# Ligament Repair Around the Knee with Suture Tape Augmentation



## Graeme Philip Hopper

### MBChB, MSc, MRCSEd


**Submitted in fulfillment of the requirements for the Degree of MD**


**College of Medical, Veterinary & Life Sciences**

**University of Glasgow**


**July 2020**

# Acknowledgements

Firstly, I would like to thank Professor Gordon Mackay for involving me in the research into this novel technique. Moreover, I would like to thank him for his support, both with funding and viewpoints throughout my degree which involved me taking time out of my training programme in Trauma & Orthopaedics in the West of Scotland between August 2017 and August 2019.

I would like to thank my supervisors, Mr Neal Millar and Professor Iain McInnes for their assistance throughout my time at the University of Glasgow. In addition, I would like to thank my reviewers, Professor Jonathan Cavanagh and Professor Tom Evans as well as Sarah Villinger for her help with the statistics.

Finally, I would like to thank my family for their support during my time at the University of Glasgow as without this support, I wouldn't have been able to complete this thesis.

# Contents

## Chapter 4 – Discussion

# Figures and Tables

## Figures

**Tables**

# Associated Publications and Presentations

## Publications

1. MacKay GM, Blyth MJ, Anthony I, **Hopper GP**, Ribbans WJ. A Review of ligament Augmentation with the InternalBrace™: the Surgical Principle is Described for the lateral Ankle Ligament and ACL Repair in Particular, and a Comprehensive Review of Other Surgical Applications and Technique is Presented. Surg Technol Int. 2015 May;26:239-55.

2. Wilson WT, **Hopper GP**, Byrne PA, MacKay GM. Anterior cruciate ligament repair with internal brace augmentation. Surg Technol Int. 2016 Oct 26;29:273-278.

3. Byrne PA, **Hopper GP**, Wilson WT, MacKay GM. Knotless repair of Achilles tendon rupture in an elite athlete: return to competition in 18 weeks. J Foot Ankle Surg. 2017 Jan-Feb;56(1):121-124.

4. **Hopper GP**, Mackay GM. Achilles Tendon Repair Using the InternalBrace Principle. Surg Technol Int. 2017 Jun;30:325-328.

5. Heusdens CHW, **Hopper GP**, Dossche L, Mackay GM. Anterior Cruciate Ligament Repair Using Independent Suture Tape Reinforcement. Arthrosc Tech. 2018 Jun 18;7(7):e747-e753.

6. Byrne PA, **Hopper GP**, Wilson WT, Mackay GM. Acromioclavicular Joint Stabilisation Using the Internal Brace Principle. Surg Technol Int. 2018 Nov 11;33:294-298.

7. Heusdens CHW, **Hopper GP**, Dossche L, Mackay GM. Anterior Cruciate Ligament Repair with Independent Suture Tape Reinforcement: a case series with 2-year follow-up. Knee Surg Sports Traumatol Arthrosc. 2019 Jan;27(1):60-67.

8. Wilson WT, **Hopper GP**, Byrne PA, MacKay GM. Repair of the ulnar collateral ligament of the elbow with internal brace augmentation: a 5-year follow-up. BMJ Case Rep. 2018 Dec 19;11(1).pii:e227113.

9. **Hopper GP**, Heusdens CHW, Dossche L, Mackay GM. Posterolateral Corner Repair with Suture Tape Augmentation. Arthroc Tech. 2018 Nov 26:7(12):e1299-e1303.

10. Heusdens CHW, **Hopper GP**, Dossche L, Mackay GM. Anterolateral Ligament Repair with Suture Tape Augmentation. Arthroc Tech. 2018 Nov 26:7(12):e1311-e1314.

11. **Hopper GP**, Heusdens CHW, Dossche L, Mackay GM. Medial Patellofemoral Ligament Repair with Suture Tape Augmentation. Arthroc Tech. 2018 Dec 3:8(1):e1-e5.

12. **Hopper GP**, Heusdens CHW, Dossche L, Mackay GM. Posterior Cruciate Ligament Repair with Suture Tape Augmentation. Arthroc Tech. 2018 Dec 3:8(1):e7-e10.

13. McIntyre V, **Hopper GP**, Mackay GM. Anterior Cruciate Ligament Repair in a Professional Soccer Player Using Internal Brace Ligament Augmentation: A Case Report Focusing on Rehabilitation. Surg Technol Int. 2019 Nov 10;35:341-348.

14. **Hopper GP**, Jenkins JM, Mackay GM. Percutaneous Medial Collateral Ligament Repair and Posteromedial Corner Repair with Suture Tape Augmentation. Arthroc Tech. 2020 Apr 3:9(5):e587-e591.

**Hopper GP**, Aithie J, Jenkins J, Wilson WT, Mackay GM. Anterior Cruciate Ligament Repair with Suture Tape Augmentation: Minimum 5-Year Patient-

Reported Outcome Measures. Under review by Knee Surgery, Sports Traumatology, Arthroscopy (KSSTA).

**Hopper GP**, Aithie J, Jenkins J, Wilson WT, Mackay GM. Combined Anterior Cruciate Ligament Repair and Anterolateral Ligament Repair with Suture Tape Augmentation: Minimum 2-Year Patient-Reported Outcome Measures. Accepted for publication in the Orthopaedic Journal of Sports Medicine (OJSM).

**Presentations**

1. Byrne PA, Wilson WT, **Hopper GP**, Mackay GM. Achilles Tendon Repair with Internal Bracing: Recovery to World-Class Sporting Activity in 18 Weeks.
   - *Poster presentation - Scottish SEM Symposium, May 2016*

2. McIntyre V, **Hopper GP**, Mackay GM. Anterior Cruciate Ligament Repair in a Professional Footballer using Internal Brace Ligament Augmentation: A Case Report Focusing on Rehabilitation.
   - *Podium presentation - Football Medicine Conference, Barcelona, May 2017*
   - *Poster presentation - Scottish SEM Symposium, May 2017*

3. Heusdens CHW, **Hopper GP**, Dossche L, Roelant E, Mackay GM. The InternalBrace™ for Anterior Cruciate Ligament Repair: A New Primary Repair Technique with 2-Year Follow-Up.
   - *Podium presentation - SICOT, December 2017*
   - *Poster presentations - BOA, September 2017, Scottish SEM Symposium, May 2017, International T&O Symposium, April 2017*

4. **Hopper GP**, Aithie J, Wilson WT, Mackay GM. Anterior Talofibular Ligament Repair with Suture Tape Augmentation: Minimum 2-Year Patient-Reported Outcome Measures.
   - *Podium presentation - Foot and Ankle Scotland Annual Meeting, September 2018*

5. **Hopper GP,** Aithie J, Mackay GM. Anterior Cruciate Ligament Repair with Suture Tape Augmentation: Minimum 5-Year Patient-Reported Outcome Measures.
    - *Poster presentation - AAOS Annual Meeting, March 2019*

6. **Hopper GP,** Aithie J, Mackay GM. Combined Anterior Cruciate Ligament Repair and Anterolateral Ligament Repair with Suture Tape Augmentation: Minimum 2-Year Patient-Reported Outcome Measures.
    - *Poster presentation - BASK Annual Meeting, March 2019*

7. Wilson WT, **Hopper GP**, Byrne PA, Mackay GM. Repair of the Ulnar Collateral Ligament of the Elbow with Internal Brace Augmentation. A Five-Year Follow-up.
    - *Podium presentation - Isokinetic Conference, April 2019*
    - *Poster presentation - GLAMOR, March 2019*

8. **Hopper GP**, Wilson WT, Miller R, Mackay GM. Customised Ligament Repair with Internal Bracing in an Elite Golfer: A Multidisciplinary Template for Sport.
    - *Poster presentation - Isokinetic Conference, April 2019*

9. Stokes A, Tompos T, **Hopper GP**, Mackay GM. Anterior Cruciate Ligament Reconstruction using Bone-Patellar Tendon-Bone Autograft with Internal Bracing in a Professional Football Player.
    - *Podium presentation - Isokinetic Conference, April 2019*

10. **Hopper GP**, Jenkins JM, Wilson WT, Mackay GM. Posterior Cruciate Ligament Repair with Suture Tape Augmentation: Minimum 2-Year Patient-Reported Outcome Measures.
    - *Poster presentation - ESSKA Speciality Meeting, November 2019*

11. **Hopper GP**, Aithie J, Jenkins JM, Wilson WT, Mackay GM. Anterior Cruciate Ligament Repair – Who is it for?
    - *Invited podium presentation - Sports Knee Meeting, November 2019*

# Abbreviations

ACL – Anterior Cruciate Ligament

PCL – Posterior Cruciate Ligament

ALL – Anterolateral Ligament

MCL – Medial Collateral Ligament

PLC – Posterolateral Corner

LCL – Lateral Collateral Ligament

MPFL – Medial Patellofemoral Ligament

IB – Internal Brace

UHMWPE – Ultra-High Molecular Weight Polyethylene

BEAR – Bridge-Enhanced ACL Repair

DIS – Dynamic Intraligamentary Stabilization

SOS – Surgical Outcome System

PROMS – Patient Reported Outcome Measures

KOOS – Knee Injury and Osteoarthritis Outcome Score

WOMAC – Western Ontario and McMaster Universities Osteoarthritis Index

VAS – Visual Analogue Pain Scale

VR-12 – Veterans Rand 12-item Health Survey

## Summary

Ligament repair around the knee was widely used in the 1970s and 1980s but with mixed outcomes. High failure rates at mid-term follow-up and the success of ligament reconstruction resulted in its demise. Reconstruction using autograft has been the gold standard surgical treatment since the 1990s. Nonetheless, ligament reconstruction is not without its complications including post-traumatic osteoarthritis, loss of proprioception and graft site morbidity. Indeed, it has been reported that 69% of patients undergoing anterior cruciate ligament (ACL) reconstruction with hamstring autograft had radiologically detectable osteoarthritis 15 years postoperatively. Furthermore, graft site morbidity including knee flexor weakness with hamstring grafts and anterior knee pain with patellar tendon grafts is commonly reported. Likewise, loss of the ACL remnant during ACL reconstruction surgery has been shown to reduce proprioception recovery postoperatively which could have detrimental effects for rehabilitation and be associated with contralateral ruptures.

Recently, an enhanced understanding of ligament healing and an improvement in arthroscopic instrumentation, suture materials, imaging techniques and rehabilitation has led to a renewed interest in ligament repair. Extra-articular ligaments that can naturally heal with nonoperative management such as the medial collateral ligament (MCL) form a fibrin clot between the ends of the torn ligament which provides a scaffold to permit the MCL to heal. Intra-articular ligaments such as the ACL do not allow the formation of this clot therefore there is no scaffold to permit the ACL to heal. As a result, modern techniques have concentrated on providing this scaffold or an augment to support intra-articular ligaments during the healing phase. Additionally, modern suture techniques and arthroscopic instrumentation allows simpler repair of the ligaments in addition to the scaffold or augment. Furthermore, recent insights into the structure and function of the anterolateral ligament (ALL) and the posterolateral corner (PLC) in providing rotational control of the knee has led to a renewed interest in supplementary techniques as these ligaments are often part of a multiligament knee injury.

Internal bracing involves the augmentation of a ligament repair with suture tape which acts as a secondary stabilizer and gives the ligament a protective environment to heal and allows early mobilization to aid rehabilitation. The suture tape is FiberTape® (Arthrex) which is an ultra-high strength 2mm width tape, consisting of a long chain ultra-high molecular weight polyethylene (UHMWPE). Its ends are tapered to FiberWire® (Arthrex) for easy suture passage which is the same material and has a similar structure. It has a high tensile strength and stiffness in comparison to other similar suture materials. In addition, it has extensive biocompatibility proven through animal and clinical testing. Finally, the multi-strand long chain UHMWPE results in an increased abrasion resistance in comparison to other similar sutures.

Internal bracing of the anterior cruciate ligament, anterolateral ligament, posterior cruciate ligament (PCL), medial collateral ligament, posterolateral corner and medial patellofemoral ligament (MPFL) is described. The surgical techniques are explained in detail along with illustrations and the advantages and disadvantages of the techniques are discussed. We hypothesized that internal bracing of these ligaments would demonstrate significant improvements in patient-reported outcome measures that would be comparable to reconstruction techniques described in the literature. Moreover, the additional rotational stability provided by repair of the anterolateral ligament would decrease the ACL re-rupture rate in comparison to isolated ACL repairs.

Patients in each group were evaluated prospectively using patient-reported outcomes measures including the KOOS, WOMAC, Visual Analog Pain Scale (VAS) VR-12 and the Marx Activity scale. This data was collected preoperatively and at 12, 24 and 60 months postoperatively. Additionally, a standard questionnaire was completed to ask the patients who did not have any further surgery about their overall satisfaction with regards to reducing pain, improving movement, resuming normal function and resuming sport. Patients were also contacted by email/telephone at the time of this analysis to seek out any postoperative complications including any further surgery on the ipsilateral and contralateral

knee. The anterior cruciate ligament group was followed up for a minimum of 5 years and the other ligament groups for a minimum of 2 years.

Encouraging results are confirmed in all of the ligaments around the knee. The mean KOOS and WOMAC scores increased significantly and the VAS score and VR-12 physical scores improved significantly in all of the groups. 6 patients had an ACL re-rupture (17.6%) after isolated ACL repair. These patients were found to be younger and have higher initial Marx activity scores than the rest of the cohort. A combined ACL and ALL repair with internal brace augmentation in these higher risk patients reduced the ACL re-rupture rate to 5.3%. As a result, a treatment algorithm for ACL ruptures and the requirements for additional ALL rotational support is produced.

As far as we are aware, these are the first cohorts of patients with minimum 5-year outcomes of ACL repair with internal brace augmentation and patients with minimum 2-year outcomes undergoing a combined ACL repair and ALL repair, PCL repair, MCL repair, PLC repair or MPFL repair with internal brace augmentation. In conclusion, it is indicated that internal bracing gives surgeons an alternative technique to traditional reconstructions and avoids the need for a graft thereby preventing donor site morbidity whilst also preserving the proprioceptive fibres of the ligament. Nonetheless, further clinical studies are necessary with larger patient numbers and longer follow-up as well as studies with a higher level of evidence to further assess these encouraging early results of ligament repair with internal bracing around the knee.

# Chapter 1 – Background

## Anterior Cruciate Ligament

The anterior cruciate ligament (ACL) is one of the main stabilisers of the knee and is the primary restraint to anterior tibial translation of the knee (Figure 1). [19]

Figure 1: The ACL is the primary restraint to anterior tibial translation of the knee

ACL rupture (Figure 2) is a common injury in the young adult population and ACL reconstruction with hamstring or patellar tendon autograft has been the gold standard surgical option for many years. However, it has been reported that only 63-65 % of the patients return to their previous level of sporting activity and 10.3% have a graft failure after ten years. [6] Indeed, the MOON group report that although

patients can maintain a high quality of life 10 years after ACL reconstruction, activity levels significantly decline over time. [163] Furthermore, they identified patient specific risk factors for poor outcomes at 10 years which included low baseline scores, high BMI, smoking, additional ipsilateral surgery and articular cartilage pathology. Some studies have also suggested that ACL reconstruction does not protect patients from developing post-traumatic osteoarthritis. [3,104,110,180] On the other hand, it has been reported that an anatomic ACL reconstruction was associated with a lower prevalence of osteoarthritis when compared to non-anatomical reconstructions. [139] However, there is a wide variability in the literature. [108] As a result of all these factors, there has been a renewed interest in primary repair of the ACL.

Figure 2: MRI scan demonstrating a proximal ACL rupture

Indeed, primary repair of the ACL was commonly performed for ACL ruptures in the 1970s and 1980s. [49,149,181] However, high failure rates were described at mid-term follow-up. [48,51,113] As a result, ACL reconstruction became the gold standard treatment in the 1990s. [7,47] despite the techniques having their own problems including the loss of proprioception, graft harvest morbidity, post-traumatic osteoarthritis and graft failure. Nevertheless, advancements in arthroscopic instrumentation, suture materials, imaging and rehabilitation protocols, in addition to an enhanced understanding of ACL healing should theoretically lead to improved outcomes with primary repair of the ACL when compared to historic techniques.

Interestingly, rehabilitation as a primary treatment has been investigated with varying results in the literature. Frobell et al looked at their five year outcomes of a randomized controlled trial looking at the differences between early reconstruction and delayed reconstruction if required. [58] They found that 49% of the patients in the delayed reconstruction group did not require an ACL reconstruction and there were no differences in patient reported function between the two groups. Further five year outcomes have also shown no difference in patients treated with ACL reconstruction versus rehabilitation alone. [182] In addition, a number of systematic reviews have shown similar outcomes with no differences in patient reported outcomes and evidence of radiographic osteoarthritis between patients undergoing ACL reconstruction and those treated nonoperatively. [26,156] On the other hand, delaying surgery has been shown to result in recurrent episodes of instability which is associated with meniscal damage and itself could result in an increase in future osteoarthritis. [159]

Evidence suggests that ACL reconstruction does not prevent future osteoarthritis. A systematic review by Ajuied et al [3] evaluated 596 patients with an ACL rupture across 9 studies and showed 20% of these patients have moderate or severe radiological changes at 10 years post-injury. In addition, they determined that patients treated nonoperatively would develop osteoarthritis quicker, however, 23% of the patients undergoing ACL reconstruction still had moderate or severe osteoarthritis at 10 years. Furthermore, a recent systematic review by Poehling-

Monaghan et al [134] evaluated 10 studies to compare patellar tendon and hamstring autografts outcomes and found a number of studies demonstrated a significantly increased rate of osteoarthritis with patellar tendon grafts. Moreover, one of the studies they reviewed by Leys et al [107] indicated that 69% of patients undergoing ACL reconstruction with hamstring autograft had radiologically detectable osteoarthritis 15 years postoperatively. We hypothesise that ACL repair will reduce rates of osteoarthritis due to the reduced morbidity associated with the technique, namely not requiring autograft, retaining proprioceptive fibres and smaller bone tunnels. However, long-term follow-up studies in the future are required to support this hypothesis.

An enhanced understanding of ACL healing and advancements in arthroscopic instrumentation, in addition to the complications still associated with ACL reconstruction are the main factors that have led to a renewed interest in ACL repair. Murray et al compared the healing of medial collateral ligament and anterior cruciate ligament tears and found that with the medial collateral ligament, a blood clot forms between the 2 ends of the tissue as a temporary scaffold which then remodels into a fibrovascular scar. However, this blood clot dissolves in the intrasynovial environment of the ACL and is the likely cause of past failures. [51,126] Therefore, they suggested that a scaffold/bridge is required for ACL repair to give it an environment to heal and they created a bioenhanced ACL repair procedure. [179]

This Bridge-Enhanced ACL Repair (BEAR) procedure involves ACL repair with No.2 Ethibond sutures and a cortical button (Endobutton, Smith & Nephew) with a scaffold comprised of extracellular matrix proteins including collagen from bovine tissue followed by the injection of 10ml of autologous blood to the scaffold. Initial results of this procedure in 10 patients as part of a nonrandomized comparison with 10 hamstring autograft ACL reconstructions showed similar outcomes at 3 months. [124] The 2-year outcome data of these patients has recently been published and again the BEAR procedure showed similar results with regards to clinical, functional and patient-reported outcome measures when compared to the ACL reconstruction group. [125] However, the use of autologous blood in addition to the

scaffold has no scientific evidence to support its use and should be used with caution. [123]

Dynamic Intraligamentary Stabilization (DIS) is another new ACL repair technique which uses a device with an internal dynamic screw-spring mechanism that stabilizes the knee during the healing phase by keeping the knee in constant posterior translation. [94] Initial results of this technique in 50 patients demonstrated a high level of secondary interventions with 18% of patients requiring further ACL surgery and 60% of patients requiring screw removal, however, 90% of patients did retain their repaired ACL 2 years postoperatively. [95] Henle et al described the results of this technique in 278 patients, however, they only had 22% of patients in the 24-month follow-up outcomes. [73] The 5-year results of the first 10 patients undergoing this procedure showed an 80% survival rate with good outcome scores in these 8 patients, however, 4 patients required removal of the metalwork. [44] Additionally, high complication rates have also been demonstrated in recent papers including a randomized controlled trial with 2-year follow-up. [78,130]

Internal bracing involves the augmentation of a ligament repair with suture tape which reinforces the ligament and acts as a secondary stabilizer. This promotes natural healing by protecting the ligament during the healing phase and allowing early mobilization. Additionally, autograft is not required thereby the unnecessary morbidity of graft harvest is avoided. The suture tape is FiberTape® (Arthrex) which is an ultra-high strength 2mm width tape, consisting of a long chain ultra-high molecular weight polyethylene (UHMWPE) and acts as an internal brace. Its ends are tapered to FiberWire® (Arthrex) for easy suture passage which is the same material and has a similar structure. It has a high tensile strength and stiffness in comparison to other similar suture materials. In addition, it has extensive biocompatibility proven through animal and clinical testing. Finally, the multi-strand long chain UHMWPE results in an increased abrasion resistance in comparison to other similar sutures.

We first described the concept of internal bracing and its various uses in our review paper. [114] In addition, the paper outlined the early results of repair of the anterior cruciate ligament (ACL) using internal bracing. The technique has also been utilised for the medial and lateral ankle ligaments, the syndesmosis complex, all of the other ligaments around the knee, the ulnar collateral ligament of the elbow, the ulnar collateral ligament of the thumb and the scapholunate ligament. [1,30,34,77,91,111,120,121,136,169,171,173] Additionally, the concept of internal bracing has been applied to repair of the acromioclavicular joint, the patellar tendon and the Achilles tendon. [20,21,80,119,142,146]

Recent biomechanical testing demonstrates that the internal brace improves the stabilisation of ACL repairs at loads occurring during normal daily activity. [11,12] Furthermore, the internal brace showed a significantly higher ultimate failure load and stiffness in comparison to isolated ACL repair. The added strength of the internal brace construct allows for the controlling of peak loads during accelerated rehabilitation and protects the repair from overstretching. However, the peak stress shielding may have the potential to impair ACL healing.

Indeed, synthetic grafts have been utilised in the past, either as a substitute for the ACL or as an augment to reconstruction. Dandy et al implanted a carbon-fibre substitute for the ACL, however, this resulted in carbon deposits in the liver and inflammatory synovitis in the knee therefore this was abandoned. [33] In the 1980s a Gore-Tex ACL graft was tested which demonstrated good preliminary results, however, longer term results again demonstrated wear debris and a synovial reaction therefore it was also abandoned. [49,86,132] The Dacron ligament was the next synthetic ligament on the market but the outcomes were poor with a high failure rate and also signs of synovitis similar to the previous synthetic ligaments. [16] The Kennedy Ligament Augmentation Device was used as an augment to protect the ACL after repair or reconstruction similar to the newer techniques we have described. However, unsatisfactory results led to it being removed from the market in 2000. Indeed, a recent 25-year follow-up randomised controlled trial demonstrated no difference between an autograft and an autograft augmented with the Kennedy LAD in any of the outcomes measured. [46] LARS ligaments

(Ligament Augmentation and Reconstruction System) are synthetic ligaments made of polyethylene terephthalate and have demonstrated varying results in the literature. Some studies have shown promising mid-term results whereas others have reported a high failure rate at 6-year follow-up. [84,127] In addition, it has been shown that this synthetic ligament can be associated with a clinically significant foreign body reaction. [151]

ACL repair with internal bracing uses FiberTape® (Arthrex) to bridge the ligament and is fixed on the femur with a button (Retrobutton® or TightRope RT®, Arthrex) and a knotless bone anchor (SwiveLock®, Arthrex) on the tibia. A looped suture (FiberLink®, Arthrex) secures the distal ACL stump to its femoral attachment. Internal bracing of the ACL acts as a secondary stabilizer which promotes natural healing of the ligament by protecting it during the healing phase and supporting early mobilization. In addition, graft harvest is not required which avoids muscle atrophy leading to an accelerated recovery. Graft harvest in patients undergoing ACL reconstruction is associated with a number of donor site morbidities. Knee flexor weakness with hamstring grafts and anterior knee pain with patellar tendon grafts are commonly reported.[96,147,185] In addition, Kowalk et al [97] demonstrated that ACL reconstruction with patellar tendon grafts restores knee stability but there is a reduction in knee power and work performed post-operatively. Additionally, the native ACL is spared with internal bracing thereby retaining the proprioceptive fibres of the ACL which is invaluable postoperatively as it is thought that the loss of these fibres leads to a lack of confidence in the knees of those who have underwent ACL reconstruction.[15,29,57] Furthermore, less than 50% of patients of patients return to playing sport at their preinjury level following ACL reconstruction and it is thought that a lot of this is due to the lack of proprioception and confidence in the knee. [9] In addition, loss of the ACL remnant during ACL reconstruction surgery has been shown to reduce proprioception recovery postoperatively which could have detrimental effects for rehabilitation and be associated with contralateral ruptures. [61]

The high failure rates (>50%) associated with primary repairs of the ACL in the 1970s and 1980s was one of the reasons behind ACL reconstruction becoming the

gold standard surgical option. [48,51,113] However, ACL reconstructions remain associated with high failure rates when using hamstring autografts and allografts and in particular, in younger age groups. [65,109,133] Internal bracing of the ACL reinforces the ligament and acts as a secondary stabilizer allowing for early mobilisation. Hypothetically this should reduce the high failure rates and associated pain and stiffness that accompanied the historic primary repairs. These patients had a large arthrotomy as well as cast immobilisation postoperatively which are essentially the opposite of our technique using arthroscopic surgery and early mobilization postoperatively. Importantly, the tunnels associated with internal bracing are situated in the same position as the larger tunnels used for hamstring or patellar tendon autografts in ACL reconstruction. As a result, any failures of our ACL repair technique would have a routine primary ACL reconstruction using autograft without compromise of the knee joint and the additional complications associated with revision surgery.[109]

We described our 2-year outcomes for ACL repair with suture tape augmentation in 42 patients undergoing surgery for an acute proximal ACL rupture. [74] This paper demonstrated good patient-reported outcome measures with a re-rupture rate of 4.8%. DiFelice recently published the results of his first 56 patients with 2-year follow-up with the latter 27 patients having an additional internal brace inserted. [88] This paper showed good objective and subjective outcomes at follow-up which adds to his previously published papers. [39-41] Internal bracing in the paediatric population has also been considered in the literature by Smith et al who demonstrated excellent outcomes in 3 children. [153] On the other hand, Gagliardi et al recently published a paper demonstrating high failure rates with internal bracing in the adolescent population. [59] However, this study only included 22 patients with 4 patients suffering from a re-rupture therefore >80% of this high-risk population underwent successful ACL repair. Further outcome papers with larger patient numbers and longer follow-up to 10 years as well as studies with a higher level of evidence are required to further assess the encouraging early results of ACL repair with internal bracing.

The aim of this study is to firstly describe this novel technique in detail then describes the 5-year outcomes of anterior cruciate ligament repair with suture tape augmentation. We hypothesized that there would be significant improvements in the patient-reported outcome measures 5 years postoperatively with fewer failures than the 25-53% described in historic literature. [48,51,113]

## Anterolateral Ligament

Although the debate on the exact anatomy and function of the anterolateral complex is ongoing, recent insights into the structure and function of the anterolateral ligament (ALL) [28] of the knee have resulted in a growing evidence of its role in rotational control of the knee. The ALL has been identified as a contributor to the anterolateral rotational stability of the knee [131,160] and there is a close association with anterior cruciate ligament (ACL) ruptures [177]. Indeed, it has been reported that around 90% of ACL ruptures also have an injury to the anterolateral ligament complex. [52,53]

There is ongoing debate on the exact location of the ALL, especially the femoral origin, which is important when performing an anatomical reconstruction [23,28,32,42,93]. Several recent biomechanical studies agree that the femoral origin is posterior and proximal to the lateral epicondyle [32,93,140]. The ALL then crosses superficial to the lateral collateral ligament (LCL) to its tibial insertion, which is halfway between Gerdy´s tubercle and the anterior margin of the fibular head, 9.5 mm distal to the joint line [93].

Several indications for ALL reconstruction or repair have been described: an ALL rupture combined with an ACL rupture, chronic ACL lesions, an ACL rupture with a grade 3 pivot shift, high demanding athletes and revision ACL surgery [162]. Multiple ACL reconstruction and repair techniques in combination with ALL reconstruction have been described in the literature [137]. Historically, anterolateral extra-articular stabilization was performed most frequently with many different techniques having been used. Most of these techniques were non-anatomical reconstructions and used a part of the iliotibial band [75]. Nowadays, several techniques for anatomical ALL reconstruction have been described [137]. Most of these techniques use a tendon autograft (Semi-Tendinosus or Gracilis) or allograft. As previously outlined, the ALL has been identified as a contributor to the anterolateral rotational stability of the knee [131,160]. By repairing or reinforcing the ALL, anterolateral stability is provided and a lower rerupture rate of the ACL should be expected. Indeed, Helito et al described better results in an ACL + ALL

reconstruction group versus an isolated ACL reconstruction group in patients who were treated for a chronic ACL lesion. The ACL + ALL group had a positive pivot shift test in 9.1% and no re-ruptures versus 35.3% and 7.3% respectively in the isolated ACL group [71]. Additionally, Helito et al described their findings in patients with ligamentous hyperlaxity and also demonstrated a lower failure rate with combined ACL and ALL reconstruction compared to ACL reconstruction alone. (21.7% v 7.3%) [72] More recently, the STABILITY trial demonstrated a statistically significant reduction in graft rupture from 11% to 4% with the addition of a lateral extra-articular tenodesis to a single-bundle hamstring autograft ACL reconstruction. [64] Good clinical outcomes have also been revealed with combined autograft procedures in high risk groups including professional athletes and it has also been shown to protect medial meniscal repairs with a significantly lower rate of failure when compared to isolated ACL reconstructions. [138,161,162] On the other hand, these techniques have some issues as demonstrated in a recent anatomical paper which reported that there is a 70% chance of tunnel convergence with a combined ACL reconstruction and lateral extra-articular tenodesis. [87]

Internal bracing of the ALL does not require a tendon graft, the native ligament is repaired in the acute case and retensioned in cases with a chronic ALL rupture. As a tendon graft is not required the risk of morbidity associated with harvesting is absent. Post operatively patients are early mobilized without a brace and with crutches as needed. As with the ACL, the internal brace suture tape augmentation reinforces the ligament as a secondary stabilizer, encouraging natural healing of the ligament by protecting it during the healing phase and supporting early mobilization. However, no clinical studies have been published to determine the outcomes of this technique.

The aim of this study is to firstly describe this novel technique in detail then describes the 2-year outcomes of combined anterior cruciate ligament repair and anterolateral ligament repair with suture tape augmentation. We hypothesized there would be a significant improvement in the patient-reported outcome measures 2 years postoperatively.

## Posterior Cruciate Ligament

The posterior cruciate ligament (PCL) is the primary restraint to posterior tibial translation of the knee and is a crucial stabilizer of the knee. [24] It originates on the medial femoral condyle and inserts on the posterior intercondylar area of the tibia. [17] The PCL is composed of two bundles, an anterolateral bundle and a posteromedial bundle. [98] PCL injury accounts for up to 20% of injuries to the ligaments around the knee. [152] The most common mechanism of injury is a direct blow to the anterior tibia with the knee flexed which is classically associated with motor vehicle accidents and soccer injuries. [92] However, isolated injuries to the PCL are rare and they are more likely to represent one aspect of a multiligament knee injury. [98]

An increased incidence of osteoarthritis in patients with posterior cruciate ligament deficiency has been reported in the literature. [172] Consequently, one of the main aims in patients with a PCL injury is to restore the function of the ligament as close to normal as possible. Surgery is therefore recommended in patients with Grade III PCL tears, symptomatic chronic tears and PCL tears associated with other ligamentous knee injuries.

Numerous techniques have been described in the literature for the surgical management of patients with PCL ruptures. [17,24,38,103,173] Even with all of the techniques described, no single technique has been shown to outdo any of the others. Historically, primary PCL repair was the most common surgical option, however, PCL reconstruction procedures are now more commonly performed.

PCL repair was originally performed as an open procedure with inconsistent results. [82,135,166] Hughston et al[82] evaluated the outcomes of 29 PCL repairs demonstrating good objective results in 65% of patients. On the other hand, Strand et al [166] established the results of 32 patients undergoing PCL repair with more than 50% of patients having posterior instability postoperatively. Moreover, Pournaras et al [135] described the results of 20 patients undergoing PCL repair and found that 100% of cases had posterior instability postoperatively. More recently,

arthroscopic PCL repair has been described using a number of different techniques. Wheatley et al [183] reported satisfactory patient reported outcome scores at a mean follow-up of 51 months in patients who underwent repair following PCL soft tissue avulsions. DiFelice et al [38] described a variation of this technique in a small case series of 3 patients. They used suture anchors to repair soft tissue peel off injuries to the PCL with satisfactory outcomes at 64 months. In addition, Van Der List et al [173] described a similar technique to ours with PCL repair and augmentation with an internal brace. However, there are no clinical outcome results of arthroscopic PCL repair with suture tape augmentation in the literature.

PCL reconstruction techniques are more commonly performed therefore several clinical outcomes studies have been published. Chahla et al [24] reviewed 441 patients in 11 studies in a systematic review and meta-analysis which compared single-bundle versus double-bundle PCL reconstructions. They conveyed significantly improved posterior stability and IKDC scores in the double-bundle group. Belk et al [17] analysed 132 patients in 5 studies in a systematic review and meta-analysis comparing PCL reconstruction with allograft versus autograft. This review demonstrated improved clinical outcomes in each group with no differences between the groups. Another study by Del Buono et al [35] reviewed 34 papers with patients undergoing PCL reconstruction or PCL augmentation. This review found comparable results in each group. The augmentation procedures analysed in the paper included a remnant posterior cruciate ligament-augmenting stent procedure and double-bundle augmentation with Achilles allograft. [89,187]

Internal bracing of the PCL with suture tape augmentation, similar to ACL internal bracing, reinforces the ligament and acts as a secondary stabilizer. This augment protects the ligament during the healing phase allowing natural healing whilst allowing early mobilization. Additionally, the morbidity associated with graft harvest is avoided leading to a reduction in muscle atrophy postoperatively thereby accelerating rehabilitation. Moreover, the proprioceptive properties that are retained in the native PCL could also contribute to an accelerated

rehabilitation period and benefit long-term recovery and return to sporting activity.

The aim of this study is to firstly describe this novel technique in detail then describes the 2-year outcomes of posterior cruciate ligament repair with suture tape augmentation. We hypothesized there would be a significant improvement in the patient-reported outcome measures 2 years postoperatively.

## Medial Collateral Ligament

The posteromedial corner of the knee consists of the superficial medial collateral ligament (MCL), deep MCL, posterior oblique ligament, oblique popliteal ligament and the posterior horn of the medial meniscus with the superficial MCL being the main medial structure as the primary static stabilizer to valgus stress of the knee.[8,27] The MCL is amongst the most commonly injured structures of the knee with the majority healing with nonoperative management. [37,66,184] However, grade III injuries or multiligament injuries of the knee are best stabilized surgically. [106]

Treatment of medial sided knee injuries presents a difficult challenge. Whilst most cases will heal with nonoperative management, grade III injuries and multiligament cases are best treated surgically. MCL reconstruction procedures are the most widely used surgical option and several techniques, graft choice and fixation methods have been described in the literature with acceptable results. [178] On the other hand, recent literature has seen a renewed interest in ligamentous repair with or without augmentation with advancements in surgical equipment and increasing knowledge. [114] MCL repair techniques have been described in the literature and it has been indicated that this is a viable option. [37]

A recent systematic review by Varelas et al of 10 studies with 275 knees revealed significant improvement in patient reported outcomes at a mean follow-up of 33 months after MCL reconstruction. The majority of cases were in multiligament knee injuries and no differences were seen between concomitant procedures as well as the array of grafts and techniques used. Interestingly, the majority of concomitant MCL injuries occur with anterior cruciate ligament (ACL) injuries and combined reconstructions of the ACL and MCL are associated with increased arthrofibrosis. [67] As a result, staged procedures are often indicated.

Posteromedial corner repair was the classical technique for treating medial sided knee injuries and an augmentation to this technique would be beneficial. [81] A number of technical notes have been described that have similarities to our repair technique with suture augmentation. Lubowitz et al [111] described the open

technique using suture tape augmentation, Van Der List et al [174] described the repair of a complete proximal avulsion and Hirahara et al [77] described a percutaneous technique with the use of ultrasound which may give some surgeons additional confidence in identifying the bony landmarks. To our knowledge, no clinical outcomes have been published on any of these techniques. Reassuringly, however, DeLong et al [37] performed a systematic review of 355 knees to evaluate the clinical outcomes of primary repair of the MCL and posteromedial corner of the knee and concluded that it was an effective and reliable treatment. They reported an improvement in patient-reported outcome scores with a failure rate of 6.1%.

MCL repair with suture tape augmentation as with the ligaments we have already discussed, reinforces the ligament, acts as a secondary stabilizer and has a number of advantages over isolated repair and reconstruction techniques. Protection of the MCL by the internal brace during the early postoperative stages promotes natural healing and also allows early mobilization. In addition, a graft is not required for the procedure and percutaneous incisions are used which avoids any unnecessary surgical morbidity leading to a quicker recovery. Moreover, a cadaveric biomechanical study by Gilmer et al [66] compared repair alone with internal bracing and reconstruction with allograft and found the internally braced cases were superior to repair alone and comparable to allograft reconstruction.

The aim of this study is to firstly describe this novel technique in detail then describes the 2-year outcomes of medial collateral ligament repair with suture tape augmentation. We hypothesized there would be a significant improvement in the patient-reported outcome measures 2 years postoperatively.

## Posterolateral Corner

The posterolateral corner (PLC) of the knee is the main restraint to varus forces of the knee as well as posterolateral rotation of the tibia relative to the femur. [25] The PLC consists of three major stabilisers, the lateral collateral ligament (LCL), the popliteofibular ligament and the popliteus tendon (PLT). [99] Most PLC injuries are associated with anterior cruciate ligament (ACL) or posterior cruciate ligament (PCL) ruptures with isolated injuries rare. [102] It is important to identify PLC injuries, in particular in multiligament knee injuries as re-rupture of the cruciate ligaments has been associated with untreated PLC injuries. [69,100,101]

PLC reconstruction procedures are the most widely used surgical option to treat both acute and chronic injuries. [122,150] Primary PLC repairs have been thought to be insufficient in providing adequate functional outcome and have been associated with a high failure rate in past literature. [63] However, with modern improved arthroscopic instrumentation and devices, there has been a renewed interest in repair of the ligaments around the knee. [114]

Historically, PLC injuries were treated with primary repair with satisfactory outcomes. [14,36] However, more recent studies indicated high failure rates with primary PLC repair leading to reconstruction techniques becoming more common. Stannard et al [165] reported on 64 posterolateral corner injuries with 39 patients undergoing repair with suture anchors and 25 patients undergoing reconstruction with either tibialis anterior or tibialis posterior allografts. 37% of the repairs failed in comparison to 9% of the reconstructions. Additionally, Levy et al [105] concluded that PLC reconstruction was a more reliable option than PLC repair in a similar study where they compared 10 repairs using suture anchors with 18 reconstructions using Achilles tendon with bone allograft. 40% of the PLC repairs failed. However, these repair techniques lacked augmentation which protects the PLC during the healing phase.

