this study, so it only relied on subjective assessment.

4.5 Conclusions

Our study has shown that functional outcome scores have improved at 2 years following ACLR surgery in comparison to preoperative post-injury scores. However, the majority of patients failed to achieve their pre-injury functional outcome scores at 2 years postoperative follow-up. The evaluation of ACLR functional outcomes needs to consider the pre-injury PROMs scores rather than the immediate pre-operative PROMs scores that are usually collected.

Chapter 5

Anteromedial Portal versus Transtibial Drilling Techniques for Femoral Tunnel Placement in Arthroscopic ACL Reconstruction: Radiographic Evaluation and Functional Outcomes at 2 Year Follow Up

5.1 Introduction

It is widely recognised that the success of ACLR surgery depends mainly on the ACL graft replicating the native ACL in terms of its morphology, tension, position, and anatomical orientation (Buoncristiani et al., 2006; Chen et al., 2017). Over the last 2 decades, ACL cadaveric studies have significantly improved our understanding for both the anatomy and function of the ACL. The ACL is composed of 2 functionally separate bundles, the anteromedial (AM) and posterolateral bundle (PL). The two bundles were named owing to the location of their tibial attachment (Furman et al., 1976; Norwood and Cross, 1979; Amis and Dawkins, 1991; Arnoczky, 1983). On the femoral side, the AM bundle originates more proximally, and the PL bundle originates more distally. The position of the two bundles varies with knee flexion angle. In extension, the two bundles are parallel (Chhabra et al., 2006). In flexion, the femoral insertion site of the PL bundle moves anteriorly, and the two bundles are crossed. The AM bundle tightens when the knee goes into flexion while the PL bundle loosens. Conversely, the PL bundle tightens when the knee is in extension whereas the AM bundle loosens (Amis and Dawkins, 1991). The PL bundle tightens during internal and external rotation of the knee (Chhabra et al., 2006).

Ferretti et al. (2007) studied the anatomy of the femoral origin of the ACL in 16 human cadavers and arthroscopically in 60 patients. They described “the lateral intercondylar ridge” as the anterior osseous border of the ACL that was present in all the patients and cadavers they studied. This osseous landmark was previously referred to as the “resident’s ridge”; a term that was coined by William Clancy in 1998 when he noticed orthopaedic residents mistakenly assumed that the ridge was the posterior wall of the lateral femoral condyle during arthroscopic ACLR (Hutchinson and Ash, 2003). Ferretti et al. (2007) also described “lateral bifurcate ridge” as the osseous ridge running between the femoral attachment of AM bundle and PL bundle; running from anterior to posterior. It runs almost perpendicular to the lateral intercondylar ridge. They noticed that the lateral bifurcate ridge was present in 49 out of 60 arthroscopic patients and 13 out of 16 knee cadavers. These anatomical landmarks have helped surgeons identifying where to locate the femoral tunnel in ACLR.

It is now well established that tunnel position in ACLR is of the utmost importance with respect to clinical outcomes and risk of revision surgery (Howell et al., 1992; Howell et al., 1993; Carson et al., 2004; Diamantopoulos et al., 2008; Marchant et al., 2010; Pinczewski et al., 2008; Kamath et al., 2011; Hosseini et al., 2012). Initially, the femoral tunnel was commonly drilled through two incision technique from outside-in (Beach et al., 1989). The endoscopic transtibial (TT) drilling technique for the femoral tunnel was later introduced and widely adopted (Rosenberg, 1989; Beck et al., 1992)(Figure 5.1). The TT technique had the advantages of a single incision technique so less surgical morbidity and shorter operative time. There were good clinical results reported with the TT technique (Williams et al., 2004). However, recent studies have reported delayed return to sports and high incidence of osteoarthritis at long term follow up (Barenius et al., 2014; Lohmander et al., 2004; Oiestad et al., 2010). Furthermore, biomechanical and cadaveric studies have demonstrated that femoral tunnel placement using TT technique is dictated by the tibial tunnel, resulting in a relatively vertical orientation of the ACL graft with non-anatomical placement of the femoral tunnel (Woo et al., 2002; Loh et al, 2002; Yagi et al., 2002; Ristanis et al., 2003; Scopp et al., 2004; Markolf et al., 2010; Bedi et al., 2010). This was reported to restore anteroposterior stability but fails to achieve rotational stability with a resultant positive pivot shift test.

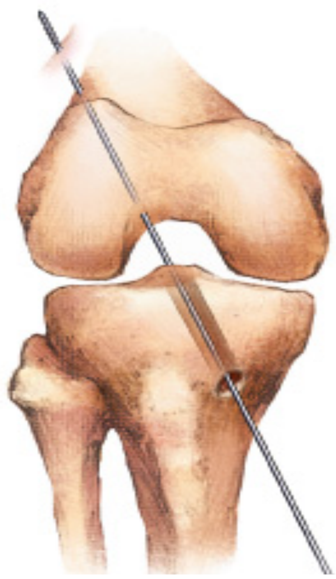


Figure 5.1: Transtibial drilling for the femoral tunnel in ACLR.

The anteromedial (AM) portal was then suggested as a method of independent drilling of the femoral tunnel (Figure 5.2). This was postulated to achieve an anatomical placement of the femoral tunnel with an oblique orientation of the ACL graft that would achieve better rotational stability compared with the TT technique (Harner et al., 2008; Gavriilidis, 2008; Steiner, 2009; Tudisco et al., 2012). However, clinical studies comparing the AM portal and TT techniques have shown variable results with no universal agreement on which technique produce better clinical outcomes (Franceschi et al., 2013; Chalmers et al., 2013; Robin et al., 2015). The aim of this study was to compare the radiological and clinical outcomes of arthroscopic single bundle ACLR using either the TT or the AM portal for femoral tunnel drilling. The hypothesis was that AM portal produces better functional outcomes compared with the TT technique in femoral tunnel drilling.

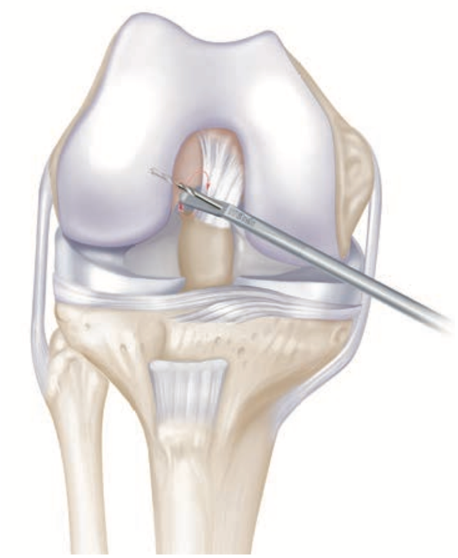


Figure 5.2: Anteromedial femoral tunnel drilling in ACLR.

5.2 Methods

We conducted a retrospective review for prospectively collected data on 404 patients who underwent arthroscopic primary single bundle ACLR with quadrupled hamstring tendon autograft. All ACLR procedures were performed at our institution between January 2006 and December 2014. The senior author has shifted from using the TT technique to the AM portal in June 2009. The first 100 patients who had ACLR using the AM portal were excluded to avoid any results related to the learning curve. The TT portal was utilized in femoral tunnel drilling in 202 patients (TT group) while the AM portal was used in 202 patients (AM group). We excluded patients who had associated other knee ligamentous injuries such as posterior cruciate ligament that would require surgical reconstruction at the same time of ACLR surgery and patients who had concomitant acute knee injury on the contralateral side. The diagnosis of ACL rupture was made by clinical examination (anterior laxity on Lachman's and drawer testing and a positive Pivot shift test) and confirmed with magnetic resonance imaging (MRI) of the knee for all patients.

5.2.1 Surgical technique

All ACLR procedures were performed by a single surgeon (FSH); either as primary surgeon or supervising a senior clinical fellow surgeon. All patients underwent examination under anaesthesia before starting the arthroscopic procedure. The gracilis and semitendinosus were harvested in all patients through a 3-cm longitudinal incision over the pes anserine starting 1 cm medial to the tibial tubercle. Both tendons were sequentially extracted using tendon stripper. Both the semitendinosus and gracilis graft were double looped and their free ends whip stitched using no.5 ethibond in the usual fashion to produce quadrupled hamstring tendon autograft. Standard medial and lateral parapatellar arthroscopic portals were used. A complete diagnostic arthroscopy was performed for every patient in this study to confirm the ACL rupture and look for possible other findings such as meniscal tears or chondral injury inside the knee.

The ruptured ACL was examined with an arthroscopic probe and debrided. The tibial footprint of the ACL was left intact. A standard notchplasty was carried out for better visualization taking care to remove the least possible amount of bone and ACL femoral attachment footprint to visualize the posterior wall of the lateral femoral condyle. With the knee in 70-90° of flexion, an ACUFEX Director (Smith and Nephew) drill guide was inserted through the medial parapatellar portal. The guide was set at 55° angle and the ACL tip aimer was positioned in the centre of the ACL stump at the ACL tibial footprint. The guide pin is then passed in the knee through centre of the tibial ACL stump and the tibial tunnel was drilled over the guidewire with a drill size that matches the hamstring autograft diameter.

Transtibial (TT) Technique - With the knee flexed to 90°, a TT ACL femoral offset guide (Smith and Nephew) was introduced and positioned over the posterior aspect of the lateral femoral condyle as close to the native femoral ACL footprint as possible. A 2.7 mm passing pin was advanced through the lateral femoral cortex and then overdrilled with 4.5 mm cannulated drill that passes through the lateral femoral cortex. Reaming over the passing pin is then performed over the guide pin with an appropriate size reamer according to the ACL graft diameter. The graft was then passed through the tibial tunnel from a distal to a proximal direction using a suture passer.

Anteromedial (AM) portal technique - The medial parapatellar portal was slightly distal and medial in the AM portal technique compared to the TT technique. This was to avoid using an accessory AM portal. This provided a good viewing angle for the ACL femoral foot print. With the knee in 120°-130° of flexion, the 2.7 mm passing pin was passed from the AM portal into the centre of the femoral native ACL footprint. Drilling for the femoral tunnel was carried out through the AM portal in a similar fashion to the TT technique. A suture passer was passed through the AM portal and exiting the femoral tunnel through the skin of the lateral femoral side. It was then retrieved through the tibial tunnel and the ACL graft was passed using the suture passer; similar to the TT technique.

Graft fixation - All patients had femoral tunnel fixation using suspensory mechanism with ENDOBUTTON (Smith and Nephew, Andover, MA, USA). Interference screws fixation for the ACL graft in the tibial tunnel were performed using Poly-l-lactide

(PLLA) screws (BioRCI; Smith and Nephew, Andover, MA, USA). A metal staple was used for additional fixation of the graft to the tibia in all patients.

5.2.2 Rehabilitation

All patients had the same rehabilitation protocol that was described in Chapter 4.

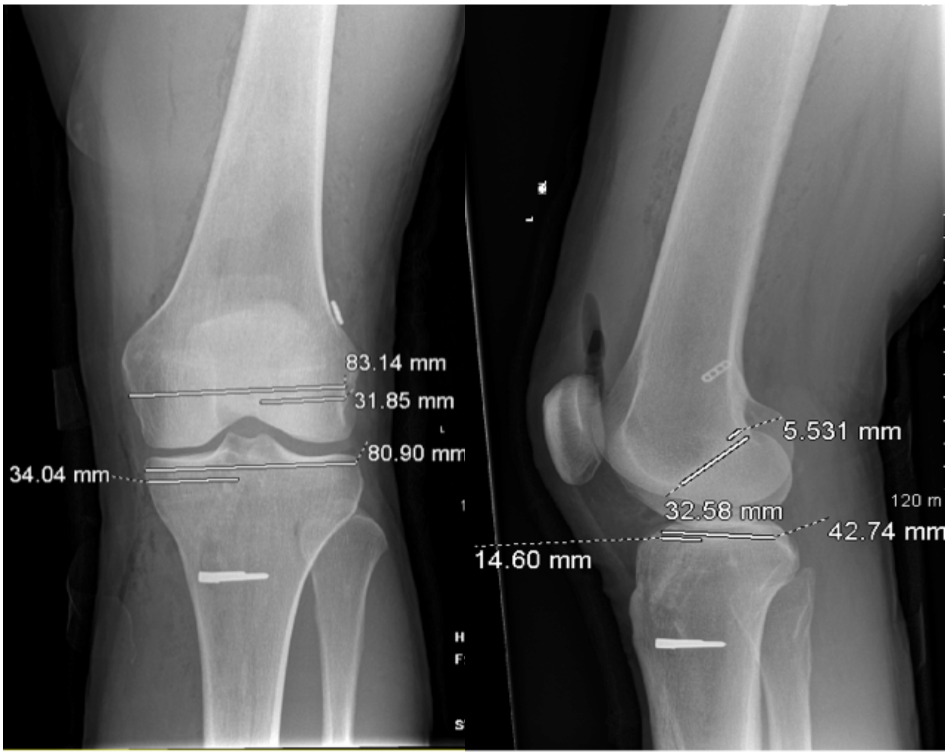
5.2.3 Radiographs

Weight bearing anteroposterior and lateral radiographs of the knee were obtained on day one postoperatively for all the patients. The radiographs were assessed by two orthopaedic fellows who were blinded to which technique was used to drill the femoral tunnels. Assessment method was adopted from Pinczewski (Pinczewski et al., 2008) study in 2008 (Figure 5.3 and 5.4).

Femoral Tunnel - Position of the tunnel was assessed on the AP radiographs by measuring the distance between the farthest points of the two femoral condyles. The distances from the lateral femoral condyle to the centre of the femoral tunnel was measured. The position of the tunnel was then expressed as percentage of the two measurements. The position on the lateral radiographs was assessed by measuring the length of Blumensaat's line as well as the distance between the centre of the femoral tunnel and the anterior and posterior femoral cortex along the Blumensaat's line. Based on these measurements, the position of the centre of the femoral tunnel was calculated and then expressed as a percentage of the total length of Blumensaat's line in relation to the anterior femoral cortex.

Tibial Tunnel - Placement of the tunnel was assessed on AP radiographs by measuring the total width of the tibial plateau. The distances from the medial edge of the medial tibial plateau to the centre of the tibial tunnel was measured and then expressed as a percentage of the total length of the tibial plateau. On the lateral radiographs, the length of the tibial plateau was measured as well as the distance between the centre of the tibial tunnel and the anterior edge of the plateau. The position of the tunnel was presented as a percentage of the total length of the tibial plateau.

The inclination angle of the graft was measured on the AP radiograph. The angle was measured between a line representing the medial wall of the femoral tunnel and a line perpendicular to the tibial plateau.



(a) (b)

Figure 5.3: Plain x-rays of the knee.
(a) AP radiograph showing the measurement for the femoral tunnel position in the coronal plan. The distance between the farthest points of the medial and lateral femoral condyles were measured. The distance from the lateral femoral condyle to the centre of the femoral tunnel was also measured and expressed as a percentage of the distance between the two condyles. (b) lateral radiograph showing the measurement of the femoral tunnel position in the sagittal plan. The length of Blumensaat's line was measured. The position of the centre of the femoral tunnel was measured from the posterior and anterior wall and then expressed as a percentage of the total length of Blumensaat's line in relation to the anterior femoral cortex.

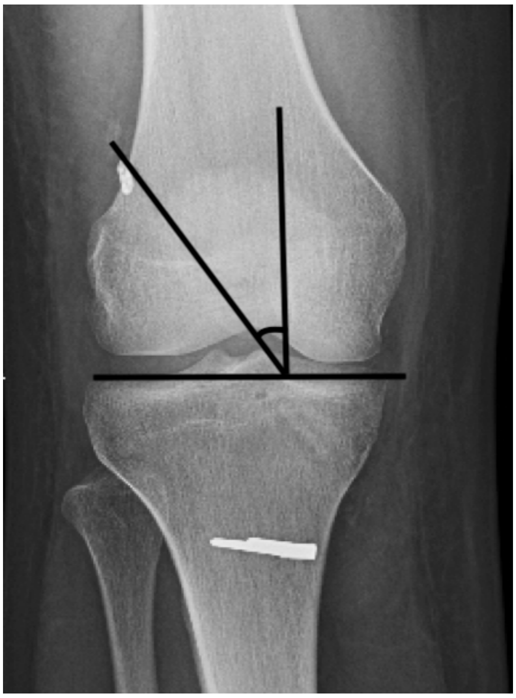


Figure 5.4: The graft inclination angle was measured on AP knee radiographs.
A line was drawn connecting the medial wall of the femoral tunnel and the medial wall of the tibial tunnel. The inclination angle of the graft was measured between this line and a line perpendicular to the tibial plateau.

5.2.4 Clinical Outcomes

All patients were routinely followed up at 6 weeks, 12 weeks, 6 months, 12 months and 24 months. Functional outcomes were assessed at 2 years postoperatively using patient reported outcome measures (PROMs). These were Knee Injury and Osteoarthritis Outcome score (KOOS) (Roos et al., 1998), Lysholm and Tegner scores (Tegner and Lysholm, 1985). Failure of the ACL graft was assessed by physical examination including anterior drawer test, Lachman's and pivot shift test. MRI scans of the knee were performed to confirm the diagnosis of ACL graft rupture.

5.2.5 Statistical Analysis

Data were analysed using the Statistical package for Social Sciences 16.0 for Windows (SPSS Inc., Chicago, IL, USA). A power calculation performed showed that 104 patients are required in each group (total of 208 patients). This was calculated as the minimum numbers required to achieve a statistically significant difference of 5 points on the Lysholm score between the two groups, with an effect size of 0.8, an alpha level of 0.05, and a power of 95%. Therefore, the number of patients included were well above the required sample size. When the numerical values for the two independent groups were normally distributed, Student's t test was used, and when normal distribution was not achieved, a Mann-Whitney U test was carried out to compare the two groups. A P value < 0.05 was considered statistically significant.

5.3 Results

A total of 404 patients were available for analysis. 202 patients had ACLR using the TT technique (TT group) and 202 patients using the AM portal (AM group). The mean patients age in the AM group 34 (range, 19 – 47) while it was 32 (range, 18-50) for the TT group. There were 111 (55%) males and 91(45%) females among the AM group whereas 122 (60%) males and 80 (40%) females were present in the TT group. The average postoperative follow up duration was 26 months (range, 24-33 months).

5.3.1 Radiographic outcomes

On the AP plain radiographs, the mean femoral tunnel position relative to the lateral femoral condyle was 46.8% for the AM group versus 48.6% in the TT group respectively ($p = 0.003$). The mean graft inclination angle was 31.9° and 22° in the AM and TT groups respectively ($p < 0.0001$). The mean tibial tunnel position was 40% and 43.9% for the AM and TT groups respectively ($p < 0.0001$).

On the lateral radiographs, the mean femoral tunnel placement across Blumensatt's line in relation to the anterior femoral cortex was 84% in AM group while it was 78% in TT group (p < 0.0001). The mean tibial tunnel position was 40.5% and 42.3% in the AM and TT groups respectively ($p = 0.1$).

Table 5.1: Radiographic assessment of femoral and tibial tunnels in both AM and TT groups.

	AM group (SD)	**TT group (SD)**	**P value**
Femoral tunnel on AP radiographs	46.8% (4.7)	48.6% (3.3)	0.003
Femoral tunnel on lateral radiographs	84% (5)	78% (4.6)	<0.0001
ACL graft inclination angle	31.9° (5.5)	22° (4.8)	<0.0001
Tibial Tunnel on AP radiograph	40% (2.9)	43.9% (3.7)	<0.0001
Tibial Tunnel on lateral radiograph	40.5% (5)	42.3% (9)	0.1

5.3.2 Clinical outcomes

At two years postoperatively, the mean Tegner scores were 6.8 (range, 1- 10) and 6.5 (range, 1-9) for the AM and TT groups respectively (*p* = 0.09). The mean Lysholm score at 2 years postoperatively were 92 and 87 for the AM and TT groups respectively (*p* = 0.06). The mean KOOS scores for AM and TT groups were: Symptoms (85, 82); Pain (87, 84); activity of daily livings (91, 90), sports and recreation function (69, 63), quality of life (64, 60) respectively. Graft failure rate at 2 years follow-up was 4.5% (n=9) in the AM group while it was 2.5% (n=5) in TT group.

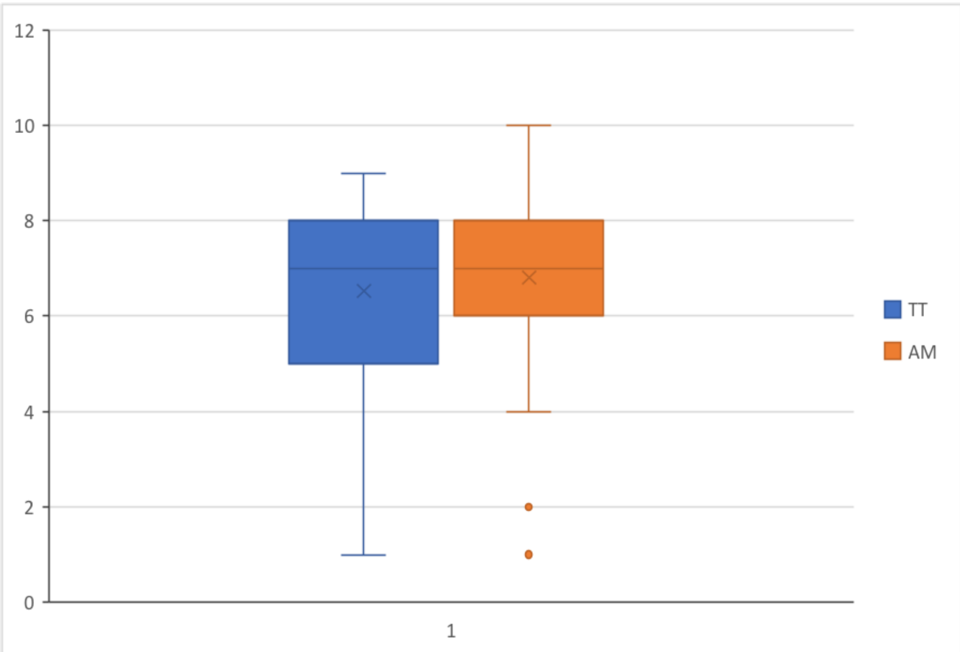


Figure 5.5: Two years postoperative Tegner scores in the AM and TT groups.

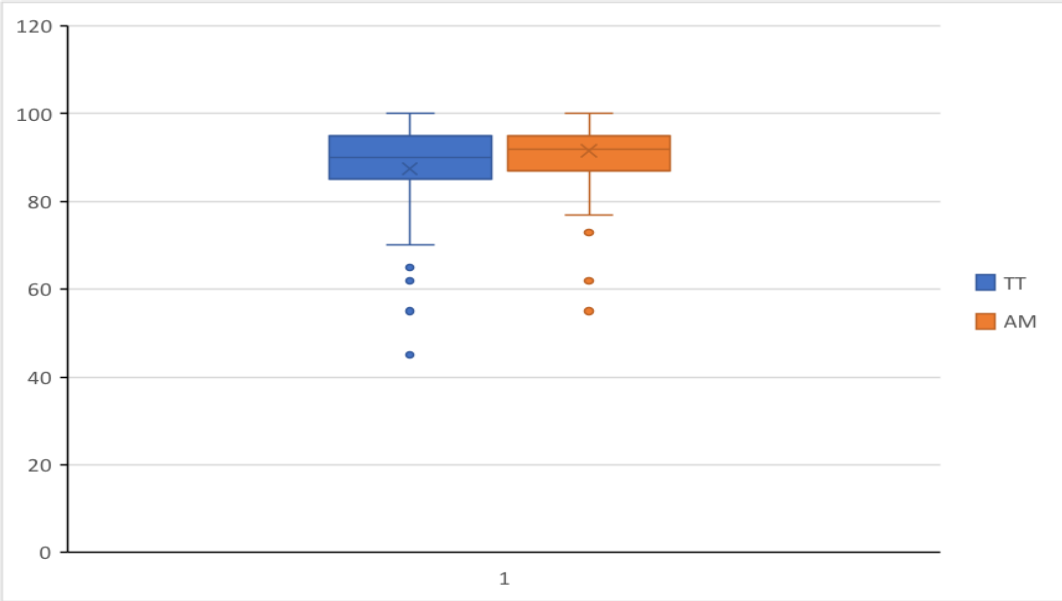


Figure 5.6: Two years postoperative Lysholm scores in the AM and TT groups.

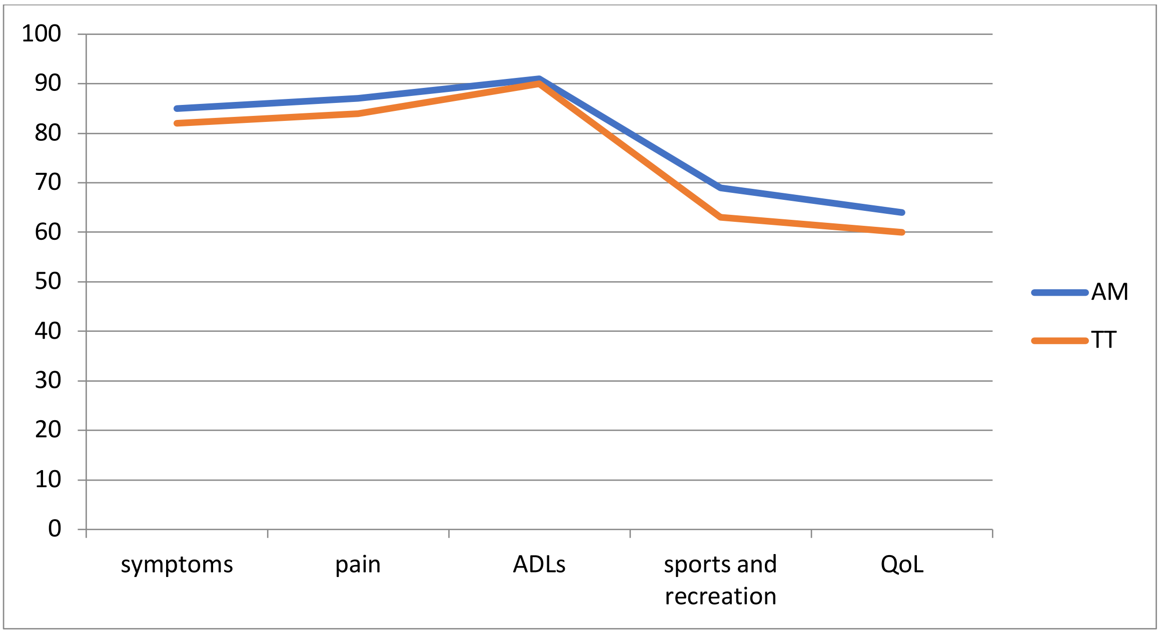


Figure 5.7: Two years postoperative KOOS scores in the AM and TT groups.

5.4 Discussion

This study aimed to compare the radiological and clinical outcomes of AM portal and TT technique in femoral tunnel drilling. There was a statistically significant difference between the two groups with respect to the radiological outcomes. The AM portal has resulted in a higher graft inclination angle which indicates increased graft obliquity compared with the TT technique. Furthermore, the femoral tunnel was more lateral and posterior when the AM portal was utilised. Conversely, the TT technique resulted in a more medial and vertical oriented femoral tunnel. This indicates that the AM portal resulted in a better anatomical position for the ACL graft. We have also observed that the tibial tunnel was in a more anterior and medial position with the AM portal compared with the TT technique.