Several other reconstruction procedures have been described in the literature with a number of different techniques and grafts. Schechinger et al [143] reported

satisfactory outcomes of 16 patients undergoing PLC reconstruction with Achilles tendon allograft similar to Levy et al[105]. Ibrahim et al [83] showed improved outcomes in 20 patients with a multiligament knee injury who underwent PLC reconstruction with the contralateral hamstrings. Furthermore, Geeslin et al [62] reported successful results of an anatomical PLC reconstruction with repair of the avulsed structures of the PLC in 25 patients.

Similar to the other ligaments described, PLC repair with suture tape augmentation reinforces the ligament, acts as a secondary stabilizer and allows early mobilization thereby providing a protection that in theory should prevent the failures previously associated with primary repair. Recovery is accelerated and muscle atrophy is prevented as graft harvest is not required and the procedure is less invasive than standard reconstruction procedures.

The aim of this study is to firstly describe this novel technique in detail then describes the 2-year outcomes of posterolateral corner repair with suture tape augmentation. We hypothesized there would be a significant improvement in the patient-reported outcome measures 2 years postoperatively.

## Medial Patellofemoral Ligament

The medial patellofemoral ligament (MPFL) is the main restraining force against lateral patellar displacement in the first 20 degrees of flexion and is often disrupted following patellar subluxation or dislocation. [79,157] It originates at the posterior aspect of the medial epicondyle and inserts along the superomedial border of the patella. [18,148,157]

Multiple techniques have been described in the literature for the operative management of patients with recurrent patellar instability. [10,18,22,43,56,79,115,118,144,148,157,168] Realignment of the distal extensor mechanism is frequently performed when there is associated lateralization of the tibial tubercle, with distalisation when there is patella alta. Trochleoplasty can also be performed in patient with dysplastic trochleas. MPFL reconstruction is the most common soft tissue technique of choice, however, a number of complications have been reported in the literature. [79,148] MPFL repair is less commonly performed as they were thought to be insufficient in providing adequate functional outcome and due to high failure rates reported in the literature. [10,22] However, recent literature has seen a renewed interest in MPFL repair with acceptable results. [43,114]

Camp et al [22] described the outcomes of 27 patients undergoing MPFL repair with either suture anchors or a medial reefing technique with a minimum 2-year follow-up. 28% of patients experienced a recurrent lateral patellar dislocation with 5 of these patients requiring further surgery. They found a significant number of recurrences were due to non-anatomical anchor placement. Additionally, Arendt et al [10] described an MPFL repair technique using suture anchors to fix the MPFL to its origin on the femur. They retrospectively reviewed 55 knees in 48 patients with a minimum follow-up of 2-years. 46% of patients suffered from recurrent patellar dislocations with 13 patients undertaking a further stabilization procedure. On the other hand, Dragoo et al [43] recently compared 24 patients at a mean follow-up of 51 months who underwent MPFL reconstruction or MPFL repair using an algorithm-based approach. They found no differences between the 2

groups and only 1 patient in the MPFL repair group experienced a further dislocation.

Several systematic reviews have been published analyzing the outcomes of MPFL reconstructions. The first review by Smith et al [157] looked at 8 studies with 186 MPFL reconstructions and found satisfactory clinical and radiological outcomes, however, they concluded that all of the papers had several methodological weaknesses. Fisher et al [56], Buckens et al [18], Mackay et al [115] and Tompkins et al [168] have since reported similar conclusions. Schneider et al [144] performed a systematic review and meta-analysis to look more specifically at return to sport following MPFL reconstructions. They reported encouraging results with 84.1% of patients returning to sports postoperatively with a low incidence of recurrent instability. On the other hand, Shah et al [148] reviewed 25 articles and found a complication rate of 26.1% with 26 patients requiring further surgery.

MPFL repair with suture tape augmentation reinforces the ligament and acts as a secondary stabilizer. This promotes natural healing by protecting the ligament during the healing phase as well as allowing early mobilization. Furthermore, it does not require the use of a graft thereby avoiding the unnecessary morbidity of graft harvest. Additionally, with protection of the ligament by the suture tape augmentation, complications previously associated with MPFL repair may be avoided. However, it is important to ensure that the suture tape is not overconstrained and it is tensioned in the first 20-30 degrees of flexion. Excess tensioning can lead to irritation and may result in quadriceps inhibition.

The aim of this study is to firstly describe this novel technique in detail then describes the 2-year outcomes of medial patellofemoral ligament repair with suture tape augmentation. We hypothesized there would be a significant improvement in the patient-reported outcome measures 2 years postoperatively.

# Chapter 2 - Surgical Techniques

## Anterior Cruciate Ligament Repair

The patient is placed in the supine position with a tourniquet placed around the upper thigh. The injured leg is prepared and draped in the surgeon's preferred position similar to an ACL reconstruction procedure.

Standard anterolateral and anteromedial portals are used and a passport cannula (Arthrex) is placed in the anteromedial portal for suture management and to prevent interposing tissues. The ACL is probed to assess its suitability for primary repair. Proximal ruptures of the ACL are repaired with internal bracing. On the other hand, mid-substance or distal ruptures and ruptures where the ACL remnant is retracted are not suitable for repair. We previously used a standard ACL reconstruction procedure for these cases but this has since progressed to the use of a hybrid ACL reconstruction with internal bracing similar to a recent technique reported in the literature. [154]

The ACL remnant is left intact and a standard tibial ACL guide is placed at the centre of the ACL footprint. A small skin incision is made above the pes anserinus and a 3.5mm tibial tunnel is drilled. The drill is subsequently exchanged for a FiberStick™ (Arthrex) then a suture grasper is used to take the FiberWire suture (Arthrex) out of the FiberStick™ and through the medial portal. A FiberLink® is passed through the midsubstance of the ACL stump using a Scorpion™ suture passer (Arthrex) and retracted through the medial portal, forming a lasso around the distal ACL stump. (Figure 3) A second FiberLink® can be added if there is any doubt about the grip on the distal stump.

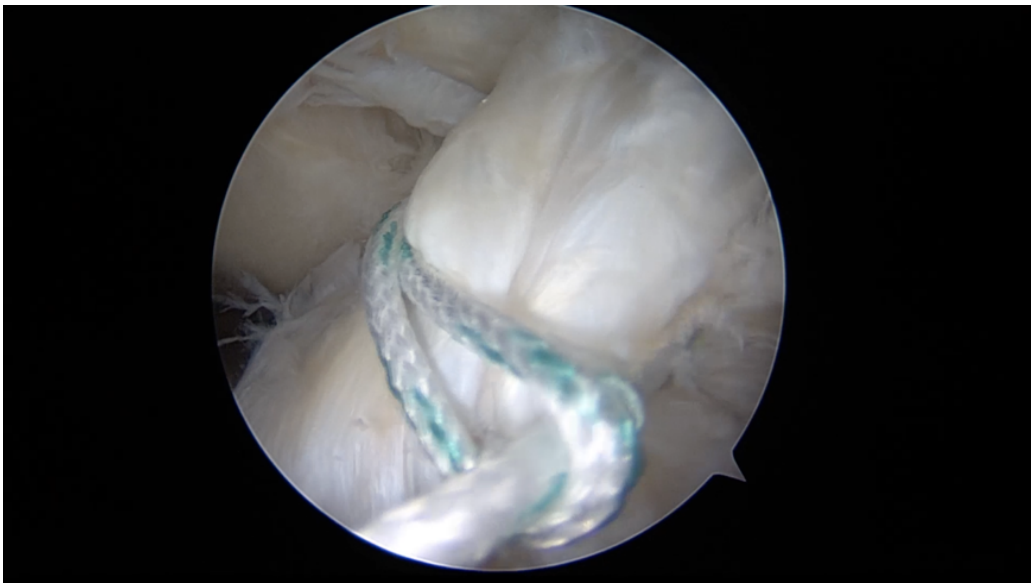


Figure 3: The FiberLink® forms a lasso around the distal ACL stump.

The femoral attachment is then identified, microfracturing is performed then a 3.5mm femoral tunnel is drilled. The FiberLink® suture and the FiberWire suture are then passed through the femoral tunnel. A femoral button (Retrobutton® or TightRope RT®, Arthrex) loaded with FiberTape® is subsequently transported proximally through the tibial tunnel, the centre of the ACL and the femoral tunnel. The button is flipped on the femoral cortex and the FiberTape® is advanced in the femoral tunnel by pulling the two tensioning strands. The suture tape is fixed distally, just below the tibial tunnel, using a 4.75 mm SwiveLock® loaded with both ends of the FiberTape®. Prior to insertion, the FiberTape® is marked at the laser line and repositioned in the eye of the SwiveLock® to avoid overtensioning. (Figure 4) Finally, the ACL is gently tensioned using the cinch to approximate the distal stump to the femoral footprint then the FiberLink® is tied on the femoral button with the appropriate tension on the ACL. (Figure 5)

Figure 4: The FiberTape® is marked at the laser line to avoid overtensioning

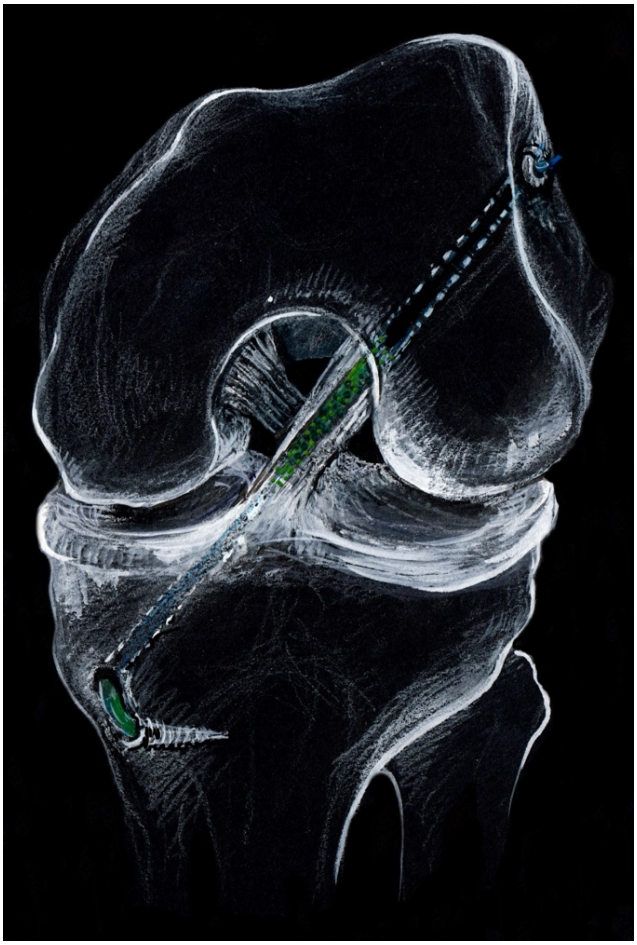


Figure 5: Final construct demonstrates internal bracing of the ACL with suture tape augmentation

Patients are allowed to fully weight bear with crutches as required during the first weeks and physical therapy focuses on early range of movement, muscle control and restoration of function. This is enabled by the limited pain and swelling, allowing accelerated early phase rehabilitation. Most patients are able to perform pivoting sports around 5 months postoperatively. Advantages and Disadvantages of this technique are demonstrated in Table 1.

| Advantages | Disadvantages |
|---|---|
| The native ACL and its proprioceptive properties are spared | Not all ACL ruptures can be repaired |
| No donor harvest morbidity | Synthetic augmentation |
| Less invasive than ACL reconstruction | Ruptures >3 months are often not suitable for repair |
| In the case of a re-rupture, a standard ACL reconstruction can be performed | The ACL stump must be of good quality with no retraction for an ACL repair to be performed |

Table 1: Advantages and Disadvantages of ACL Repair

**Anterolateral Ligament Repair**

Anterolateral ligament (ALL) repair can be used in acute injuries as well as chronic ruptures of the ALL. ALL repair using suture tape augmentation is a percutaneous technique, which can be performed within 5 minutes. This procedure is often performed in combination with ACL repair or reconstruction and would be performed as the second procedure.

The patient is placed in a supine position with a tourniquet on the upper thigh. As ALL repair is often combined with an ACL procedure, the injured leg can be placed in the surgeons preferred position for an ACL procedure.

The lateral femoral epicondyle, the distal joint line, Gerdy´s tubercle and the anterior margin of the fibular head are palpated and marked. The tibial insertion is marked halfway between Gerdy´s tubercle and the anterior margin of the fibular head, 9.5 mm distal to the joint line. (Figure 6)

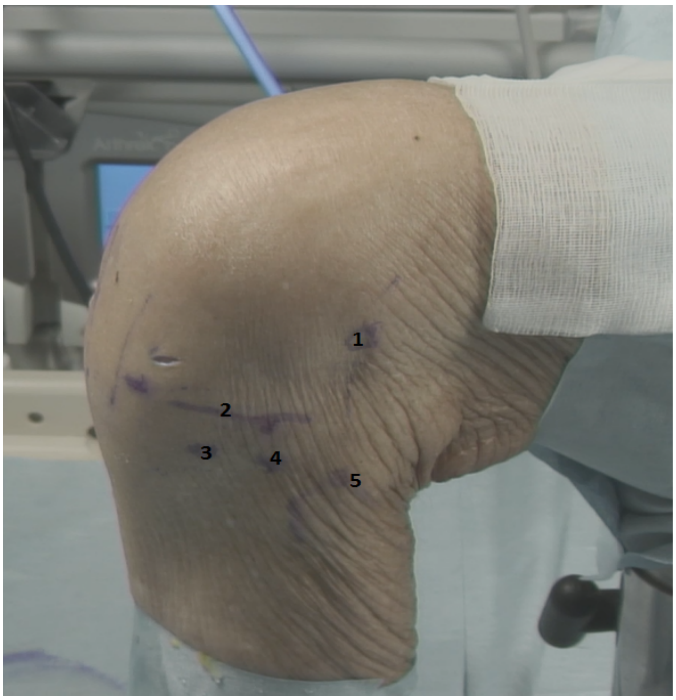



Figure 6: A left knee with marking on the lateral femoral epicondyle (1), the joint line (2), Gerdy´s tubercle (3), ALL tibial insertion (4) and the anterior margin of the fibular head (5).

A 3cm incision is made starting over the lateral femoral epicondyle in a posterior and proximal direction. The iliotibial band is split. The femoral origin of the ALL is approximately 7mm posterior and proximal to the lateral epicondyle. After pre-drilling, with a 4.5 mm drill and a 20 mm drill stop, followed by tapping, a 4.75 mm bone anchor loaded with FiberTape® is placed. The femoral drill hole is kept under direct vision to avoid superficial placement of the bone anchor in the bone or losing the position of the drill hole. (Figure 7)

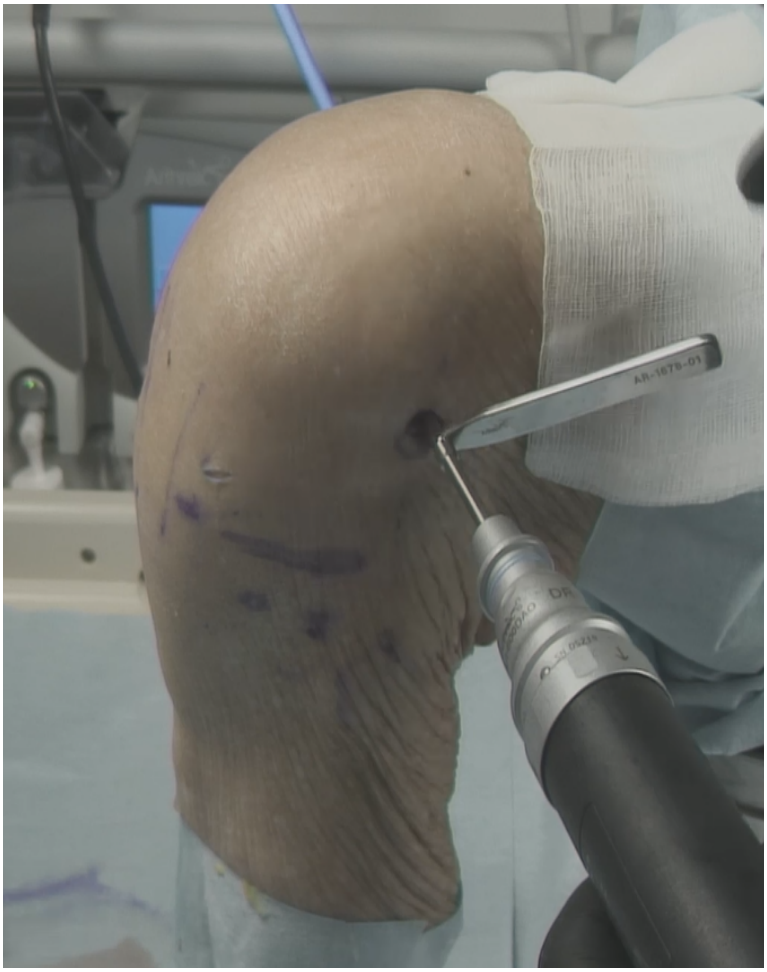


Figure 7: Predrilling the femoral origin of the ALL, approximately 7.0 mm posterior and proximal to the lateral epicondyle. Left knee, lateral view.

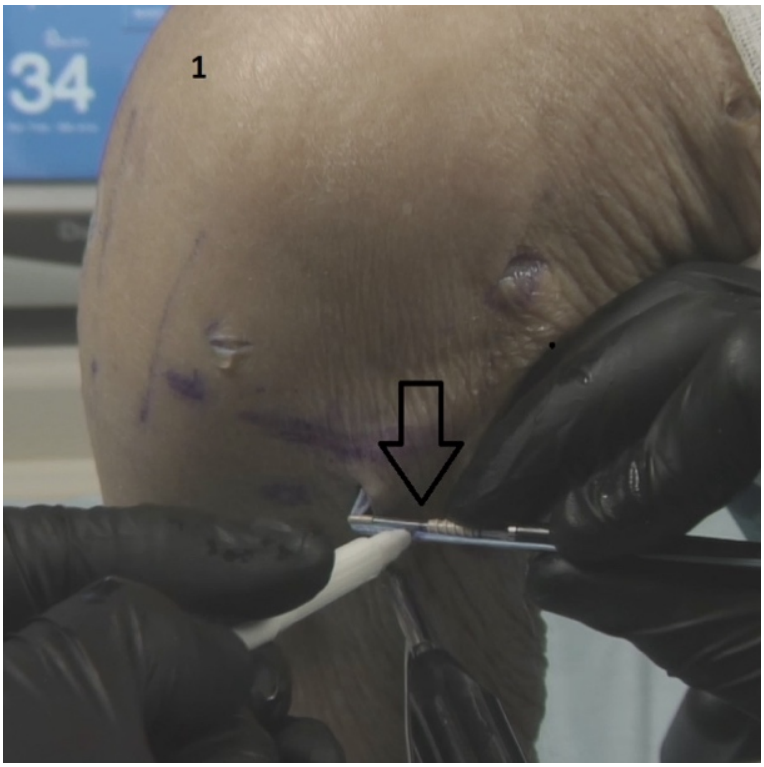
A hemostat is directed distally under the iliotibial band, superficial to the lateral collateral ligament. To break any adhesions the hemostat is distally moved sideways to create a tunnel for the FiberTape®. The skin is incised over the tip of the hemostat at the previous marked ALL insertion. Using a lead suture transported by the hemostat, the suture tape is brought to the tibial incision.

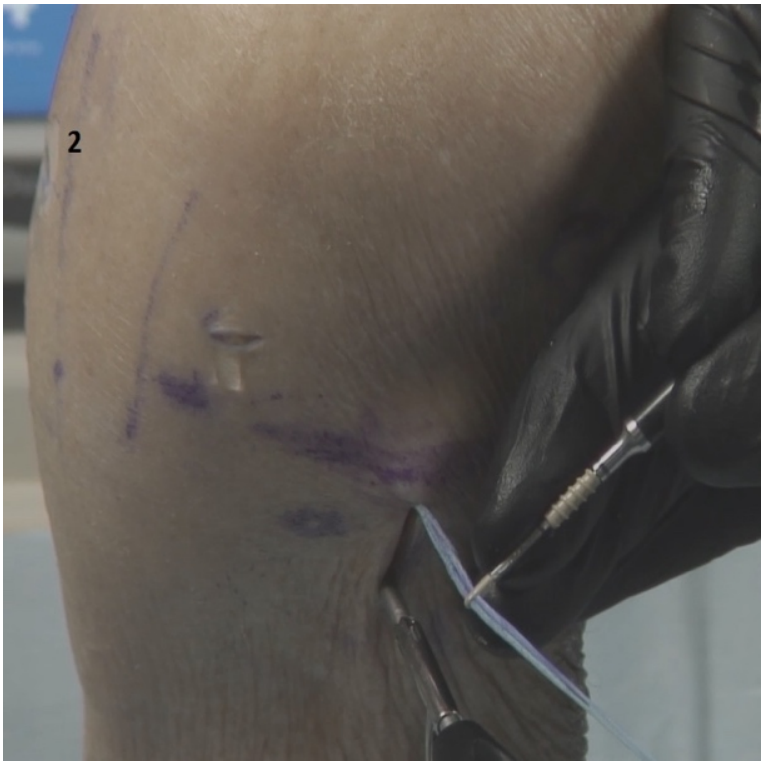
Under direct vision of the bony ALL insertion location, the 3.5 mm bone anchor is predrilled and tapped, with the tap left in place. A 3.5mm anchor gives sufficient strength in the strong tibial bone and is preferred over larger sizes given the proximity of the joint (Figure 8)


Figure 8: Predrilling the tibial insertion, halfway between the Gerdy´s tubercle and the anterior margin of the fibular head, 9.5 mm distal to the joint line. The ultra-high strength tape is temporarily being held aside, as not to interfere with the drilling. Left knee, lateral view.

The ultra-high strength suture tape is placed around the tap with the knee in 30° of flexion, followed by a full range of movement to check the isometric position. The suture tape should be tensioned in 30° of flexion and become less tensioned during further flexion. The FiberTape® is loaded in the distal bone anchor and pretensioned in 30° of flexion with the foot in a neutral position. The suture tape

is marked at the beginning of the screw of the bone anchor, repositioned in the eye of the bone anchor at the marked level and finally the bone anchor is placed in the drill hole (Figure 9).



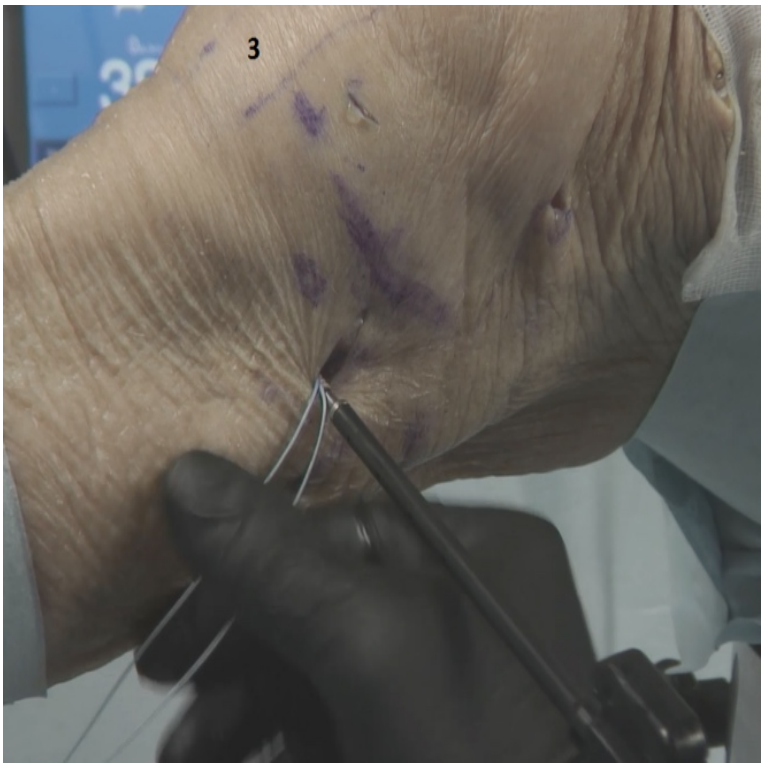



Figure 9: The ultra-high strength tape is marked at the beginning of the screw of the bone anchor (1) after pretensioning in 30° of flexion, then repositioned in the eye of the bone anchor at the marked level (2) followed by placement of the bone anchor in the drill hole (3). Left knee, lateral view.

In chronic ALL ruptures the ALL can be advanced with the No. 0 suture, which is loaded in the bone anchor, to regain its natural tension.

Most patients have a combined ACL and ALL procedure and a standard ACL rehabilitation program is recommended. Patients who receive an isolated ALL repair are allowed to fully weight bear with crutches as required. Physical therapy focuses on early range of movement, muscle control and restoration of function. This is facilitated by the limited pain and swelling, allowing accelerated early phase rehabilitation. No brace is required. Advantages and Disadvantages and Pearls and Pitfalls of this technique are demonstrated in Tables 2 and 3.

| Advantages | Disadvantages |
|---|---|
| No interference with ACL fixation | Additional procedure |
| No donor harvest | Synthetic augmentation |
| Quick procedure therefore limited theatre time | Unforgiving if over constrained |
| Easily reproducible | |
| Minimal risk of over constraint in 30° of flexion | |

Table 2: Advantages and Disadvantages of ALL Repair

| Pearls | Pitfalls |
|---|---|
| Key position of proximal fixation is 7 mm proximal and posterior to lateral epicondyle | Incorrect proximal or distal fixation will guarantee poor biomechanical outcome |
| Clear adhesions below the iliotibial band before shuttling tape | |
| Establish full ROM before securing tibial fixation | |
| Tensioned in 30° of flexion with foot in neutral – 'tight but not too tight' | Excessive tension can cause proximal screw fixation failure or even lateral meniscal pathology |

Table 3: Pearls and Pitfalls of ALL repair

## Posterior Cruciate Ligament Repair

Standard anteromedial and anterolateral portals are used with the addition of an accessory posteromedial portal. The first step is to elevate the PCL and track it down to its tibial insertion. The residual PCL fibres are retained and pushed posteriorly with the other posterior structures allowing for a safe and adequate exposure. An anteromedial incision is made over the proximal tibia then a standard PCL guide is used to drill a 3.5mm tunnel. The drill is advanced under direct vision to minimize any risk of complication. The anterior tibial cortex is tapped and the drill is switched for a FiberStick™ (Arthrex). The FiberWire® (Arthrex) is grasped out of the FiberStick™ and taken through the anteromedial portal.

The insertion point of the PCL on the femur is then identified and marked using electrosurgery which guarantees accuracy when the guide pin is passed. Reaming allows easier passage of the femoral button (Retrobutton® or TightRope RT®, loaded with FiberTape®, Arthrex) when it is shuttled from the anterolateral port directly through the tunnel. (Figure 10) The suture tape is then secured 1cm distal to the tibial tunnel using a 4.75mm SwiveLock® (Arthrex) with the knee in 90 degrees of flexion and an assistant providing anterior translation to hold the tibia in a reduced position with adequate tension on the PCL. Prior to insertion the laser line is marked which indicates the anatomical length of the PCL. If there are any reservations the knee should be put through a full range of movement in the reduced position prior to marking as excessive tensioning can result in difficulty achieving full extension. Securing the suture tape distally is an essential step as this restores the length of the anatomical PCL. (Figure 11)

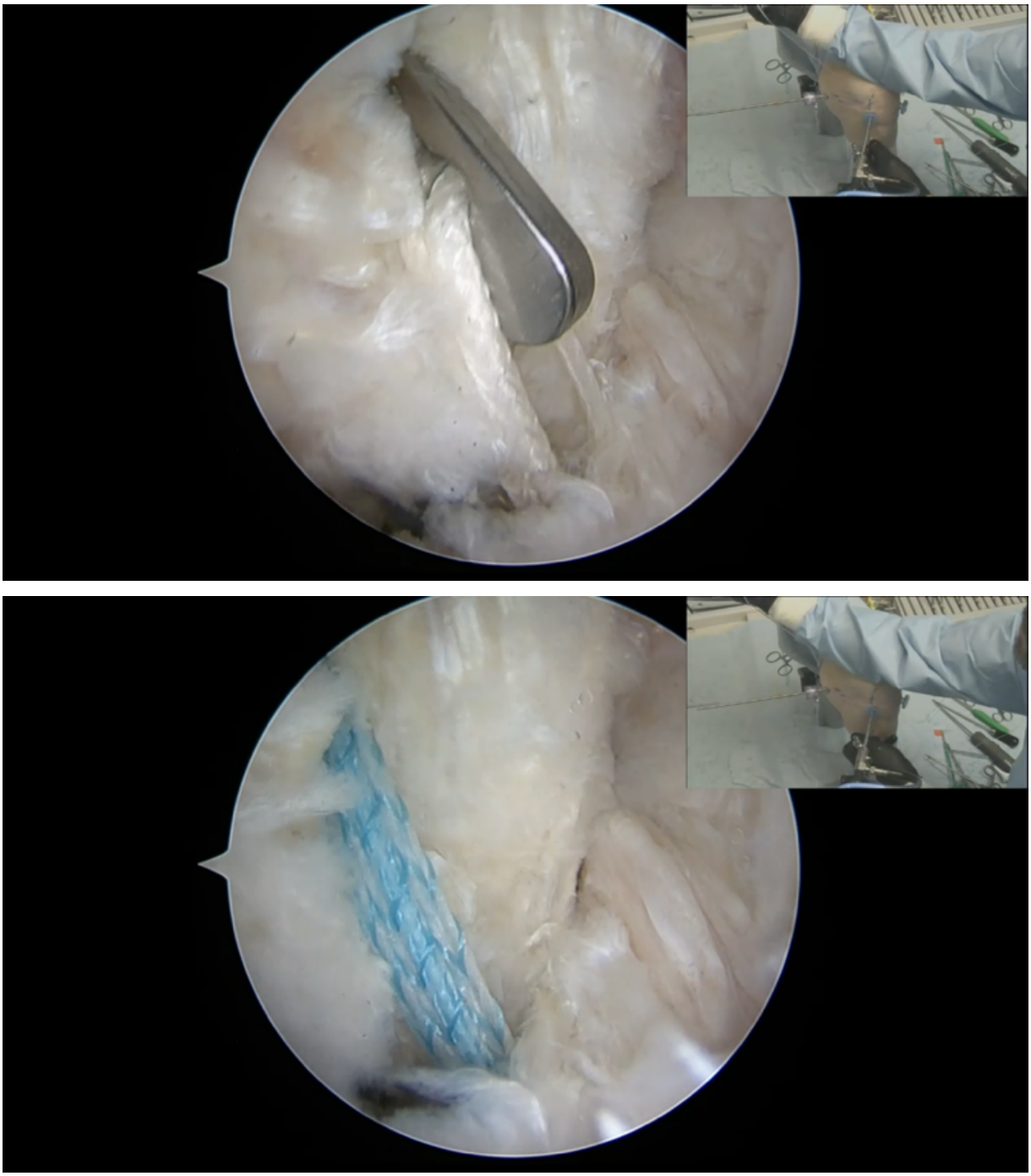


Figure 10: The femoral button (Retrobutton® or TightRope RT®, with FiberTape®, Arthrex) shuttled from the anterolateral port directly through the tunnel

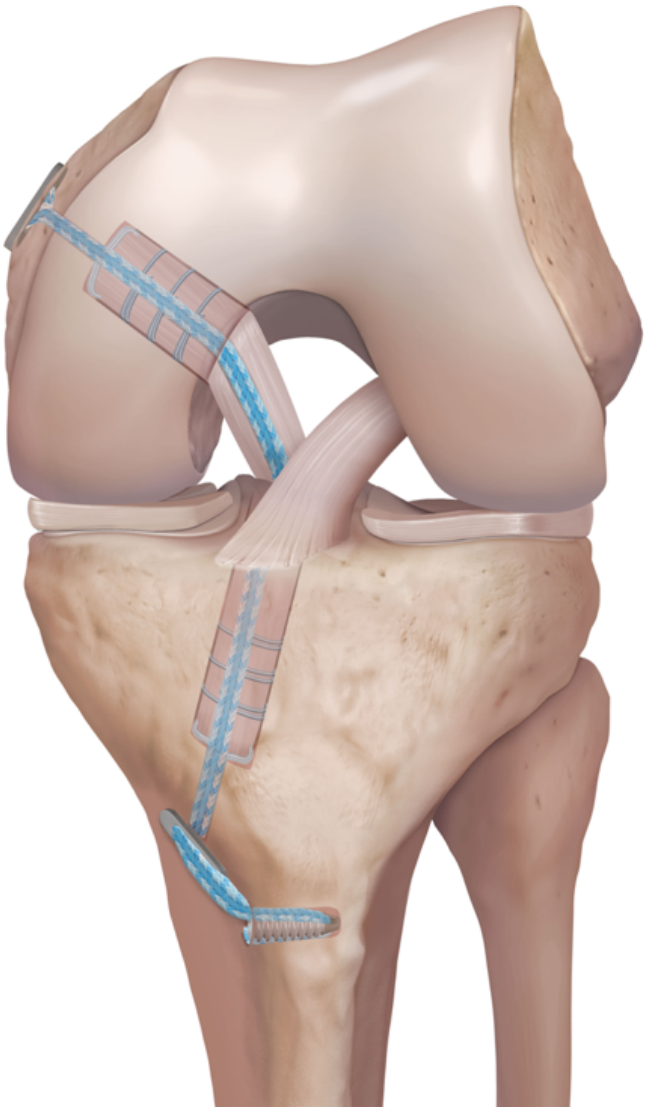


Figure 11: Final construct demonstrates internal bracing of the PCL with suture tape augmentation

Patients fully weight bear with crutches as required during the first weeks after surgery. The limited pain and swelling of this procedure in comparison to other techniques allows accelerated early phase rehabilitation with a focus on early range of movement and restoration of function. Most patients will return to pivoting sports around 5-6 months following surgery when neuromuscular function has recovered.

Advantages and Disadvantages as well as Pearls and Pitfalls of this technique are outlined in Tables 4 and 5.

| Advantages | Disadvantages |
|---|---|
| No graft harvest required | Not all PCL ruptures can be repaired |
| Less invasive than PCL reconstruction | Synthetic augmentation |
| Facilitates rehabilitation | Reliance on biological healing |
| In the case of re-rupture, a standard PCL reconstruction can be performed easily | |

Table 4: Advantages and Disadvantages of PCL repair with suture tape augmentation

| Pearls | Pitfalls |
|---|---|
| Ideal repair within first 4 weeks from injury | Excessive tensioning can result in difficulty achieving full extension |
| Posteromedial portal is used to facilitate suture passage and helps protect residual fibres of PCL | Malposition of fixation points can constrain joint |
| Using electrosurgery to mark the fixation point on the femur ensures accuracy when the guide pin is passed | If tissue is not adequate, additional augmentation may be required |

Table 5: Pearls and Pitfalls of PCL repair with suture tape augmentation

**Medial Collateral Ligament Repair**

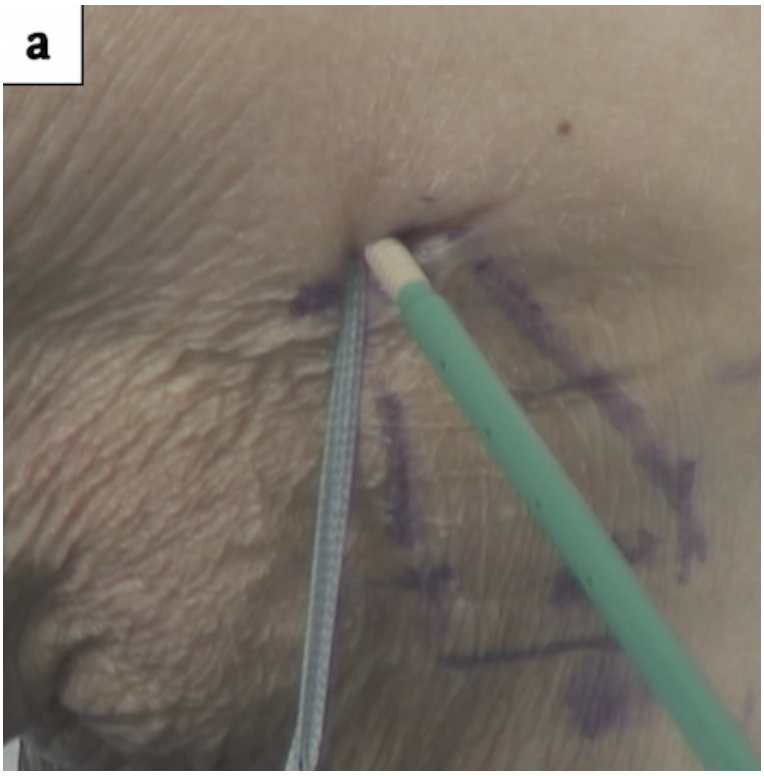
The patient is placed in the supine position and a tourniquet is placed on the upper thigh. The injured leg is prepared and draped in the surgeons preferred position similar to any arthroscopic procedure around the knee. Appropriate landmarks are palpated and marked including the medial epicondyle and a point roughly halfway between the joint line and the pes anserinus. (Figure 12)

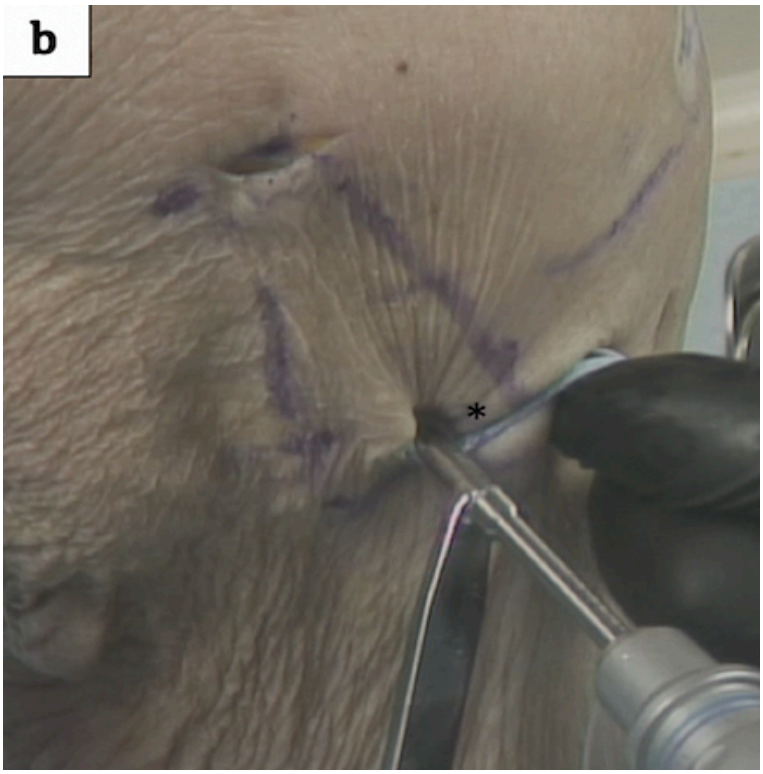

Figure 12: Left knee, medial view. Demonstrates the medial epicondyle (*) and the distal insertion site of the MCL, roughly halfway between the joint line and the pes anserinus (**)

A stab incision is then made over the medial epicondyle. The next step is to pre-drill with a 4.5mm drill and tap just posterior and proximal to the medial epicondyle, ensuring to be perpendicular to the cortex. A 4.75 mm SwiveLock® (Arthrex) pre-loaded with FiberTape® (Arthrex) is then inserted, ensuring it is

flush with the cortex to minimize any subcutaneous irritation and to ensure optimal strength of the fixation itself. (Figure 13) The FiberTape® is an ultra-high strength 2 mm width tape, consisting of a long chain ultra-high molecular weight polyethylene (UHMWPE).