Multiple studies have demonstrated that non-anatomical placement of the ACL graft is a leading cause of ACL graft failure (Loh et al., 2003; Marchant et al., 2010; Stevenson and Johnson, 2007). Until recently, the aim of femoral tunnel was to achieve ACL graft isometry. Placing the femoral tunnel in an isometric point implies that the distance between the femoral and tibial attachment sites of the graft does not change as the knee flexes (Amis and Zavras, 1995). Placing the femoral tunnel in a non-isometric point was postulated to cause potential complications including graft tightening, blocking knee range of motion, graft slackening elsewhere in the arc of knee flexion, instability and graft failure due to excessive tension (Zavras et al., 2001). It was then believed that the optimal femoral tunnel position to achieve graft isometry was 11 o' clock for the right knee or 1 o'clock position for the left; where the intercondylar notch is considered as clock face. However, the native ACL is not isometric as its length and tension change throughout the knee range of movement (Amis, 2012). The AM bundle tightens in flexion and relaxes in extension. Further cadaveric studies challenged the concept of graft isometry and the subsequent 11 and 1 o'clock position of the femoral tunnel.

Loh et al. (2003) conducted a biomechanical study on 10 human cadaveric knees. They compared the 11 o'clock to 10 o'clock femoral tunnel positions in ACLR with bone patellar tendon bone (BPTB) graft. They compared the effect of applying two external loading conditions: 134 N of anterior tibial load with the knee at full extension, 15°, 30°, 60° and 90° of flexion and a combined rotatory load of 10 Nm valgus and 5 Nm internal tibial torque at 15° and 30° of knee flexion. The authors found that both the 10- and 11 o'clock tunnel positions were equally effective under an anterior tibial load. However, the 10 o'clock position was more effective in resisting rotatory loads when compared to the 11 o'clock position. Scopp et al. (2007) conducted a similar cadaveric study to compare ACLR using the standard femoral tunnel position (30° from vertical) and oblique tunnel placement (60° from vertical) in relation to the native knees. Anterior tibial translation was measured when a 100-N load was applied at a rate of 10 N/second. External and internal tibial rotation were measured with 6.5 Nm was applied. They found that the anterior stability was equivalent between the standard and oblique ACLR. However, the oblique reconstruction resulted in a better rotational stability thus they concluded that it was more successful in restoring normal knee kinematics.

The concept of "moving further around the clock" was also supported by clinical studies. Lee et al. (2007) reviewed 137 patients who had ACLR with BPTB autograft at a minimum of 2 years postoperative follow up. They correlated the position of the femoral tunnels radiographically with clinical assessment that included Lachman test, pivot shift test, KT-1000 and Lysholm score. The authors found that a vertically oriented graft is associated with significantly lower Lysholm score as well as residual pivot shift although there was no anteroposterior laxity. They concluded that a more oblique orientation of the graft achieves better rotation stability that would increase subjective patient satisfaction.

Using the "clock face" reference of the intercondylar notch has been criticised by many surgeons though. This is due to the fact that a 2-dimensional (2D) clock face representation is an oversimplification of what is essentially a 3- dimensional (3D) structure (Martins et al., 2012). Moreover, the orientation of the clock face changes as the femoral AM and PL insertion sites move from vertical to horizontal alignment as the knee move from extension to 90° of flexion (Martins et al., 2012). Moreover, the clock face description does not correlate with any anatomical landmark so would not account for variation in patients' anatomy.

The concept of "anatomical" reconstruction then gained popularity over the "isometric" construction. Anatomical construction of the ACL could be defined as the functional restoration of the ACL to its native dimensions, collagen orientation and insertion sites (van Eck et al., 2010). The four principles of anatomical ACLR that have proposed by Freddie Fu and colleagues are to restore the two functional bundles of AM and PL, placing the tunnels in the true anatomic positions by appropriate sized graft in order to restore the native insertion sites of the ACL, appropriately tension each bundle according to knee flexion angle, individualize surgery for each patient considering specific variations in the anatomy and needs of each patient (Rahnemai-Azar et al., 2016). These were the basis for utilising the double bundle (DB) ACLR with aim of reconstructing the AM and PL bundles.

However, the literature is not all in favour of the DB ACLR. Song et al. (2009) conducted a prospective comparative study between DB and SB ACLR. They found that DB ACLR produces better intraoperative stabilities than SB ACLR. However, both techniques were similar in terms of clinical outcomes and postoperative stabilities after a minimum of 2 years of follow-up. In a recent systematic review, Qi et al. (2016) found that no superiority could be established between the two techniques in terms of biomechanical stability or clinical outcomes. There are concerns over drilling four tunnels in the knee that would create a big void if any further revision surgery is required. DB ACLR is considered to be rather complex, more time consuming and technically difficult when compared with single bundle (SB) ACLR (Carmont et al., 2011). This has caused the attention to be drawn back to SB ACLR with anatomical placement of the graft utilising the AM portal (Carmont et al., 2011).

Clinical studies comparing the AM and TT technique have produced variable results with uncertainty to which technique has superior clinical results. In a prospective non-randomized trial, Koutras et al. (2013) compared the short term (6 months) outcomes of 51 male patients receiving either the TT or AMP techniques. They showed improved Lysholm scores at 3 months and better performance in the timed lateral movement functional tests at 3 and 6 months scores at 3 and 6 months in the AM group. The AM portal group had better Lysholm scores at 3 months and better performance in the timed lateral movement functional tests at 3 and 6 months. The authors suggested possible quicker return of function and performance for the anteromedial approach group. Noh et al. (2013) conducted a randomised controlled trial with a longer follow up of 30 months. They reviewed 64 young male patients who underwent ACLR with allograft either using the AM portal or the TT technique. At the last follow-up, there was no significant difference between the 2 groups in results from the Lachman test, pivot shift test, IKDC score, Tegner activity scale, and single leg hop test. The Lysholm score and side-to-side difference results in the AM group were superior to the TT group. In another prospective randomised controlled trial, Hussein et al. (2012) reported significant improvement in anteroposterior and rotational stability as assessed by KT-1000 and pivot shift testing in the AM group, respectively. However, the differences in Lysholm and subjective IKDC scores were statistically insignificant. They conclude that the objective differences detected were small and may not be clinically relevant. In a recent meta-analysis, Chen et al. (2015) demonstrated that the AM portal had better objective IKDC knee score, Lachman test, and pivot-shift test. However, there was no difference in patient- reported functional outcome in the form of Lysholm score.

Our study showed similar results to the aforementioned studies. Our hypothesis that AM portal results in better functional outcomes, compared with TT technique, was not supported in this study. Although we found that the AM portal technique had slightly better patient reported outcome measures compared with the TT technique, these small changes were not clinically or statistically significant. We also observed that the AM portal group had a higher graft failure rate compared with the TT technique. This was a rather unexpected finding considering that we demonstrated radiological evidence of a more anatomical graft position with the AM portal technique. However, this finding was similar to reports from other clinical studies. Rahr-Wagner et al. (2013) conducted the first national registery cohort study to compare the risk of revision surgery following the use of AM portal or TT technique in primary ACLR. They reviwed 1,945 patients who had AM portal and 6,430 patients with TT technique for primary ACLR in the Danish Ligament Registry. At 4 year follow up, the cumulative revision rates for ACLR with the AM portal and TT techniques were 5.16% and 3.20% respectively. In a recent registry-based study, Desai et al. (2017) investigated 17,682 patients who had ACLR on the Swedish National Ligament Registery over a 10 years period. The authors reported an increased risk of revision surgery following primary

ACLR with the AM portal compared with the TT technique. The authors suggested that the learning curve for the more complex AM portal technique could be one of the reasons for increased revision rates with this technique. However, we have not encountered this in our study as we have excluded the first 100 cases of ACLR with the AM portal to eliminate the potential effect of the learning curve.

Another possible explanation would be increased in situ forces on the ACL graft when it is placed in an anatomical position using the AM portal technique (Araujo et al., 2015). Xu et al. (2011) demonstrated in a cadaveric study that anatomiclly recostructed AM bundle restores knee kinematics but the graft was exposed to higher in situ forces compared with non-anatomic high placement of the graft. The greater load carried by the anatomically reconstructed graft could lead to premature failure of the graft. Conversely, a non-anatomically reconstructed graft had lower in situ forces with the resultant increase in load distributed to other stuctures in the knee. It is important to appreciate that there has been no change in the current postoperative rehabilitation protocol and time to return to sport; to account for the recent shift towards anatomical ACLR with the subsequent incease in the situ force on the ACL graft (Araujo et al., 2015). Accelerated rehabilitation protocols and early return to sport might expose anatomically placed grafts to higher forces before they reach complete healing and maturation resulting in graft failure. Unfortunately, we couldn't draw any conclusion from the NLR data to whether there is a differernce in functional outcome between anteromedial and transtibial drilling of the femoral tunnel. This is due to the limited compliance with completing the 2 years postoperative outcome measures on the NLR.

Our study has shown that the AM portal technique has resulted in an anatomical placement of the graft. However, this technique is not without problems. Femoral tunnel placement using the AM portal technique is technically demanding and requires a learning curve (Brown et al., 2010; George, 2010; Logan et al., 2012; Rahr-Wagner et al., 2013). Bedi et al. (2010) demonestrated in a cadaveric study that the AM portal technique has increased risk of critically short femoral tunnel(<25 mm) and higher potential for posterior femoral wall compromise. Similarly, Chang et al. (2011) reported in a clinical study that using the AM portal to place the femoral tunnel at more horizontal than 10:30 o'clock position could result in a siginficantly short femoral tunnel. Other complications that have been described before with the AM portal include femoral tunnel "blow out", potential damage to the posterior articular cartilage, low portal placement that might cause injury to the anterior horn of medial meniscus and iatrogenic injury to the common peroneal nerve (Robin et al., 2015).

5.4.1 Limitations

This study has limitations. We relied on plain radiographs alone to assess graft inclination and tunnel positions. MRI scans or 3D CT scans could have provided a more accurate assessment for tunnel positions (Bowers et al., 2011; Clockaerts et al., 2016). However, there is a high cost associated with using CT and MRI scans as well as high irradiation exposure in CT scans. We have not specifically collected data on time to return to sports in both cohorts. Also, we have not formally recorded objective assessment for our patients to compare anteroposterior and rotational stability between the two patient groups. Although procedures were carried out by a single surgeon, the two patient cohorts did not have their surgery at the same time period which is another limitation. The short follow up period did not allow studying the long-term outcomes for both techniques especially in terms of graft failure and degenerative changes in the knee.

5.5 Conclusions

Femoral tunnel placement during arthroscopic ACLR was more anatomical with the AM portal technique compared with the TT technique. However, there was no significant difference in postoperative functional outcomes between the two patient groups. The AM portal technique appears to have a higher graft failure rate when compared to the TT portal technique. This may be attributed to increased graft loading in an anatomical position. Further high quality randomised controlled trials are required to assess the medium and long-term outcomes of both surgical techniques.

Chapter 6

The Medium-term Outcomes of Meniscal Repair with and without Concomitant Anterior Cruciate Ligament Reconstruction

6.1 Introduction

The menisci are two crescentic-shaped wedges of fibrocartilage positioned between the tibia and the femur in the medial and lateral compartments of the knee. It is now recognised that the menisci have various important functions (McDermott and Amis, 2006). They play a key role in load bearing, nutrition, shock absorption and stability in the knee.

Meniscal tears are the most common injury of the knee, with a reported annual incidence of meniscal injury resulting in meniscectomy of 61 per 100,000 population (Baker et al., 1985). Meniscal pathology in younger patients are often consequent to an acute traumatic event, while degenerative changes are more frequent at an older age. More than one third of all meniscal tears are associated with an anterior cruciate ligament (ACL) injury, with a peak incidence in men aged 21–30 years and in girls and women aged 11–20 years (Maffulli et al., 2010). The lateral meniscus is injured more often in acute ACL tears, and the medial meniscus is more likely involved in chronic ACL deficient knee (Bellabarba et al., 1997; Thompson and Fu, 1993). Historically, meniscal injuries were managed with meniscal resection either as a partial or total meniscectomy. It is well known that meniscectomy surgery causes increase in the intra-articular contact stresses (Mcdermott and Amis, 2006). Pengas et al. (2012, 2017) reported on the outcomes of open total meniscectomy in adolescents. They demonstrated significant changes in the tibiofemoral angle with malalignment and radiographic changes of osteoarthritis at 40 years follow up. Meniscal repair is an alternative surgical option for meniscal injuries that has gained popularity over the last three decades.

6.1.1 Anatomical considerations

The menisci are wedge-shaped in cross-section and attach to the joint capsule at their convex peripheral rim; and to the tibia anteriorly and posteriorly by insertional ligaments. The lateral meniscus is C-shaped with a shorter distance between its anterior and posterior horns. The medial meniscus is U-shaped with larger antero-posterior separation of the two horns. The medial and lateral menisci have distinctly different dimensions: lateral meniscus is approximately 32.4-35.7 mm in length and

26.6-29.3 mm wide, while medial meniscus is approximately 40.5-45.5 mm long and 27 mm wide (Makris et al., 2011). The medial meniscus covers around 60% of the articulating surface of the medial compartment while the lateral meniscus covers 80% of the lateral compartment (Kohn and Moreno, 1995). The peripheral portion of the lateral meniscus is not firmly attached to the joint capsule. The meniscofemoral ligaments join the posterior horn of the lateral meniscus to the lateral side of the medial condyle of the femur in the intercondylar notch. The anterior meniscofemoral ligament runs anterior to the posterior cruciate ligament (PCL), and is known as the ligament of Humphrey. The posterior meniscofemoral ligament runs posterior to the PCL and is known as the ligament of Wrisberg (Kawamura et al., 2003).

Normal meniscal tissue has water (72%), collagen (22%), glycosaminoglycans, adhesion glycoproteins, DNA and elastin (Herwig et al., 1984; Proctor et al., 1989). Collagen fibres (predominantly Type I) run circumferentially while other radially oriented fibres act as cross-links, preventing longitudinal splitting of the circumferential fibres. The predominant cell type in the meniscus is the fibrochondrocyte, found mostly at the periphery of the cartilage. A further superficial zone cell type has also been identified, which may have a specific function in meniscal repair (Getgood and Robertson, 2010).

The vascular supply to the menisci arises mainly from the medial and lateral inferior, and the middle geniculate arteries. Arnoczky and Warren (1982) studied the microvascular anatomy of the human meniscal tissue. They found that the meniscal microvasculature penetrates 10% to 30% of the width of the medial meniscus and 10% to 25% of the width of the lateral meniscus. They also noted that a vascular synovial fringe extends a distance of 1 to 3 mm over the peripheral rim of the meniscus but does not contribute a blood supply to the meniscal tissue itself. This was the basis for dividing the meniscus into three zones. The outer peripheral third tends to have good blood supply and so termed the red zone. The inner third is avascular and so termed the white zone. The red-white zone separates the two zones.

6.2 Biomechanics

The medial and lateral menisci have important biomechanical functions within the knee joint. These include load bearing, shock absorption, joint stability, joint lubrication, and proprioception. This is the basis for recent popularity of meniscal preservation surgery.

During axial loading the meniscus experiences tensile, compressive and shear stress. When the meniscus is loaded on weight bearing, the meniscal fibres elongate as they are displaced away from the centre. Hoop stress is generated as the axial load is converted to tensile strain. The menisci transmit around 50% of the axial load in extension and nearly 90% of the load in 90 degrees of flexion (Maitra et al., 1999). The lateral meniscus transmits 70% of the load in the lateral compartment while the medial meniscus transmits 50% of the load in the medial compartment (Cole et al., 2002). In 1948, Fairbank described radiological changes following meniscectomy (Fairbank, 1948). These changes were joint space narrowing, flattening of the femoral condyle and ridge formation (osteophyte formation). Further studies have shown that removal of the medial meniscus results in a 50% to 70% reduction in femoral condyle contact area and in a 100% increase in contact stress. Total lateral meniscectomy causes a 40% to 50% decrease in contact area and increases contact stress in the lateral compartment from 200% to 300% of normal (Greis et al., 2002). Roos et al. (1998) demonstrated that open total meniscectomy can lead to a 14-fold increase in incidence of osteoarthritis.

The high-water content of the menisci helps with shock absorption. Voloshin and Wosk (1983) reported a 20% reduction in the shock absorption capacity of the knee after meniscectomy. The meniscus has an important role in joint stability. Although medial meniscectomy has a little effect on the anteroposterior motion in the ACL intact knee, it has shown to increase the anterior tibial translation by up to 58% at 90° of flexion in the ACL deficient knee (Levy et al., 1982). In a cadaveric study, the posterior horn of the medial meniscus was the most important structure resisting an applied anterior tibial force in an ACL-deficient knee (Shoemaker et al., 1986).

6.3 Types of meniscal tear

Meniscal tear can be classified according to the aetiology, shape or location of the tear. The two etiologic categories are acute tears from excessive application of force to a normal meniscus and degenerative tears, which occur in a meniscus that has been worn down by age, malalignment or chronic knee instability.

Fu et al. (1994) described common shape patterns of meniscal tear that include vertical (longitudinal), oblique (flap), bucket handle, complex (including degenerative), transverse (radial), and horizontal tears. The location of the tear can be described according to its blood supply in the three meniscal zones (i.e. red-red, red-white and white-white tear).

The aim of this study was to assess the medium-term outcomes of meniscal repair in a selected patient population and to investigate the influence of concomitant ACLR on the repair outcomes. This is a follow up study for the short-term outcomes study that was reported by Konan and Haddad (2010) on the same patients' cohort.

6.2 Methods

6.2.1 Patient Selection Criteria

We conducted a prospective observational study on patients who underwent arthroscopic meniscal repair surgery at the University College of London Hospital between January 2004 and December 2008. Patients were included in this study according to strict inclusion and exclusion.

a) Inclusion criteria:

1. Adult patients aged between 18 and 50 years old.
2. History of trauma or sports-related meniscus tears.
3. Absence of degenerative changes in the meniscus.
4. Meniscal tears Typically in the red-rad or red-white zones but white-white tears were included in selected cases.

b) Exclusion criteria:

1. Concomitant knee dislocation
2. Meniscal tears in patients who sustained major trauma.

3. Medicolegal cases.

The decision to repair a torn meniscus was made by the senior surgeon intraoperatively. Multiple factors contributed to deciding on proceeding with meniscal repair including preoperative clinical symptoms, the location of the tear, and the quality of the meniscus.

All morphological types of meniscal tears were considered for repair, including vertical tears, horizontal tears, bucket handle tears, and complex tears. In situations where complex meniscal tears had irreparable components, the tears were trimmed to stable torn edges before performing the repair.

Red-white tears were generally considered for repair. Repair of white-white tears were performed in selected cases if there was a risk of loss of a large area of torn meniscus, especially in the lateral meniscus and particularly with tears noticed during ACL reconstruction (ACLR) surgery.

6.2.1 Surgical technique

In all cases, the surgeon used arthroscopic all-inside repair devices. Depending on the type of tear, a vertical or horizontal mattress pattern of suturing was used to approximate the torn edges of the meniscus. Before repair, the edges of the meniscus tears were roughened up using an arthroscopic shaver to promote bleeding.

The surgeon initially used meniscus arrows (Bionx Implants, Malvern, PA) for the all-inside repair but then changed his practice, after the first 9 months of the study, to using meniscus repair sutures (FasT-fix; Smith & Nephew, Andover, MA). The type of tear was documented, according to its morphology as described by Fu (Fu et al., 1994) such as bucket handle tears, vertical tears, horizontal tears, capsular detachment and complex tears. The location of the repaired meniscus was documented using the system described by Cooper et al. (1990). This system divides the meniscus into 3 radial and 4 circumferential zones. From posterior to anterior, the radial zones are referred as A, B, and C for the medial and D, E, and F for the lateral meniscus. Each zone refers to one third of the meniscus, with A and F being the posterior third for the medial and lateral meniscus, respectively. The 4 circumferential zones are 0 for meniscocapsular junction, 1 for outer third, 2 for middle third and 3 for inner third.

In patients with ACL deficiency, meniscus tears were often repaired at the time of arthroscopic ACLR surgery. All ACLR procedures were performed arthroscopically using either four-strand semitendinosus and gracilis autograft or two semitendinosus allograft. Femoral tunnel drilling was performed using the transtibial technique. Femoral tunnel fixation for the graft was achieved using an Endoloop (Smith & Nephew, Mansfield, MA) while interference screws (RCI; Smith & Nephew, Andover, MA) were used for tibial tunnel fixation. The grafts were tensioned at 20 degrees of knee flexion.

6.2.2 Rehabilitation

Postoperative rehabilitation was started under the supervision of specialist knee physiotherapists. Patients were allowed to fully weight bear. However, weight bearing with the knee flexed beyond 90 degrees was restricted for the first 12 weeks. Rotational as well as pivoting movements of the knee were restricted for the first 6 weeks. In patients who underwent concomitant ACLR, there was no change in the rehabilitation program from our routine protocol. Closed kinetic chain physiotherapy exercises were started and lasted for 6 to 9 months depending on the progress of the individual patient.

6.2.3 Outcomes

The primary outcome measure for this study was failure of the meniscal repair. Failure of the repair was defined by persistence of knee symptoms that are swelling, locking, or joint pain; and/or the requirement for repeat knee arthroscopy and meniscectomy. This evaluation was performed by the senior author before the repair was considered as a failure. Clinical diagnosis of a failed meniscal repair was supplemented by magnetic resonance imaging (MRI) of the knee when necessary. In these cases, failure was also defined by an MRI diagnosis of a persistent tear beyond 52 weeks of surgery and inability to achieve the preoperative level of knee function. However, knee MRI scans were not routinely performed in all patients. The indication for requesting an MRI scan postoperatively was persistent knee symptoms in the absence of definite clinical evidence of meniscus tears.

6.3 Results

A total of 372 consecutive all-inside meniscus repairs were performed by the senior author (FSH) in 331 patients who met the inclusion and exclusion criteria. 49 meniscal repairs were lost to follow up so a total of 323 (177 lateral menisci and 146 medial menisci) meniscal repairs in 295 patients were available for analysis. There were 159 males and 136 female patients with an average age of 32 years (range, 17-46 years). The mean follow-up period was 76 months (range, 62-135 months).

The most common tear pattern was a peripheral red on white type tear involving the body and posterior horn (Table 6.1 and 6.2). In 65 cases, the meniscus was stabilized by trimming an unstable edge before repair. Meniscectomy was performed on one meniscus while the other meniscus was repaired in 72 cases. Meniscus arrows (Bionx Implants, Malvern, PA) were used for the initial 54 cases of all-inside meniscal repairs while meniscus repair sutures (FasT-Fix; Smith & Nephew, Andover, MA) were used in the remaining 269 meniscal repairs. An average of two arrows (range, 1–4; SD, 0.97) were used in the Bionx system (Bionx Implants, Malvern, PA) and 2.5 (range, 1–7; SD, 1.37) sutures in the FasT-Fix system (Smith & Nephew, Andover, MA). Concomitant ACLR was performed in 52% cases (167 meniscus repairs, 149 patients). Of these, 68 and 99 meniscal repairs were performed for medial and lateral meniscus tears respectively (Table 6.3).

Table 6.1: Number of medial and lateral meniscal tears according to morphological appearance

Type of tear	Medial meniscus tears	Lateral meniscus tears	Total
Bucket handle tears	16	26	42
Horizontal tears	24	46	70
Vertical tears	41	32	73
Partial vertical tears	18	36	54
Complex tears	39	33	72
Capsular detachment	9	3	12
Total	147	176	323

Table 6.2: Number of medial and lateral meniscal tears according to location as described by Cooper (Cooper et al., 1990)

Medial meniscus tears	Number of tears	Lateral meniscus tears	Number of tears
A1	42	E1F1	69
B1	29	F1	29
A1B1	58	E1	31
A0	6	E2	12
B2	6	F2	14
A0B0	3	E2F2	18
B1C1	3	E0	3

Table 6.3: Number of medial and lateral meniscal repairs with and without ACL reconstruction

	Without ACLR (%)	With ACLR (%)	Total (%)
Medial meniscal repair	79 (51%)	68 (41%)	147 (46%)
Lateral meniscal repair	77 (49%)	99 (59%)	176 (54%)
Total	156	167	323

6.3.1 Surgical complications

There were no major intraoperative complications and no nerve injuries. Failure of the suture mechanism and/or wasted sutures was noted in an average of 0.4 occasions per case. There were three painful capsular sutures that required removal and two cases of complex regional pain syndrome. Deep venous thrombosis developed in two cases postoperatively and both were managed successfully with low-molecular-weight heparin.

6.3.2 Outcomes

At one year follow up; a total of 289 repairs out of 323 meniscal repairs were successful in 268 patients. This gives an overall success rate of 89%. Out of the failed 34 meniscal repairs, 9 repairs (5 Lateral meniscus and 4 medial meniscus) were concomitantly performed with ACLR while the remainder 25 were isolated meniscal repairs (14 medial meniscus and 11 lateral meniscus).

At two years follow up; further 19 meniscal repairs have failed bringing the overall success rate to 83.5%. Eight failed meniscal repairs (4 lateral and 4 medial repairs) were associated with ACLR and the remainder 11 repairs (7 medial and 4 lateral) were isolated meniscal repairs.

At 5 years follow up; further 13 meniscal repairs have failed bringing the overall success rate to 79.5% (Figure 6.1). Six failed meniscal repairs (4 medial meniscus and 2 lateral meniscus) were concomitantly performed with ACL reconstruction while the remainder 7 repairs were isolated meniscal repairs (4 medial meniscus and 3 lateral meniscus). The success rate of meniscal repair was 86% when it was performed with ACLR while it was 72% for isolated meniscal repairs. However, because these two groups were not comparable, no statistical significance could be identified. Failure of meniscus repair occurred in 18.5% (47 repairs: FasT-Fix; Smith & Nephew, Andover, MA) of the cases in which the suture mechanism was used. A higher failure rate 35% (19 repairs: meniscus arrow; Bionx Implants) was noted when meniscus arrows were used. In the majority of failed meniscal repairs, there were ongoing symptoms postoperatively, although some patients were transiently better. Repeat surgery was typically undertaken at a mean of 19 months (range, 1–65 months).

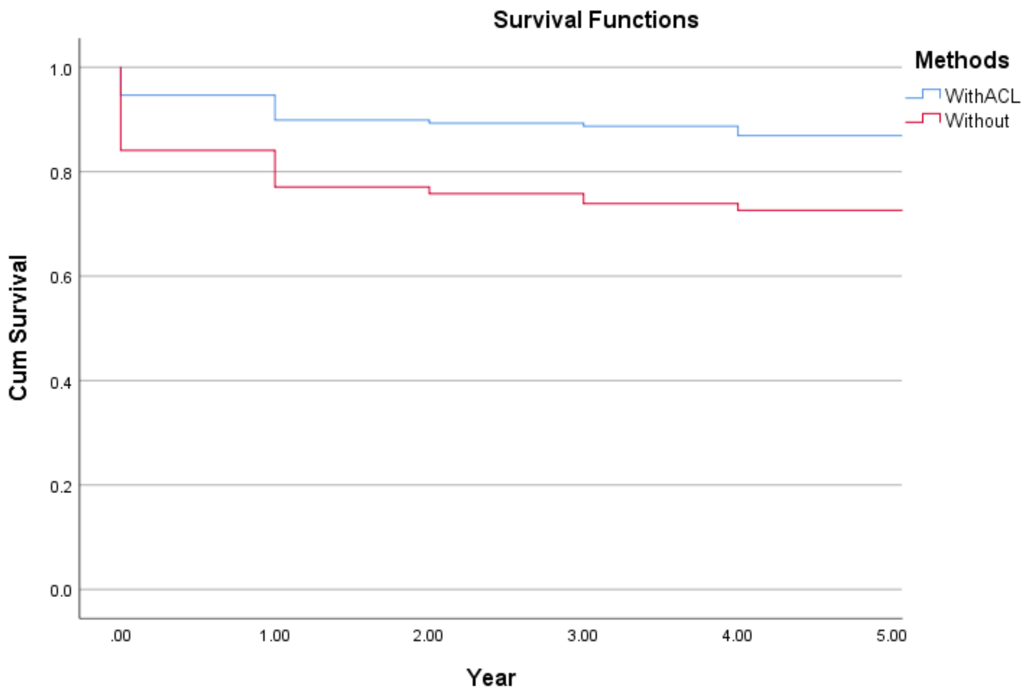


Figure 6.1: Kaplan-Meier survival analysis curve showing the cumulative survival of meniscal repairs with ACLR (blue) and without ACLR (red)

6.4 Discussion

The first case of meniscal repair was performed by Thomas Annandale in 1883 (Annandale, 1885). Various surgical techniques have evolved since then. There are basically three techniques for arthroscopic meniscal repair: inside-out, outside-in, and all-inside. The inside-out technique was the first to be described and was the most commonly used. It utilises sutures placed in the menisci from within and then tied over the capsule through a limited open approach. The medial meniscal repair sutures are tied with the knee in 20° of flexion, whereas the lateral sutures are tied with the knee in 90° of flexion. The advantages of the inside-out technique include its proven clinical success and the ability to place vertical mattress sutures associated with optimal strength characteristics with access to the middle one-third and, to a lesser extent, the posterior horns (Sgaglione et al., 2003). In the outside-in technique, sutures are passed through the meniscus from the outside, thus avoiding the more extensive incisions and retractions involved in inside-out repairs. As with inside-out repairs, however, outside-in repairs are largely limited to anterior portions of the medial and lateral menisci. All-inside repair devices were developed to reduce surgical time, prevent complications resulting from external approaches, and allow access to tears of the posterior horn (Labile et al., 2013). The evolution of the all inside devices has now seen several generations. The latest fourth generation devices include anchors separately placed at the rim of the meniscus through the tear, and then a slipknot is tensioned across the tear. They share the ability of adjusting tension across the tear. Furthermore, some authors believe they are much less damaging to chondral surfaces and may enhance healing rates compared to previous generations (Diduch and Kornekis, 2003).