A hemostat is then passed subcutaneously to the pre-marked insertion site distally and a short stab incision is made. The suture that has been removed from the anchor is then used to shuttle the suture tape distally. The insertion point is between the anterior third and posterior two thirds of the MCL. Preparation is then carried out for a further 4.75mm anchor by pre-drilling. The suture tape is wrapped around the drill sleeve to ensure a degree of isometricity and the knee taken through a range of motion to make sure the knee is balanced prior to drilling. Tapping is then performed, ensuring to be flush with the cortex. The second 4.75mm anchor is loaded with the suture tape and placed at the tip of the tap then the tape is marked at the laser line which allows for the length of the anchor itself and prevents any additional tensioning of the construct during its insertion. Excessive tensioning may be detrimental as it may constrain and compress the medial compartment of the knee. The suture tape is then repositioned in the eye of the anchor at the marked level, the knee is taken through a range of motion and finally the anchor is placed in the drill hole. (Figure 13) The suture tape restores the anatomical length of the MCL and acts as a seatbelt to prevent any attenuation during the early phases of healing.


a


b
*

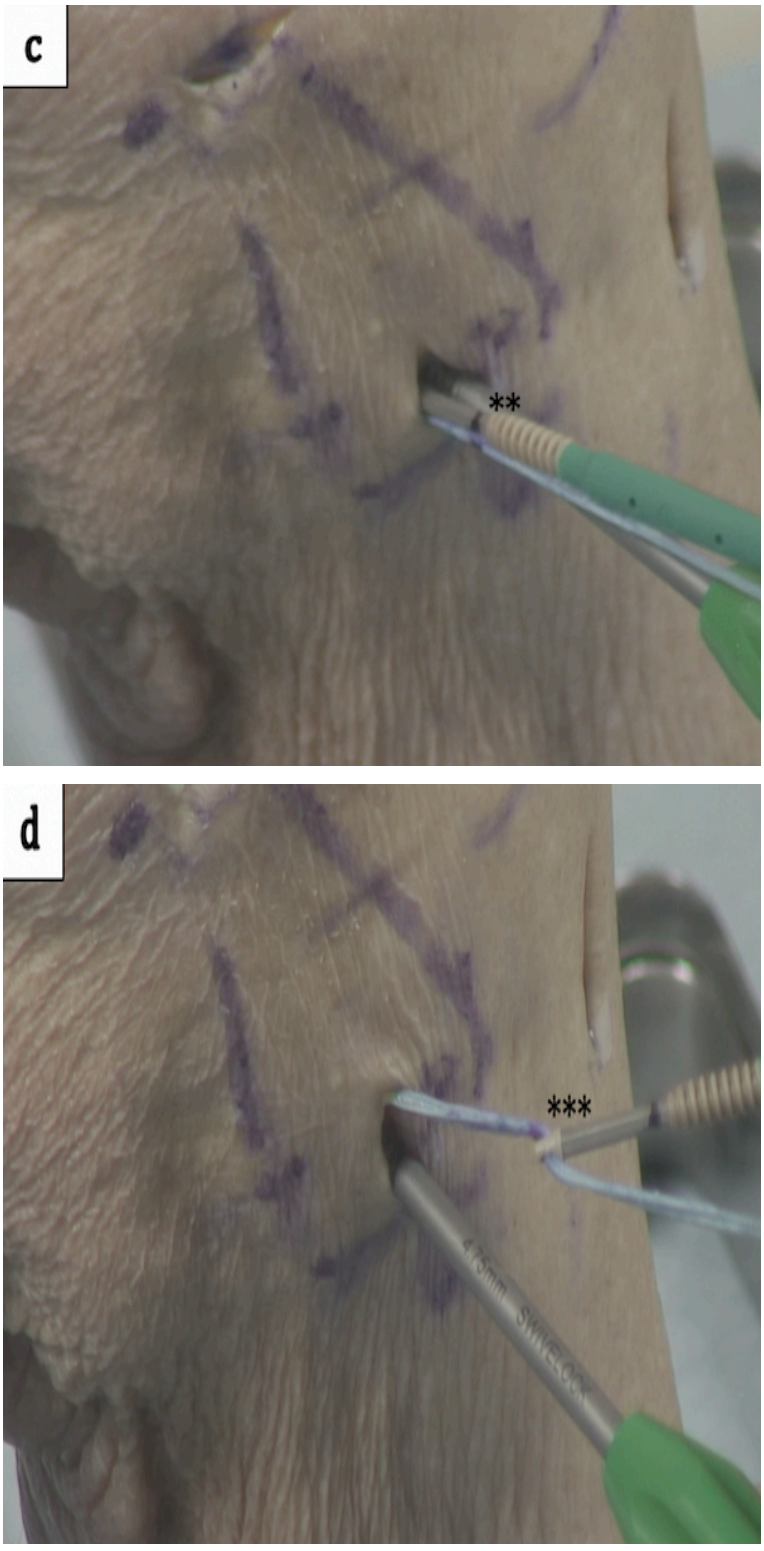
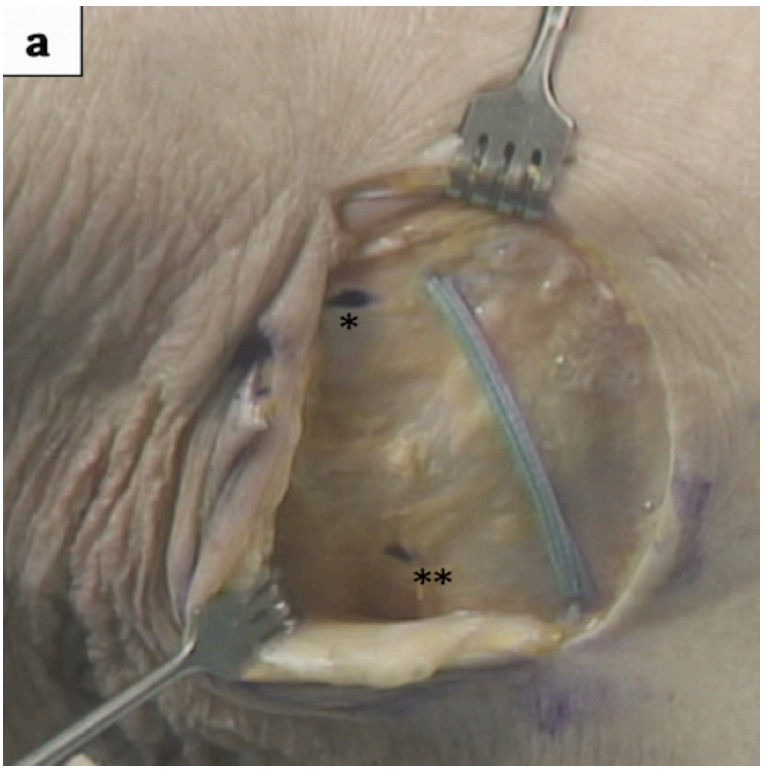
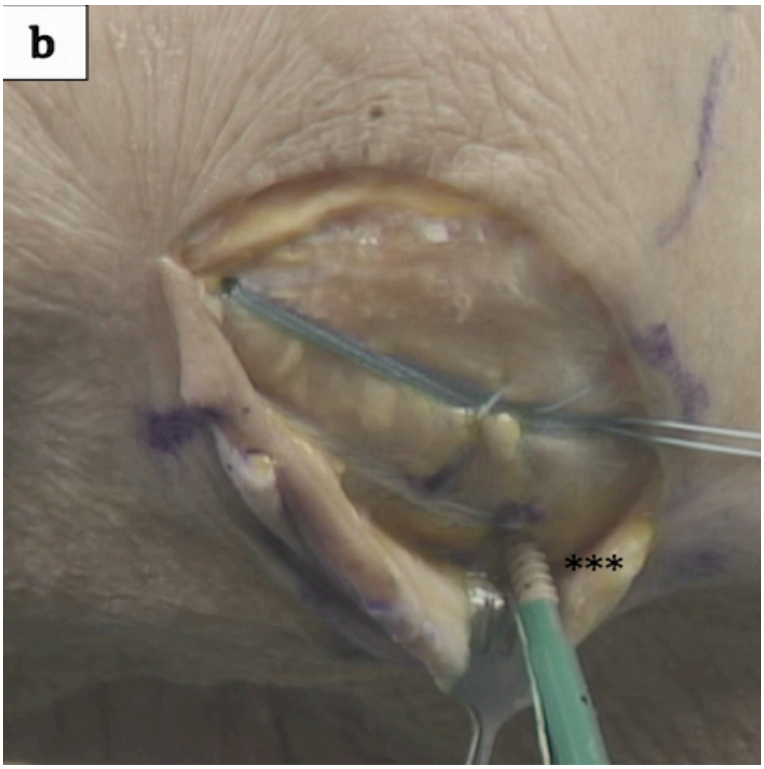


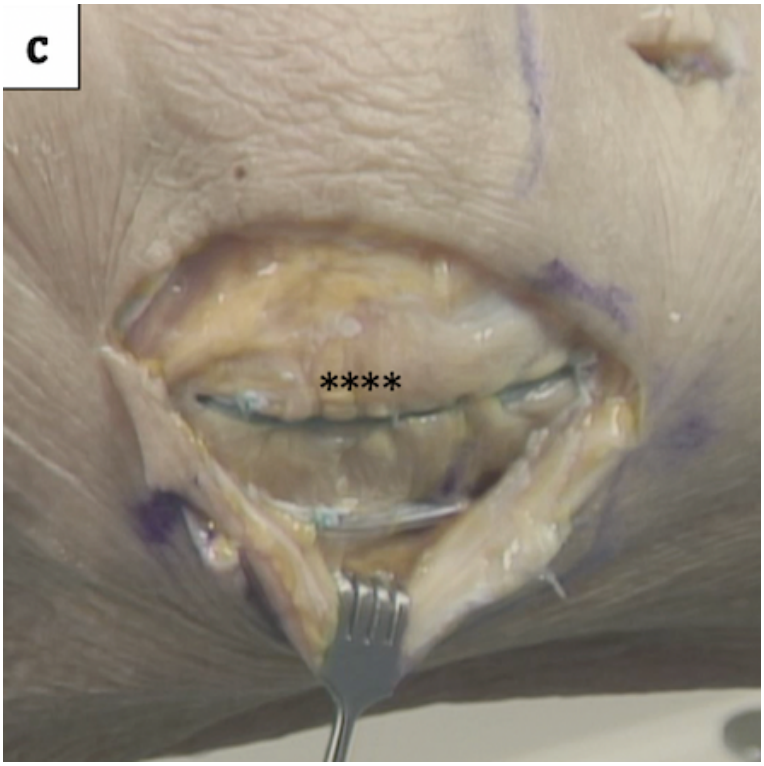

Figure 13: Left knee, medial view. (a) The 4.75 mm anchor that is pre-loaded with the suture tape is inserted proximally. (b) The suture tape is wrapped around the drill sleeve to ensure a degree of isometricity (*). (c) The suture tape is marked at the laser line (**) which allows for the length of the anchor itself and prevents any

additional tensioning of the construct during its insertion. (d) The suture tape is then repositioned in the eye of the anchor at the marked level (***)

In cases of a severely disrupted posteromedial corner [81], the posterior oblique ligament can also be augmented. This is an open procedure rather than the percutaneous approach we have described for the MCL. The semimembranosus insertion is identified distally and the adductor tubercle identified proximally. Preparation is then carried out for a 4.75mm anchor proximally by pre-drilling and tapping. The anchor is then inserted with the loaded suture tape, ensuring to be flush with the cortex. The suture tape is then secured distally with a further 4.75mm anchor after loading the suture tape. Measurement takes place in full extension as the POL is only taught in this position. A purse string suture is also used to approximate the soft tissues to the initial suture tape and can be used to rebalance the soft tissues to ensure that adequate tension is restored. (Figure 14)




b
***


c
****

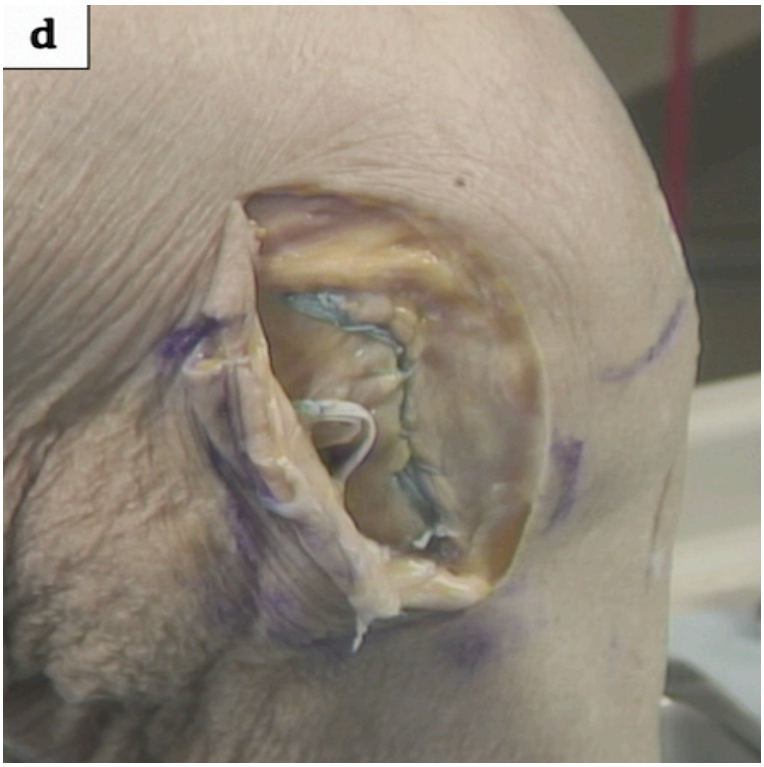



Figure 14: Left knee, medial view. (a) The semimembranosus insertion is identified distally (*) and the adductor tubercle identified proximally (**). (b) The suture tape is secured distally with a 4.75mm anchor (***) after loading the suture tape. (c) Completed repair. A purse string suture is used to approximate the soft tissues to the initial suture tape (****) (d) Demonstrates how the POL is only taught in full extension.

The rehabilitation protocol could be compared with an accelerated MCL reconstruction protocol. Patients are allowed to fully weight bear with crutches as required during the first weeks. Physical therapy focuses on early range of movement, muscle control and restoration of function. This is facilitated by the limited pain and swelling, allowing accelerated early phase rehabilitation. Patients are allowed to perform sports when the neuromuscular function has recovered. No brace is required. Advantages and Disadvantages as well as Pearls and Pitfalls of this technique are outlined in Tables 6 and 7.

| Advantages | Disadvantages |
|---|---|
| Simple and reproducible | Synthetic augmentation |
| No graft harvest required | Medial epicondyle tenderness |
| Facilitates rehabilitation | Irritation from bone anchor in subcutaneous position |
| Minimal surgical morbidity | |

Table 6: Advantages and Disadvantages of MCL repair with suture tape augmentation

| Pearls | Pitfalls |
|---|---|
| The use of ultrasound may give some surgeons additional confidence when identifying the medial epicondyle[77] | Important to establish anatomical accuracy |
| Ensure excessive constraint not applied | Excessive tensioning may constrain and compress the medial compartment of the knee |
| A purse string suture can be used to approximate the soft tissues to the initial suture tape to rebalance the soft tissues ensuring that adequate tension is restored in open cases | |

Table 7: Pearls and Pitfalls of MCL repair with suture tape augmentation

**Posterolateral Corner Repair**

The patient is placed in the supine position and a tourniquet is placed on the upper thigh. The injured leg is prepared and draped in the surgeons preferred position similar to any procedure around the knee. Appropriate landmarks are palpated and marked. (Figure 15) A curved incision is used, passing just superior to the lateral epicondyle. A flap is then dissected from the iliotibial band down to the head of the fibula. Two deep incisions are made in the iliotibial band to permit accuracy of the suture tape placement and to allow additional tensioning at the end of the procedure. (Figure 16) The peroneal nerve is identified and protected under direct vision.


Figure 15: Left knee, lateral view. Appropriate landmarks are marked before the procedure begins including the lateral epicondyle (*) and the head of the fibula (**) which are key landmarks for suture tape placement.

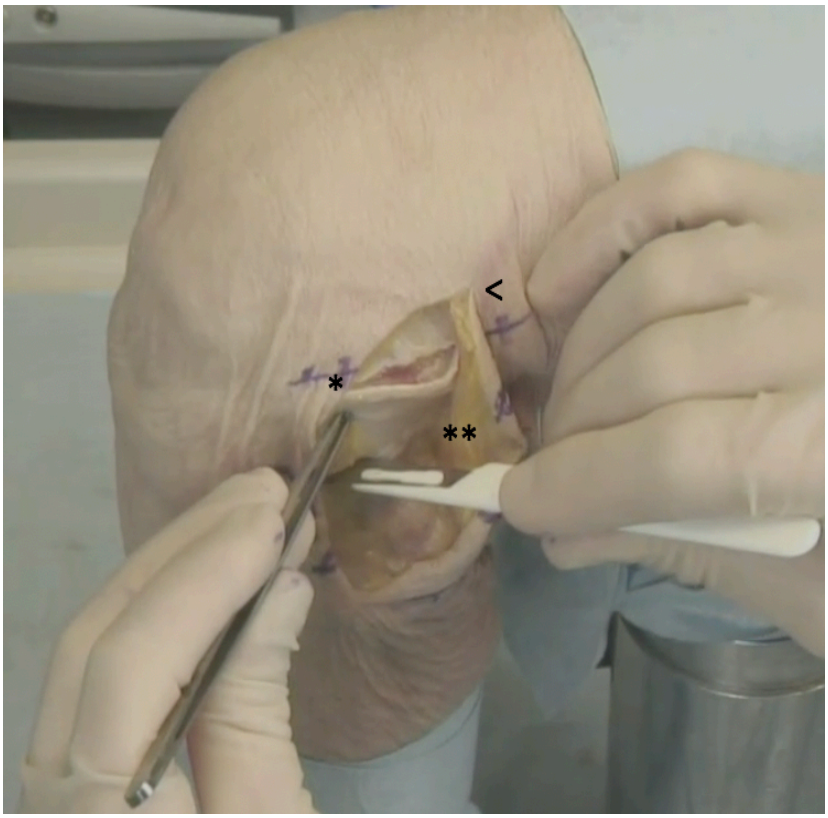
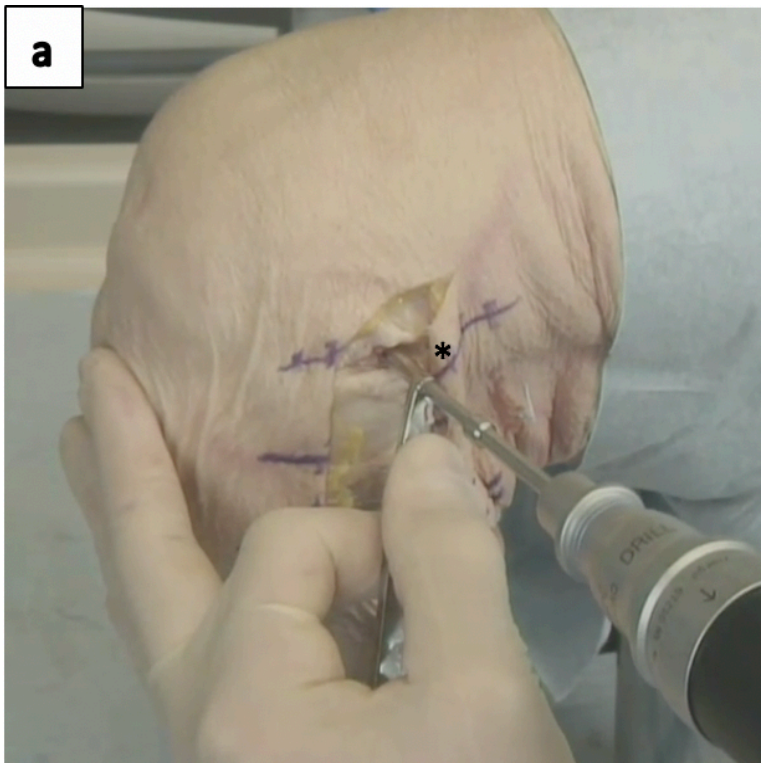
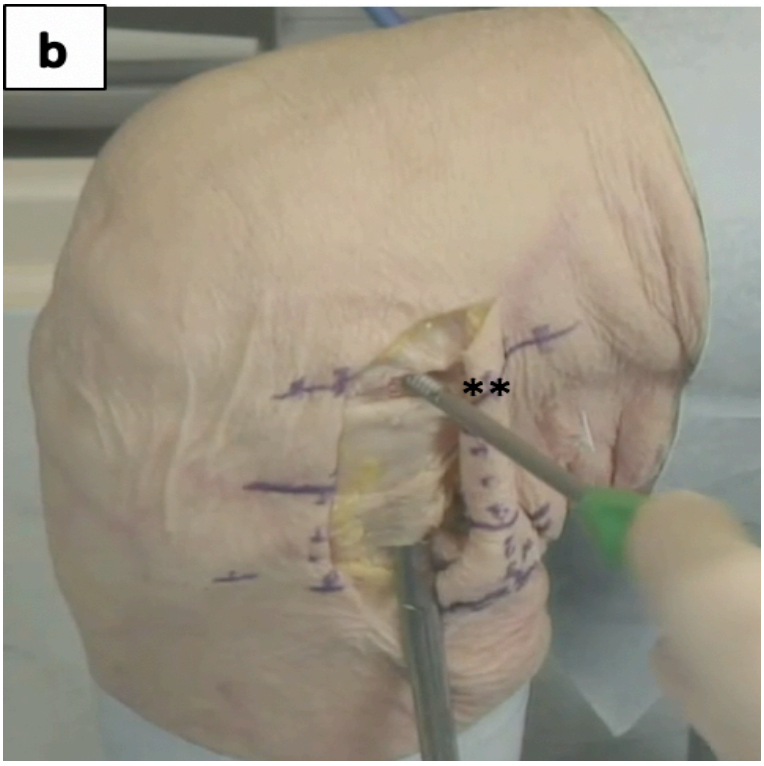



Figure 16: Left knee, lateral view. A curved incision (<) passing just superior to the lateral epicondyle is used then two deep incisions (* and **) are made in the iliotibial band for accuracy of suture tape placement and to permit tensioning.

The next step is to pre-drill with a 4.5mm drill and tap at the origin of the LCL just proximal to the lateral epicondyle, ensuring to be perpendicular to the cortex. A 4.75 mm SwiveLock® (Arthrex) pre-loaded with FiberTape® (Arthrex) is then inserted, ensuring it is flush with the cortex. (Figure 17) The FiberTape® is an ultra-high strength 2 mm width tape, consisting of a long chain ultra-high molecular weight polyethylene (UHMWPE). The suture tape is then shuttled towards the head of the fibula mirroring the lateral collateral ligament (LCL). (Figure 18)


a
*


b
**

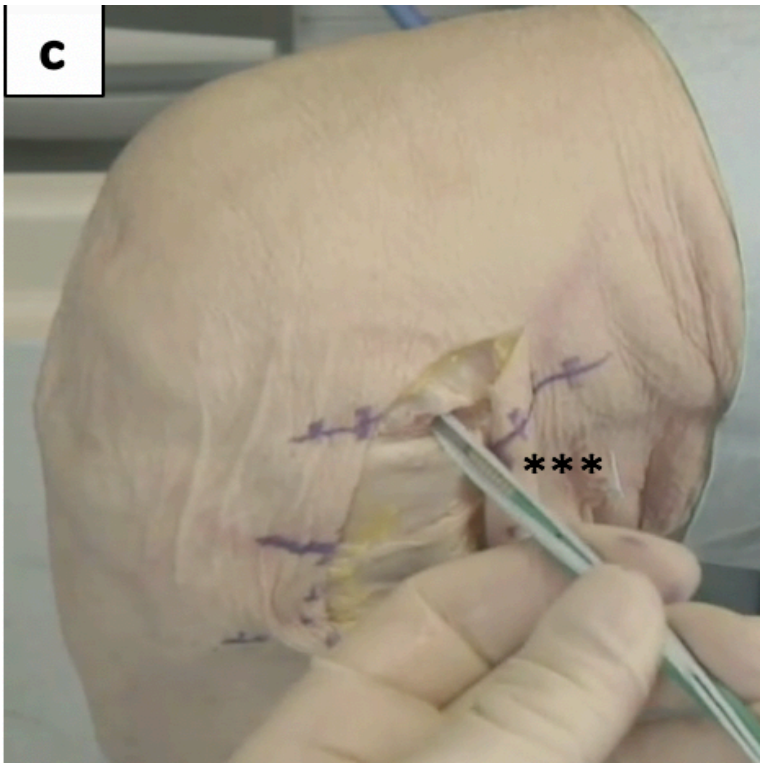



Figure 17: Left knee, lateral view. (a,b) The origin of the LCL is identified just proximal to the lateral epicondyle then pre-drilled (*) and tapped (*). (c) The suture tape preloaded in the anchor is then inserted, ensuring to be flush with the cortex.

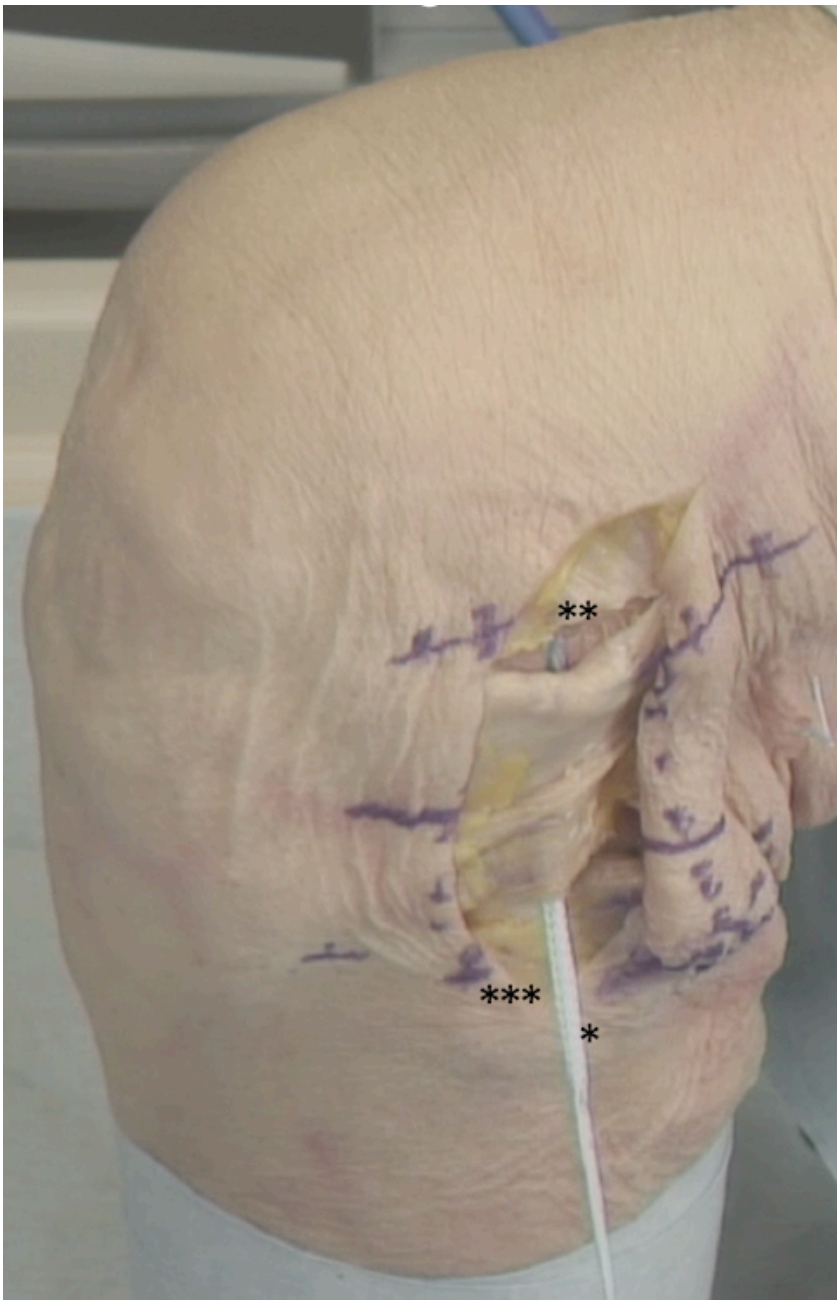
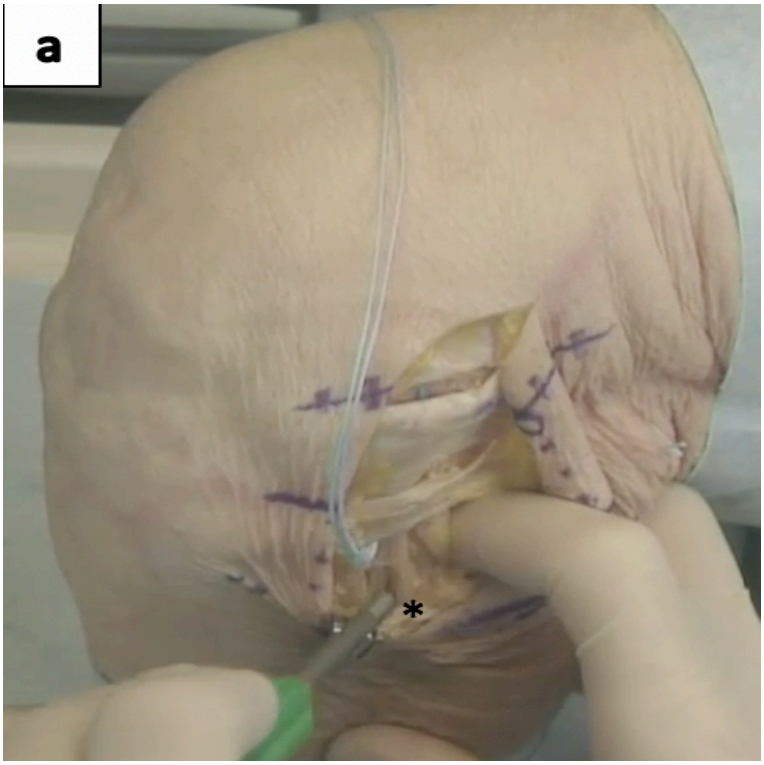



Figure 18: Left knee, lateral view. The suture tape (*) is shuttled from the lateral epicondyle (**) to the head of the fibula (***) mirroring the LCL

The head of the fibula is then exposed and the insertion point of the LCL is identified. The technique aims to restore the soft tissue balance around the head of the fibula which is recognized as the focus of injury during disruption of the PLC. The next step is to pre-drill with a 4.5mm drill and tap whilst using your finger to protect the peroneal nerve. A whipstitch is inserted into the biceps tendon. (Figure 19) The 4.75mm suture anchor is then advanced to the end of the tap and the laser line is marked after putting the knee through a range of motion

with the foot in a neutral position with no additional tension which should identify the anatomical length of the LCL. (Figure 20) The anchor is then inserted until it is flush with the cortex and the core suture is retained and used as a post to secure soft tissue sutures. Repair is then performed using the core suture from the anchor and the whipstitch around the biceps tendon thereby providing a rebalancing of the soft tissues around the head of the fibula. No attempt is made to directly repair the popliteus although the suture tape can be split with one strand used to repair the Anterolateral Ligament (ALL) if required. Finally, the iliotibial band is repaired. (Figure 21) This is an essential component of the technique as this sheet of soft tissue is also attenuated during injury and slight double breasting with approximately 5mm of overlap improves the stability of the soft tissue repair.



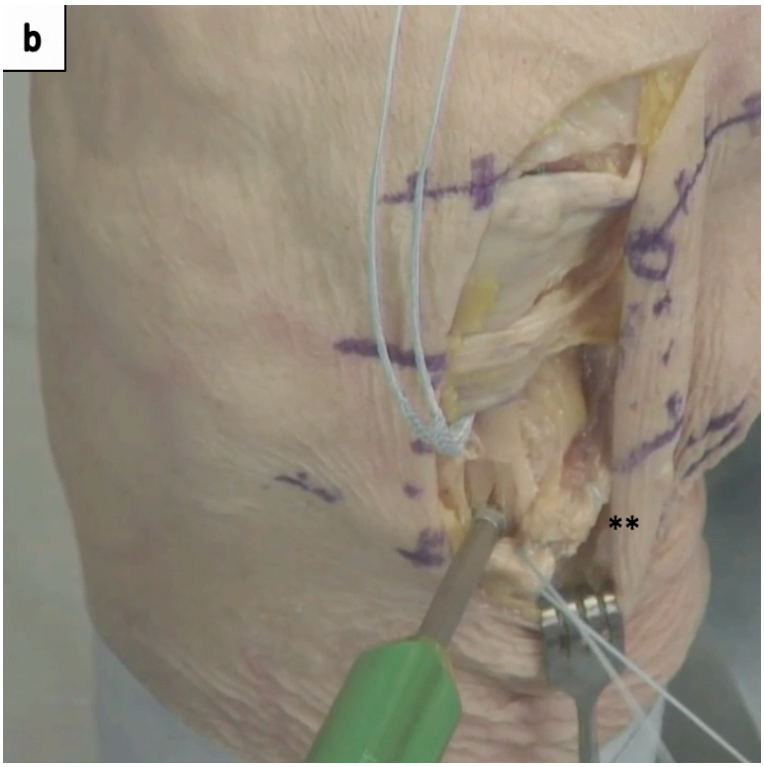



Figure 19: Left knee, lateral view. (a) The head of the fibula is exposed and predrilling and tapping (*) takes place at the LCL insertion point (b) A whipstitch is inserted into the biceps tendon (**).

Figure 20: Left knee, lateral view. The 4.75mm suture anchor is advanced to the end of the tap and the laser line is marked then the anchor is advanced into the head of the fibula.

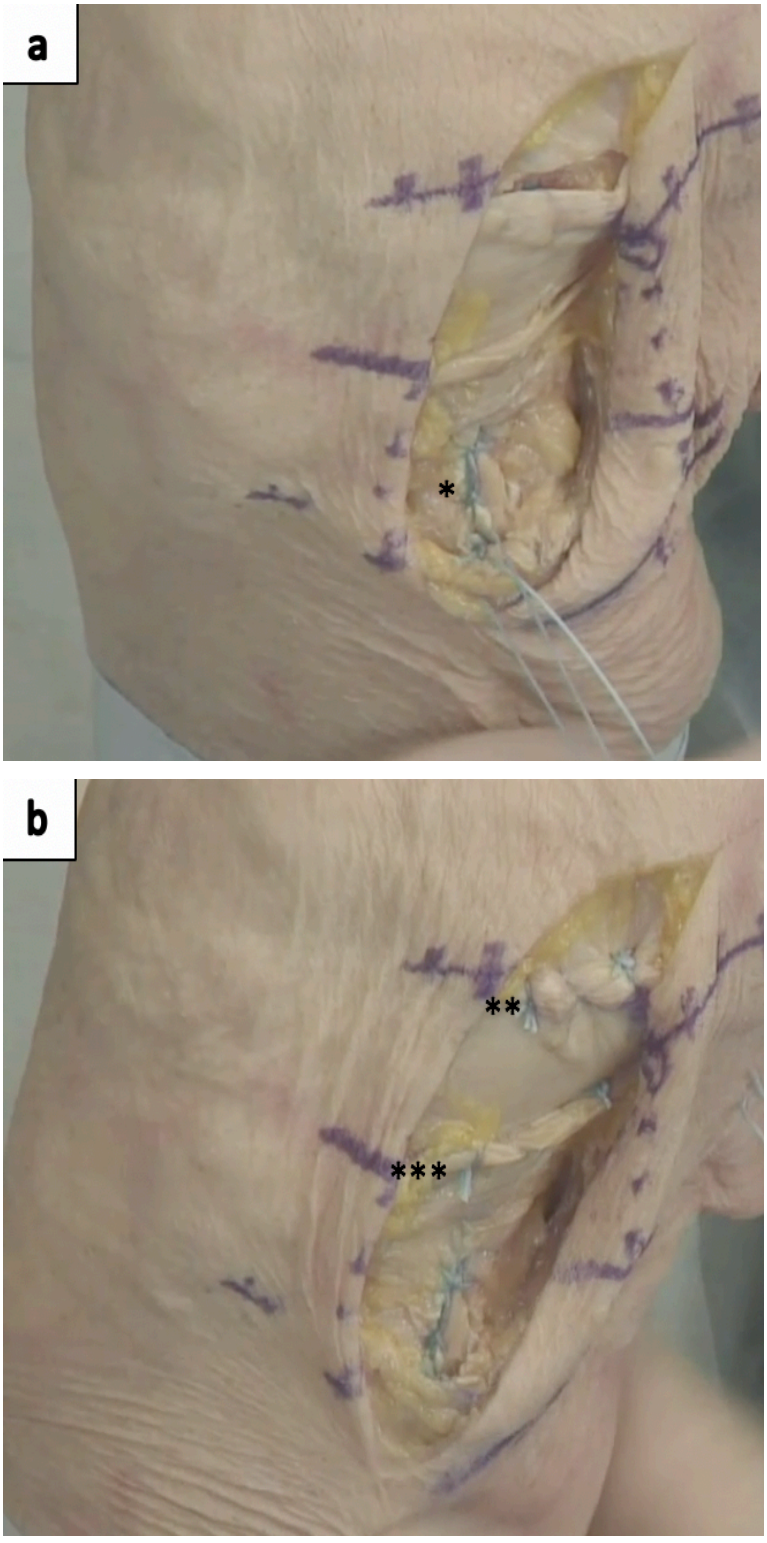



Figure 21. Left knee, lateral view. (a) Repair consists of the core suture from the anchor and the whipstitch around the biceps tendon (*) (b) Both incisions in the iliotibial band are then repaired (** and ***).