There are many factors that would affect healing of the meniscal tear following arthroscopic repair. The ideal tear for repair is an acute, vertical, longitudinal tear in the peripheral red-red zone of the meniscus in a young patient who has a stable knee or will have concomitant reconstruction of the ACL (Kawamura et al., 2003). The vascular supply of a meniscal tear is the most determining intrinsic factor for healing. Most meniscal repairs are performed for tears that are close to the vasculature supply that are in the red-red or red-white zone. In general, the more peripheral the tear is the greater chance of healing (Cannon et al.,1992; Woodmass et al., 2017). However, extension of the meniscal tear into the avascular zone is not considered an absolute contraindication for reapir (Noyes et al., 2002). Barber-Westin and Noyes (2014) conducted a systematic review on studies reporting the outcomes of meniscal repair in the red-white zone. They reported 83% success rate of meniscal healing clinically. Meniscal tears were considered clinically healed if patients had no obvious clinical meniscus symptoms or any additional meniscal surgery. They also reported that age, chronicity of injury and gender did not adversely influence the clinical outcome. In a retrospective study, Uzun et al. (2017) reviewed 223 patients who underwent arthroscopic medial meniscal repair. Healing of the meniscal tears were assessed both clinically and radiologically with knee MRI scans. They reported five time increase in failure rate with meniscal repair were performed in the red-white zone. Early repairs had better results compared to chronic meniscal tears and smoking adversely affected the meniscal healing in their case series.

6.4.1 Outcomes of meniscal repair for isolated meniscal injury

Various studies have reported the outcome of the meniscal repair with a few reporting more than 10 years outcome. However, there is no consensus on the criteria used to define successful meniscal repair. Most of the studies defined success as no or little knee pain that doesn't interfere with activity, no locking or other mechanical knee symptoms, negative McMurray test and no subsequent surgical procedure on the repaired meniscus. Miao et al. (2011) compared the diagnostic value of second look arthroscopy for determination of meniscal healing following arthroscopic repair; in comparison to clinical assessment and magnetic resonance imaging (MRI). They concluded that second look arthroscopy was the most dependable way to determine meniscal healing. Clinical assessment for meniscal healing was reported to have 58.3% sensitivity and 75.3% specificity (Miao et al., 2011). However, performing a routine second look arthroscopy might not be a feasible option in routine clinical practice.

A few clinical studies have compared the outcomes of meniscal repair to partial meniscectomy. Stein et al. (2010) compared the long-term outcome of arthroscopic meniscal repair versus arthroscopic partial meniscectomy in patients who had traumatic meniscal tears. They retrospectively reviewed 42 patients who had meniscal repairs and 39 patients who had partial meniscectomy at 8.8 years follow up. There was a significant loss of sports activity level in the partial meniscectomy group while there was no significant change in the meniscal repair group. Furthermore, 94.4% reached the preinjury sports activity level at 8 years follow-up while only 43.75% of the partial meniscectomy group reached the preinjury level. Only 20% of the meniscal repair group showed radiographic evidence of osteoarthritic changes compared with 60% in the partial meniscectomy group. Xu and Zhao (2015) reported similar findings in a recent meta-analysis. They demonstrated that meniscal repairs had better functional outcomes and lower failure rate compared with partial meniscectomy at long term follow up. The functional outcomes were assessed using the International Knee Documenation Committee (IKDC), Tegner and Lysholm outcome scores.

The overall success rate of meniscal repairs in our study was 79.5% at 5 years follow up. This is similar to what has been reported in the literature. We also observed that meniscal repairs with meniscal arrows had higher failure rate compared with FasT-Fix sutures. Majewski et al. (2006) studied the long-term outcome of 88 patients who had meniscal repairs utilising the outside-in technique in stable knees. They reported a success rate of 76.2% with good functional outcomes at a mean follow up of 10 years. Nepple et al. (2012) conducted a systematic review on outcomes for all three techniques of meniscal repair at greater than 5 years follow up. They reported a failure rate of 22.3% to 24.3%. Bogunovic et al. (2014) conducted a retrospective review for 75 meniscal repairs that were undertaken with use of FasT-Fix all inside meniscal repair technique. Isolated meniscal repairs represented 35% of their patients' cohort while the remaining 65% were associated with ACL reconstruction. They reported a success rate of 84% for the meniscal repairs at minimum of 5 years follow-up. For the meniscus arrows, Gill and Diduch (2002) presented an initial clinical success rate of 91% at a mean follow up of 2.3 years that dropped down to a 71% success rate at 6.6 years. Similarly, Siebold et al. (2007) reported a high clinical failure rate of 28% in 113 patients who had meniscal repairs using meniscal arrows at 6 years postoperative follow up. More than 80% of all failure occurred during the first 3 years postoperatively.

A few studies have suggested that meniscal repair of the medial compartment has a higher failure rate compared to the lateral compartment (Logan et al., 2009; Cannon and Vittori, 1992; Eggli et al., 1995). We have noted similar observation in our study with failure rate of 25% and 20% for medial and lateral meniscal repairs respectively. Possible explanations for this observation is the higher incidence of acute lateral tears compared with the chronicity of medial tears. Also, the differential movement of the menisci with flexion, with more stress placed on the relatively immobile posterior horn of the medial meniscus, could theoretically put more pressure on a medial meniscal repair. Another explanation could also be that lateral meniscal repairs that have failed can remain asymptomatic. It has been noticed that many lateral meniscal tears remain asymptomatic when left alone at the time of ACLR (Fitzgibbons and Shelbourne, 1995).

Lyman et al. (2013) studied the risk factors for meniscal repair failure and subsequent meniscectomy. They reviewed 9609 meniscal repair cases with median follow up of 156 weeks. They concluded that repairing a meniscus is a safe and effective procedure in the long term. They reported that the risk for undergoing subsequent meniscectomies were reduced in patients undergoing a concomitant ACLR, in cases of isolated meniscal repairs for patients of older age, and in patients undergoing meniscal repair by surgeons with a high case volume (more than 24 cases per year). The lower failure rate in the older age group (over 40 years) was justified by their compliance and adherence to the rehabilitation programme compared to the young athletes age group. Also, the latter group of patients are often interested in higher risk competitive and recreational activities and experience a greater urgency to return to sports; sometimes at a premature stage.

6.4.2 Outcome of meniscal repair with concomitant ACLR

The 5 years success rate of meniscal repairs in our study was 86% when performed with concomitant ACLR. The success of meniscal repair is highly dependent on the stability of the supporting ligamentous structures of the knee. Dehaven and Arnoczky (1994) reported significantly worse results of meniscal survival in ACL-deficient knees both at 5 years (38% failure) and at 9 years (54% failure).

Gallacher et al. (2012) compared 24 patients who underwent meniscal repair before having their ACLR with 148 patients who underwent meniscal repair at the time of ACLR. The success rate in the latter group was 72% while it was 50% in the former group with seven patients undergoing meniscectomy at the time of ACLR and five patients afterwards.

Good results have been described in the literature for meniscal repair in conjunction with ACLR, better than that following meniscal repair in isolation (Krych et al., 2010). This might be due to restoration of normal knee biomechanics and stability, lack of degeneration of the meniscal tissue in the ACL deficient knee and the haemoarthrosis associated with ACLR procedure which is a biological stimulus for tissue healing (Cannon and Vittori, 1992; Meister et al., 2004).

Several studies have demonstrated that meniscal repair has better short-term outcome compared to meniscectomy in patients undergoing ACLR with meniscal tear (Cannon and Vittori, 1992; Toman et al., 2009; Konan and Haddad, 2010; Wasserstein et al., 2013). Toman et al. (2009) prospectively studied the outcome of 437 unilateral primary ACLR procedures performed with 82 concomitant meniscal repairs (54 medial, 28 lateral) in 80 patients. Patient follow-up was obtained on 94% (77 of 82) of the meniscal repairs, allowing confirmation of meniscal repair success (defined as no repeat arthroscopic procedure) or failure. The overall success rate for meniscal repairs was 96% (74 of 77 patients) at 2-years follow-up. They recommended that whenever there is a “repairable” meniscal tear at the time of ACLR, one can expect an estimated >90% clinical success rate of meniscal repair at 2-years follow-up. Similarly, Wasserstein et al. (2013) conducted a review on 1332 patients who underwent meniscal repair and ACLR, in which 1239 (93%) were matched with patients who underwent isolated meniscal repair. The rate of meniscal reoperation was significantly lower in the cohort that underwent meniscal repair with ACLR (9.7%) compared to the cohort that underwent isolated meniscal repair (16.7%). They concluded that a meniscal repair performed in conjunction with ACLR carries a 7% absolute and 42% relative risk reduction of re-operation after 2 years compared with isolated meniscal repair. Westermann et al. (2014) studied the success rate of meniscal repairs in the Multicentre Orthopaedic Outcomes Network (MOON) patient cohort. They reported an 86% success rate of meniscal repairs at 6 years follow up in 235 patients who underwent meniscal repair with concomitant ACLR.

However, a few studies have shown no superiority in outcomes of meniscal repair compared to partial meniscectomy at long term follow up in patients with meniscal tear and concomitant ACLR (Logan et al., 2009; Lee and Diduch, 2005; Shelbourne and Carr, 2003). Shelbourne and Carr (2003) retrospectively reviewed the records of 155 patients who had isolated bucket-handle medial meniscal tears and ACL tears. Fifty-six menisci were arthroscopically repaired while 99 were degenerative tears and so were resected. There was no statistically significant difference in the subjective Noyes score or the IKDC objective scores between the two groups at a mean follow up of 6-8 years.

Registry studies have provided conflicting evidence on the outcomes of ACLR when performed with concomitant meniscal repair or partial meniscectomy. LaPrade et al. (2015) studied the functional outcomes of 4691 patients, who underwent ACLR, on the Norwegian Knee Ligament Register. They compared the functional outcomes of isolated ACLR with combined ACLR and meniscal repair or partial meniscectomy. They reported that, in comparison with isolated ACLR at 2 years postoperatively, there was no difference in knee osteoarthritis Outcome Score (KOOS) between patients with ACLR and lateral meniscal repair, lateral meniscus resection or medial meniscus resection. However, patients who had ACLR with medial meniscal repair had significantly lower KOOS scores on the Other Symptoms and Quality of Life (QoL) subscales. Using similar methodology, Phillips et al. (2018) reviewed the 2 years postoperative outcomes in 15,392 patients, who underwent ACLR, on the Swedish National Knee Ligament Register. In this study, 10,001 (65.0%) patients had isolated ACLR, 588 (3.8%) had ACLR with medial meniscus repair, 2307 (15.0%) had ACLR with medial meniscus resection, 323 (2.1%) had ACLR with lateral meniscus repair, and 2173 (14.1%) had ACLR with lateral meniscus resection. They reported that patients who underwent ACLR with meniscus resection demonstrated significantly worse results with respect to the KOOS Symptoms subscale for both the medial and lateral meniscus resection groups; at 2 years postoperative follow up. Patients who had ACLR with medial meniscus resection also demonstrated worse results for the KOOS (QoL) subscale of the KOOS score. There was no difference in the outcomes between patients who underwent isolated ACLR and patients who had ACLR with medial or lateral meniscal repairs. Further long-term follow up studies are required to evaluate the influence of meniscal repair and meniscectomy on the outcome of ACLR.

6.4.3 Limitations

Our study has a few limitations. We relied on clinical symptoms only as an indication for failure of meniscal repair although we supplemented that assessment with knee MRI whenever there was a clinical suspicion. Another limitation is that we did not routinely collect outcome scores in our patients. The study relies on patients reporting symptoms after their procedure. We appreciate that there may be a small group of patients who do not report their inability to get back to specific sports or who change their lifestyle post-injury. The study involved two all inside meniscal repair devices; FasT-Fix and meniscal arrows. However, the two patient groups were not matched so further statistical analysis could not be undertaken.

6.5 Conclusion

Our study has demonstrated good overall medium-term outcomes for all-inside meniscal repairs in highly selected group of patients. Meniscal repair that was performed with concomitant ACLR has shown better clinical results compared with patients who had isolated meniscal repair. This suggests that surgeons should have a low threshold to undertake a meniscal repair when faced with a potentially repairable meniscal tear during ACLR procedures as there would be a higher chance of meniscal healing. Further long-term studies are required to evaluate the functional outcomes of meniscal repairs with and without concomitant ACLR at ten and 15 years postoperative follow up.

Chapter 7

The Healing Response Technique in the Management of Complete Proximal ACL Tears: Outcomes at Two Years Follow up

7.1 Introduction

In 2006, Steadman (Steadman et al, 2006) described the Healing Response Technique (HRT) as an alternative method to ACLR. This is a non-reconstructive technique whereby the microfractures are created at the ACL femoral attachment site arthroscopically. It is postulated this permits access to the underlying bone marrow and therefore mesenchymal cells and resultant inflammatory cascade of cytokines, which stimulates a healing response (Steadman et al., 2012). Our aim was to assess the functional and clinical outcomes of the HRT in patients who had complete proximal ACL tears at our institution.

7.2 Methods

7.2.1 Patient Selection Criteria

We enrolled 14 subjects (9 males and 5 females) of mean age 31 years (range: 24 to 37 years) between January 2006 and December 2014 to undergo the Healing Response Technique by a single-surgeon at a single-centre. Mean time from injury to surgery was 29 days (range: 12 - 51 days). All patients were recruited according to a strict inclusion and exclusion criteria.

(a) Inclusion criteria:

1. All active patients with mechanical instability
2. Proven complete tear of proximal ACL on knee Magnetic Resonance Imaging (MRI).
3. Time between sustain the ACL injury and surgical procedure is less than 60 days.

(b) Exclusion criteria:

1. Elite athletes
2. Greater than grade 2 Lachman test
3. Greater than grade 1 pivot-shift test
4. Contralateral ACLR surgery

Patient outcomes were assessed preoperatively and postoperatively with Lachman testing, KT-1000 arthrometer, Tegner scores, Lysholm scores (Tegner and Lysholm, 1985) and Knee injury and Osteoarthritis Outcome Score (KOOS) (Roos et al., 1998). The KT-1000 arthrometer (MEDmetric Corp, San Diego, California, USA) measured the difference in antereior tibial translation between the injured and the uninjured knee (Bach et al., 1990).

7.2.2 Surgical technique

An Examination Under Anaesthesia (EUA) was performed first followed by a diagnostic knee arthroscopy. Any associated meniscal or chondral damage were documented and managed arthroscopically. Five patients were found to have an associated meniscal injury on diagnostic arthroscopy. Three patients had medial meniscal tears while two had lateral meniscal tears. Of these five patients, two patients had meniscal repair with FasT-Fix sutures (Smith and Nephew, Andover, MA). After arthroscopic confirmation of the proximal ACL tear, the healing response technique was performed as described by Steadman et al.(2006). An arthroscopic Awl with an angle was used to penetrate the cortex at the femoral attachment site of the torn ACL. The awl was placed at a perpendicular angle to the cortical bone and six to ten microfracture holes were made with a diameter of 2 to 3 mm and a depth of 3 to 5 mm till bone starts to bleed. The distal stump of the torn ACL was also perforated with the awl multiple times over its entire length to aid blood clot invasion. The distal ACL stump was then manipulated to align as close as possible to its femoral origin.

7.2.3 Rehabilitation

All patients underwent the same postoperative rehabilitation programme. This included a knee brace locked in full extension for six weeks to minimise ACL disruption and maximise the healing response. The patients were allowed to partial weight bearing with the help of crutches for this duration. Physical therapy commenced on day one post-surgery and included full passive range of motion (ROM), strengthening exercises for the hamstrings and the quadriceps muscle. Active assisted ROM exercises were commenced at week 2 post-surgery and full weight bearing was allowed at the sixth week post-surgery. Between six to 12 weeks post-surgery, physical therapy concentrated on progressive strengthening exercises, eccentric loading and initiation of open chain exercises. Thereafter they progressed through proprioceptive training, continuous strengthening, and sport-specific conditioning, and were allowed to return to full activity by 24 weeks post-surgery.

7.3 Results

All 14 patients completed a minimum of 2 years follow-up. Out of the 14 patients, three patients required subsequent ACLR surgery (two for re-injury and one for no clinical improvement) at mean 7 months from index procedure (range: 4 to 9 months. The remaining 11 patients showed good clinical and functional outcomes.

The KT-1000 measurements preoperatively showed a 5 mm of an average manual maximum difference between the injured and the healthy knee (range: 4-7 mm). At two years follow up, this has improved to an average of 2 mm (range: 1 - 4 mm) (Table 7.1). The average preoperative and two-years postoperative Tegner scores were three (range, 2-4) and six (range, 3-7) respectively (Figure 7.1). The average preoperative and two-years postoperative Lysholm scores were 70 (range, 55-76) and 93 (range, 85-100) respectively (Figure 7.2). The respective pre- and two-years postoperative average KOOS scores were: symptoms (72 and 81), pain (74 and 80), activity of daily living (78 and 87), sports and recreation function (38 and 65) and quality of life (36 and 58) (Figure 7.3).

Table 7.3: Patient characteristics and outcomes. Postoperative scores were obtained at two years follow up. Patient number 6, 9 and 13 had failure of HRT procedure and underwent subsequent ACLR. Abbreviations: MM= medial meniscus, LM = lateral meniscus

Patient no.	Age/ Sex	Time to injury (days)	Conco-mitant Injuries	Pre-operative				Post-operative (2 years)			
				Lachman/ Pivot	KT-1000	Tegner	Lysholm	Lachman /Pivot	KT-1000	Tegner	Lysholm
1	32/M	17	MM	2/1	6	2	65	1/0	2	7	90
2	29/M	42		2/1	7	3	71	2/0	3	8	100
3	26/F	51		2/1	5	4	76	1/0	1	6	90
4	33/M	34	LM	1/1	5	2	55	1/0	2	7	95
5	37/F	31		2/1	6	3	70	0/0	3	6	95
6	35/F	19		2/1	4	4	75				
7	24/M	33		2/1	3	3	70	0/0	1	6	95
8	35/M	37	MM	1/1	5	3	66	1/1	2	3	85
9	29/M	12	MM	2/1	6	4	75				
10	36/F	31		2/1	6	3	70	1/0	3	5	100
11	28/M	27		2/1	4	5	75	1/0	2	7	100
12	35/M	29		2/1	5	4	65	1/1	2	7	90
13	33/F	21	LM	2/1	5	4	70				
14	31/M	25		2/1	6	3	76	0/0	3	8	85

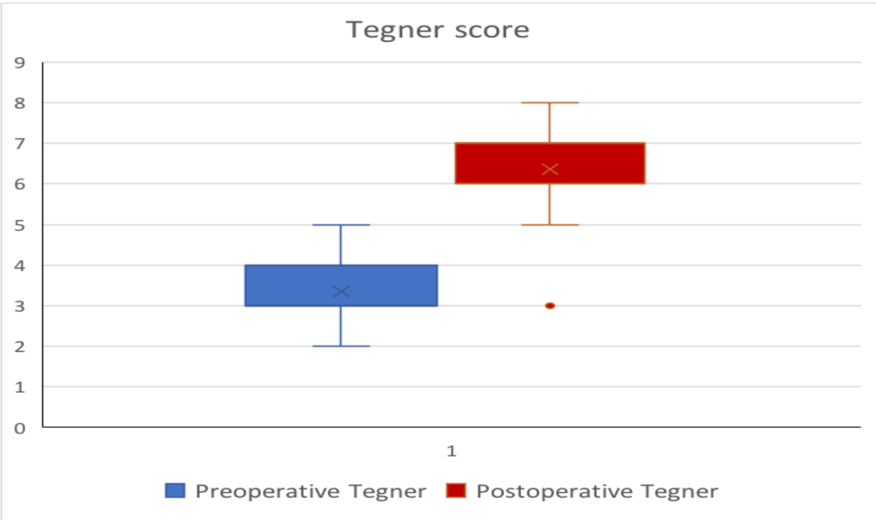


Figure 7.1: The average preoperative and two years postoperative Tegner scores

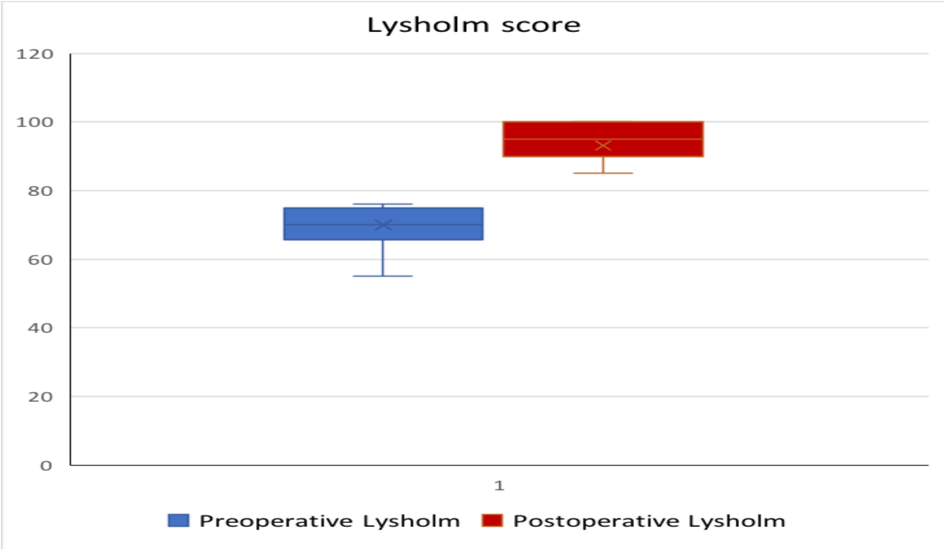


Figure 7.2: The average preoperative and two years postoperative Lysholm scores

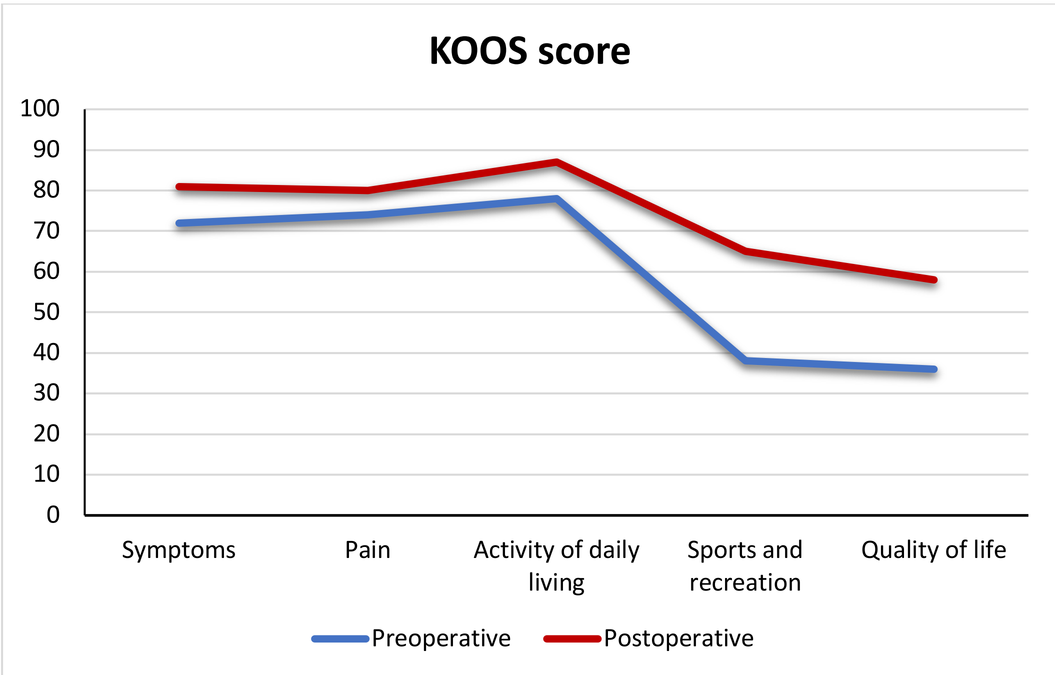


Figure 7.3: The average preoperative and two years postoperative KOOS scores.

7.4 Discussion

Historically, ACL tears were treated by primary repair using sutures to approximate the torn fibres. However, this technique resulted in poor outcomes in canine studies (Cabaud et al., 1979; O'Donoghue, 1963; O'Donoghue et al, 1966, O'Donoghue et al., 1971); as well as human studies. Feagin and Curl (1976) studied the outcomes of 32

ACL repairs at 2 and 5 years postoperative follow up. They reported that 30 of 32 patients (94%) described symptoms of instability and 24 of 32 patients (75%) described impairment of athletic activities at 5 years post-ACL repair despite reporting good results 2 years postoperatively.

Furthermore, the sole published randomised controlled trial examining primary repair versus conservative management showed no significant difference in functional outcomes (Sandberg et al., 1978), although the study methodology is noted to be poor (Linko et al., 2005). The healing potential of the ACL has long been considered to be relatively poor (Murray et al., 2007; Murray et al., 2000; Kaipour and Muray, 2014). This has led to surgeons steering away from ACL repair surgery in favour of ACLR surgery. The poor healing potential of ACL repair is thought to be due to its intraarticular position and the inhibitory effect of the synovial fluid (Andrish and Holmes R, 1979; Woo et al., 2000). Furthermore, the difference noted in the healing capacity of the ACL compared to other extra-articular ligaments such as the Medial Collateral Ligament (MCL) has been attributed to the intrinsic differences in cell behaviour, load bearing and insufficient vascularity following injury (Lyon et al., 1991; McKean et al., 2004; Zhang et al., 2009; Quatman et al., 2014; Bray et al., 2003).

However, Nguyen et al. (2013) studied the intrinsic healing response of the ACL in humans using standard histology and immunostaining of α-smooth muscle actin and collagen type 3. They reported that the histological features of the proximal third of the ACL and the MCL were similar and a similar healing response can be expected. Moreover, Spindler et al. (1996) has demonstrated that, similar to the MCL, collagen production continues within the ACL up to one year following injury. The work undertaken by Murray (Murray et al., 2000; Murray, 2009) demonstrated that a fibrin-platelet clot that would form a scaffold and bridges the gap between the two torn ACL ends, does not form at the site of ACL injury; in contrast to other ligaments. This scaffold promotes cell migration, tissue remodelling and therefore ligament healing such as in the extra-articular MCL that often heals uneventfully following an injury. Furthermore, synovial fluid within the knee inhibits ACL fibroblasts and also contains plasmin which may degrade the fibrin-platelet clot prematurely (Andrish and Holmes, 1996; Rosc et al., 2002). Modern tissue engineering methods have allowed scientists to design biologically active artificial scaffolds that can survive within the synovial environment (Vavken and Murray, 2010). Further research is underway to bring this technique from animal models to clinical trials.