Patients are allowed to fully weight bear with crutches as required during the first weeks. Physical therapy focuses on early range of movement, muscle control and restoration of function. Patients are allowed to perform sports when the neuromuscular function has recovered. No brace is required. Advantages and Disadvantages as well as Pearls and Pitfalls of this technique are demonstrated in Tables 8 and 9.

| Advantages | Disadvantages |
|---|---|
| Simple and reproducible | Mild suture anchor irritation during end range extension |
| No graft harvest required | Synthetic augmentation |
| Facilitates rehabilitation | |

Table 8: Advantages and Disadvantages of PLC repair with suture tape augmentation

| Pearls | Pitfalls |
|---|---|
| Restoring the soft tissue balance around the head of the fibula | Excessive tensioning if not positioned in neutral |
| A full ROM with the foot in neutral should be established before insertion of the augmentation | Peroneal nerve exposure |
| Occasional sutures can be passed through the FibreTape to prevent cheese wiring of the soft tissues and to improve the overall strength of the construct | Popliteofibular ligament is not addressed. |

Table 9: Pearls and Pitfalls of PLC repair with suture tape augmentation

**Medial Patellofemoral Ligament Repair**

The patient is placed in the supine position and a tourniquet is placed on the upper thigh. The injured leg is prepared and draped in the surgeons preferred position similar to an MPFL reconstruction procedure. Appropriate landmarks are palpated and marked. (Figure 22) A short parapatellar incision is made exposing the medial border of the patella. A tissue plane is then established underneath the fascia and over the top of the MPFL. A second short incision is then made over the medial epicondyle. (Figure 23) Adequate exposure is obtained to ensure the correct placement of the suture tape.

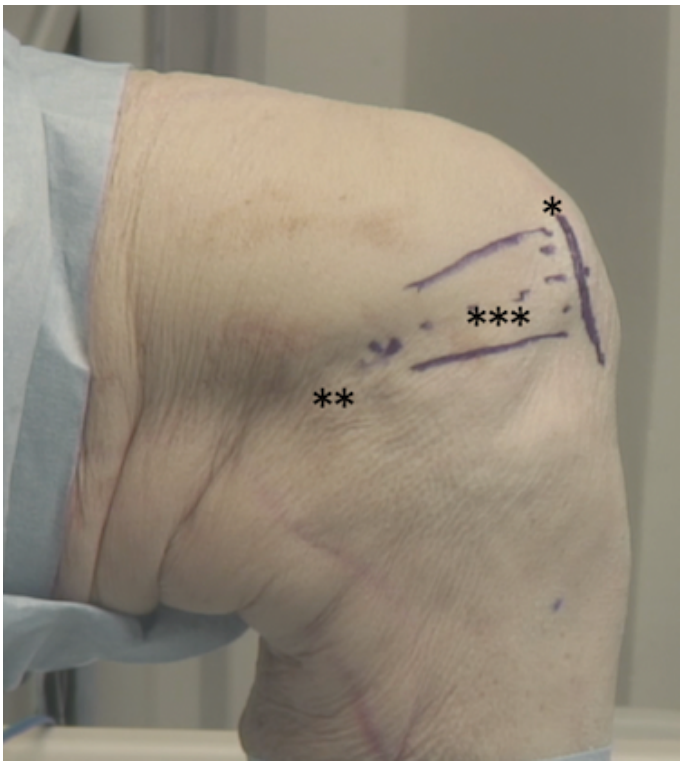
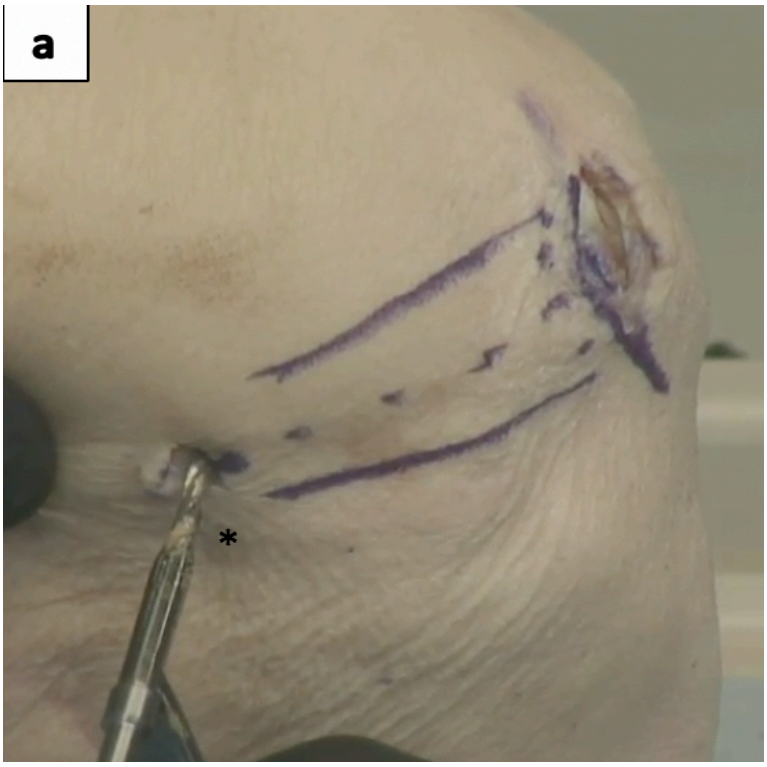
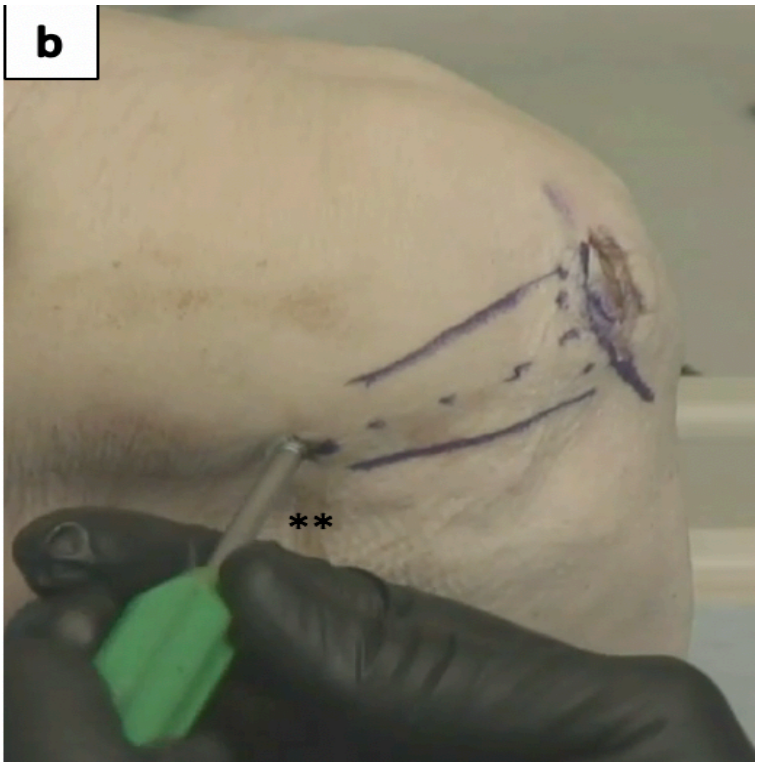



Figure 22: Left knee, medial view. Demonstrates the medial border of the patella (*), medial epicondyle (**) and the medial patellofemoral ligament (***)


Figure 23: Left knee, medial view. A short parapatellar incision (*) is made to expose the medial border of the patella then a stab incision (**) is made over the medial epicondyle

The next step is to pre-drill with a 4.5mm drill and tap just posterior and proximal to the medial epicondyle, ensuring to be perpendicular to the cortex. A 4.75 mm SwiveLock® (Arthrex) pre-loaded with FiberTape® (Arthrex) is then inserted, ensuring it is flush with the cortex. (Figure 24) The FiberTape® is an ultra-high strength 2 mm width tape, consisting of a long chain ultra-high molecular weight polyethylene (UHMWPE). The suture tape is then shuttled through the previously defined tissue plane to come out through the initial incision. (Figure 25)


a
*


b
**

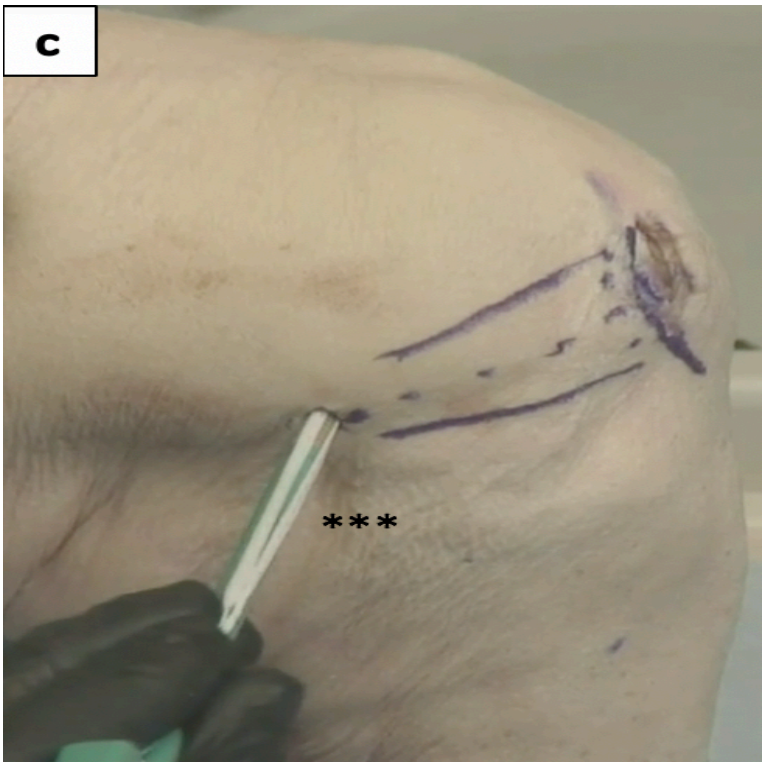



Figure 24. Left knee, medial view. (a,b) Preparation for the anchor by pre-drilling (*) and tapping (**) just posterior and proximal to the medial epicondyle. (c) The anchor preloaded with the suture tape (***) is then inserted ensuring to be flush with the cortex.

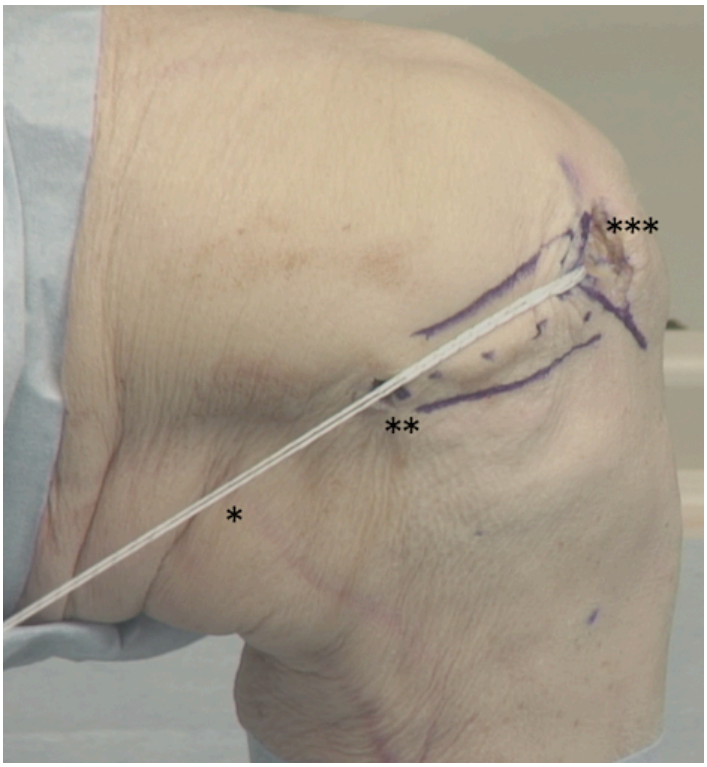



Figure 25: Left knee, medial view. The suture tape (*) has been shuttled from the medial epicondyle (**) towards the medial border of the patella (***) in the direction of the MPFL.

The insertion of the MPFL on the medial border of the patella is then identified. Preparation is then carried out for a 3.5mm SwiveLock® (Arthrex) by pre-drilling and tapping. (Figure 26) It is important that the insertion point of the anchor is at the midpoint of the insertion of the MPFL at the anteromedial angle where the superior surface meets the medial wall. This allows the repair to be secured below. Primary repair of the MPFL is then performed using two suture anchors with FiberWire® (Arthrex) inserted into the medial border of the patella with one above and one below the initial anchor. (Figure 27) The 3.5mm anchor is then loaded with the suture tape and the knee taken through a full range of motion, with particular attention made to the tension on the suture tape during the first 20-30 degrees of flexion. A hemostat can be passed gently underneath during early flexion to ensure excessive tension has not been applied. Excessive tension at this point will result in postoperative irritation and could lead to quadriceps inhibition. The suture tape is marked at the laser line during early phase flexion to ensure that adequate length is provided and the patella is not over-constrained

as this will result in pain and ongoing restriction in function. It is then repositioned in the eye of the anchor at the marked level and finally the anchor is placed in the drill hole. (Figure 28)

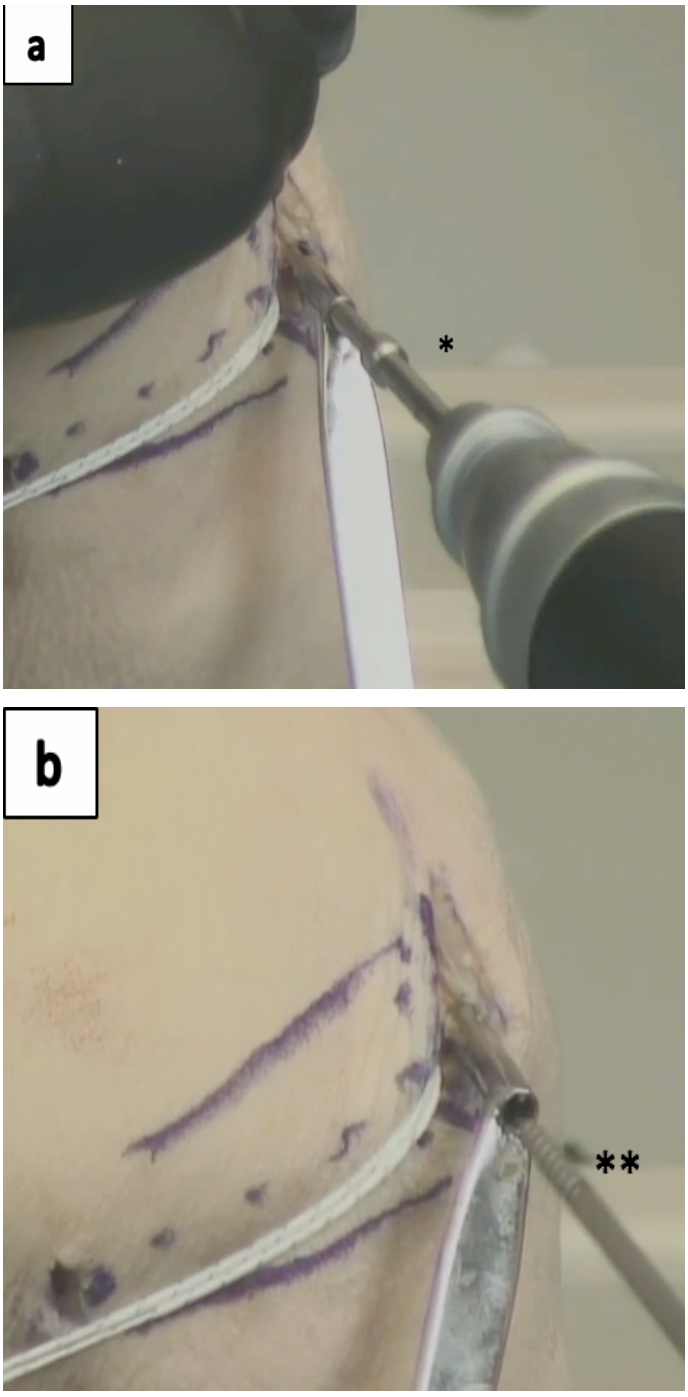



Figure 26: Left knee, medial view. (a,b) preparation is carried out for the second anchor by predrilling (*) and tapping (**) at the anteromedial angle of the patella where the superior surface meets the medial wall

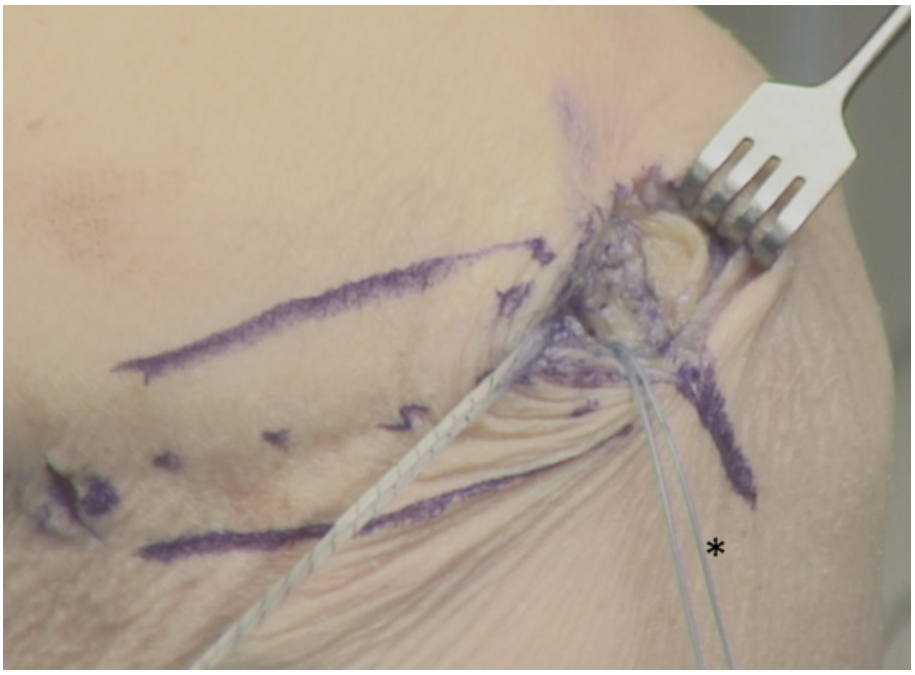


Figure 27: Left knee, medial view. MPFL repair using FiberWire® (*)

Figure 28: Left knee, medial view. The suture tape is repositioned in the eye of the anchor at the marked level (*) to ensure the anatomical length of the MPFL is restored.

The rehabilitation protocol could be compared with an accelerated MPFL reconstruction protocol. Patients are allowed to fully weight bear with crutches as required during the first weeks. Physical therapy focuses on early range of movement, muscle control and restoration of function. This is facilitated by the limited pain and swelling, allowing accelerated early phase rehabilitation. Moreover, the anchor in the dense bone of the patella and the angulation of the suture tape augmentation provides a very secure fixation that can mimic the strength of the native MPFL. Patients are allowed to perform sports if the neuromuscular function has recovered. No brace is required.

Advantages and Disadvantages as well as Pearls and Pitfalls of this technique are outlined in Tables 10 and 11.

| Advantages | Disadvantages |
|---|---|
| Simple and reproducible | Synthetic augmentation |
| No graft harvest required | Medial epicondyle tenderness |
| Facilitates rehabilitation | |
| Minimal surgical morbidity | |

Table 10: Advantages and Disadvantages of MPFL repair with suture tape augmentation

| Pearls | Pitfalls |
|---|---|
| The use of ultrasound may give some surgeons additional confidence when identifying the medial epicondyle[77] | Important to establish anatomical accuracy |
| Ensure excessive constraint not applied | Excessive tension will result in postoperative irritation and may lead to quadriceps inhibition |
| Tension the suture tape during the first 20-30 degrees of flexion | |

Table 11: Pearls and Pitfalls of MPFL repair with suture tape augmentation

# Chapter 3 – Patient-Reported Outcome Measures

## Clinical and Functional Evaluation

I became involved with the patient-reported outcome measures in 2015 as an independent collector and reviewer of the data. I was not involved in any clinical assessment or any of the surgery. The data presented is a single surgeon case series.

Patients were evaluated prospectively using the Surgical Outcome System (SOS, Arthrex, Naples, Fl, USA). SOS is a web-based tool which sends questionnaires and Patient-Reported Outcome Measures (PROMs) by e-mail at prescheduled time-points, after informed consent was given by the patient preoperatively. Prior to introducing the SOS system and analyzing the prospective follow-up data, permission was sought from the local medical ethic committee. The committee approved this analysis and deemed further institutional review board approval unnecessary.

The PROMS were already chosen prior to my involvement in this research by the senior author. The collected PROMs were the Knee Injury and Osteoarthritis Outcome Score (KOOS) which is a validated outcome score for patients following ACL surgery (Appendix 1), the Western Ontario and McMaster Universities Osteoarthritis index (WOMAC) which is a validated scoring system for patients with osteoarthritis and aimed more for our longer term follow-up (Appendix 2), the Visual Analogue Pain Scale (VAS-pain) which is a validated scoring system for pain around the knee (Appendix 3), the Veterans RAND 12 Item Health Survey (VR-12) which is an established scoring system with widespread use to assess a patients physical and psychological health status (Appendix 4) and the Marx Activity Scale which measures activity levels of patients and is important in this patient population (Appendix 5). [31,117,129,141,145] If I was involved in the selection of these PROMS in the beginning I would have used a number of different scores. These would have included the Lysholm score which is designed to evaluate symptoms following knee ligament surgery, the Tegner activity level which complements the Lysholm score and the International Knee Documentation Committee (IKDC) score which was also designed for knee ligament injuries. [70,167] Additionally, I would have arranged follow-up for

clinical assessment, however, this would have been difficult as all of the patients have been treated in the private sector.

Data was collected preoperatively and at 12, 24 and 60 months postoperatively. Additionally, a standard questionnaire was completed to ask the patients who did not have any further surgery about their overall satisfaction with regards to reducing pain, improving movement, resuming normal function and resuming sport (Appendix 6). All of the patients were also contacted by email/telephone at the time of this analysis to collect data about any complications.

Descriptive statistics were calculated to summarise the demographics and clinical characteristics and described with means +/- standard deviations with ranges. Analysis of variance was used to compare the preoperative and postoperative patient-reported outcome measures after confirmation of normally distributed data using a Shapiro-Wilk test. Tukey-Kramer testing was used to compare all pairs. Results were considered significant if $p < 0.05$. All analyses were performed by a statistician (SV) with JMP, version 14 (SAS Institute Inc., Cary, North Carolina, USA)

## Anterior Cruciate Ligament Repair

### Demographics

Between September 2011 and February 2014, 37 patients with an acute proximal ACL rupture underwent ACL repair with suture tape augmentation and were included in this study. These patients were prospectively followed up for a minimum of 5-years postoperatively. Patients with midsubstance and distal ACL ruptures or retracted ACL remnants in this timeframe underwent a standard ACL reconstruction. (Figure 29) Patients with multiligament knee injuries and chronic ruptures were excluded. 3 patients were lost to follow-up leaving 34 patients in the final analysis (91.9%).

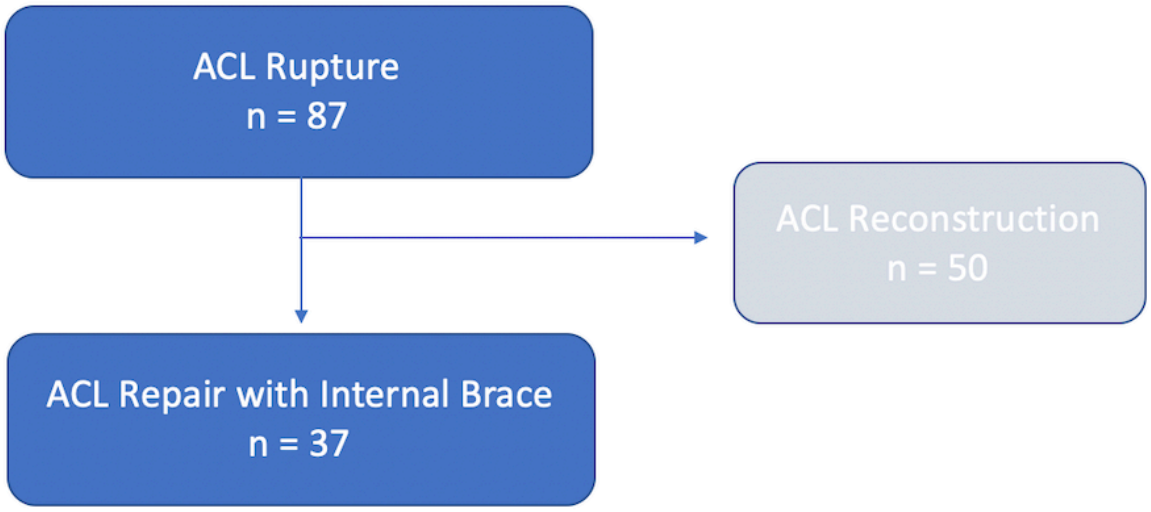



Figure 29: Enrollment flowchart

Mean follow-up was 68.0 (+/- 6.0) months (range, 60-89 months). The mean age at the time of surgery was 37.8 (+/-15.5) years (range, 13-60). 18 patients were male and 16 patients were female.

### Complications

6 patients suffered from a re-rupture (17.6%). One patient had a re-rupture at five months after returning to football and landing in valgus after a mid-air collision.

The second patient had a re-rupture after 15 months and he was also playing football at the time of injury. The other 4 patients suffered from a re-rupture between 2 and 5 years postoperatively and all involved trauma during sport. All of these patients underwent a standard ACL reconstruction for their revision surgery and have had no issues since then. No other complications or further surgery on the knee were reported. The 6 patients in the re-rupture group were found to be significantly younger than the rest of the patients (p=0.017) as summarized in Figure 30 and Table 12. No significant differences were found with gender.

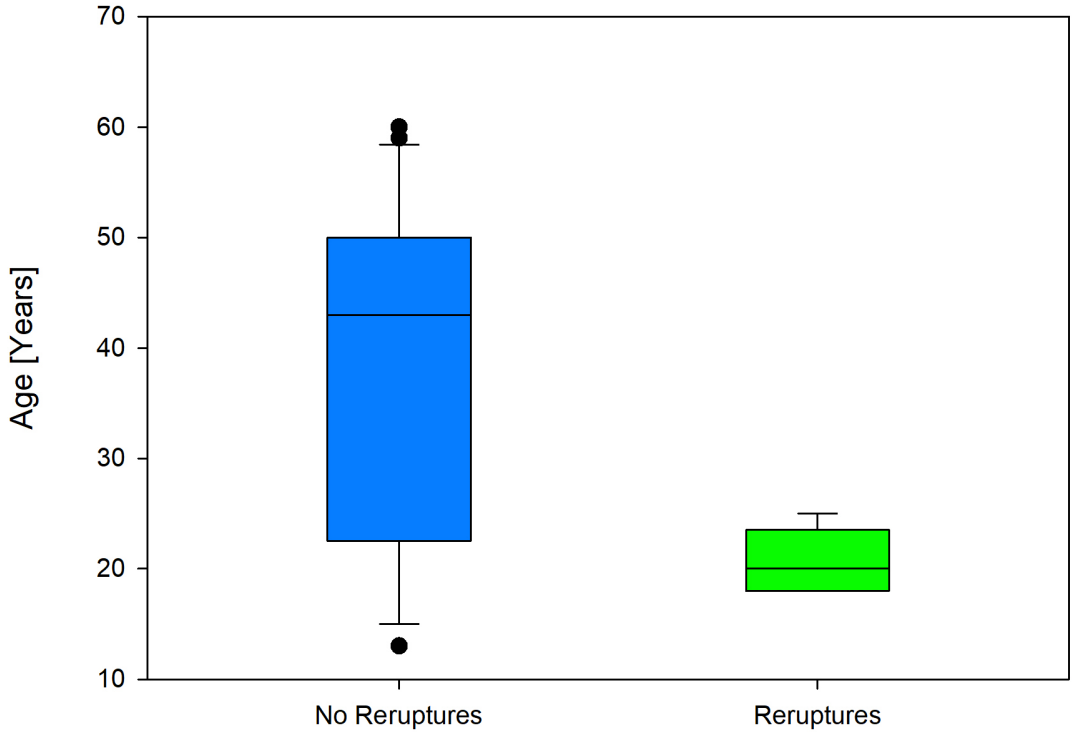



Figure 30: Graph demonstrating the significant differences in age between the re-rupture group and the rest of the patients.

| Age at time of surgery | ≤25 | >25 |
|---|---|---|
| Number of patients | 14 | 20 |
| Re-ruptures | 6 | 0 |
| % Re-ruptures | 42.9 | 0 |

Table 12: This data again demonstrates the higher rate of re-ruptures in the younger patients

The 6 patients in the re-rupture group were excluded from the subsequent PROMs data therefore 28 patients were included for analysis. However, separate analyses were carried out to see if there were any significant differences between the re-rupture group and the rest of the patients.

**Knee Injury and Osteoarthritis Outcome Score (KOOS)**

All sections of the KOOS demonstrated significant improvements at 5-year follow-up ($p<0.0001$) as outlined in Figure 31.

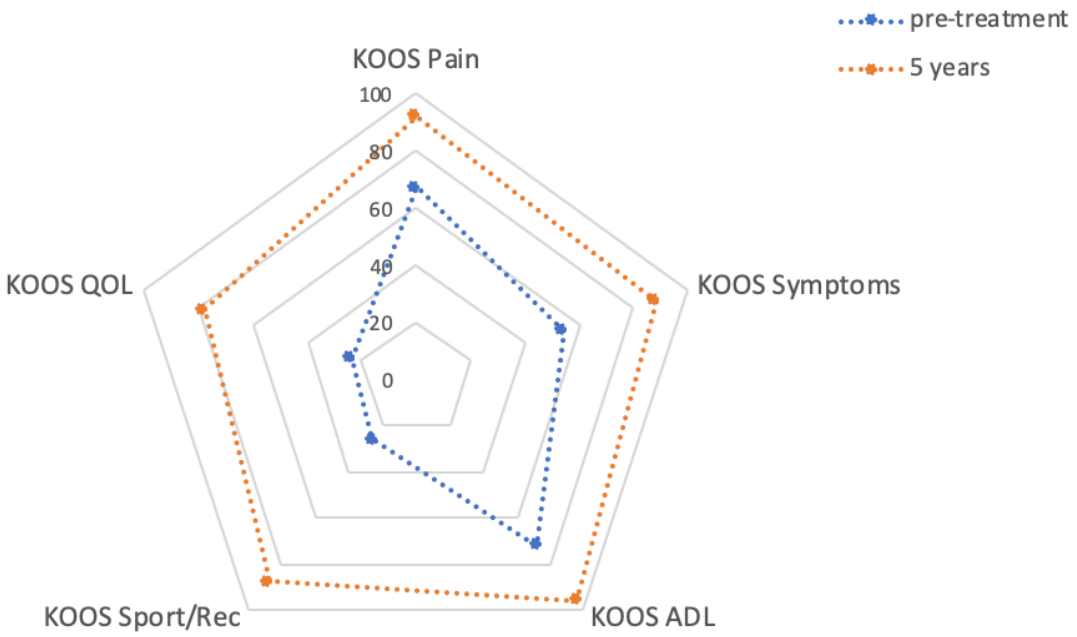



Figure 31: Spider chart demonstrating significant improvements at 5-year follow-up in all sub-sections of the KOOS.

The KOOS for pain was 67.0 preoperatively and increased significantly to 92.2 at 5-year follow-up ($p<0.0001$). The KOOS for symptoms was 54.1 preoperatively and increased significantly to 88.4 at 5-year follow-up ($p<0.0001$). The KOOS for ADLs was 72.0 preoperatively and increased significantly to 95.9 at 5-year follow-up ($p<0.0001$). The KOOS for Sport and Recreation was 26.2 preoperatively and increased significantly to 87.8 at 5-year follow-up ($p<0.0001$). The KOOS for Quality of Life was 24.0 preoperatively and increased significantly to 78.0 at 5-year follow-up ($p<0.0001$). No significant differences were seen between the

different postoperative time intervals for any of the KOOS subsections. (Figures 32-36)

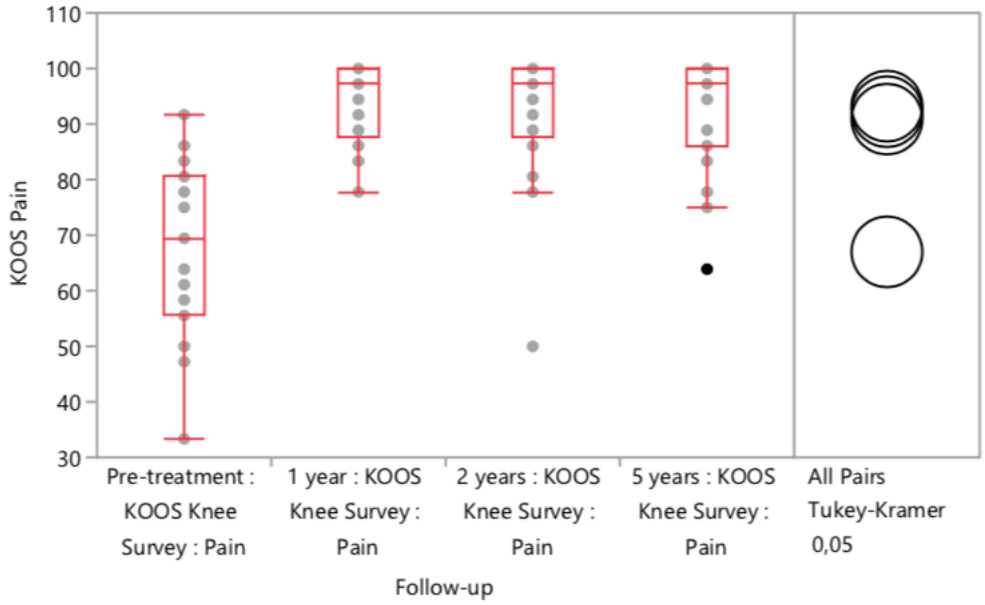



Figure 32: Chart demonstrating the KOOS for pain at the different time intervals

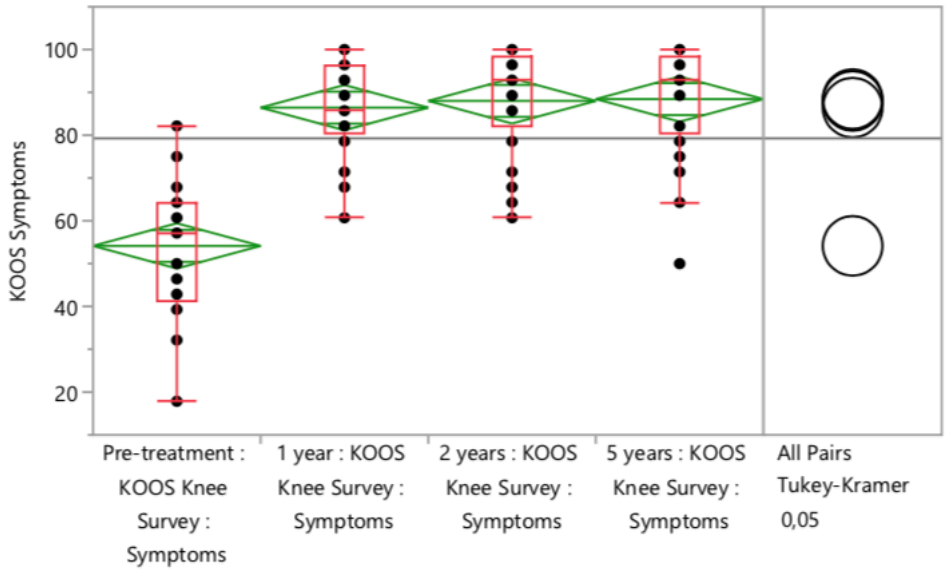



Figure 33: Chart demonstrating the KOOS for symptoms at the different time intervals

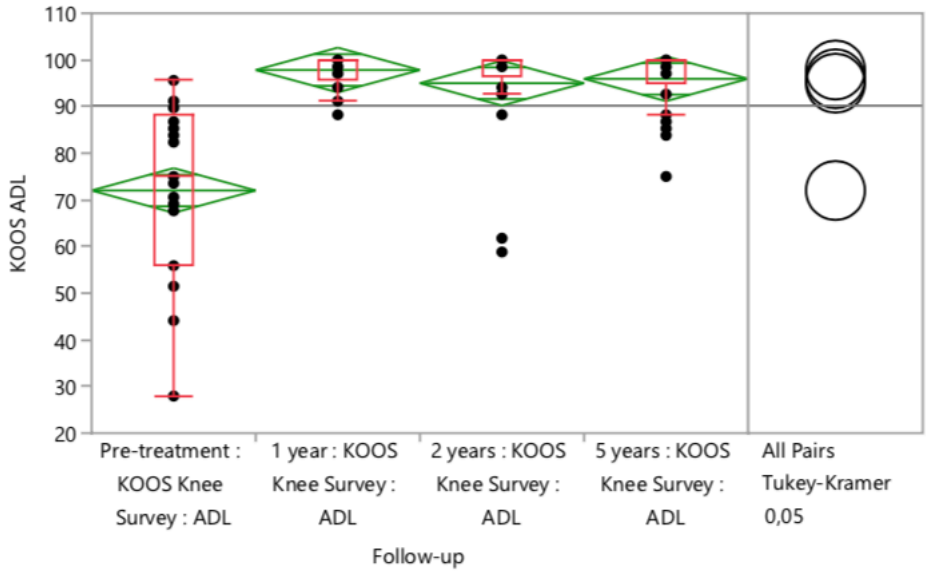



Figure 34: Chart demonstrating the KOOS for ADLs at the different time intervals

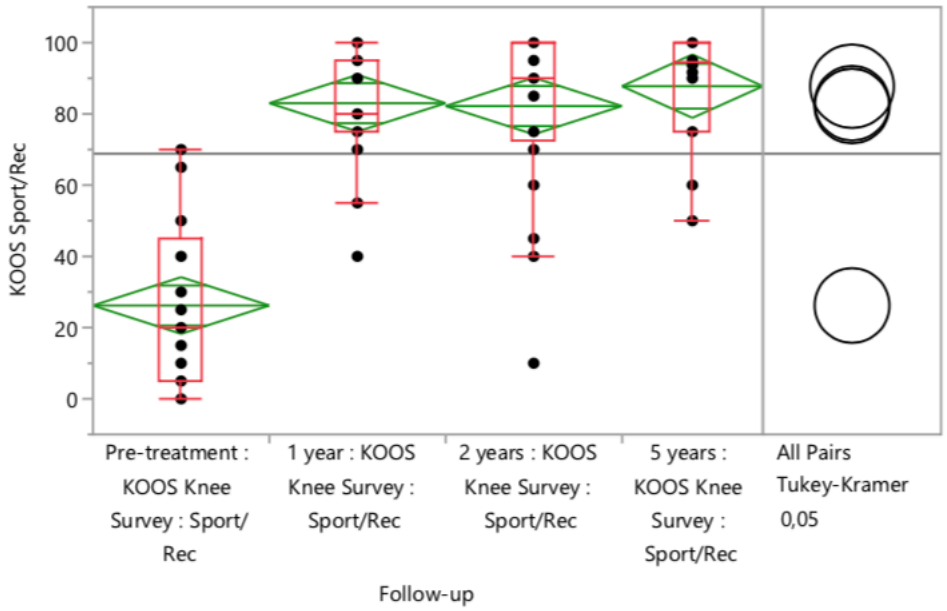



Figure 35: Chart demonstrating the KOOS for sport and recreation at the different time intervals

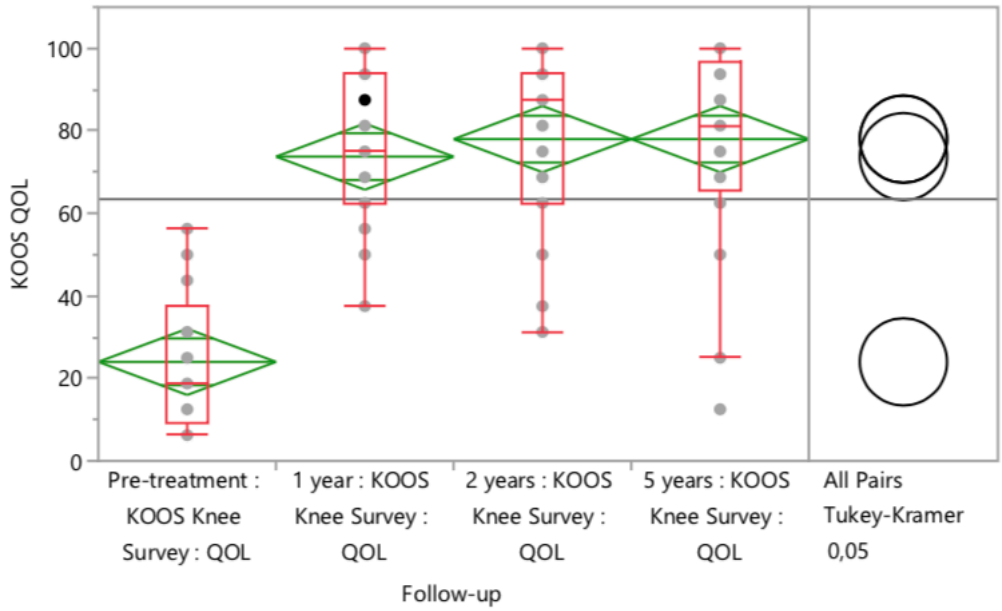



Figure 36: Chart demonstrating the KOOS for quality of life at the different time intervals

Additionally, no differences were seen between the KOOS in the re-rupture group when compared to those who did not suffer from a re-rupture.

**Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)**

All sections of the WOMAC demonstrated significant improvements at 5-year follow-up ($p<0.0001$) as outlined in Figure 37.

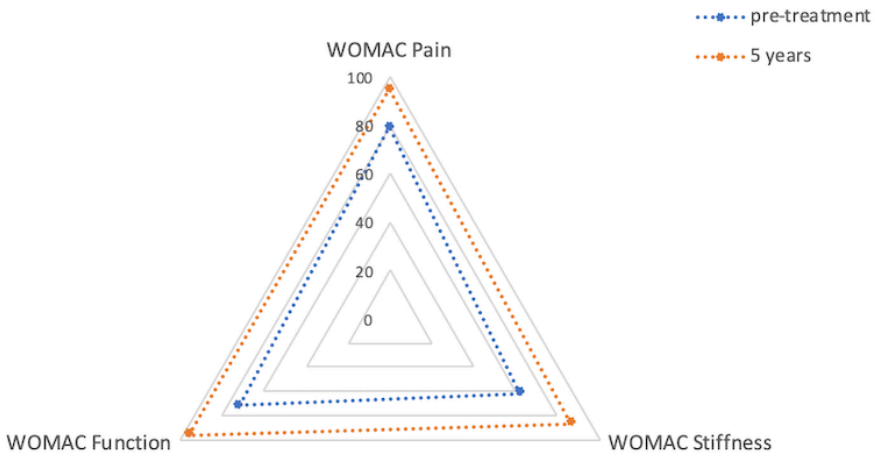



Figure 37: Spider chart demonstrating significant improvements at 5-year follow-up in all sub-sections of the WOMAC score.

The WOMAC for pain was 79.0 preoperatively and increased significantly to 94.8 at 5-year follow-up ($p<0.0001$). The WOMAC for stiffness was 62.0 preoperatively and increased significantly to 86.5 at 5-year follow-up ($p<0.0001$). The WOMAC for function was 72.0 preoperatively and increased significantly to 95.9 at 5-year follow-up ($p<0.0001$). No significant differences were seen between the different postoperative time intervals for any of the WOMAC subsections. (Figures 38-40)

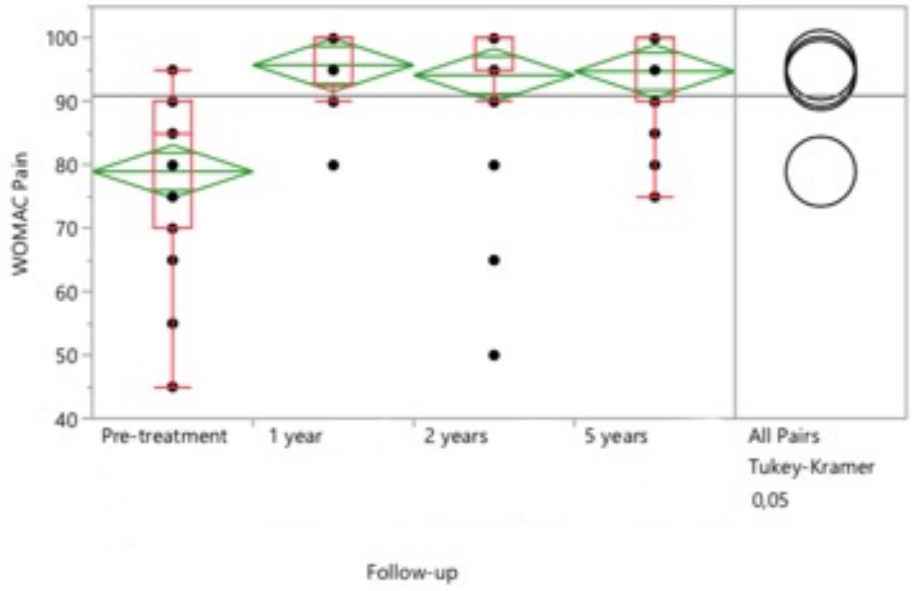



Figure 38: Chart demonstrating the WOMAC for pain at the different time intervals

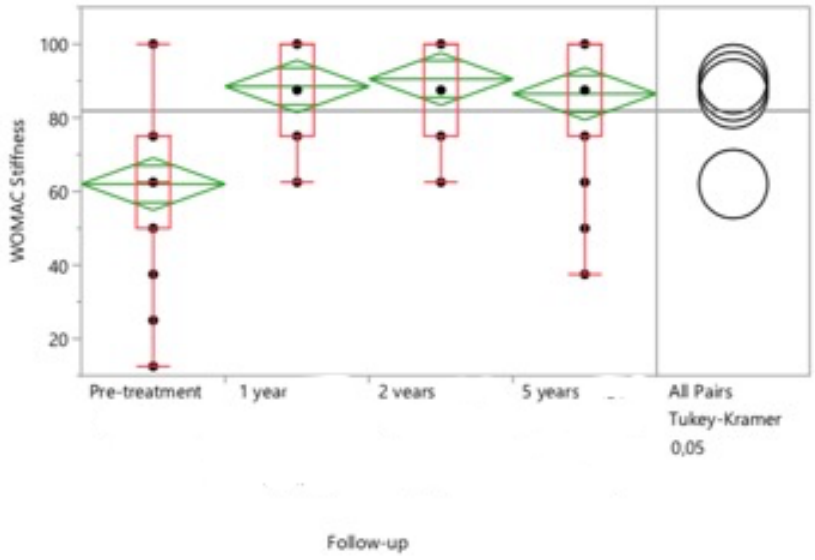



Figure 39: Chart demonstrating the WOMAC for stiffness at the different time intervals

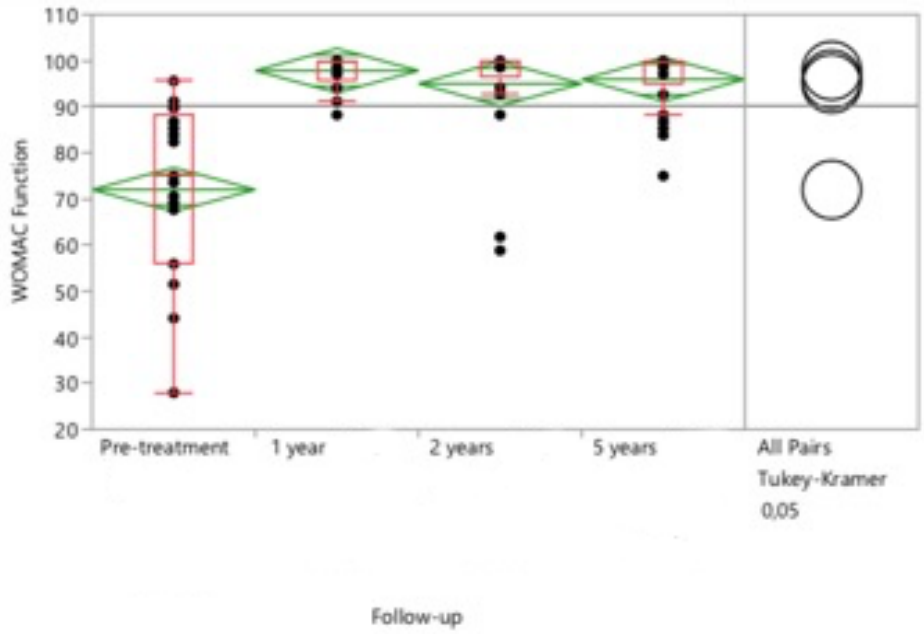



Figure 40: Chart demonstrating the WOMAC for function at the different time intervals

Additionally, no differences were seen between the WOMAC scores in the re-rupture group when compared to those who did not suffer from a re-rupture.

**Visual Analogue Pain Scale (VAS)**

The VAS for pain decreased significantly from 2.3 preoperatively to 1.0 at 5-year follow-up (Figure 41). No significant differences were seen between the other postoperative time intervals. In addition, no differences were seen between the re-rupture group and the rest of the patients.

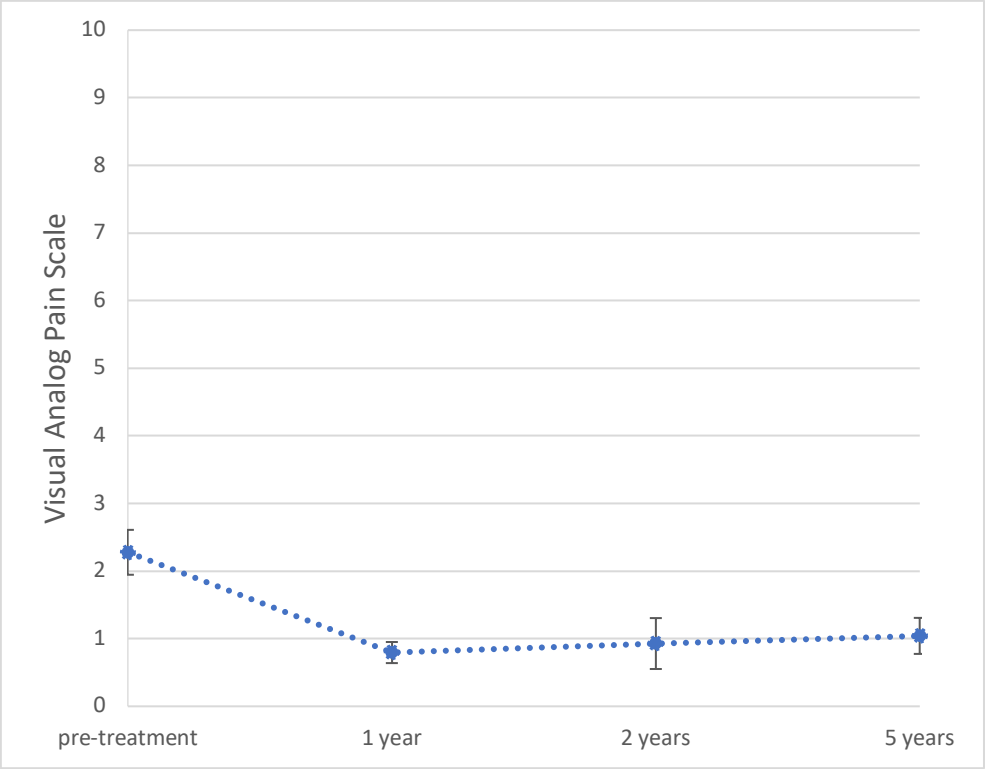



Figure 41: Line graph demonstrating the significant decrease in the VAS for pain from preoperatively to 5-year follow-up with no change between 1 year and 2 years and 2 years and 5 years.

**Veterans RAND 12 Item Health Survey (VR-12)**

The VR-12 physical score was 35.9 preoperatively and increased significantly to 52.4 at 5-year follow-up ($p<0.0001$). (Figure 42) The VR-12 mental score was 54.3 preoperatively and there was minimal change to 53.9 at 5-year follow-up ($p=0.68$). (Figure 43) No significant differences were seen between the different postoperative time intervals and no differences were shown between the re-rupture group and the other patients.

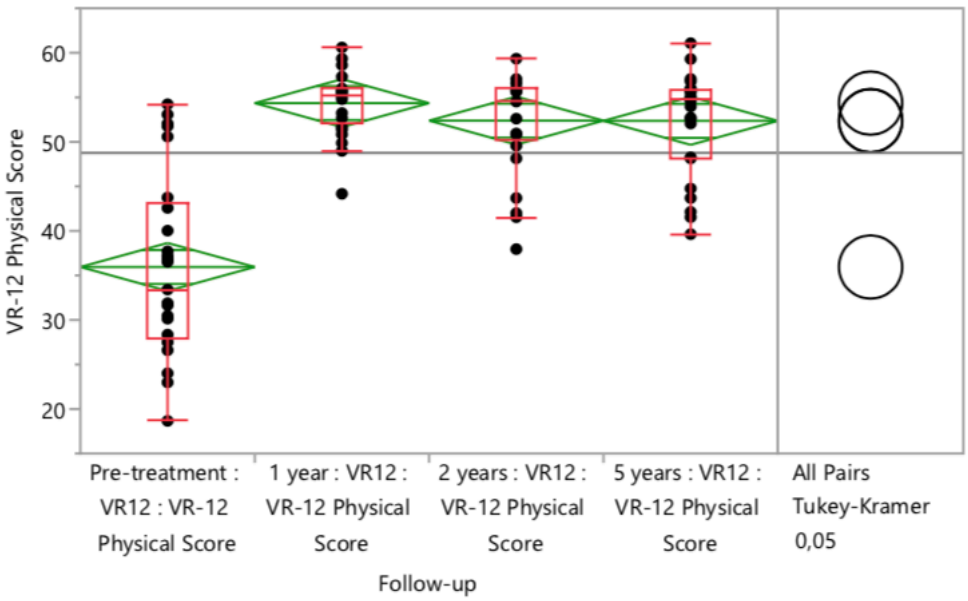



Figure 42: Chart demonstrating the VR-12 physical scores at the different time intervals

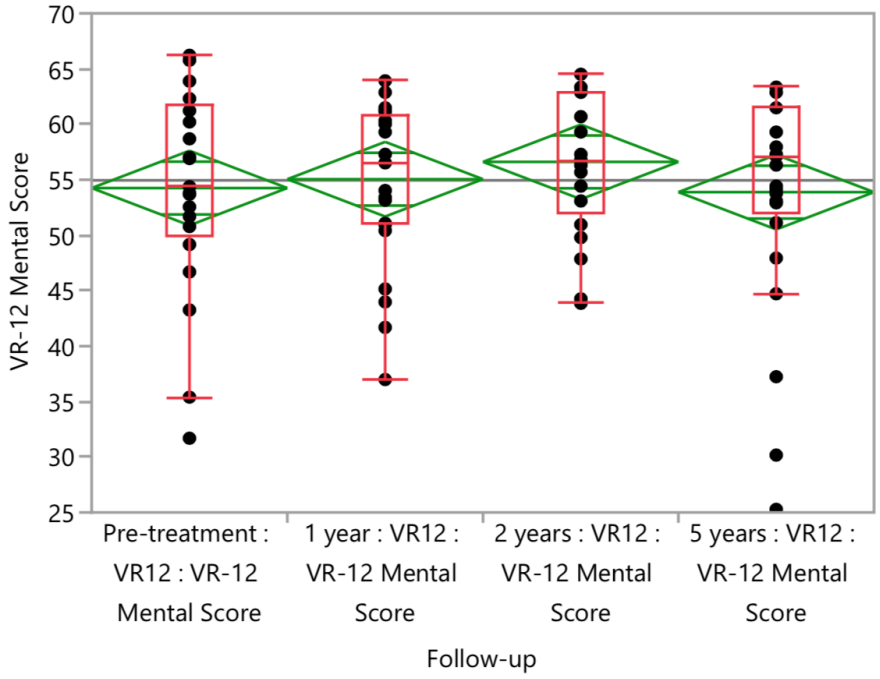



Figure 43: Chart demonstrating the VR-12 mental scores at the different time intervals

**Marx Activity Scale**

The Marx activity scale decreased significantly from 12.4 preoperatively to 7.3 at 5-year follow-up (p=0.02). There was also very little change between 1 year and 2 years and 2 years and 5 years postoperatively. Moreover, there was a significant difference between the re-rupture group and the other patients (p=0.04) as outlined in Figure 44 and Table 13.

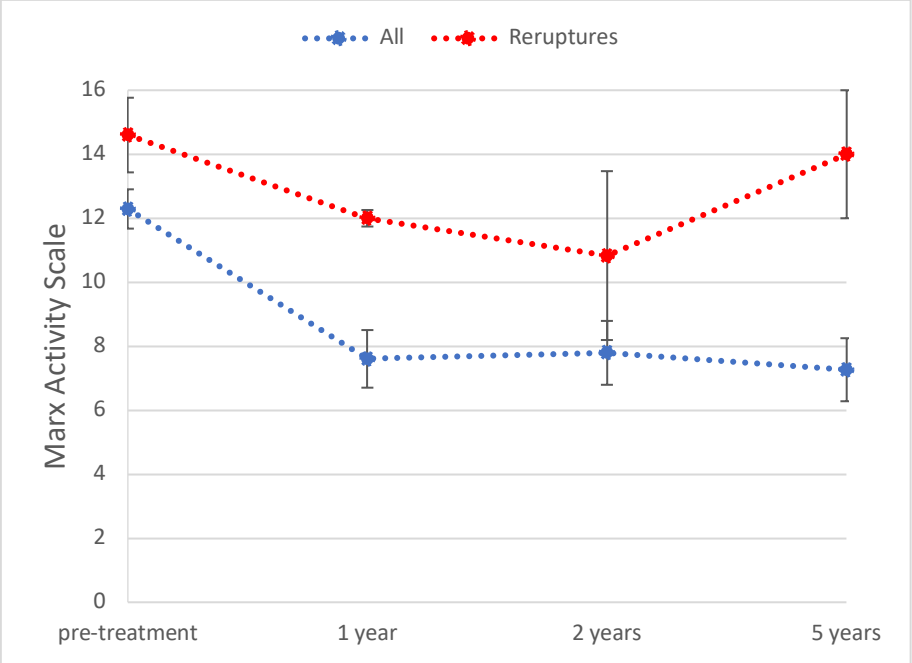



Figure 44: Line graph demonstrating an overall decrease in the Marx activity score and also a significant difference between the 2 groups.

| Marx Activity Scale Preoperatively | >14 | <14 |
|---|---|---|
| Number of patients | 13 | 21 |
| Re-ruptures | 5 | 1 |
| % Re-ruptures | 38.5 | 4.8 |

Table 13: This data again demonstrates the higher rate of re-ruptures in the patients participating in a higher level of activity.

**Overall satisfaction**

As outlined in Table 14, the majority of patients who did not suffer from a re-rupture were happy with their ACL repair with suture tape augmentation at 5-years. 96% of patients felt the surgery exceeded or met their expectations with regards to reducing pain. 100% of patients felt the surgery exceeded or met their expectations with regards to improving movement and strength of the knee as well as resuming normal functions of daily living. 85% of patients felt the surgery exceeded or met their expectations with regards to resuming normal sporting activities.

| | **Pain (% patients)** | **Movement (% patients)** | **Function (% patients)** | **Sports (% patients)** |
|---|---|---|---|---|
| **Exceeded expectations** | 57 | 61 | 57 | 39 |
| **Met expectations** | 39 | 39 | 43 | 46 |
| **Did not meet expectations** | 4 | - | - | 11 |
| **Not applicable** | - | - | - | 4 |

Table 14: This table demonstrates the overall satisfaction of patients at 5-year follow-up

## Anterolateral Ligament Repair

### Demographics

Between April 2014 and March 2017, 43 patients with an acute proximal ACL rupture who had an associated Segond fracture, Grade 3 pivot shift or patients with a high level of sporting activity underwent a combined ACL and ALL repair technique with suture tape augmentation and were included in this study. These patients were prospectively followed up for a minimum of 2-years postoperatively. Patients who had acute proximal ACL ruptures without the above risk factors underwent isolated ACL repair and patients with midsubstance and distal ACL ruptures or retracted ACL remnants underwent a standard ACL reconstruction (+/- ALL suture tape augmentation) in this timeframe. (Figure 45) Patients with multiligament knee injuries and chronic ruptures were excluded. 5 patients were lost to follow-up leaving 38 patients in the final analysis (88.4%).

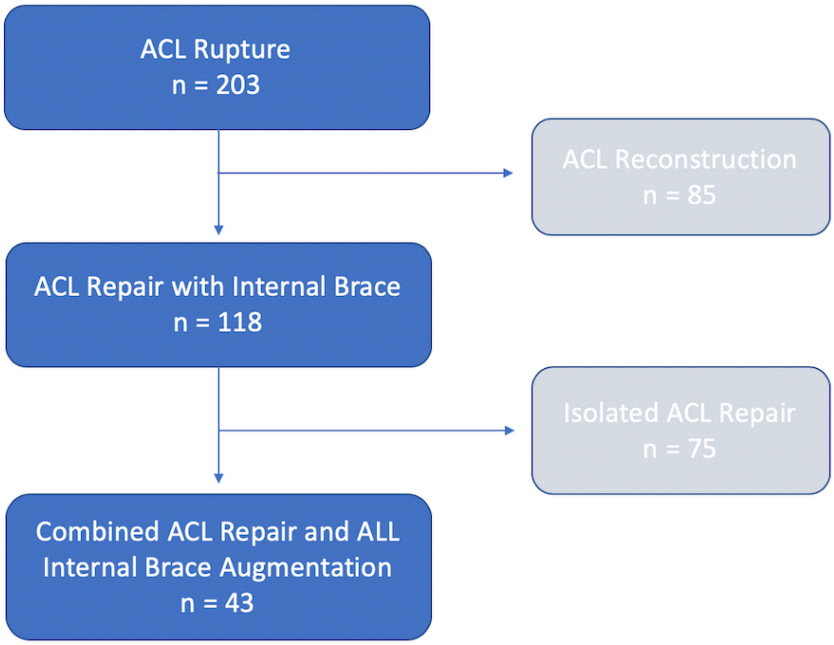



Figure 45: Enrollment flowchart

Mean follow-up was 44.8 (+/- 9.1) months (range, 24-59 months). The mean age at the time of surgery was 25.7 (+/-10.1) years (range, 13-56). 21 patients were male and 17 patients were female.

**Complications**

2 patients suffered from a re-rupture (5.3%). Both of these patients underwent a standard ACL reconstruction for their revision surgery and have had no issues since then. No other complications or further surgery on the knee were reported. No significant differences were found between the 2 patients in the re-rupture group and the other patients in terms of age, gender and patient-reported outcome measures.

**Knee Injury and Osteoarthritis Outcome Score (KOOS)**

All sections of the KOOS demonstrated significant improvements at 2-year follow-up as illustrated in Figure 46 ($p<0.0001$).

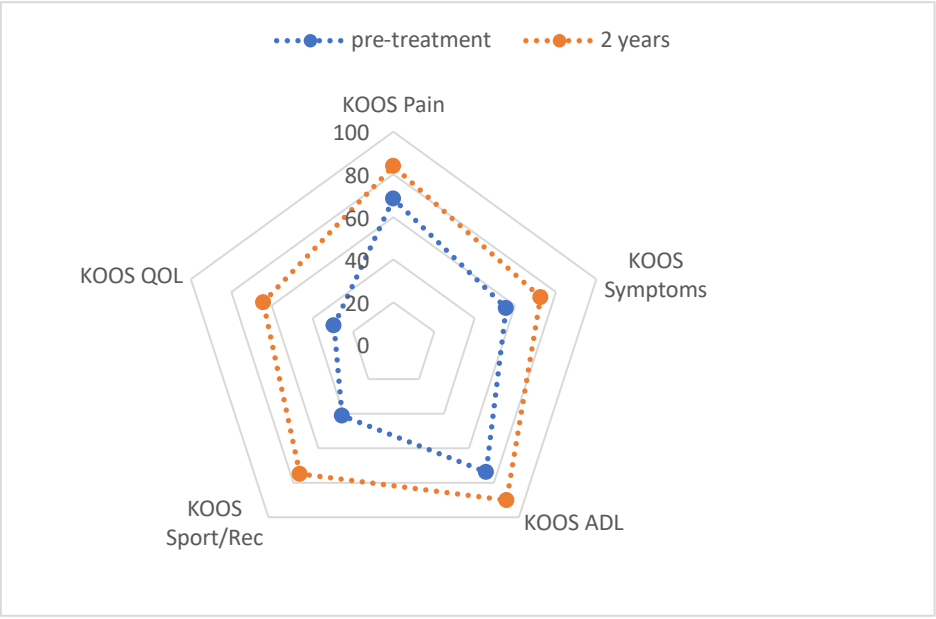



Figure 46: Spider chart demonstrating significant improvements at 2-year follow-up in all sub-sections of the KOOS.

The KOOS for pain was 64.9 preoperatively and increased significantly to 91.1 at 2-year follow-up ($p<0.0001$). The KOOS for symptoms was 58.6 preoperatively and increased significantly to 81.8 at 2-year follow-up ($p<0.0001$). The KOOS for ADLs was 75.0 preoperatively and increased significantly to 96.1 at 2-year follow-up

(p<0.0001). The KOOS for Sport and Recreation was 33.7 preoperatively and increased significantly to 82.8 at 2-year follow-up (p<0.0001). The KOOS for Quality of Life was 28.9 preoperatively and increased significantly to 74.3 at 2-year follow-up (p<0.0001). No significant differences were seen between the 1-year and 2-year time intervals for any of the KOOS subsections. (Figures 47-51)

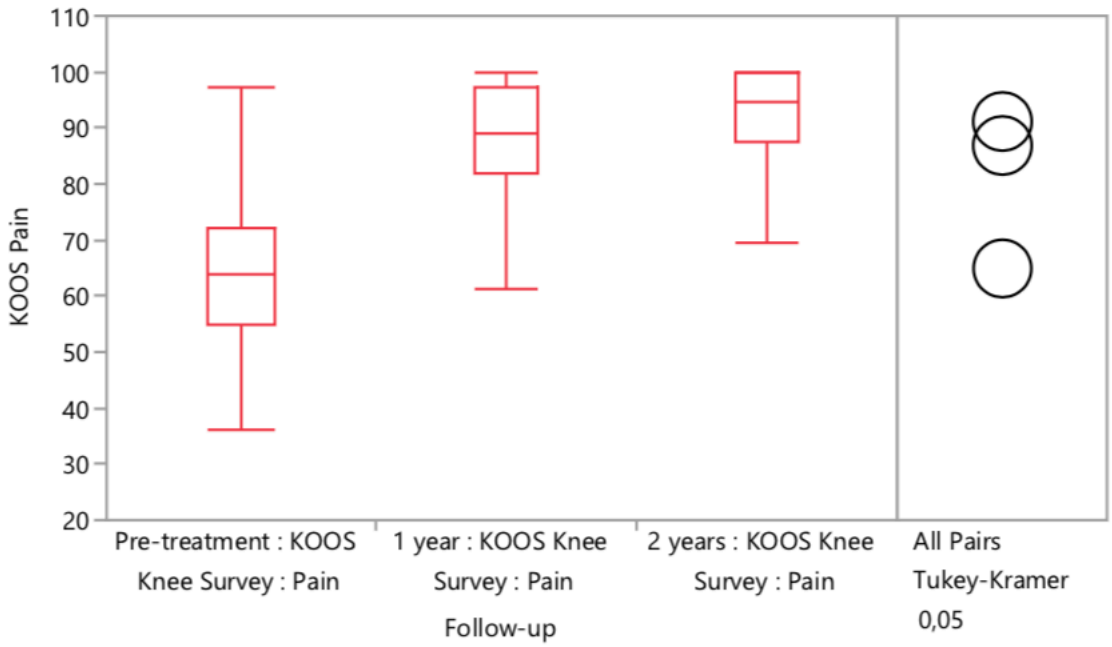



Figure 47: Chart demonstrating the KOOS for pain at the different time intervals

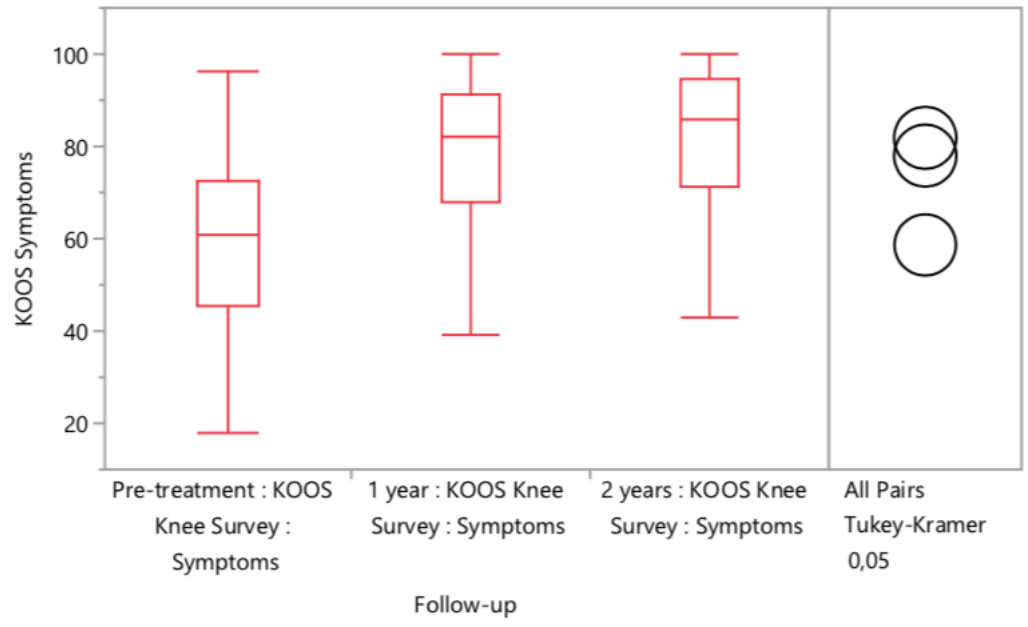



Figure 48: Chart demonstrating the KOOS for symptoms at the different time intervals

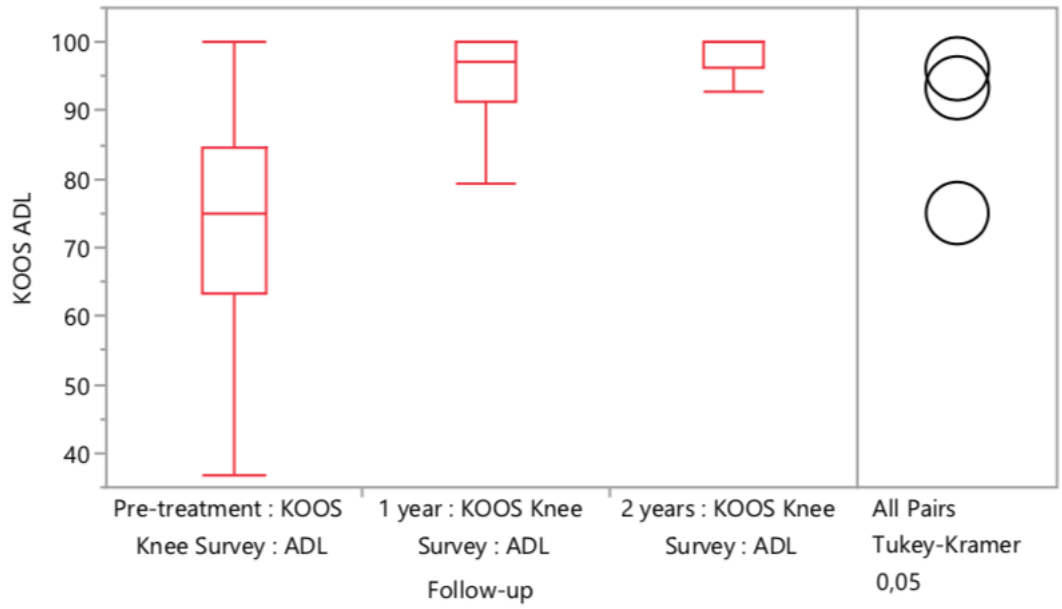



Figure 49: Chart demonstrating the KOOS for ADLs at the different time intervals

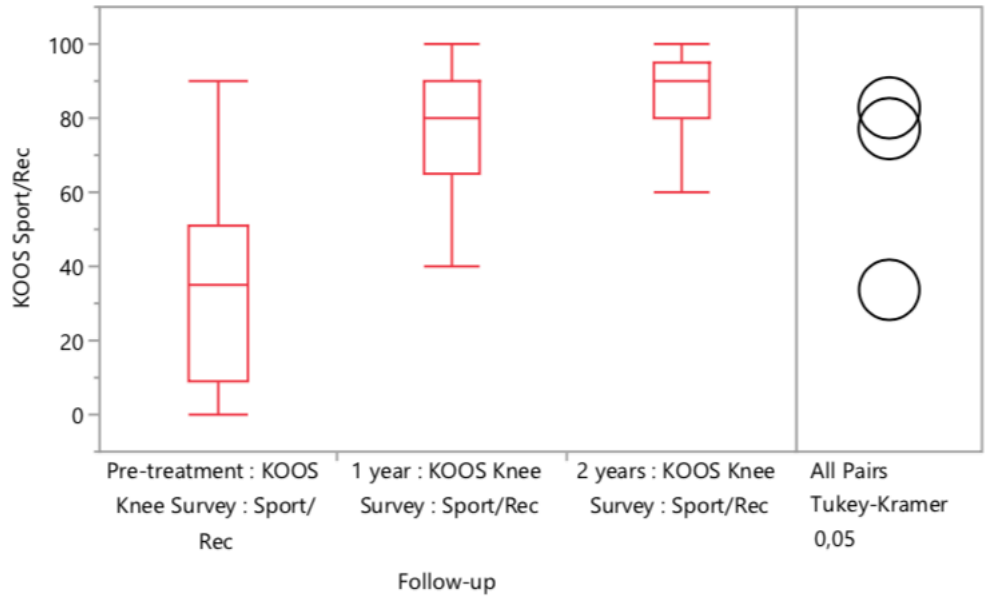



Figure 50: Chart demonstrating the KOOS for sport and recreation at the different time intervals

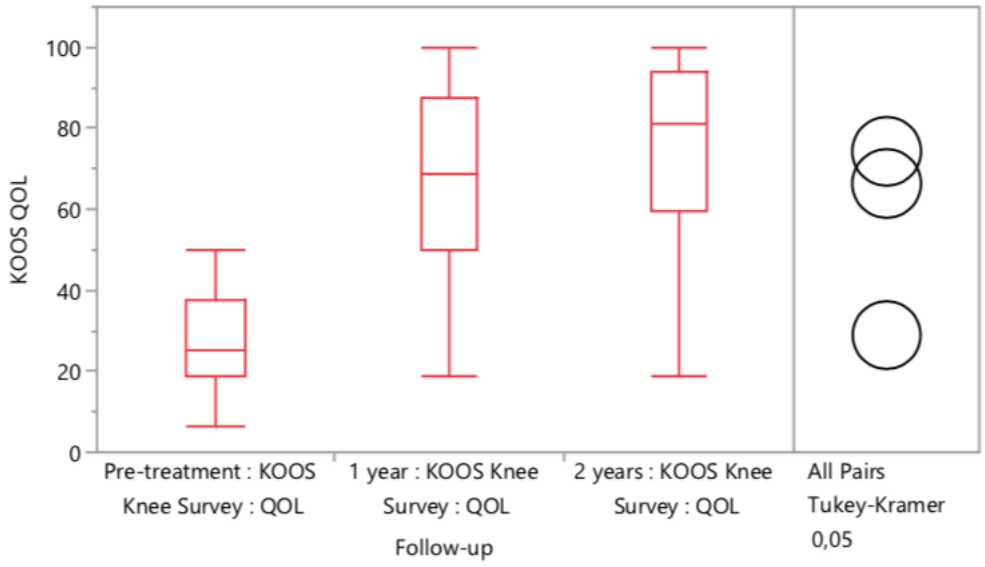



Figure 51: Chart demonstrating the KOOS for quality of life at the different time intervals

**Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)**

All sections of the WOMAC demonstrated significant improvements at 2-year follow-up as illustrated in Figure 52 ($p<0.0001$).