When reviewing the current evidence in the literatures, the location of ACL tears appears to be influencing the outcome of ACL repairs. Sherman et al. (1991) used multivariate analysis to investigate the deterioration of their results in fifty open primary ACL repairs at medium term follow-up. They were the first to classify ACL tears into 4 tear types. They reported that patients with type I (proximal avulsion) tears were associated with better outcomes when compared with type III or IV (mid-substance) tears. Weaver et al. (1985) investigated the outcomes of primary ACL repair in skiers. They reported that 79% of their athletes with a proximal tear had good patient-reported outcomes, while only 23% of athlets with a mid-substance tear reported good functional outcomes. Kuhne et al. (1991) reported on 75 patients who underwent primary ACL repairs for proximal tears and found a 0% failure rate at 4-year follow-up. Eighty-eight percent of their patients had a negative pivot- shift result, 87% had a Lachman result of 1+ or lower and return to sports was 89%.4. Conversely, Frank et al. (1982) demonstrated poor results of primary repair in 42 patients with mid-substance tears. They reported that 22% of their patients had a positive pivot shift, 44% had a +2 or +3 anterior drawer test, and only 61% reported being satisfied with the procedure; at four years postoperative follow up. In our study, we only included patients with proximal ACL tears in order to avoid potentially high complication rates associated with repair of mid-substance tears.

The Healing Response Technique was originally described by Steadman et al. (2006). They used this technique in 13 skeletally immature athletes with proximal ACL tear between 1992 and 1998. The benefit of not violating the growth plate with the trans-physeal bone drilling was a great advantage for the HRT technique. Three patients (23%) sustained re-injury requiring subsequent ACLR surgery. The remaining ten patients reported no mechanical symptoms or pain at mean follow-up 69 months. Patients showed an improvement in KT-1000 measurements from 5mm (range: 3-10 mm) preoperatively to 2 mm (range: 0-3 mm) postoperatively. Steadman (Steadman et al., 2012) later investigated the outcome of HRT in patients above the age of 40 years. They reviewed 43 patients who had HRT treatment for complete proximal ACL tears. At 7.4 years follow up, the average postoperative Lysholm score was 54 while the average Tegner activity scale was 5. They also demonstrated high levels of patient satisfaction with only 9% of their patients requiring subsequent ACLR surgery.

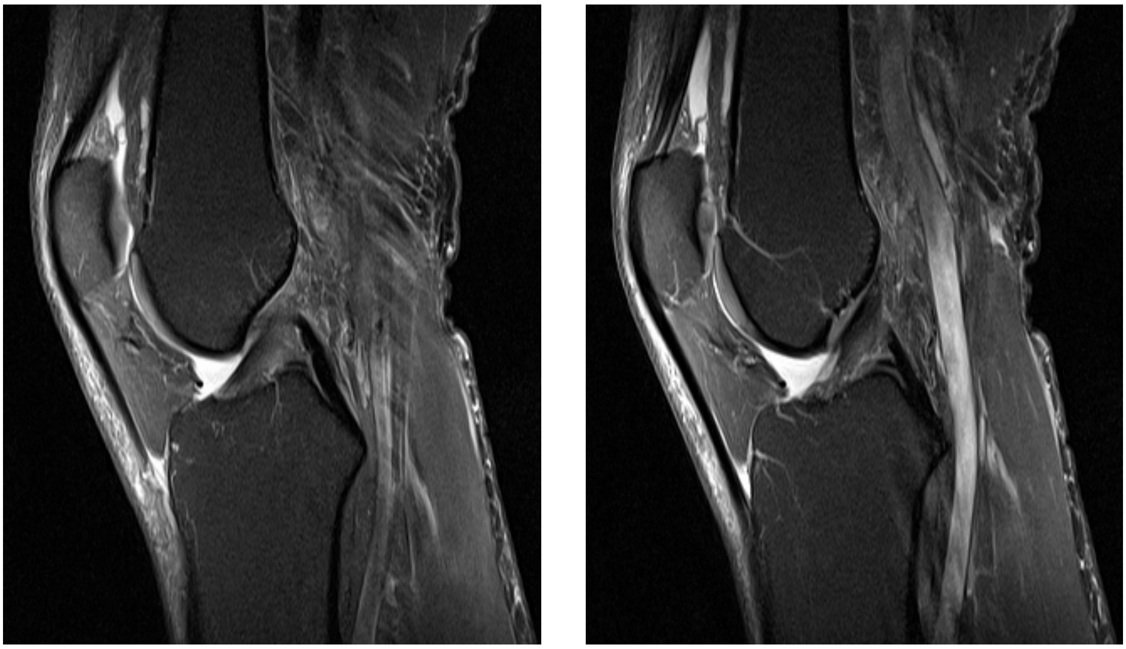
Wasmier et al. (2013) performed the HRT in 30 skeletally mature patients (mean age 31 years) with proximal ACL tear. Ten (36%) patients needed definitive ACLR after mean period of 19 months (range: 6 to 41 months), due to persistent instability (n=2) or reinjury (n=8). Although the remaining two-thirds of the study population showed good to excellent results, they reported a 16% lower median activity level than the preinjury level. Furthermore, there was no significant difference between the HRT group without secondary ACLR surgery(n=18) when compared with age- and gender-matched patients treated conservatively (n=19). However, the different age population could justify the higher failure rate and subsequent ACLR in Wasmier's study compared to the two Steadman's studies. Steadman's first study was on skeletally immature patients who have greater potential for ligament healing (Murray et al., 2007; Murray et al., 2000; Kaipour and Muray, 2014). His second study investigated the HRT in patients above the age of 40 years old with an average age of 51 years. This age group is less likely to participate in elite level sport activities hence might have lower risk for ACL re-injury.

Current ACL repair techniques have utilised the HRT but have also taken the advantage of the advance in technology. Patrick and Bley (2017) have described their surgical technique for arthroscopic ACL repair in patients with proximal ACL tears. After a diagnostic arthroscopy, the HRT is performed with microfracture of the ACL femoral footprint. This is followed by tagging sutures for both the AM bundle and PL bundles of the ACL stump that are later passed through the drilled femoral tunnel and secured by femoral suspensory button that is locked against the lateral femoral cortex. The AM bundle fixation is augmented with a suture tape as an internal brace that is passed within the substance of the ACL stump and passed through the tibial tunnel to be fixed with anchor sutures in the tibia. This technique allows separate tensioning of the AM and PL bundles resulting in an anatomical double bundle ACL repair that is consistent with normal ACL biomechanics. Although the concept of HRT is a fundamental part of this technique and similar ACL repair techniques, the clinical outcome of these repair techniques is likely to supersede the HRT. The HRT has paved the way for the newer ACLR repair techniques that are essentially capitalising on the HRT success rates in selected group pf patients.

Our study showed subjective and objective improvements in 11 out of 14 patients following the HRT technique. Three patients required revision to a primary ACLR and made good recovery. The results were comparable to the limited number of studies in the literature reporting on the outcome of HRT management for ACL tears. Although the NLR started to collect data on ACL repairs, there are only a few patients currently on the database with little postoperative functional outcomes recorded. Therefore, it is not possible to draw any conclusion on the results of ACL repair from this data. However, the NLR will be a great tool to monitor the outcomes of the new ACLR repair techniques over the next few years.

7.4.1 Limitations

Our study has a few limitations. We did not have a control group to compare our results with and therefore it was difficult to predict how these patients would have done with conservative treatment alone. The sample size was small, and this is attributed to the selectivity in recruiting patients who met our inclusion and exclusion criteria for HRT treatment. Therefore, it was difficult to identify the risk factors for failure of HRT. Another limitation is that we have not routinely assessed the ACL healing radiologically with MRI scans following the HRT. However, satisfactory ACL healing was observed in knee MRI scans that were performed to rule out possible ACL re-tear in patients who had further knee injuries following HRT procedures (Figure 7.4).



(A) (B)

Figure 7.4 (A&B): Knee MRI (T2) sagittal images showing healing of the proximal ACL at one year postoperatively following HRT procedure

7.5 Conclusion

Patients had significant improvement in the knee functional outcome scores following the healing response technique at 2 years follow up. Our results highlight the potential use of this technique as a non-reconstructive treatment modality in highly selected group of patients with ACL injuries. High quality randomised controlled trials are required to assess the outcomes of HRT management in comparison with conservative management and arthroscopic ACLR. There has been recently a growing interest in ACL preservation surgery, but it remains to be seen whether new repair techniques will give better results compared with conventional ACLR surgery.

Chapter 8

Discussion

8.1 Introduction

This thesis sought to investigate the functional outcome of anterior cruciate reconstruction (ACLR) surgery. Different aspects of ACLR surgery have been examined through various studies that have been discussed in previous chapters. This chapter represents a summary of key findings from my thesis as well as implications for practice and recommendations for future research.

8.2 Summary of findings and Implication for practice

ACL injury is one of the most extensively studied orthopaedic conditions with over 11000 published clinical studies. Surgical reconstruction remains to be the gold standard treatment in physically active patients with symptoms of instability attributed to the ACL injury. The main aim of my thesis was to investigate the functional outcome of ACLR surgery, so it was logical to start with identifying what constitutes a successful ACLR outcome and how this could be measured. A systematic review was undertaken to establish commonly reported outcome measures in ACLR literature. We hypothesised that there is great variability in outcome instruments used to assess the functional outcome of ACLR. The search was limited to Level I and II studies over a 10-year period from the 21st century. This was intentionally chosen in order to search high quality clinical trials from contemporary ACLR literature. 58 randomised clinical trials and 41 prospective cohort studies were reviewed. We found extensive variability in outcome measures utilised in these studies. This variability extended further to ACLR studies that investigate the same research question such as studies comparing ACL graft types or fixation methods.

Instrumented measurement of anterior knee laxity with KT-1000 and KT-2000 arthrometer was the most frequently utilised outcome instrument in ACLR studies (72.7%). Lysholm score was the most commonly used subjective outcome measure (56.5%). The second most frequently utilised objective outcome measure was the pivot shift test whereas both IKDC subjective form and Tegner score were the second most commonly used subjective outcome measures. It was interesting to observe that instrument measurement of anterior knee laxity was the most frequently utilised objective outcome measure despite being previously reported that anterior knee laxity does not correlate with subjective patients' satisfaction following ACLR (Sydney-marker et al., 1997; Kocher et al., 2002). We found that the majority of studies used a combination of subjective and objective outcome measures. However, seven studies did not use any subjective outcome measures whereas four studies did not utilise any objective outcome measures.

The World Health Organization (WHO) introduced the International Classification of Functioning, Disability and Health (ICF) in order to establish a common language for describing health and health-related states. We found that 24% of the included ACLR studies did not satisfy both domains of the ICF model; that are body function and structure, and activity and participation. The inconsistency in reporting outcome measures hinders generalisation of research findings and agreement on resultant conclusions. Furthermore, the wide variability in outcome measures used in clinical studies deters any attempts at pooling of the results or producing a conclusive meta-analysis of high quality clinical trials. Based on the results from this systematic review, we recommend that assessment of patients with ACLR should ideally include a combination of subjective and objective outcome measures in order to satisfy all domains of the WHO ICF model. Moreover, objective outcome measures should be reported separately and not to replace any patient reported outcome measures (PROMs). The choice of PROM should ideally include a generic as well as knee specific instruments. More importantly, an outcome measure should be appropriate to the population targeted and the question asked.

Five-year results from the United Kingdom National Ligament Registry (NLR) were analysed in chapter 3 of my thesis. The data were prospectively collected since the launch of the NLR in 2013. There was a total of 9002 ACLR patients between December 2012 and December 2017. Men in their 20s were the predominant group of patients who underwent ACLR surgery. Sports injuries and specifically football injuries were the most common cause for ACL injury. Medial meniscus surgery was the most frequently associated procedure with ACLR surgery. Allograft was used in only 1% of patients who had ACLR procedures in the NLR. Four-strand hamstring tendon was the most frequently used autograft. AM portal drilling was the most commonly used technique for femoral tunnel drilling while it was the outside-in technique for the tibial tunnel drilling. The Endobutton suspensory mechanism was the most frequently used method for graft fixation in the femoral tunnel while interference screws predominated for tibial tunnel fixation. Patients who underwent ACLR surgery showed steady progress of their functional outcome scores at six months, 1 year and 2 years postoperatively compared to their preoperative scores. Complications are not well recorded on the registry, but implant malfunction was the most common intraoperative complication while graft failure was the most common postoperatively. Although PROMs demonstrated significant improvement in patient functional status postoperatively, compliance rate with completing PROMs was relatively low. The response rate preoperatively was up to 58%. However, this drops down to approximately 35% at one year postoperatively and further down to approximately 30% at 2 years postoperatively. We found that online completion of PROMs resulted in better compliance compared with paper forms. This indicates that online platforms and web-based collection of PROMs is the way forward for better data collection in institutional and registry studies. We recommend that surgeons should strive to ensure that their patients have valid email addresses in order to facilitate their access for completion of PROMs. It was also observed that compliance rates with completing PROMs are not the same across the various PROMs collected for the same time points. This indicates that patients sometimes complete some PROMs but not all sets of PROMs. The NLR collects four sets of PROMs that include both IKDC and KOOS scores. Based on the findings from the systematic review in Chapter 2 of this thesis, we recommend that the NLR should collect either the KOOS or IKDC scores as both scores cover the same domains on the WHO ICF models. Collection of both IKDC and KOOS scores were uncommon in our systematic review with only 3% of the included clinical studies collected both scores. Minimising the numbers of PROMs required to be completed by the patients would decrease the time and efforts required to fill in the questionnaires thus improving patient compliance. The KOOS score is the main PROM used in the Scandinavian ligament resisters so would be useful for collaborative studies. However, it has been reported that the IKDC subjective score is more useful in assessing patients following ACLR surgery (Van Meer et al., 2013). The NLR is a great tool for data collection but it suffers from multiple shortfalls as any other registry. There is a high percentage of missing data on the registry. The highest record was 80% of missing data in thromboembolic prophylaxis strategy. Furthermore, there is currently no established data cleaning process in the NLR electronic data management system. Duplication of data was also observed due to importing of data from external sources. The data on the NLR has not been validated yet which affect the reliability of the results. Recommendations for improving the quality of data on the NLR are fully detailed in Chapter 3 of this thesis.