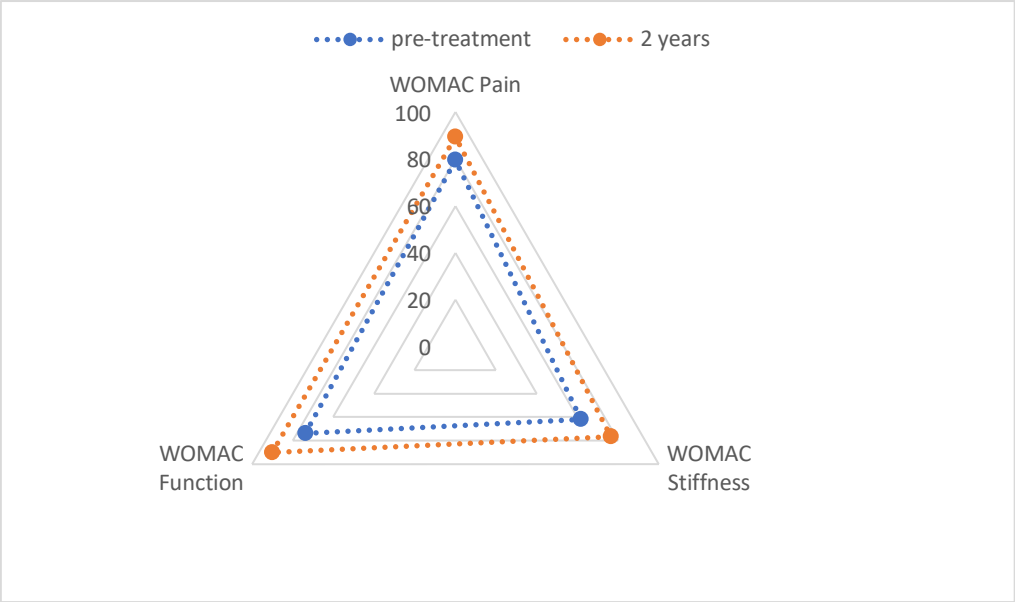



Figure 52: Spider chart demonstrating significant improvements at 2-year follow-up in all sub-sections of the WOMAC.

The WOMAC for pain was 77.5 preoperatively and increased significantly to 94.6 at 2-year follow-up ($p<0.0001$). The WOMAC for stiffness was 65.3 preoperatively and increased significantly to 88.6 at 2-year follow-up ($p<0.0001$). The WOMAC for function was 75.0 preoperatively and increased significantly to 96.0 at 2-year follow-up ($p<0.0001$). No significant differences were seen between the different postoperative time intervals for any of the WOMAC subsections. (Figures 53-55)

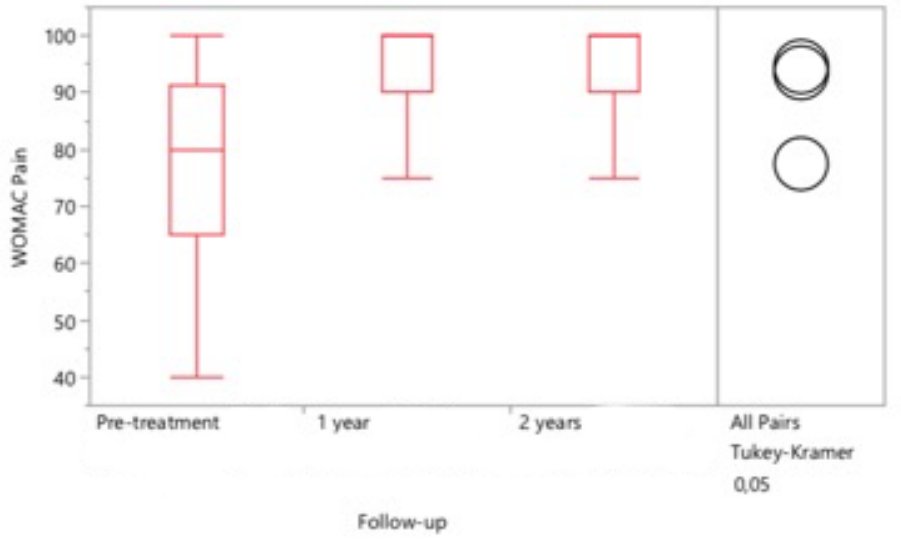



Figure 53: Chart demonstrating the WOMAC for pain at the different time intervals

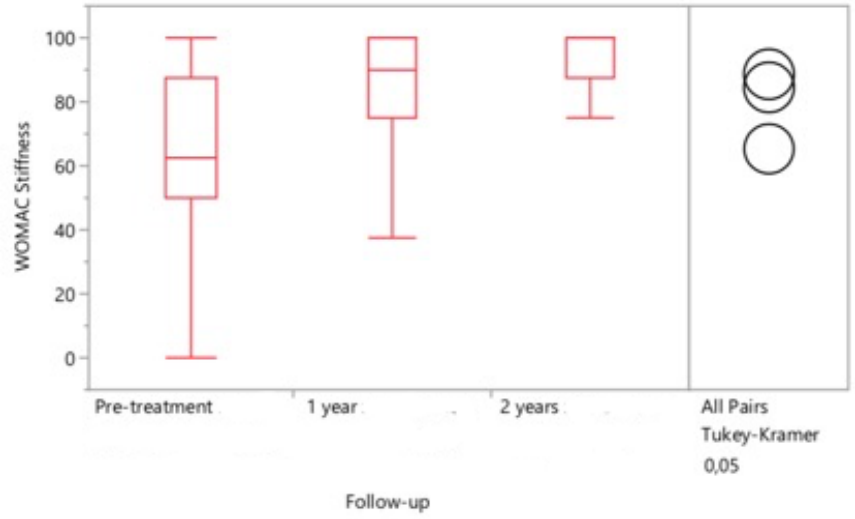



Figure 54: Chart demonstrating the WOMAC for stiffness at the different time intervals

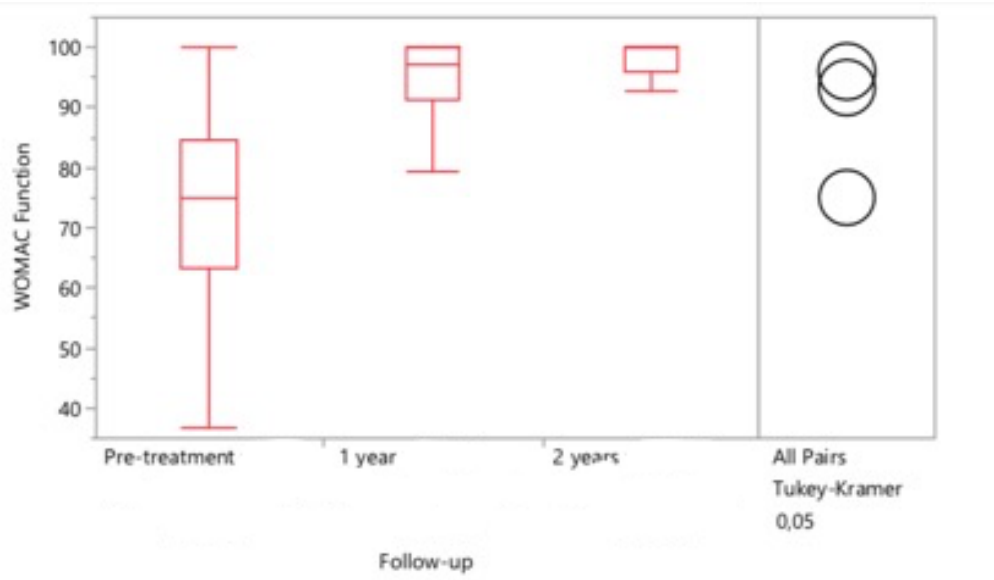



Figure 55: Chart demonstrating the WOMAC for function at the different time intervals

**Visual Analogue Pain Scale (VAS)**

The VAS for pain decreased significantly from 3.4 preoperatively to 0.7 at 2-year follow-up ($p<0.0001$). (Figure 56) No significant differences were seen between the 1-year and 2-year postoperative time intervals.

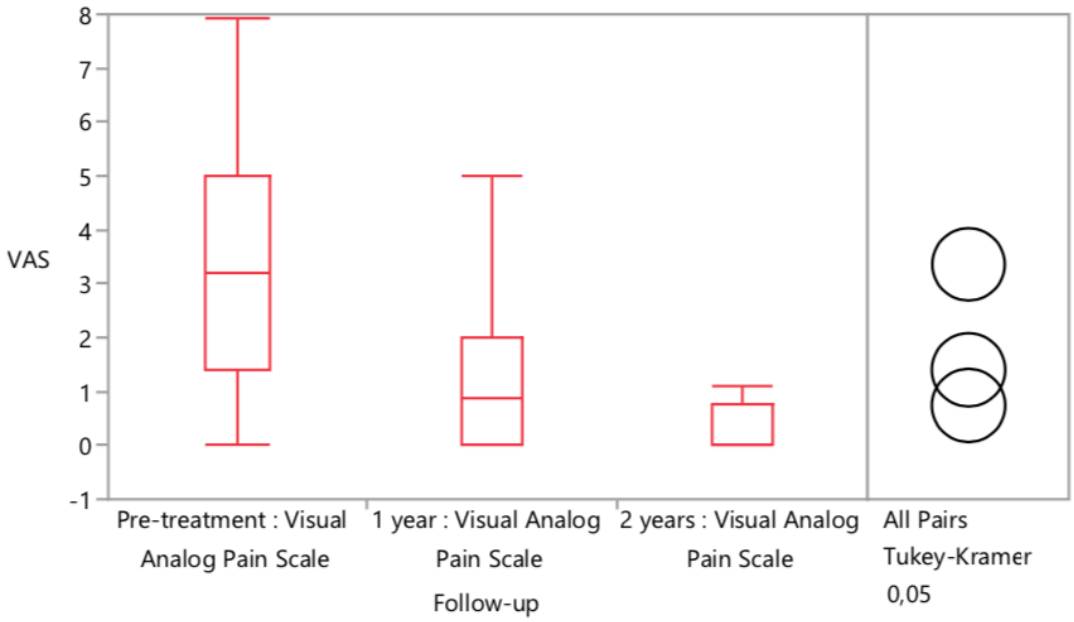



Figure 56: Chart demonstrating a significant decrease in pain scores from preoperatively to 2-year postoperatively.

**Veterans RAND 12 Item Health Survey (VR-12)**

The VR-12 physical score was 34.4 preoperatively and increased significantly to 52.7 at 2-year follow-up ($p<0.0001$). (Figure 57) The VR-12 mental score was 51.6 preoperatively and this increased to 55.8 at 2-year follow-up, however, this was not significant ($p=0.07$). (Figure 58) No significant differences were seen between the 1-year and 2-year postoperative time intervals.

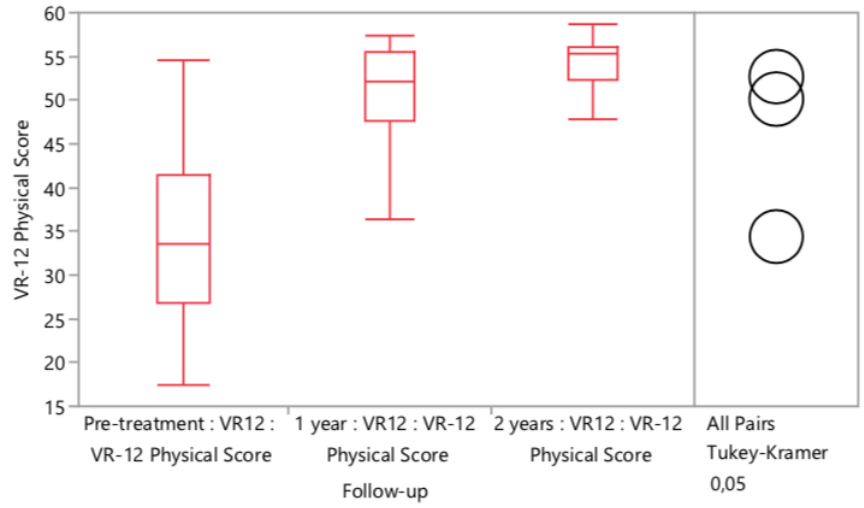



Figure 57: Chart demonstrating the VR-12 physical scores at the different time intervals

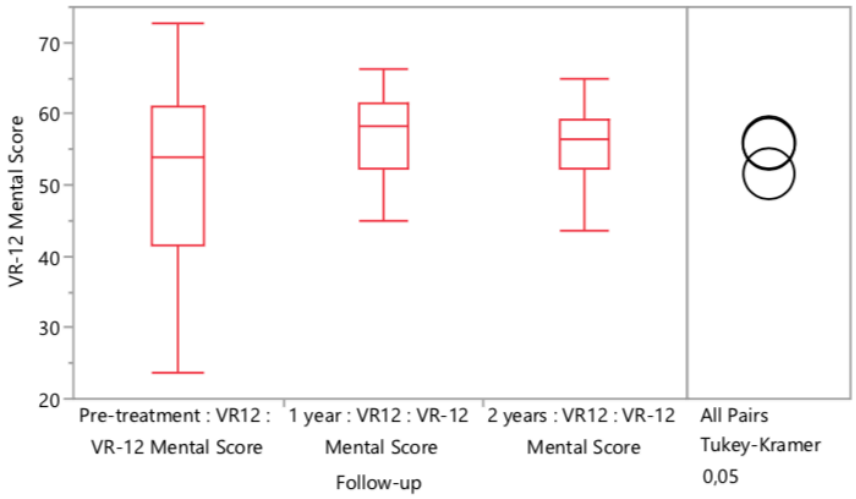



Figure 58: Chart demonstrating the VR-12 physical scores at the different time intervals

**Marx Activity Scale**

The Marx activity scale decreased significantly from 13.3 preoperatively to 10.6 at 2-year follow-up (p=0.01). There was also very little change in the scores between 1-year and 2-years postoperatively. (Figure 59) However, there was no significant difference between the re-rupture group and the other patients (p=0.04) comparable with the ACL repair group as outlined in Figure 60 albeit these were small numbers.

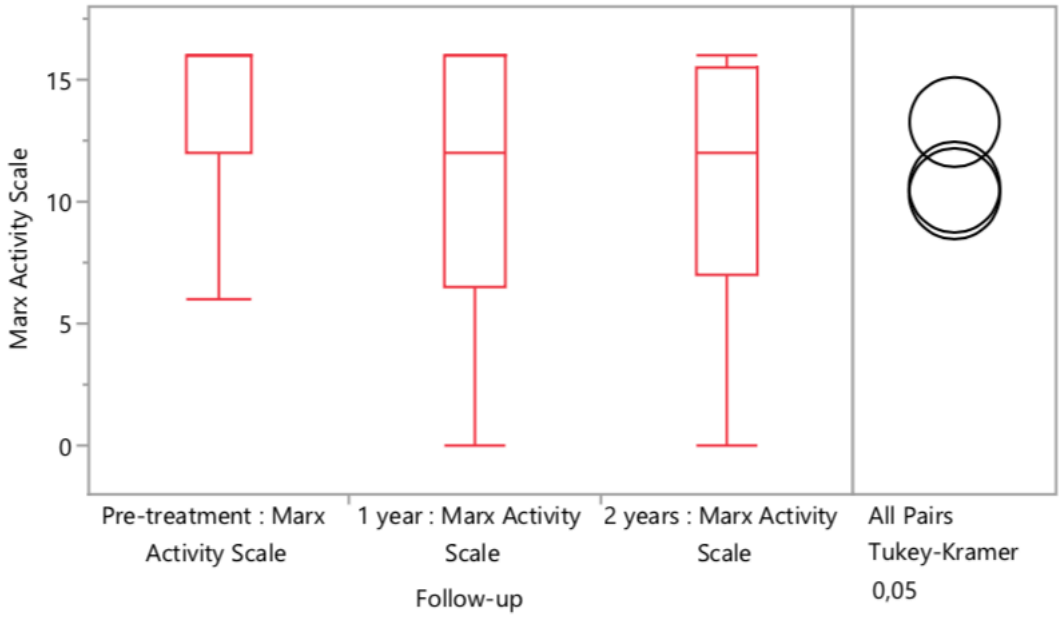



Figure 59: Chart demonstrating an overall decrease in the Marx activity score

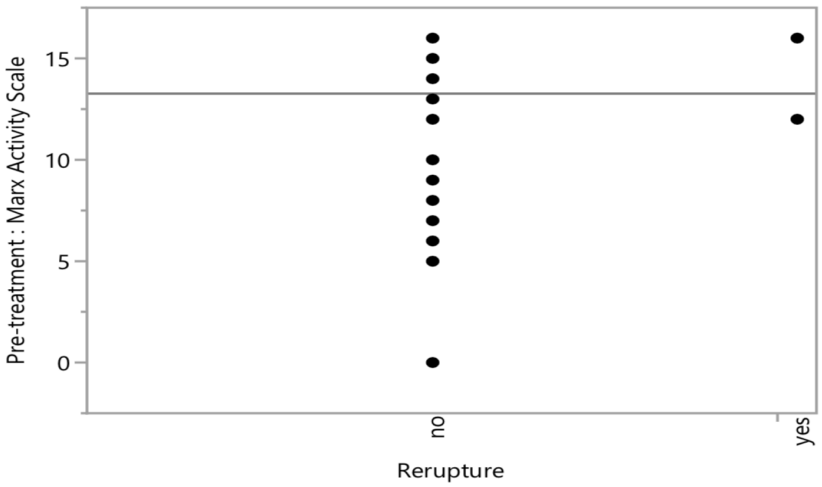



Figure 60: Chart demonstrating no significant differences in the Marx activity score between the re-rupture group and the other patients

**Overall satisfaction**

As outlined in Table 15, the majority of patients were happy with their combined ACL repair and ALL repair with suture tape augmentation at 2-years. 94% of patients felt the surgery exceeded or met their expectations with regards to reducing pain. 94% of patients felt the surgery exceeded or met their expectations with regards to improving movement and strength of the knee as well as resuming normal functions of daily living. 86% of patients felt the surgery exceeded or met their expectations with regards to resuming normal sporting activities.

| | **Pain (% patients)** | **Movement (% patients)** | **Function (% patients)** | **Sports (% patients)** |
|---|---|---|---|---|
| **Exceeded expectations** | 55 | 44 | 50 | 50 |
| **Met expectations** | 39 | 50 | 44 | 36 |
| **Did not meet expectations** | 6 | 6 | 6 | 14 |
| **Not applicable** | - | - | - | - |

Table 15: This table demonstrates the overall satisfaction of patients at 2-year follow-up

## Posterior Cruciate Ligament Repair

### Demographics

Between August 2013 and February 2017, 17 patients with a PCL rupture underwent PCL repair with suture tape augmentation and were included in this study. These patients were prospectively followed up for a minimum of 2-years postoperatively. Indications for this procedure were Grade III PCL tears, symptomatic chronic tears and PCL tears as part of a multi-ligament injury. Patients with retracted PCL remnants or poor tissue quality would have underwent a standard PCL reconstruction, however, there were no cases like this during this timeframe. 1 patient was lost to follow-up leaving 16 patients in the final analysis (94.1%). 5 patients were part of a multiligament injury (1 ACL repair with PLC repair and 4 PLC repairs) and 11 patients were isolated PCL repairs with suture tape augmentation.

Mean follow-up was 48.0 (+/- 10.6) months (range, 24-66 months). The mean age at the time of surgery was 37.2 (+/-10.9) years (range, 19-57). All 16 patients were male.

### Complications

2 patients who had isolated PCL repairs underwent further surgery on the same knee (12.5%). One patient underwent microfracture for a new osteochondral injury. The other patient suffered from a re-rupture and underwent a PCL reconstruction using allograft. No other complications or further surgery on the knee were reported. No significant differences were found between the 2 patients in this group and the other patients in terms of age and patient-reported outcome measures.

**Knee Injury and Osteoarthritis Outcome Score (KOOS)**

All sections of the KOOS demonstrated significant improvements at 2-year follow-up as illustrated in Figure 61.

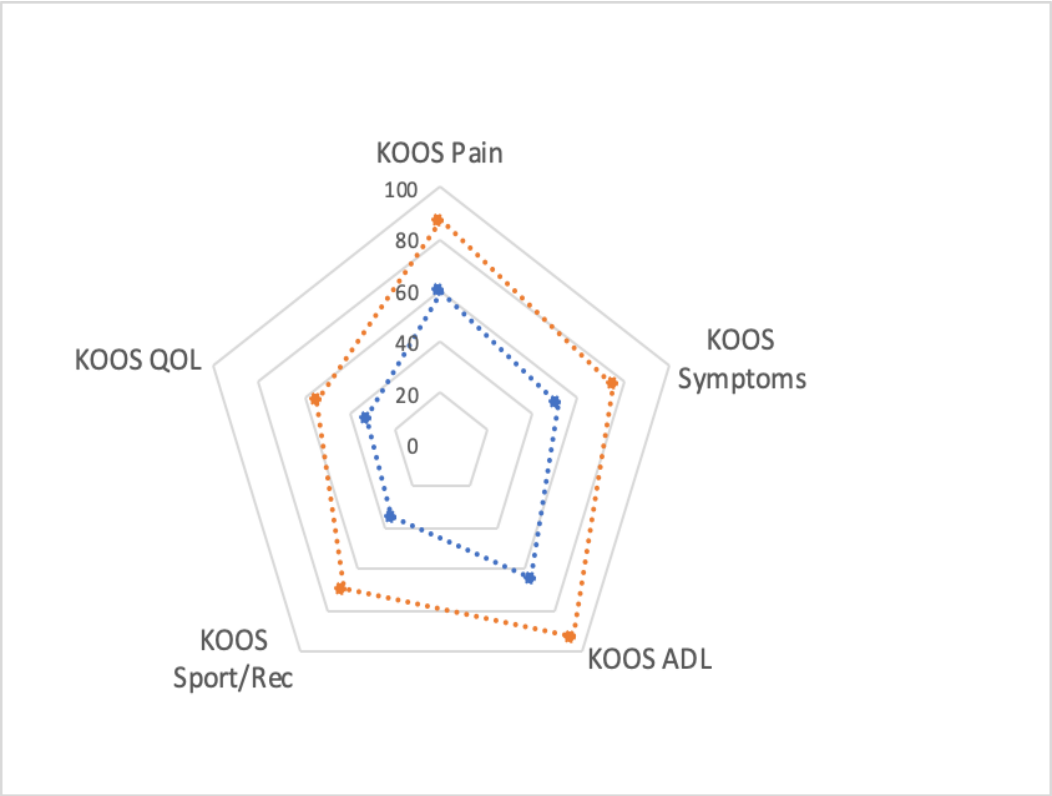



Figure 61: Spider chart demonstrating significant improvements at 2-year follow-up in all sub-sections of the KOOS.

The KOOS for pain was 60.2 preoperatively and increased significantly to 87.0 at 2-year follow-up ($p=0.0002$). The KOOS for symptoms was 49.8 preoperatively and increased significantly to 75.5 at 2-year follow-up ($p<0.0001$). The KOOS for ADLs was 65.0 preoperatively and increased significantly to 93.0 at 2-year follow-up ($p<0.0001$). The KOOS for Sport and Recreation was 33.0 preoperatively and increased significantly to 69.6 at 2-year follow-up ($p=0.0027$). The KOOS for Quality of Life was 34.2 preoperatively and increased significantly to 54.2 at 2-year follow-up ($p=0.018$). No significant differences were seen between the different postoperative time intervals for any of the KOOS subsections. (Figures 62-66)

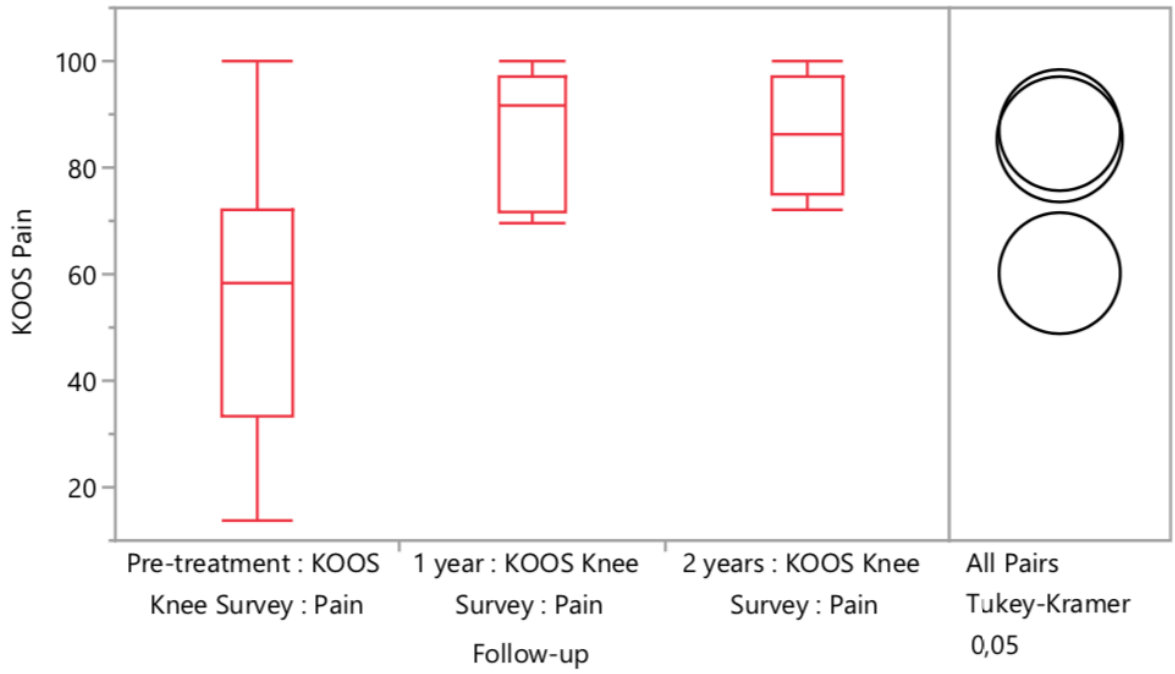



Figure 62: Chart demonstrating the KOOS for pain at the different time intervals

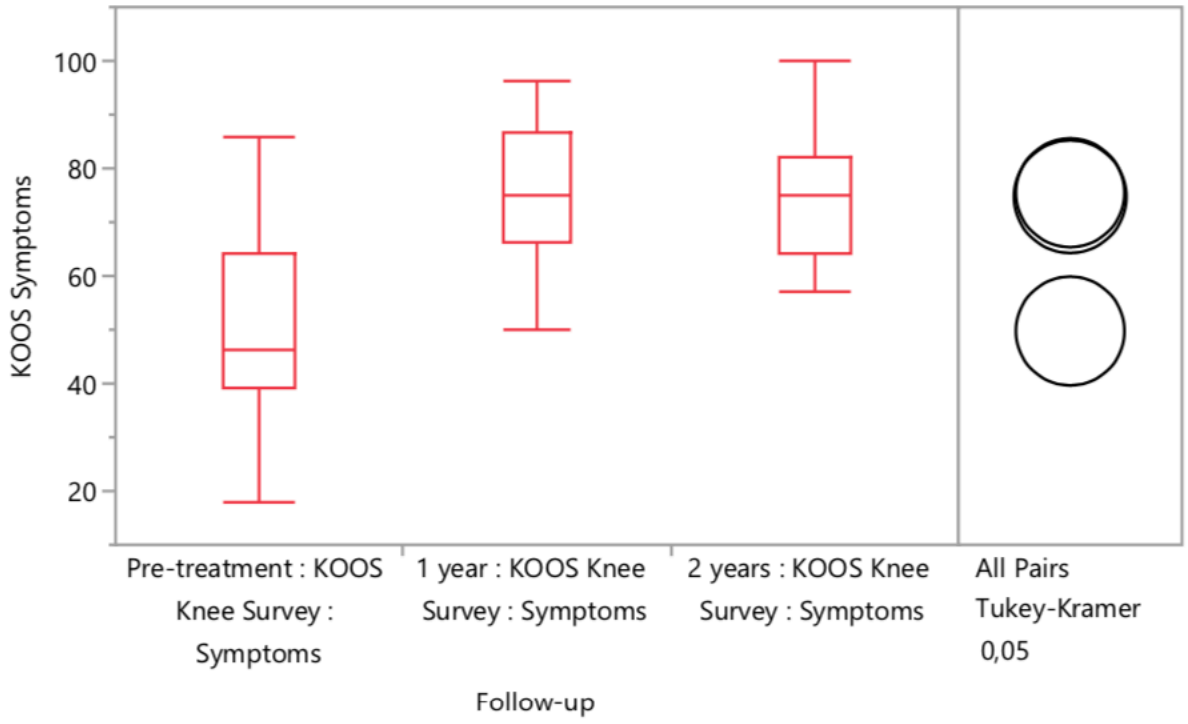



Figure 63: Chart demonstrating the KOOS for symptoms at the different time intervals

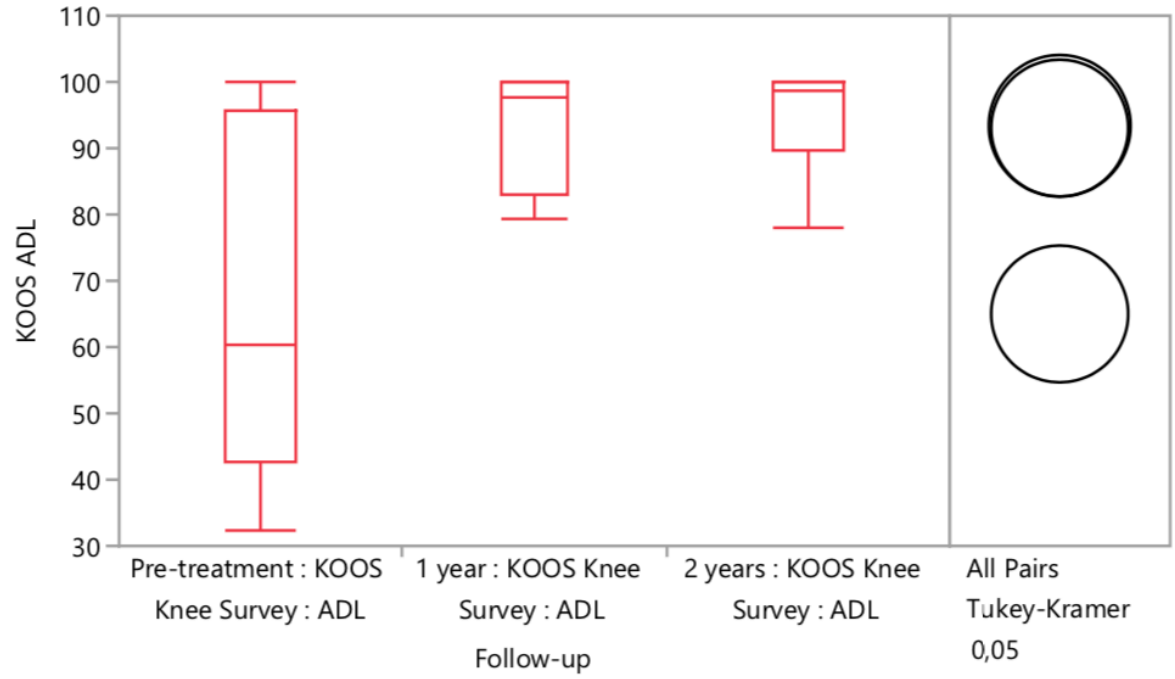



Figure 64: Chart demonstrating the KOOS for ADLs at the different time intervals

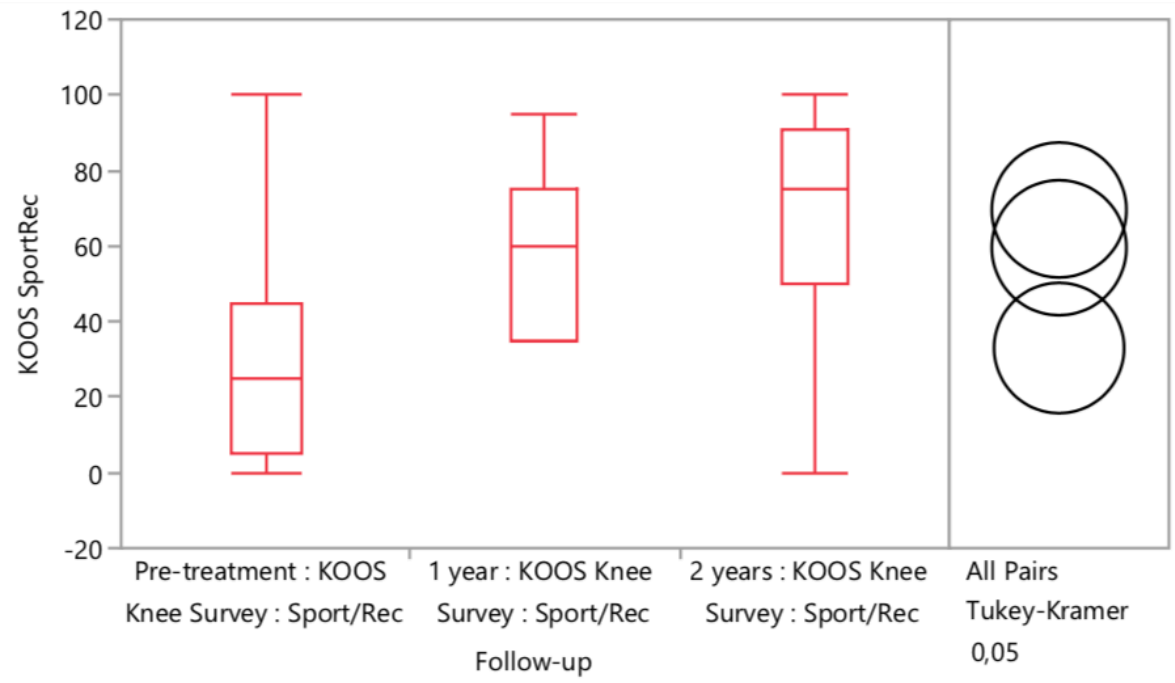



Figure 65: Chart demonstrating the KOOS for sport and recreation at the different time intervals

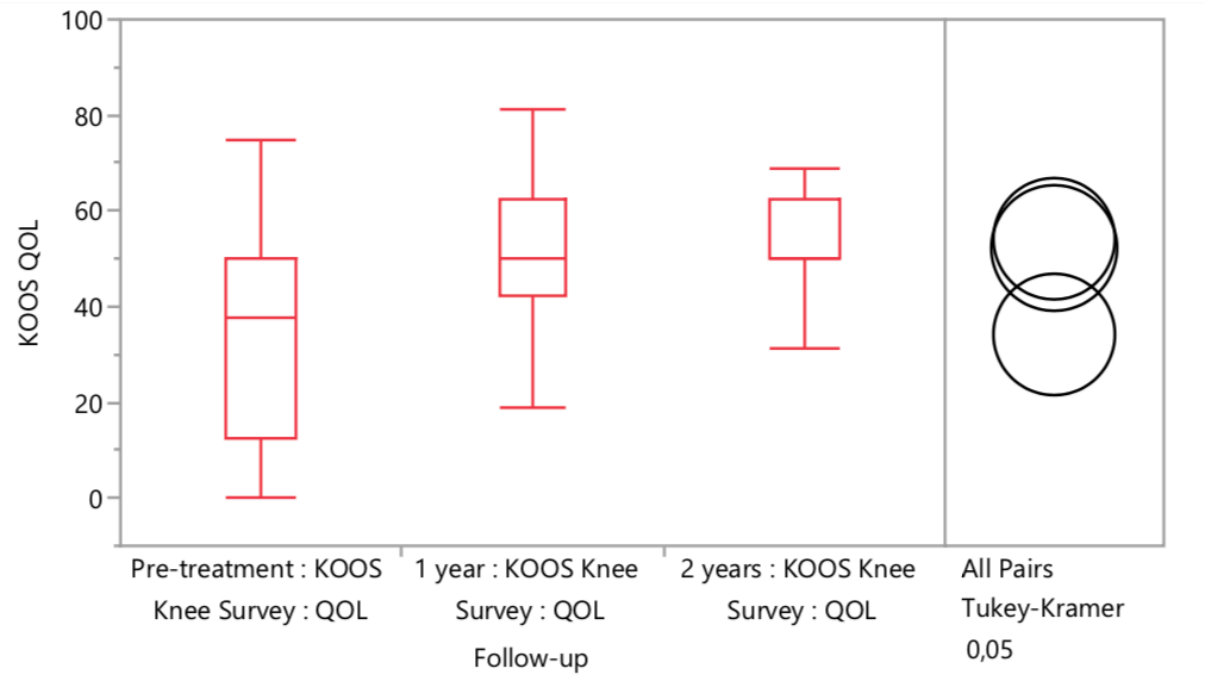



Figure 66: Chart demonstrating the KOOS for QOL at the different time intervals

**Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)**

All sections of the WOMAC demonstrated significant improvements at 2-year follow-up as illustrated in Figure 67.

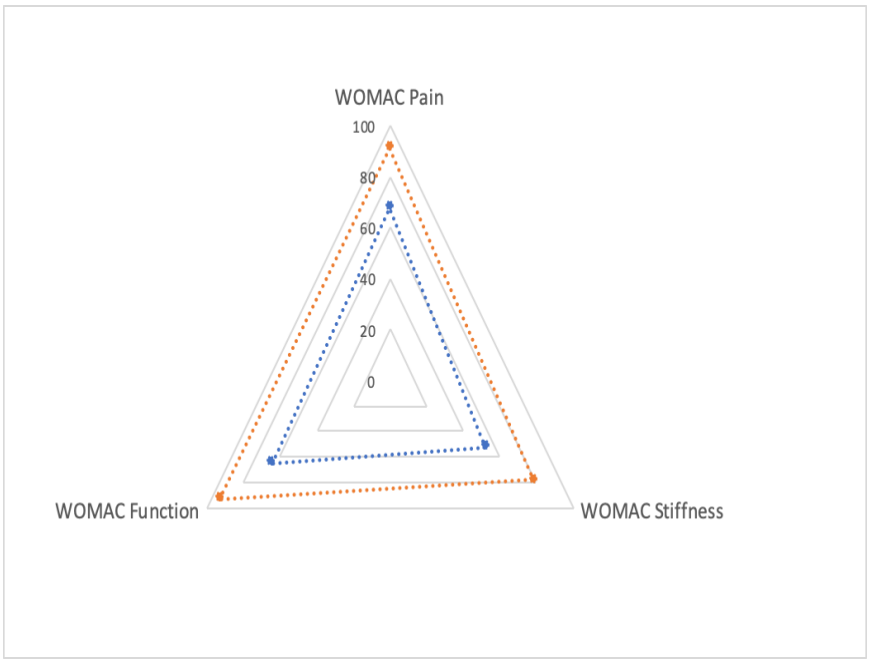



Figure 67: Spider chart demonstrating significant improvements at 2-year follow-up in all sub-sections of the WOMAC.

The WOMAC for pain was 68.3 preoperatively and increased significantly to 91.0 at 2-year follow-up (p=0.0005). The WOMAC for stiffness was 51.7 preoperatively and increased significantly to 78.3 at 2-year follow-up (p=0.0015). The WOMAC for function was 65.0 preoperatively and increased significantly to 93.0 at 2-year follow-up (p<0.0001). No significant differences were seen between the different postoperative time intervals for any of the WOMAC subsections. (Figures 68-70)

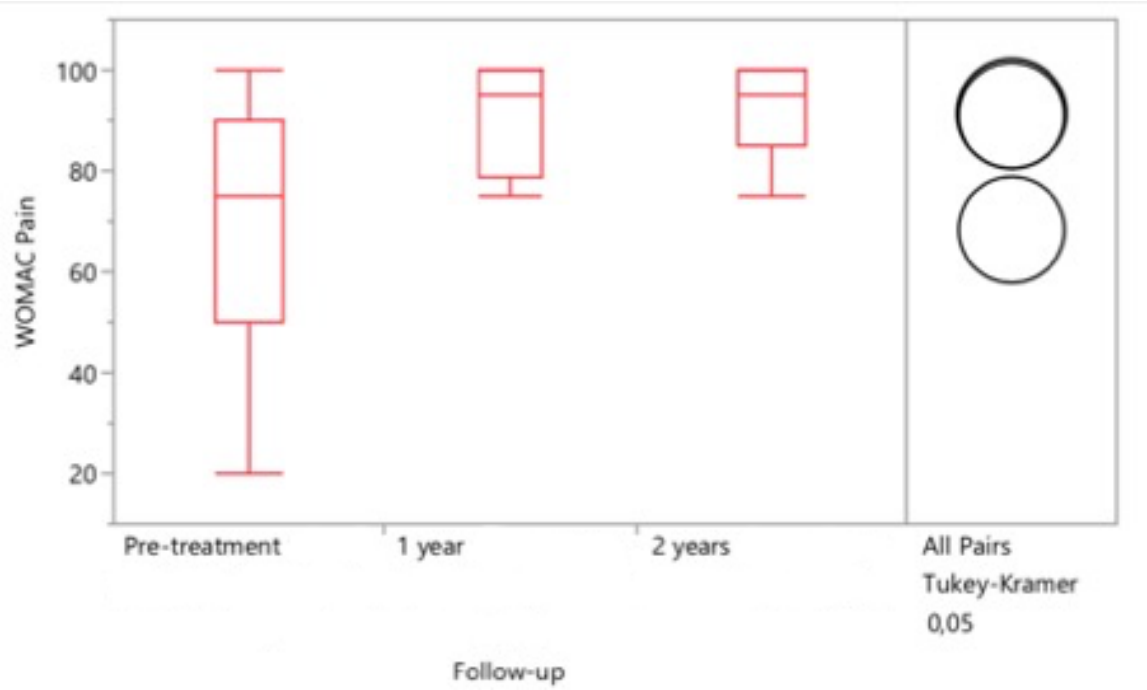



Figure 68: Chart demonstrating the WOMAC for pain at the different time intervals

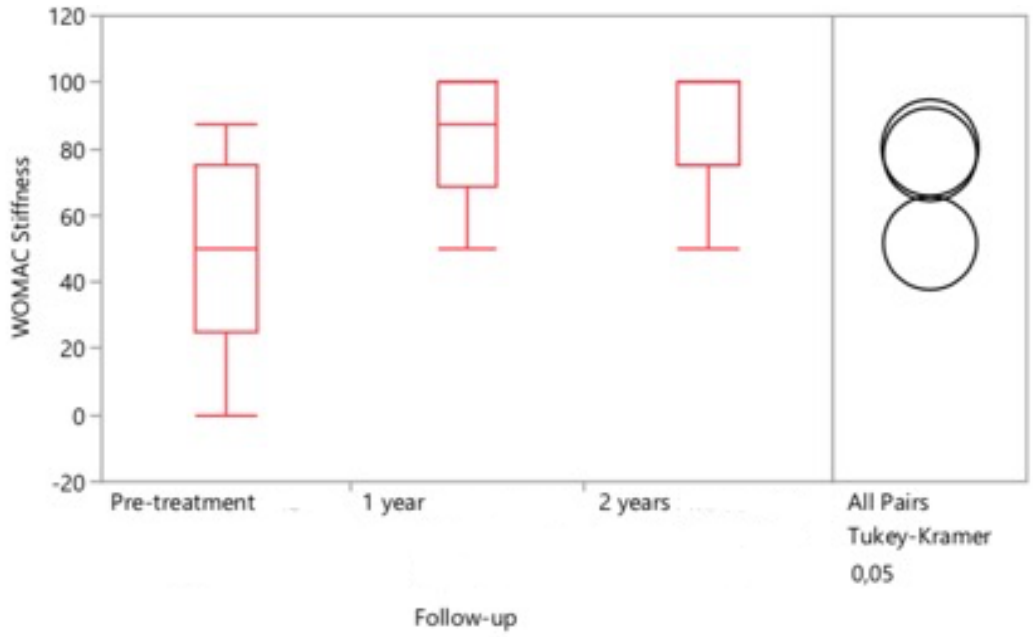



Figure 69: Chart demonstrating the WOMAC for stiffness at the different time intervals

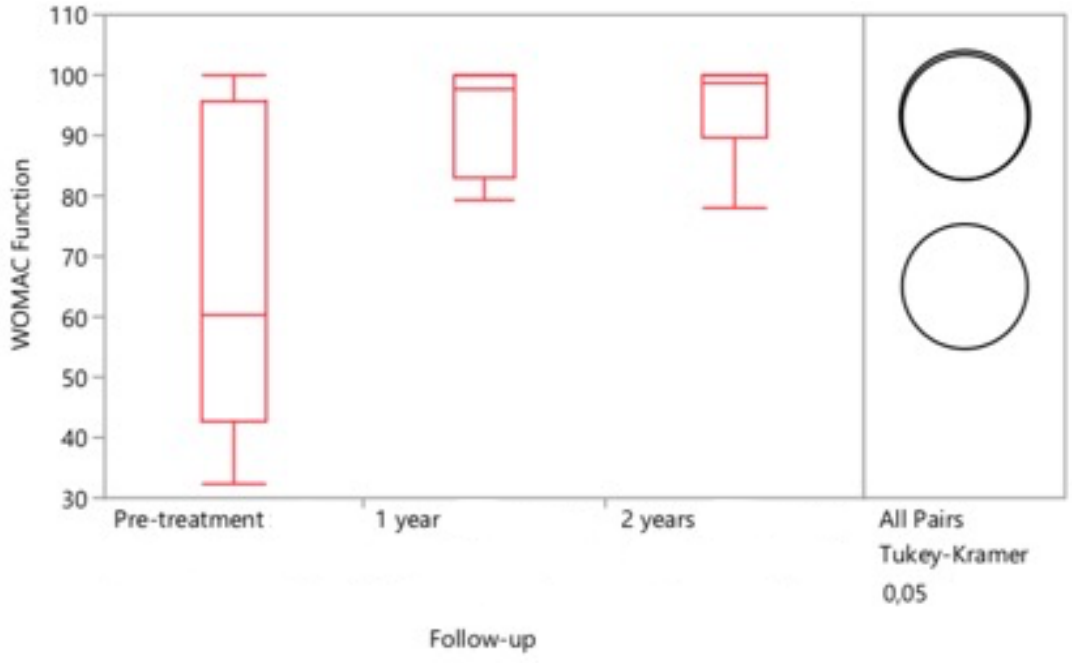



Figure 70: Chart demonstrating the WOMAC for function at the different time intervals

**Visual Analogue Pain Scale (VAS)**

The VAS for pain decreased significantly from 3.0 preoperatively to 0.8 at 2-year follow-up (p=00027). (Figure 71) No significant differences were seen between the 1-year and 2-year postoperative time intervals.

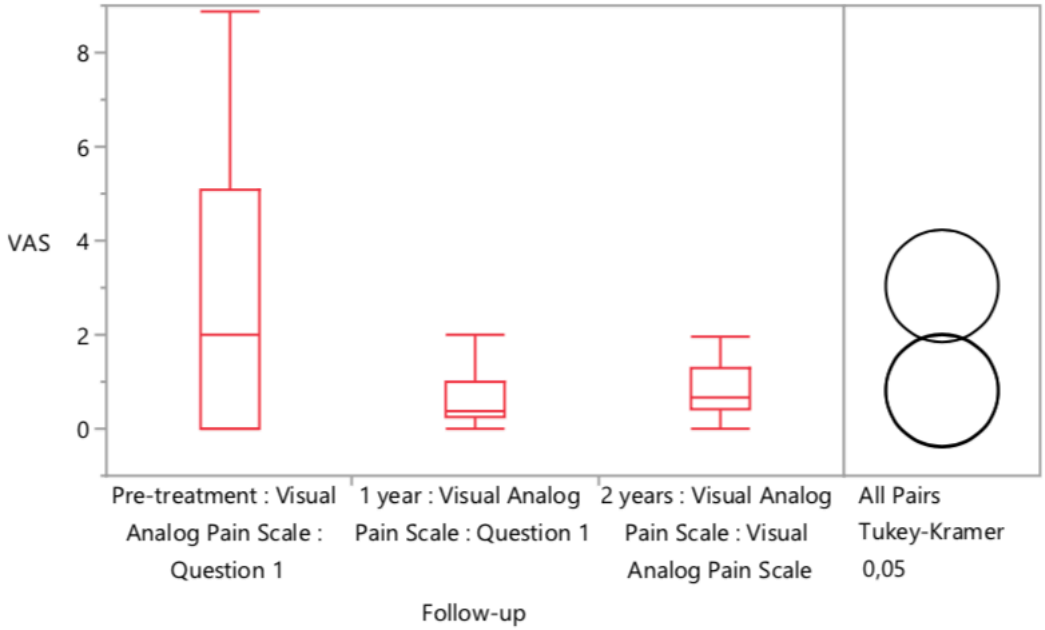



Figure 71: Chart demonstrating a significant decrease in pain scores from preoperatively to 2-year postoperatively.

**Veterans RAND 12 Item Health Survey (VR-12)**

The VR-12 physical score was 34.9 preoperatively and increased significantly to 50.9 at 2-year follow-up (p<0.0001). (Figure 72) The VR-12 mental score was 52.1 preoperatively and there was minimal change to 56.7 at 2-year follow-up (p=0.33). (Figure 73) No significant differences were seen between the 1-year and 2-year postoperative time intervals.

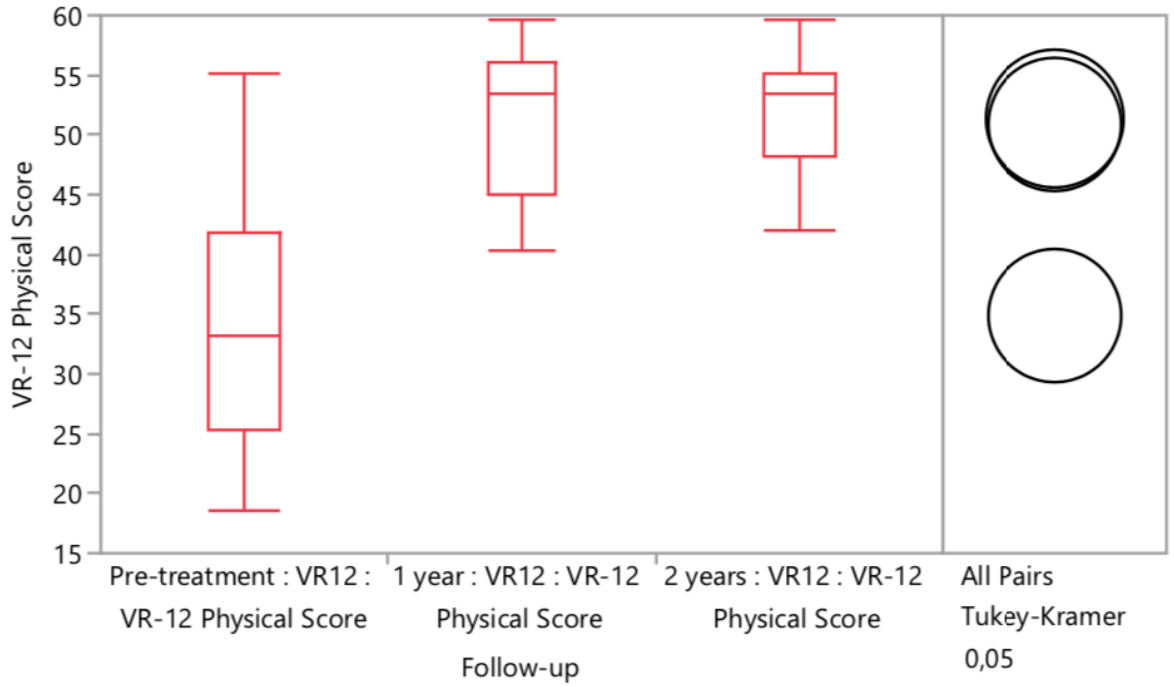



Figure 72: Chart demonstrating the VR-12 physical scores at the different time intervals

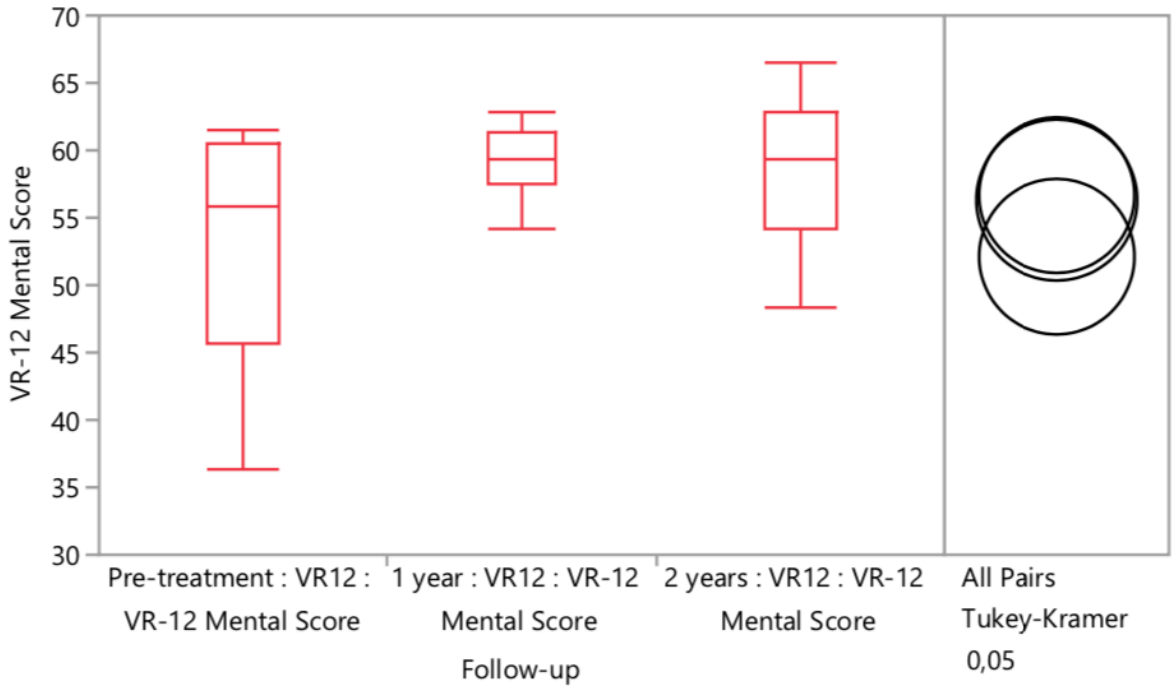



Figure 73: Chart demonstrating the VR-12 mental scores at the different time intervals

**Marx Activity Scale**

The Marx activity scale decreased from 8.7 preoperatively to 6.3 at 2-year follow-up but this was not a statistically significant result (p=0.47). There was also very little change in the scores between 1-year and 2-years postoperatively. (Figure 74)

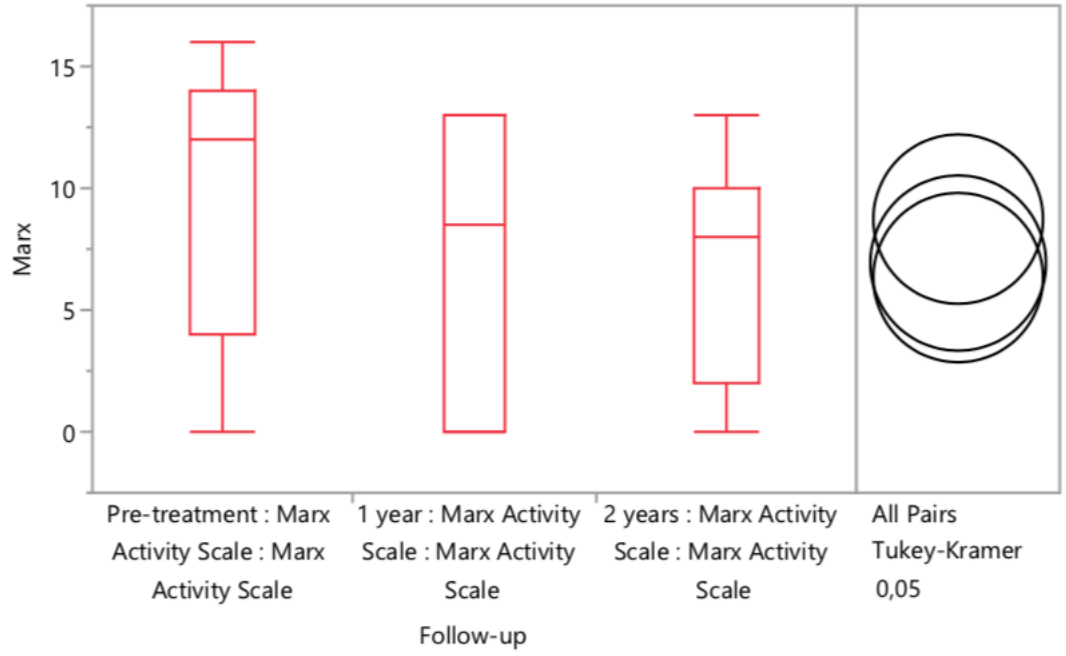



Figure 74: Chart demonstrating an overall decrease in the Marx activity score but not of statistical significance

**Overall satisfaction**

As outlined in Table 16, the majority of patients were content with their PCL repair with suture tape augmentation at 2-years. 86% of patients felt the surgery exceeded or met their expectations with regards to reducing pain. 86% of patients felt the surgery exceeded or met their expectations with regards to improving movement and strength of the knee as well as resuming normal functions of daily living. 71% of patients felt the surgery exceeded or met their expectations with regards to resuming normal sporting activities.

| | Pain (% patients) | Movement (% patients) | Function (% patients) | Sports (% patients) |
|---|---|---|---|---|
| **Exceeded expectations** | 36 | 29 | 29 | 14 |
| **Met expectations** | 50 | 57 | 57 | 57 |
| **Did not meet expectations** | 14 | 14 | 14 | 29 |
| **Not applicable** | - | - | - | - |

Table 16: This table demonstrates the overall satisfaction of patients at 2-year follow-up

## Medial Collateral Ligament Repair

### Demographics

Between February 2013 and March 2017, 39 patients underwent MCL repair with suture tape augmentation and were included in this study. These patients were prospectively followed up for a minimum of 2-years postoperatively. Indications for this procedure were patients with Grade III MCL tears or patients with MCL tears as part of a multiligament knee injury. 3 patients were lost to follow-up leaving 36 patients in the final analysis (92.3%). 4 patients were isolated Grade III MCL tears and 32 patients were part of a multiligament injury. The multiligament injuries consisted of 14 ACL repairs, 12 ACL reconstructions, 2 combined ACL and ALL repairs, 2 combined ACL and PLC repairs and 2 ACL reconstructions with ALL augmentation.

Mean follow-up was 39.1 (+/- 13.7) months (range, 24-73 months). The mean age at the time of surgery was 34.7 (+/-11.9) years (range, 14-57). 30 patients were male and 6 patients were female.

### Complications

2 patients underwent further surgery on the same knee (5.6%), neither for the MCL. One patient who was a multiligament knee injury underwent ACL reconstruction for a re-rupture. The other patient also had a multiligament knee injury and suffered from a PCL rupture and underwent a PCL reconstruction using allograft. In addition, one patient reinjured his MCL which was managed conservatively with physiotherapy and he has had no issues since then. No significant differences were found between the patients in this group of complications and the other patients in terms of age, gender and patient-reported outcome measures.

**Knee Injury and Osteoarthritis Outcome Score (KOOS)**

All sections of the KOOS demonstrated significant improvements at 2-year follow-up ($p<0.0001$) as demonstrated in Figure 75.

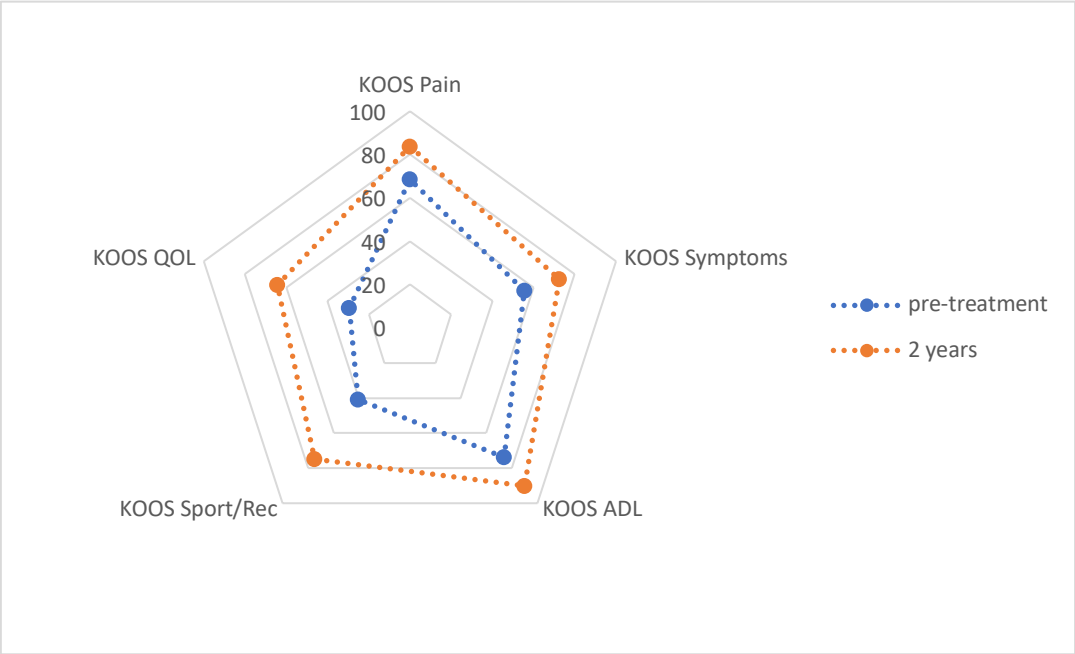



Figure 75: Spider chart demonstrating significant improvements at 2-year follow-up in all sub-sections of the KOOS.

The KOOS for pain was 65.7 preoperatively and increased significantly to 88.6 at 2-year follow-up ($p<0.0001$). The KOOS for symptoms was 60.0 preoperatively and increased significantly to 82.8 at 2-year follow-up ($p<0.0001$). The KOOS for ADLs was 72.0 preoperatively and increased significantly to 93.9 at 2-year follow-up ($p<0.0001$). The KOOS for Sport and Recreation was 31.9 preoperatively and increased significantly to 79.0 at 2-year follow-up ($p<0.0001$). The KOOS for Quality of Life was 27.0 preoperatively and increased significantly to 71.9 at 2-year follow-up ($p<0.0001$). No significant differences were seen between the 1-year and 2-year time intervals for any of the KOOS subsections. (Figures 76-80)

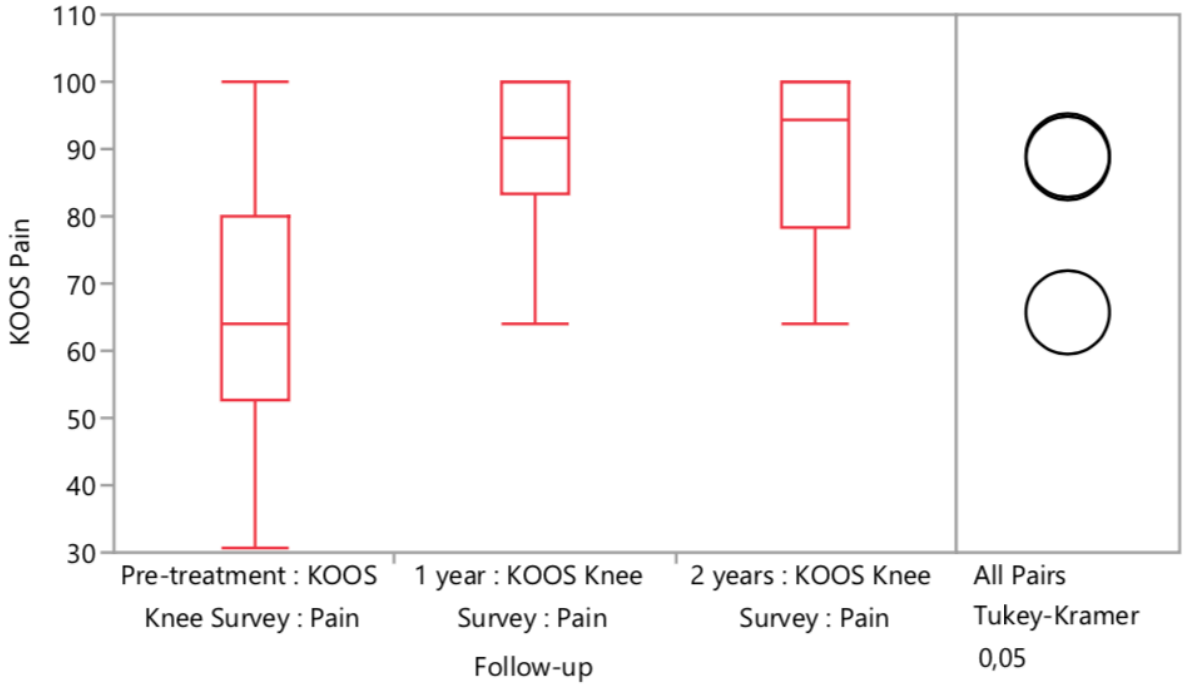



Figure 76: Chart demonstrating the KOOS for pain at the different time intervals

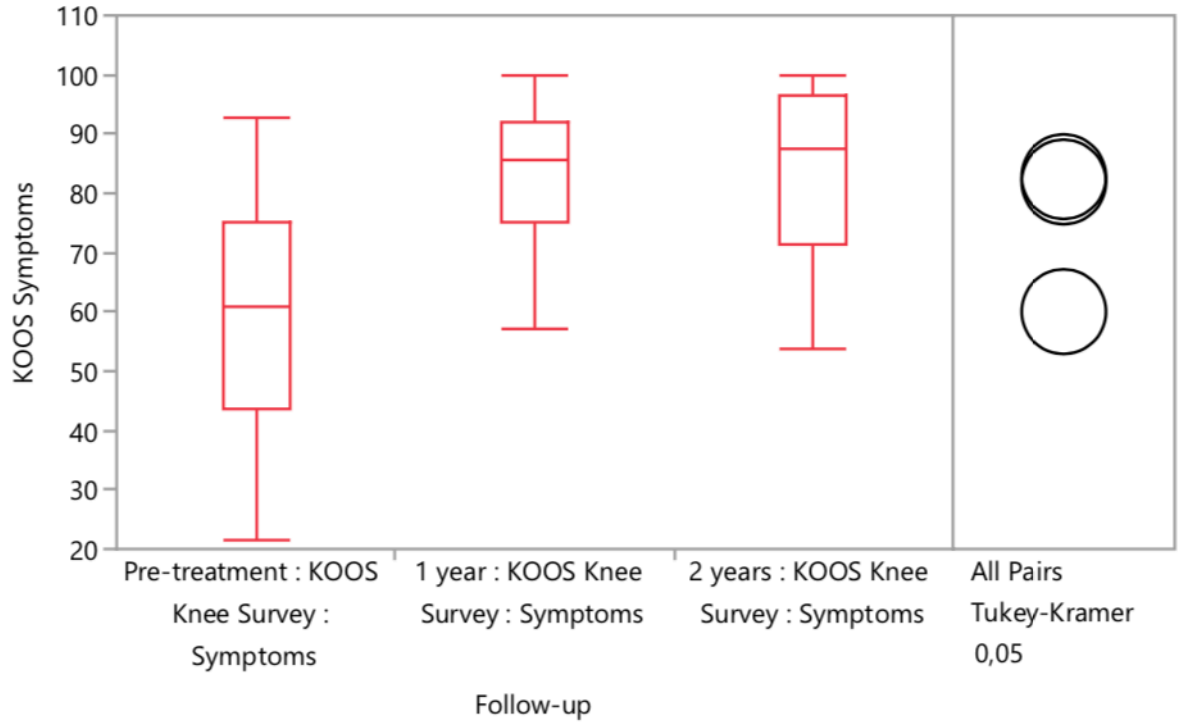



Figure 77: Chart demonstrating the KOOS for symptoms at the different time intervals

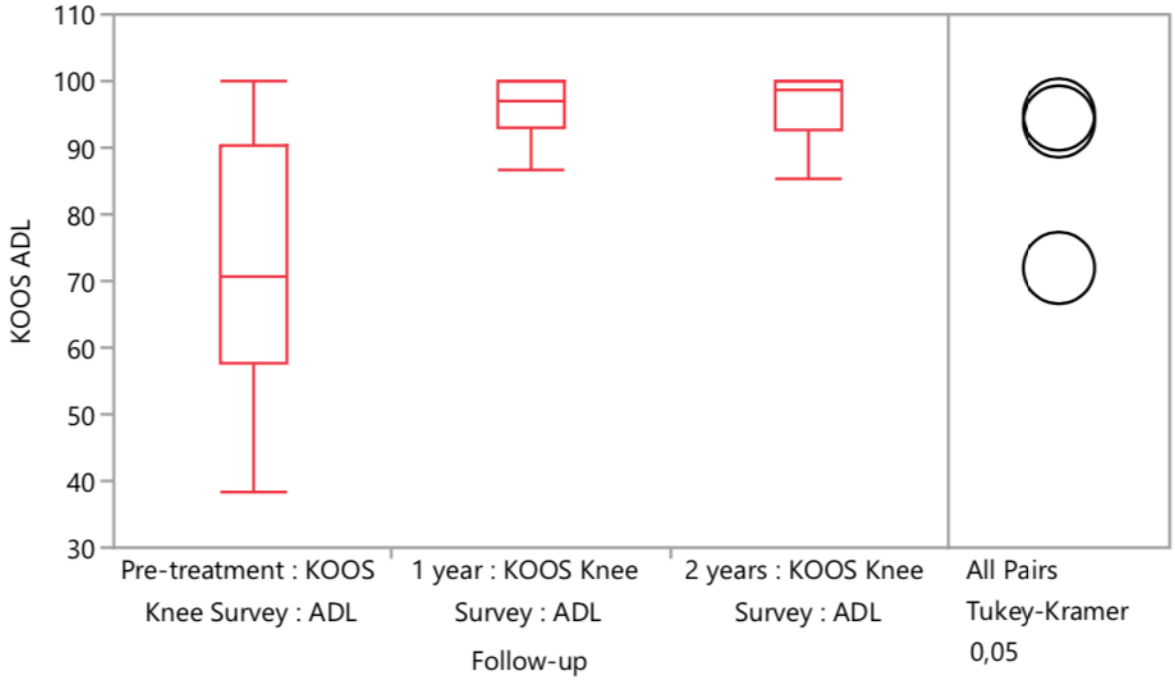



Figure 78: Chart demonstrating the KOOS for ADLs at the different time intervals

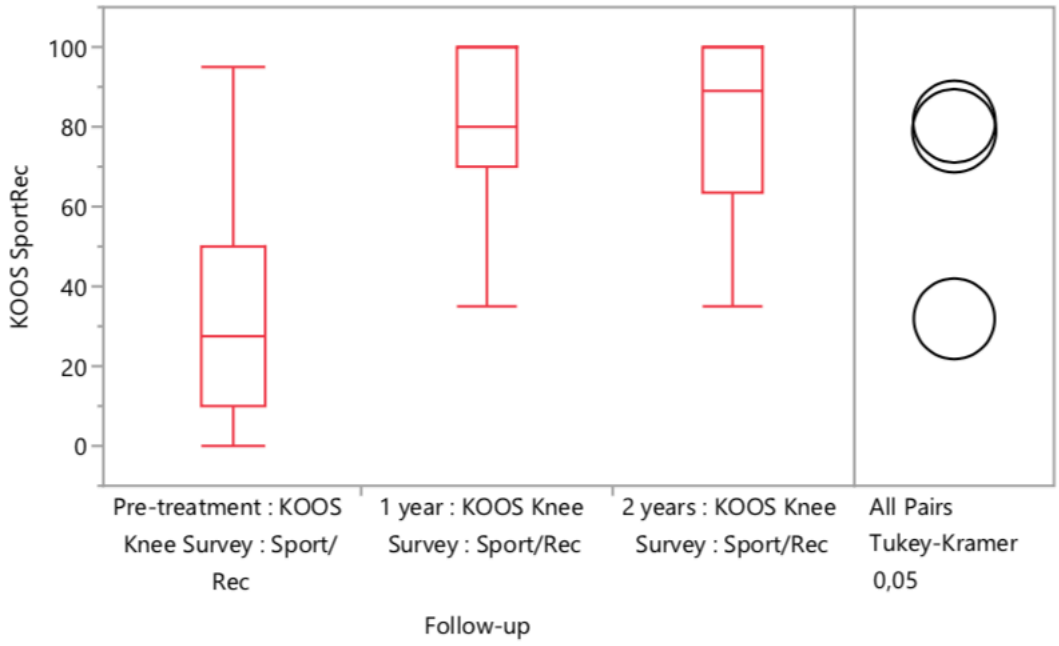



Figure 79: Chart demonstrating the KOOS for sport and recreation at the different time intervals

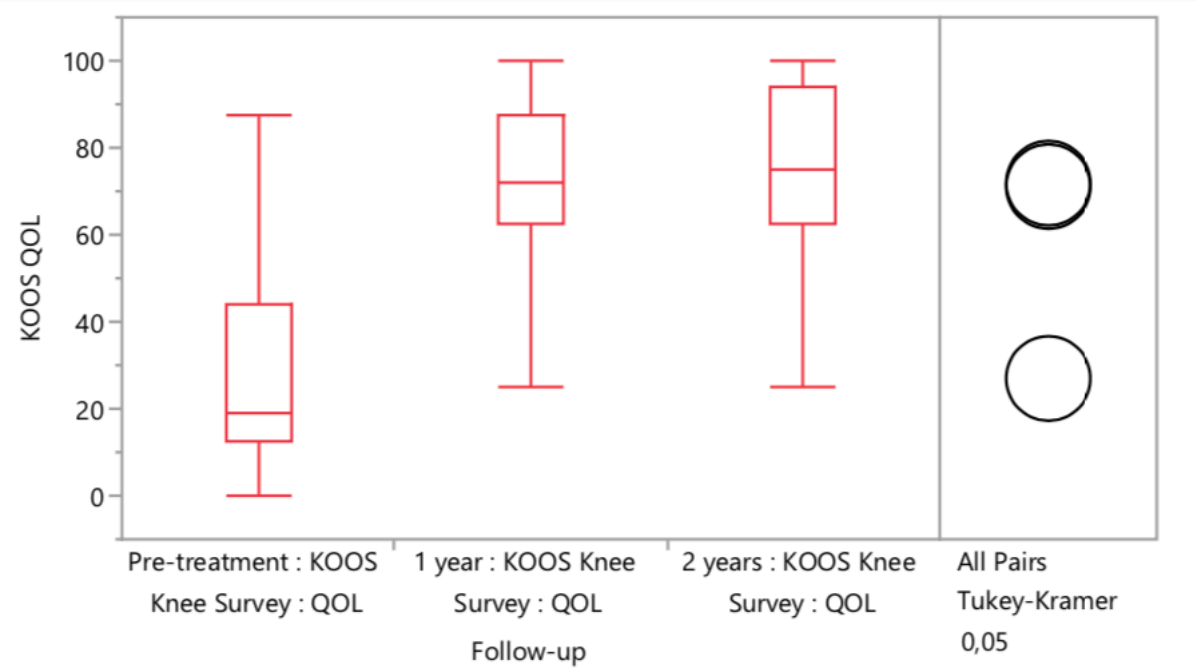



Figure 80: Chart demonstrating the KOOS for quality of life at the different time intervals

**Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)**

All sections of the WOMAC demonstrated significant improvements at 2-year follow-up ($p<0.0001$) as demonstrated in Figure 81.

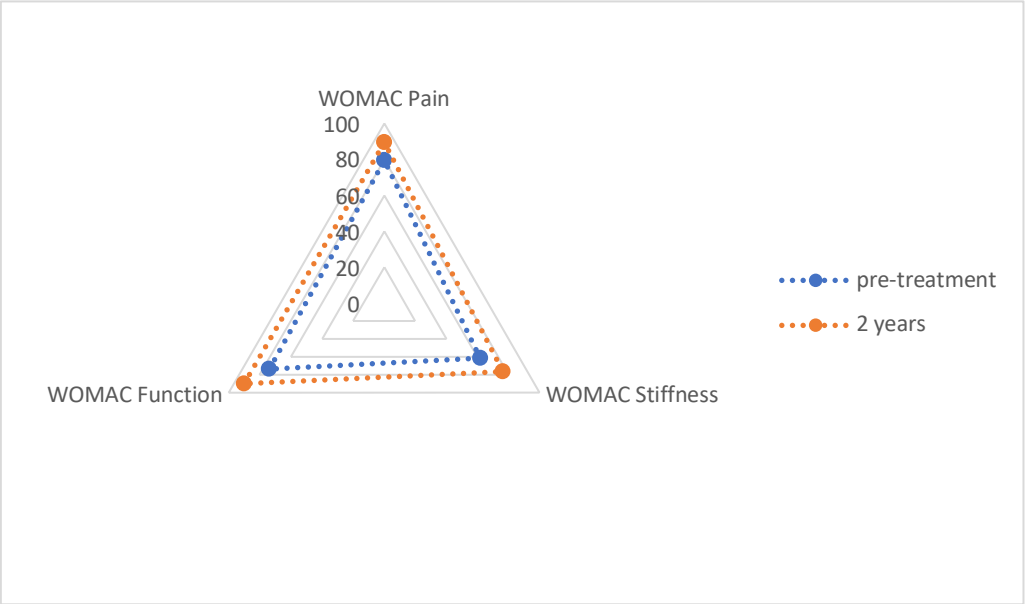



Figure 81: Spider chart demonstrating significant improvements at 2-year follow-up in all sub-sections of the WOMAC.