In chapter 4 of this thesis, pre-injury scores were studied for patients with ACL tears. The hypothesis was that patients undergoing ACLR do not return to their pre-injury functional status at 2 years postoperatively. A prospective review for patients undergoing ACLR was undertaken with collection of PROMs that assess patient functional status at the time of pre-injury preoperatively, post-injury preoperatively, one year and two years postoperatively. We found that the majority of patients showed significant improvement postoperatively on PROMs at one- and two years follow up compared to their post-injury preoperative scores. The Sport and QoL subscales of the KOOS score were the most sensitive subscales pre-operatively and most sensitive to change post-operatively. However, most of the patients have failed to achieve their pre-injury functional status at two years postoperatively. This study highlighted the importance of collecting pre-injury outcome scores when comparing the outcomes of ACLR surgery. However, it is well appreciated that retrospective collection of pre-injury PROMs has limitations. These include recall bias and response shift although it is difficult to quantify their effects. This study provides important information when counselling patients for ACLR surgery. It provides patients and surgeons with a better understanding for patient functional outcome following ACLR surgery. It is of fundamental importance to manage patients' expectations when obtaining consent for ACLR surgery. This study provides guidance for the patients on recovery to their pre-injury health level and helps to manage their expectations. This may help patients deciding whether to opt for conservative or surgical management for ACL tears.

The femoral tunnel drilling techniques in ACLR surgery were investigated in Chapter 5 of this thesis. The anteromedial portal (AM) and the transtibial (TT) techniques were compared with regard to radiological and functional outcomes. The AM portal was found to produce a more anatomical position of the graft in the femoral tunnel compared with the TT technique. However, there was no statistically or clinically significant difference between the two techniques with respect to PROMs at 2 yeas postoperatively. Despite achieving an anatomical graft position in the femoral tunnel, we observed a higher graft failure rate with the AM portal technique compared with the TT technique. This unexpected finding was previously reported in other clinical studies (Rahr-Wagner et al., 2013; Desai et al., 2017). This might be explained by the increased in situ forced on the graft when it is placed in an anatomical position (Araujo et al., 2015). Accelerated rehabilitation protocol and early return to sports might expose anatomically located graft to higher forces before it reaches complete healing and maturation resulting in graft failure. Rehabilitation protocols need to consider the recent trend towards anatomical ACLR and tailor the rehabilitation program to individualised patient's needs and surgical technique utilised (Haddad, 2014).

In Chapter 6, we investigated the medium term functional outcomes of meniscal repairs and the impact of concomitant ACLR. The overall success rate of all inside meniscal repairs was 79.5% at 5 years postoperative follow up. Meniscal repair using meniscal arrows had a higher failure rate compared with meniscal suture mechanism. Lateral meniscal repairs had a higher success rate compared with medial meniscal tears. The success rate for isolated meniscal repair was 72% whereas it was 86% when performed with concomitant ACLR. This might be explained by restoration of normal knee biomechanics and stability with ACLR. Furthermore, the haemoarthrosis associated with ACLR procedure serves as a biological stimulus for tissue healing (Cannon and Vittori, 1992; Meister et al., 2004). This suggests that surgeons should have a low threshold for meniscal repair whenever faced with a potentially repairable meniscal tear during ACLR surgery.

The healing response technique (HRT) in the management of proximal ACL tears was investigated in Chapter 7 of this thesis. 14 patients with complete proximal ACL were selected for this study. 11 patients showed significant subjective and objective improvement at 2 years postoperatively. The remaining three patients required revision to ACLR. This study highlights the potential use of the HRT in highly selected group of patients with acute proximal ACLR tears. The selective indications for this surgical technique might limit its generalised use in routine practice but it remains to be one the fundamental techniques in ACL preservation surgery.

8.3 Future work

Future research work is required in the areas that were covered in this thesis. There is still no consensus on what defines a successful outcome following ACLR. Future research should determine whether consensus could be developed for a standardized set of outcome measures that are considered to be the most important predictors of success following ACLR. This is of utmost importance to future collaborative studies as well as registry studies. Identifying the relevant outcome measures to be used would help national registers to limit the number of PROMs collected that could result in better patient compliance. This is more relevant to recently established registers such as the NLR. The NLR is still in its infancy and future work is needed to establish a data cleaning process in the electronic data management system as well as validation of the data.

In my thesis, the importance of pre-injury scores in assessing the functional outcome of ACLR was studied but there are limitations with routine use of pre-injury scores in clinical practice. Further studies are needed to investigate the effect of recall bias and response shift associated with retrospective collection of pre-injury scores. Moreover, further research should investigate the differences between pre-injury scores in patients with ACL tears and normative data for PROMs in demographically matched populations.

Further research work is needed to investigate the higher failure rate observed with the AM portal technique compared with the TT technique. Studies need to evaluate the impact of a prolonged rehabilitation protocol for anatomically positioned ACLR graft and whether this would minimise the risk of graft failure. Moreover, the long-term benefits of an anatomical graft position through the AM portal need to be evaluated. It is thought that an anatomically positioned graft would result in lower stresses going through intraarticular structures of the knee thus minimising the risk of developing degenerative changes compared with a non-anatomical position of the graft through the TT technique. However, randomised controlled trials are required to prove this and investigate if there is any long-term difference in functional outcomes between the AM portal and the TT techniques.

Medium term outcomes of all inside meniscal repair were reported in this thesis but long term follow up results are required to establish the clinical course of the surgical intervention and investigate its role in prevention of secondary degenerative changes in the knee. Further studies are also needed to investigate whether there is a difference in the functional outcome for patients with ACLR who had concomitant meniscal repair compared with those who had concomitant partial meniscectomies.

Although the HRT resulted in good functional outcomes in most of the patients studied in this thesis, it remains to be seen whether it produces better results compared to non-operative treatment. Further randomised multi-arm trials are needed to investigate the outcomes of the HRT in comparison with non-operative treatment and conventional ACLR.

8.4 Conclusion

My thesis focused on studying various aspects related to the functional outcomes of anterior cruciate ligament reconstruction surgery. It is my hope that the work presented in this thesis would change clinical practice for management of anterior cruciate ligament injuries and enhance patient care. This thesis paves the way for further research work to be undertaken by clinicians and researches in order to improve our understanding for the clinical course and functional outcome of anterior cruciate ligament reconstruction surgery.

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Appendix

Table 1: list of clinical studies included in the systematic review (Chapter 2).

	Year	Authors	Journal	Type of Study	Level of Evidence	Number of patients	Mean Follow up period
Graft type	2013	Inagaki et al.	Journal of Orthopaedic Science	Cohort	2	120	2
	2013	Noh et al.	Arthroscopy	RCT	2	72	2.5
	2013	Indelicato et al.	KSSTA	RCT	2	67	2
	2013	McRae et al.	AJSM	RCT	1	100	2
	2012	Leys et al.	AJSM	Cohort	2	180	15
	2012	Sun et al.	KSSTA	RCT	1	78	3.5
	2011	Sajovic et al.	AJSM	RCT	2	64	11
	2011	Noh et al.	KSSTA	RCT	1	65	2.4
	2011	Leal-Blanquet et al.	AJSM	RCT	2	51	2
	2011	Sun et al.	AJSM	RCT	2	186	7.8
	2011	Wang et al.	EJOST	RCT	2	169	3
	2011	Sadoghi et al.	International Orthopaedics	Cohort	2	41	2
	2010	Barenius et al.	AJSM	RCT	1	153	8
	2010	Holm et al.	AJSM	RCT	1	72	10
	2010	Heijne and Werner	KSSTA	RCT	1	68	2
	2010	Jagodzinski et al.	AJSM	RCT	1	20	2
	2010	Holm et al.	AJSM	RCT	1	72	10
	2009	Taylor et al.	AJSM	RCT	1	53	2
	2009	Sun et al.	Journal of Zhejiang University: Science B	RCT	2	65	2
	2009	Sun et al.	Arthroscopy	RCT	2	156	5.6
	2009	Sun et al.	KSSTA	RCT	2	102	2.5
	2009	Sun et al.	Arthroscopy	Cohort	2	172	5
	2009	Sun et al.	Journal of Zhejiang University Science B	RCT	1	68	3.9
	2008	Edgar et al.	CORR	Cohort	2	84	3
	2008	Edgar et al.	CORR	Cohort	2	84	3
	2007	Keays et al.	AJSM	Cohort	2	80	6

	2007	Pinczewski et al.	AJSM	Cohort	1	180	10
	2007	Liden et al.	AJSM	RCT	1	71	7
	2006	Sajovic et al.	AJSM	RCT	1	64	5
	2006	Zaffagnini et al.	KSSTA	RCT	1	75	5
	2006	Petrou et al.	BJJ	Cohort	2	71	5
	2005	Roe et al.	AJSM	Cohort	2	180	7
	2005	Wagner et al.	AJSM	Cohort	2	72	2
	2004	Aglietti et al.	JBJS	RCT	1	120	2
Surgical technique	2013	Noh et al.	Arthroscopy	RCT	1	61	2.5
	2013	Rahr-Wagner et al.	Arthroscopy	Cohort	2	8375	2
	2013	Song et al.	AJSM	RCT	2	130	4
	2013	Lubowitz et al.	Arthroscopy	RCT	1	150	2
	2013	Fleming et al.	AJSM	RCT	1	90	3
	2012	Lee et al.	KSSTA	Cohort	2	42	2
	2012	Suomalainen et al.	AJSM	RCT	1	90	5
	2012	Hussein et al.	AJSM	RCT	2	101	2.5
	2012	Hussein et al.	AJSM	RCT	1	281	4.2
	2012	Nunez et al.	Arthroscopy	RCT	1	55	2
	2012	Jiang et al.	AJSM	Cohort	2	52	4
	2012	Ochiai et al.	Archives of Orthopaedic & Trauma Surgery	Cohort	2	84	2
	2012	Hong et al.	AJSM	RCT	2	90	2.1
	2012	Mutsuzaki et al.	AJSM	RCT	1	64	2
	2011	Fujita et al.	Arthroscopy	Cohort	2	55	2.7
	2011	Zaffagnini et al.	KSSTA	RCT	1	79	8
	2011	Zaffagnini et al.	KSSTA	RCT	1	79	8
	2010	Aglietti et al.	AJSM	RCT	1	70	2
	2010	Park et al.	Arthroscopy	Cohort	2	113	2
	2009	Song et al.	AJSM	Cohort	2	40	2
	2008	Zaffagnini et al.	Scandinavian Journal of Medicine and Science in Sports	RCT	2	72	3
	2008	Hart et al.	Arthroscopy	RCT	1	80	2.3
	2007	Maletis et al.	AJSM	RCT	1	99	2
	2007	Moisala et al.	KSTTA	Cohort	2	104	2

	2007	Aglietti et al.	CORR	Cohort	2	75	2
	2006	Yasuda et al.	Arthroscopy	Cohort	2	72	2
	2006	Plaweski et al.	AJSM	RCT	1	60	2
	2004	Chen et al.	KSSTA	Cohort	2	62	2
	2013	Gifstad et al.	KSSTA	RCT	2	102	7
Fixation methods	2013	Bourke et al.	Arthroscopy	RCT	1	60	2
	2012	Kondo et al.	KSSTA	Cohort	2	46	2
	2012	Noh et al.	Arthroscopy	RCT	2	80	2
	2011	Drogset et al.	KSSTA	RCT	1	41	7
	2011	Drogset et al.	KSSTA	RCT	1	41	7
	2010	Stener et al.	AJSM	RCT	1	77	8
	2010	Price et al.	ANZ Journal of Surgery	RCT	1	29	2
	2008	Myers et al.	Arthroscopy	RCT	1	114	2
	2008	Moisala et al.	KSSTA	RCT	1	55	2
	2008	Moisala et al.	KSSTA	RCT	1	62	2
	2006	Laxdal et al.	AJSM	RCT	1	77	2
	2005	Drogset et al.	JBJS	RCT	1	41	2
	2005	Harilainen et al.	Arthroscopy	RCT	1	62	2
	2004	Ma et al.	Arthroscopy	Cohort	2	30	2
	2012	Bourke et al.	BJJ	Cohort	2	100	15
Longitudinal and registry studies	2014	Desai et al.	KSSTA	Cohort	2	22699	5
	2013	Oiestad et al.	KSSTA	Cohort	2	221	12
	2013	Ericsson et al.	BJSM	Cohort	2	87	5
	2013	Barenius et al.	KSSTA	Cohort	2	8584	2
	2012	Rotterud et al.	KSSTA	Cohort	1	89	5
	2011	Tohyama et al.	AJSM	Cohort	2	123	2
	2011	Spindler et al.	AJSM	Cohort	2	448	6
	2010	Oiestad et al.	AJSM	Cohort	2	181	12.4
	2010	Ageberg et al.	AJSM	Cohort	2	10164	2
	2009	Lind et al	KSSTA	Cohort	2	5818	10
	2008	Hara et al.	AJSM	Cohort	2	342	2
	2006	Mahirogullarui et al.	KSSTA	Cohort	2	35	2
	2005	Spindler et al.	JBJS	Cohort	2	217	5
	2010	Raviraj et al.	BJJ	Cohort	2	105	2.6
Timing and rehabilitation	2013	Janssen et al.	KSSTA	RCT	2	100	10
	2011	De Wall et al.	AJSM	RCT	1	113	2
	2010	Grant and Mohtadi	AJSM	RCT	1	129	3

	2009	Risberg and Holm	AJSM	RCT	1	74	2
	2008	Birmingham et al.	AJSM	RCT	1	150	2
	2004	McDevitt et al.	AJSM	RCT	1	95	2