The WOMAC for pain was 75.6 preoperatively and increased significantly to 91.2 at 2-year follow-up ($p<0.0001$). The WOMAC for stiffness was 63.7 preoperatively and increased significantly to 84.4 at 2-year follow-up ($p<0.0001$). The WOMAC for function was 72.0 preoperatively and increased significantly to 93.9 at 2-year follow-up ($p<0.0001$). No significant differences were seen between the different postoperative time intervals for any of the WOMAC subsections. (Figures 82-84)

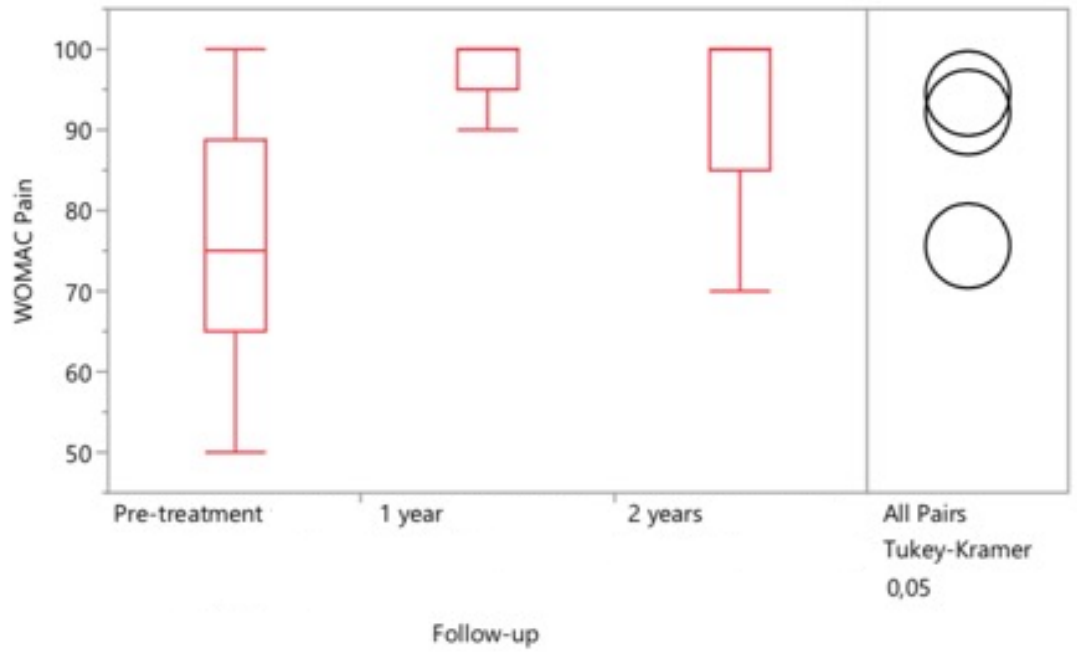



Figure 82: Chart demonstrating the WOMAC for pain at the different time intervals

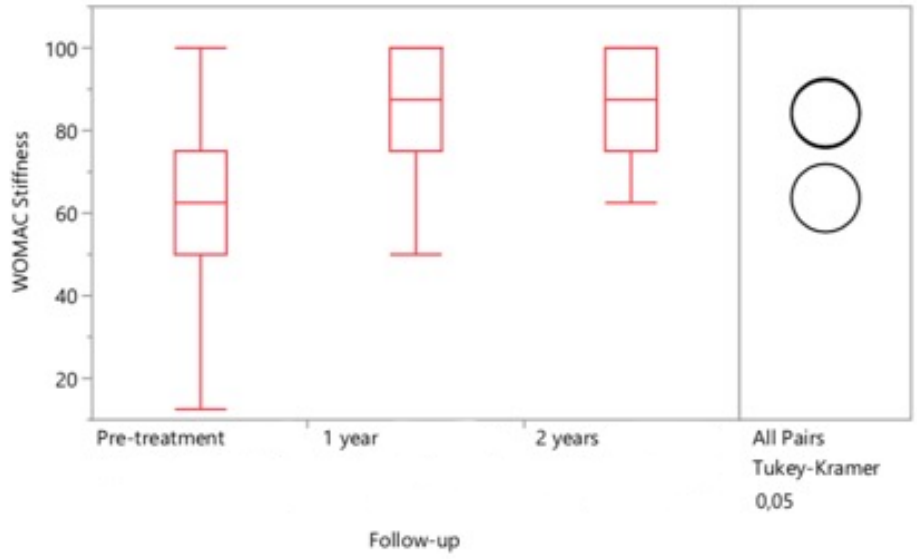



Figure 83: Chart demonstrating the WOMAC for stiffness at the different time intervals

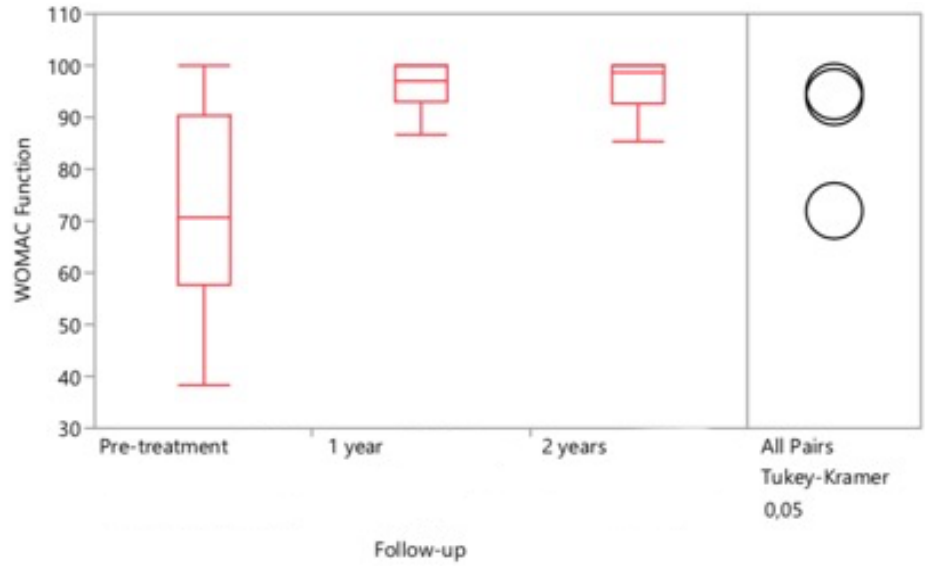



Figure 84: Chart demonstrating the WOMAC for function at the different time intervals

**Visual Analogue Pain Scale (VAS)**

The VAS for pain decreased significantly from 2.4 preoperatively to 0.8 at 2-year follow-up ($p<0.0001$). (Figure 85) No significant differences were seen between the 1-year and 2-year postoperative time intervals.

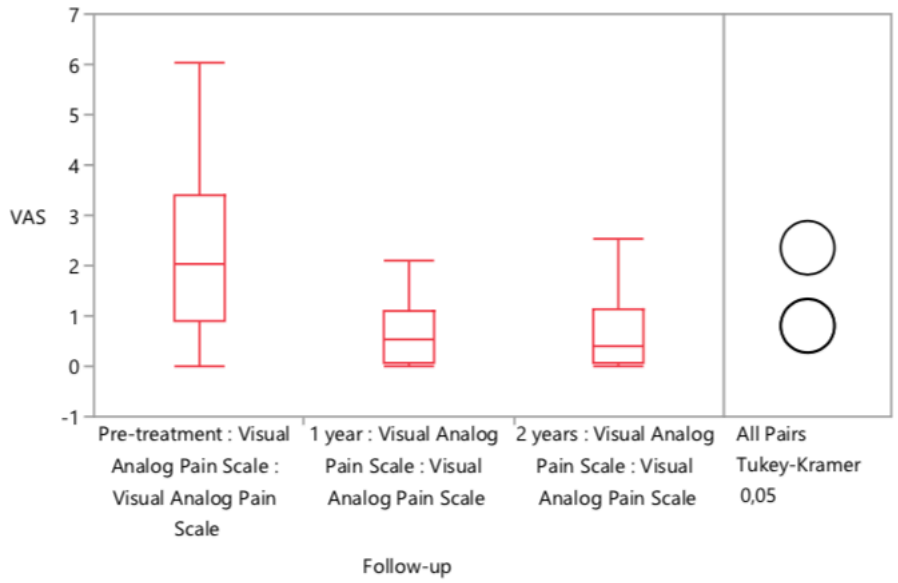



Figure 85: Chart demonstrating a significant decrease in pain scores from preoperatively to 2-year postoperatively.

**Veterans RAND 12 Item Health Survey (VR-12)**

The VR-12 physical score was 38.7 preoperatively and increased significantly to 51.0 at 2-year follow-up (p<0.0001). (Figure 86) The VR-12 mental score was 55.3 preoperatively and there was minimal change to 54.4 at 2-year follow-up (p=0.91). (Figure 87) No significant differences were seen between the 1-year and 2-year postoperative time intervals.

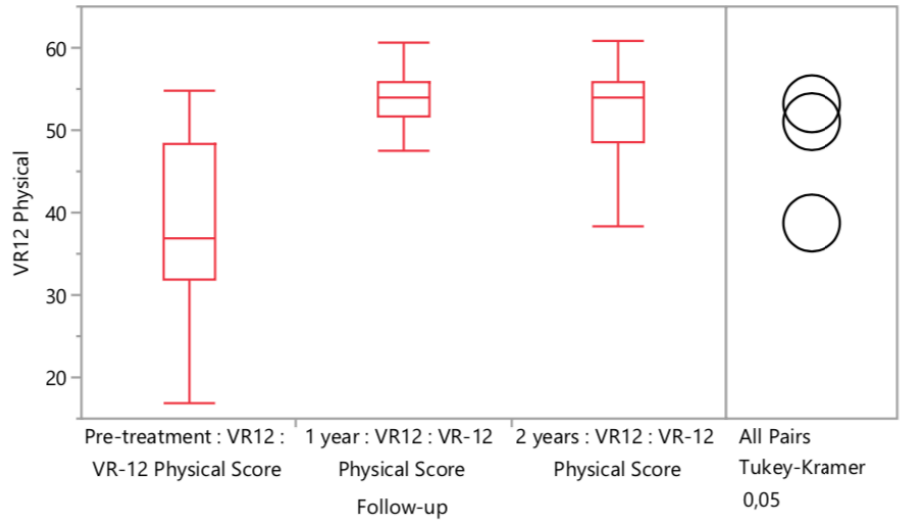



Figure 86: Chart demonstrating the VR-12 physical scores at the different time intervals

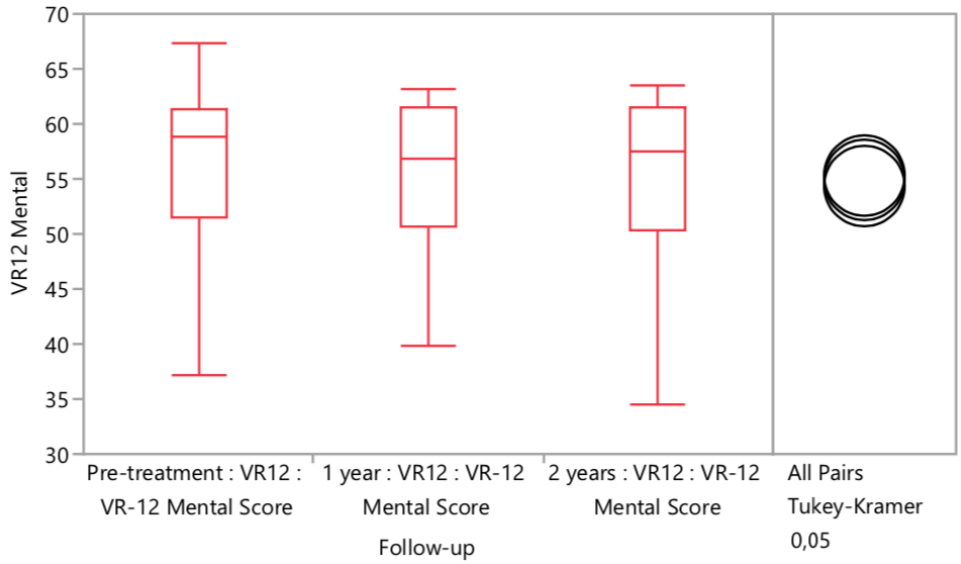



Figure 87: Chart demonstrating the VR-12 mental scores at the different time intervals

**Marx Activity Scale**

There was minimal change in the Marx activity scale which went from 9.8 preoperatively to 9.4 at 2-year follow-up but this was not a statistically significant result (p=0.43). There was also very little change in the scores between 1-year and 2-years postoperatively. (Figure 88)

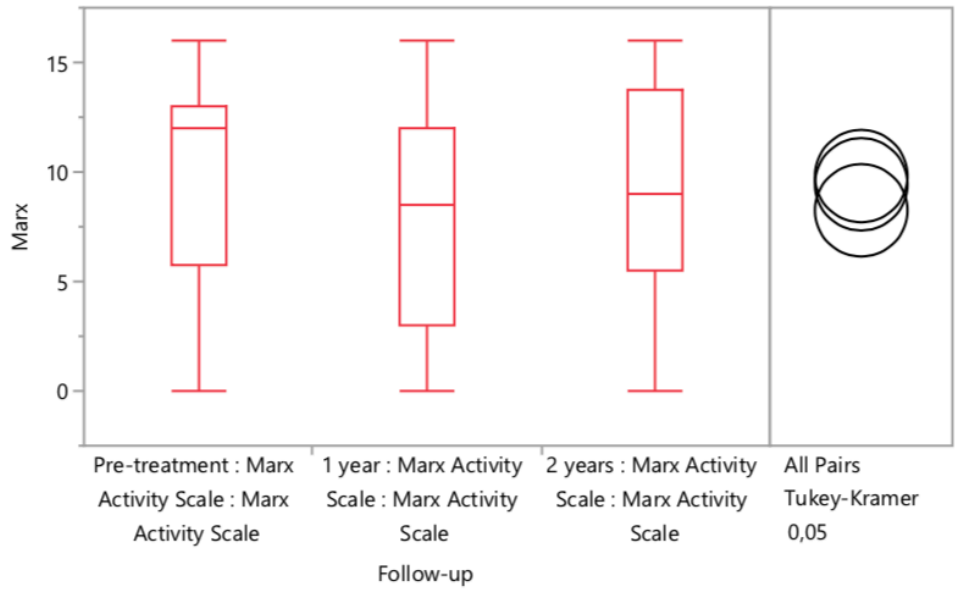



Figure 88: Chart demonstrating minimal change in the Marx activity score at 1 year and 2 years postoperatively

**Overall satisfaction**

As outlined in Table 17, the majority of patients were happy with their MCL repair with suture tape augmentation at 2-years. 94% of patients felt the surgery exceeded or met their expectations with regards to reducing pain. 87% of patients felt the surgery exceeded or met their expectations with regards to improving movement and strength of the knee. 95% of patients felt the surgery exceeded or met their expectations with regards to resuming normal functions of daily living. 81% of patients felt the surgery exceeded or met their expectations with regards to resuming normal sporting activities.

| | Pain (% patients) | Movement (% patients) | Function (% patients) | Sports (% patients) |
|---|---|---|---|---|
| **Exceeded expectations** | 53 | 53 | 47 | 47 |
| **Met expectations** | 41 | 34 | 47 | 34 |
| **Did not meet expectations** | 6 | 13 | 6 | 19 |
| **Not applicable** | - | - | - | - |

Table 17: This table demonstrates the overall satisfaction of patients at 2-year follow-up

## Posterolateral Corner Repair

### Demographics

Between August 2013 and March 2017, 22 patients underwent PLC repair with suture tape augmentation and were included in this study. These patients were prospectively followed up for a minimum of 2-years postoperatively. Indications for this procedure were patients with isolated injuries to the posterolateral corner or patients with PLC injuries as part of a multiligament knee injury. 3 patients were lost to follow-up leaving 19 patients in the final analysis (86.4%). 2 patients were isolated PLC injuries and 17 patients were part of a multiligament injury. The multiligament injuries consisted of 4 PCL repairs, 1 ACL and PCL repair, 2 ACL and MCL repairs, 3 ACL repairs and 7 ACL reconstructions

Mean follow-up was 38.6 (+/- 13.3) months (range, 24-67 months). The mean age at the time of surgery was 34.8 (+/-10.8) years (range, 18-54). 15 patients were male and 4 patients were female.

No complications were reported in the patients included in this study.

### Knee Injury and Osteoarthritis Outcome Score (KOOS)

All sections of the KOOS demonstrated significant improvements at 2-year follow-up ($p<0.0001$) as illustrated in Figure 89.

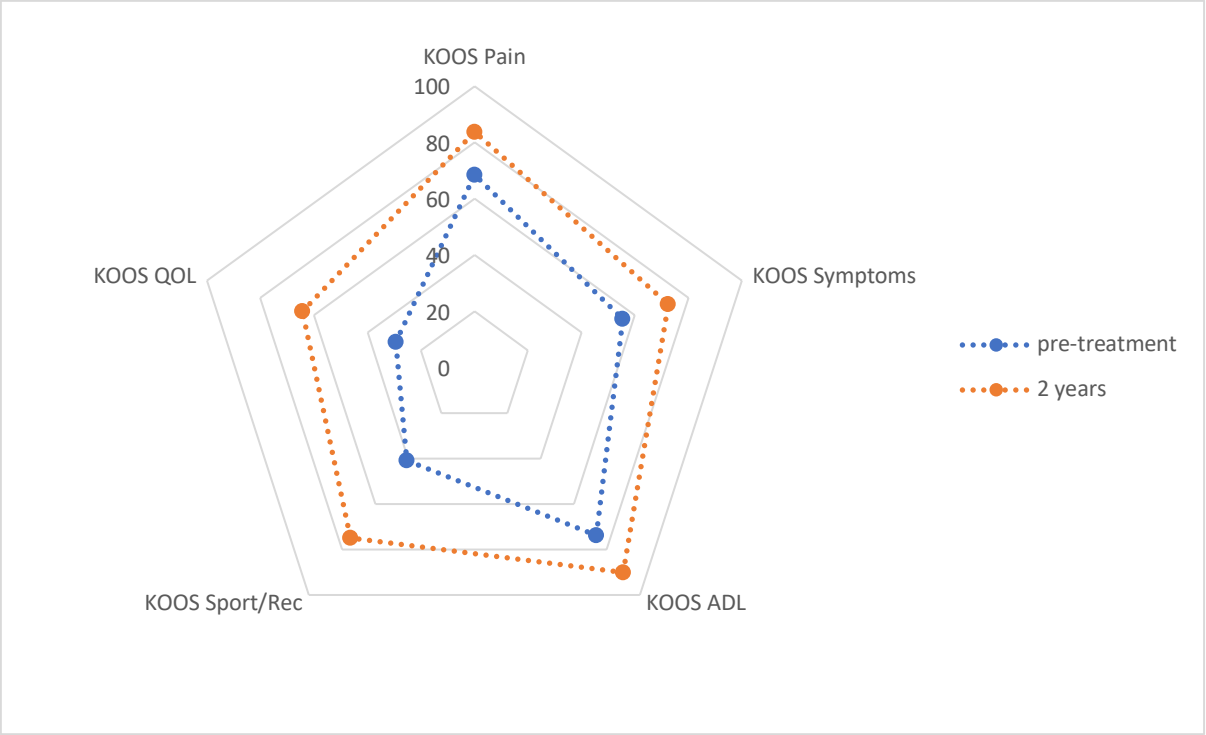



Figure 89: Spider chart demonstrating significant improvements at 2-year follow-up in all sub-sections of the KOOS.

The KOOS for pain was 49.2 preoperatively and increased significantly to 88.3 at 2-year follow-up ($p<0.0001$). The KOOS for symptoms was 43.3 preoperatively and increased significantly to 81.7 at 2-year follow-up ($p<0.0001$). The KOOS for ADLs was 60.0 preoperatively and increased significantly to 97.4 at 2-year follow-up ($p<0.0001$). The KOOS for Sport and Recreation was 21.1 preoperatively and increased significantly to 80.2 at 2-year follow-up ($p<0.0001$). The KOOS for Quality of Life was 29.1 preoperatively and increased significantly to 68.1 at 2-year follow-up ($p<0.0001$). No significant differences were seen between the 1-year and 2-year time intervals for any of the KOOS subsections. (Figures 90-94)

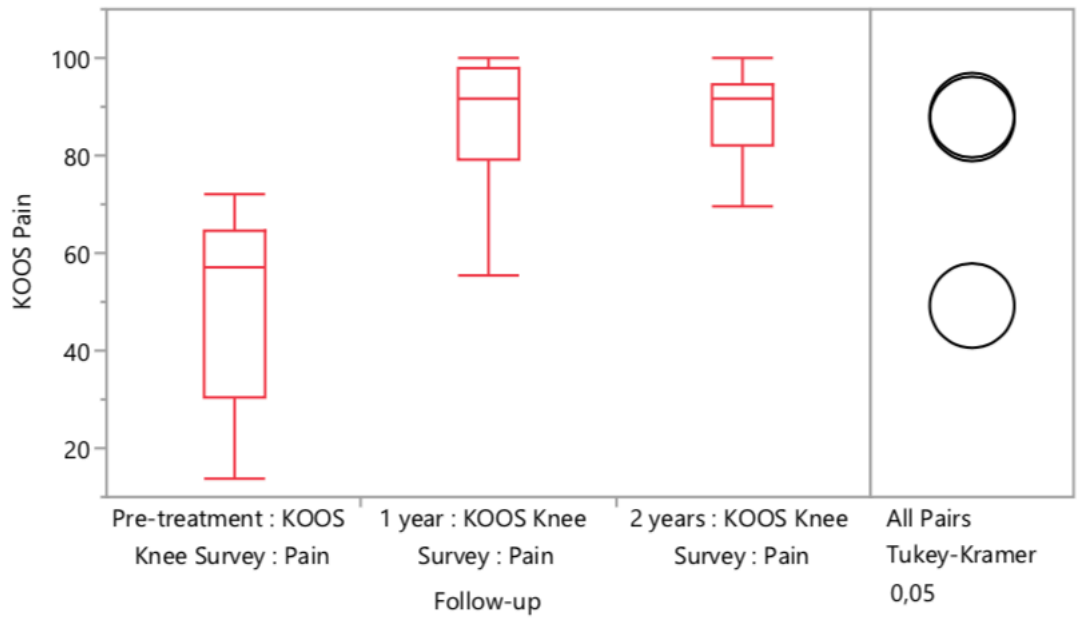



Figure 90: Chart demonstrating the KOOS for pain at the different time intervals

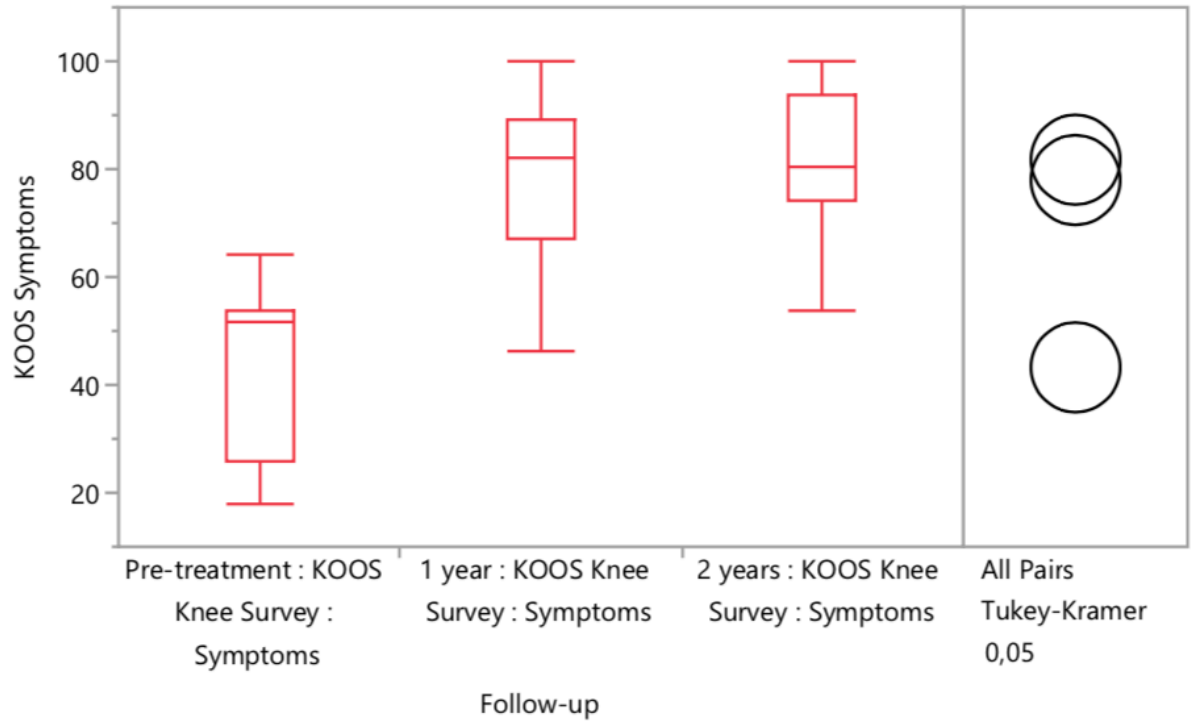



Figure 91: Chart demonstrating the KOOS for symptoms at the different time intervals

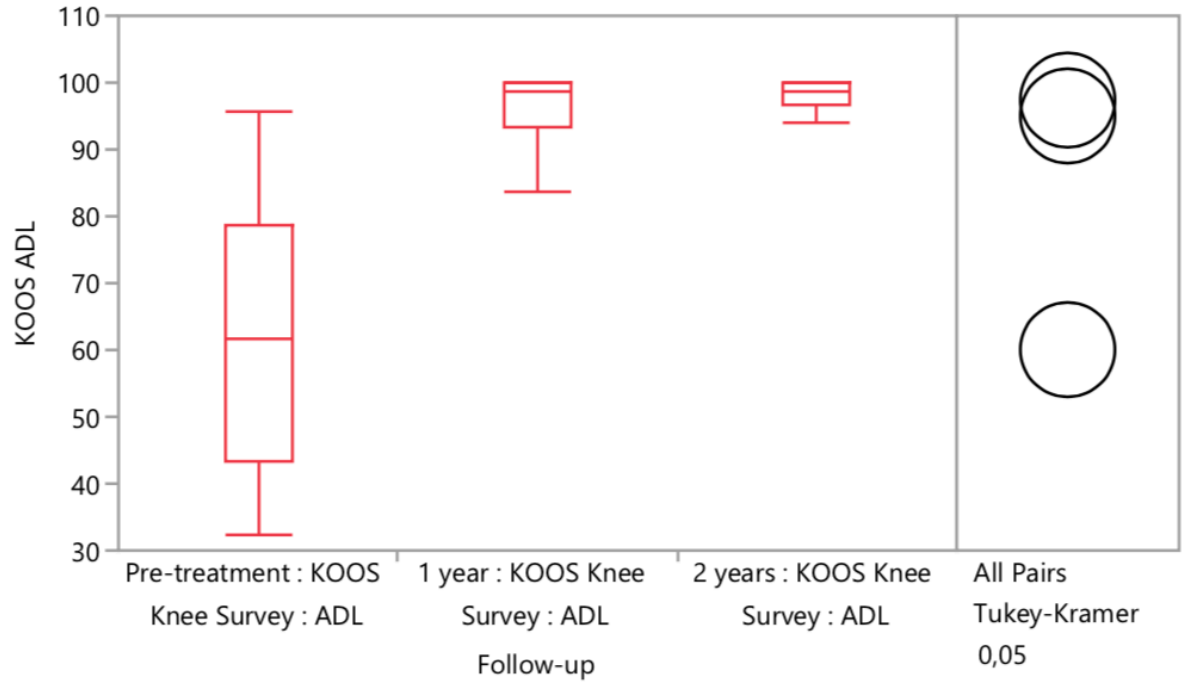



Figure 92: Chart demonstrating the KOOS for ADLs at the different time intervals

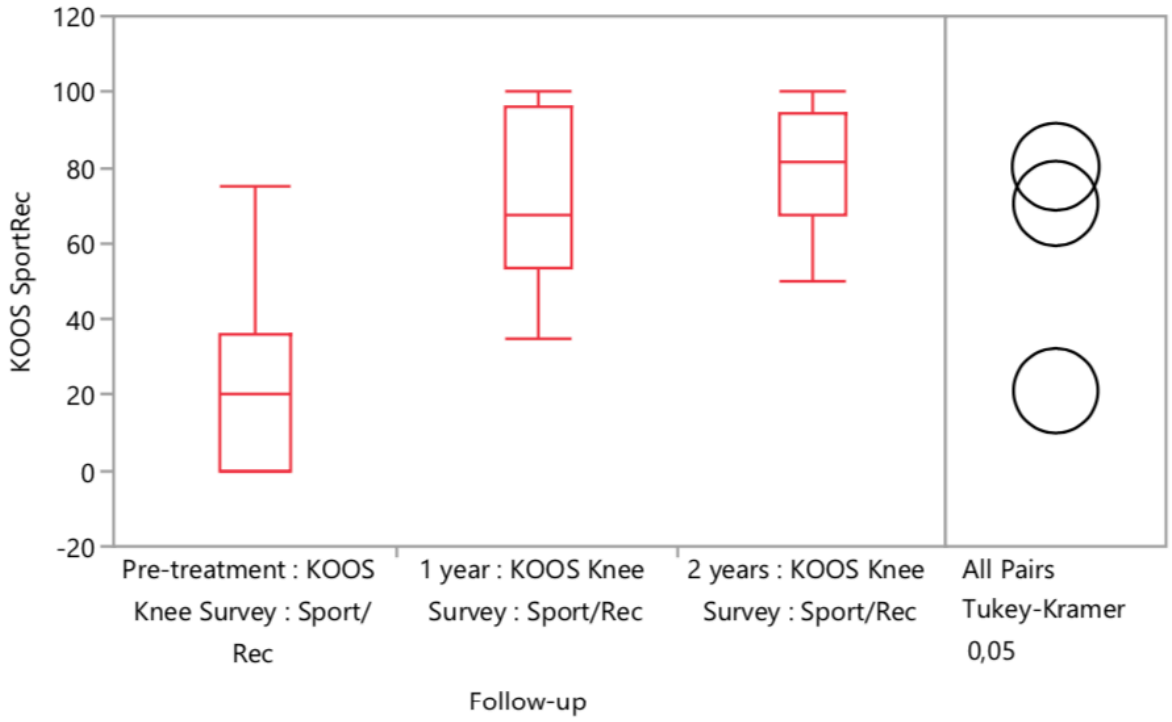



Figure 93: Chart demonstrating the KOOS for sport and recreation at the different time intervals

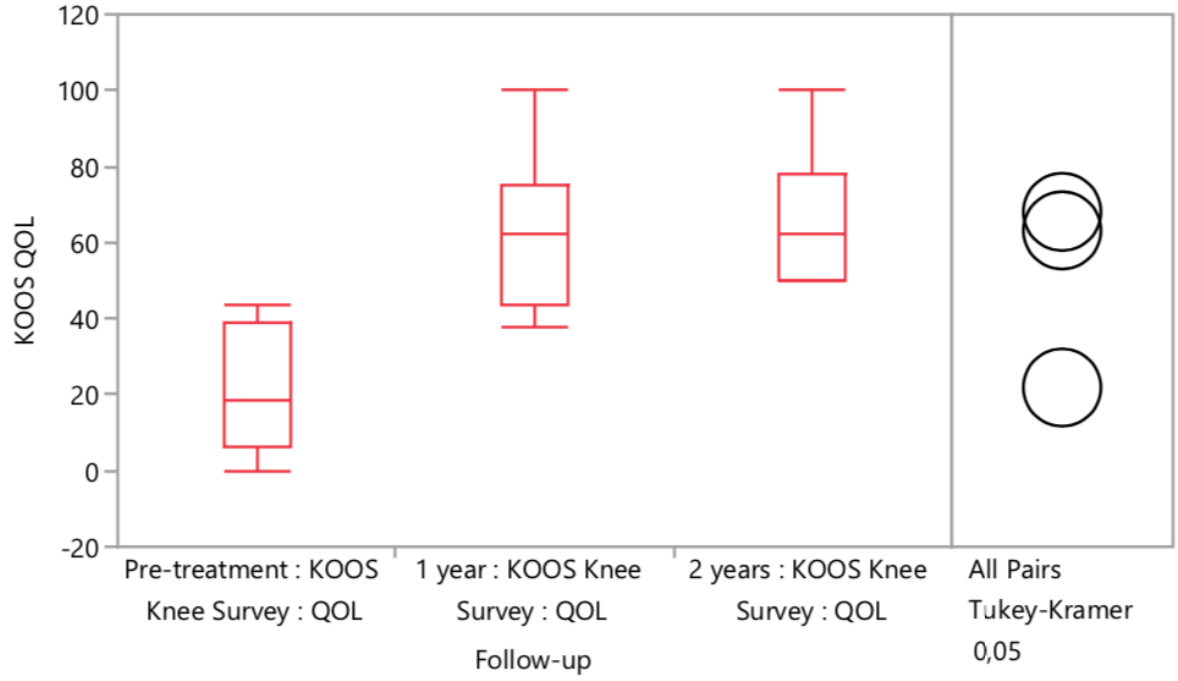



Figure 94: Chart demonstrating the KOOS for quality of life at the different time intervals

**Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)**

All sections of the WOMAC demonstrated significant improvements at 2-year follow-up ($p<0.0001$) as illustrated in Figure 95.

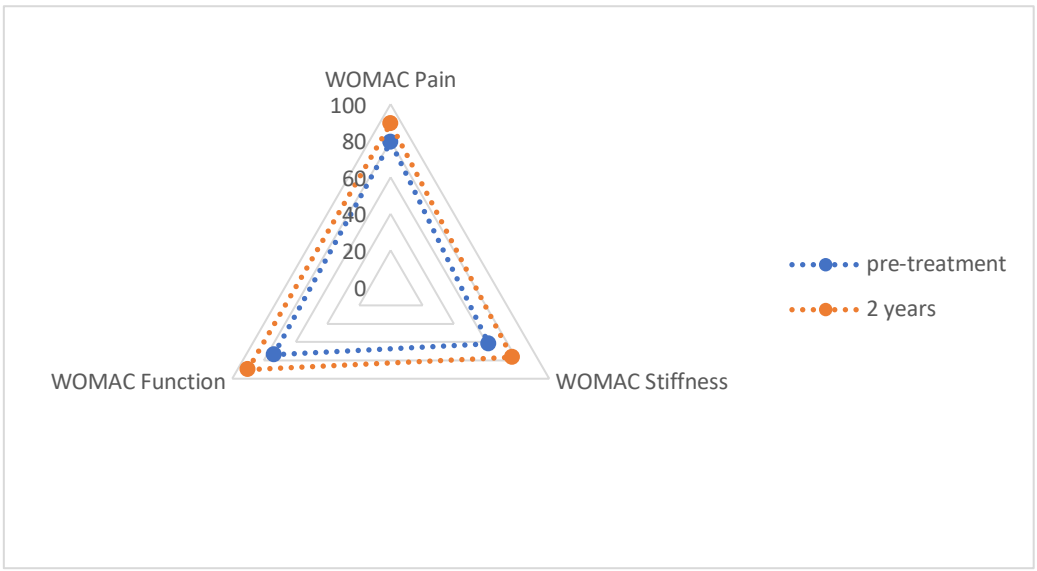



Figure 95: Spider chart demonstrating significant improvements at 2-year follow-up in all sub-sections of the WOMAC.

The WOMAC for pain was 59.7 preoperatively and increased significantly to 94.7 at 2-year follow-up ($p<0.0001$). The WOMAC for stiffness was 48.6 preoperatively and increased significantly to 82.6 at 2-year follow-up ($p<0.0001$). The WOMAC for function was 60.0 preoperatively and increased significantly to 97.3 at 2-year follow-up ($p<0.0001$). No significant differences were seen between the different postoperative time intervals for any of the WOMAC subsections. (Figures 96-98)

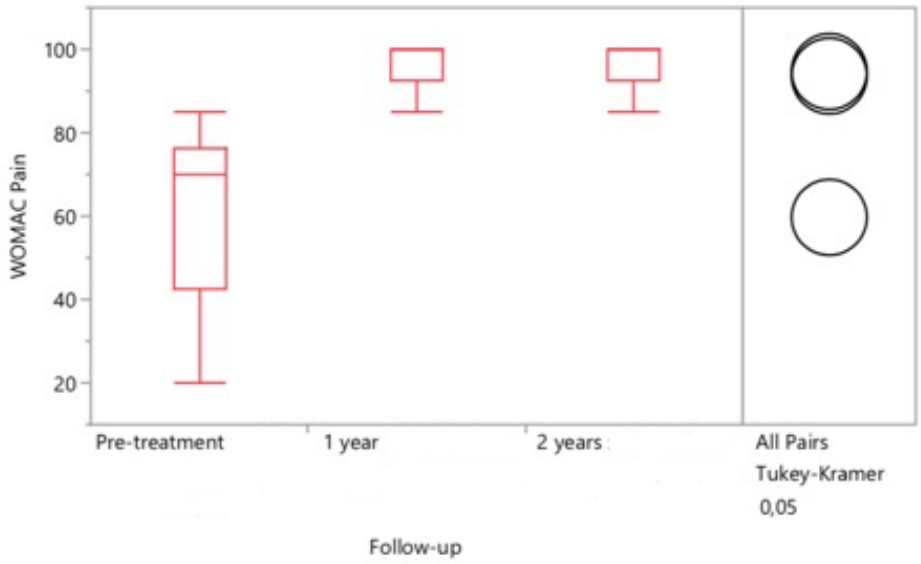



Figure 96: Chart demonstrating the WOMAC for pain at the different time intervals

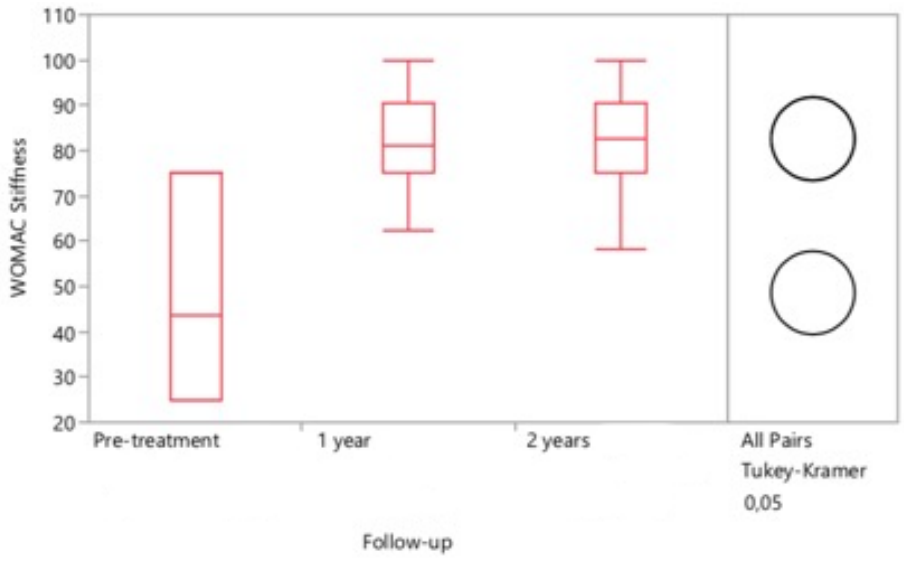



Figure 97: Chart demonstrating the WOMAC for stiffness at the different time intervals

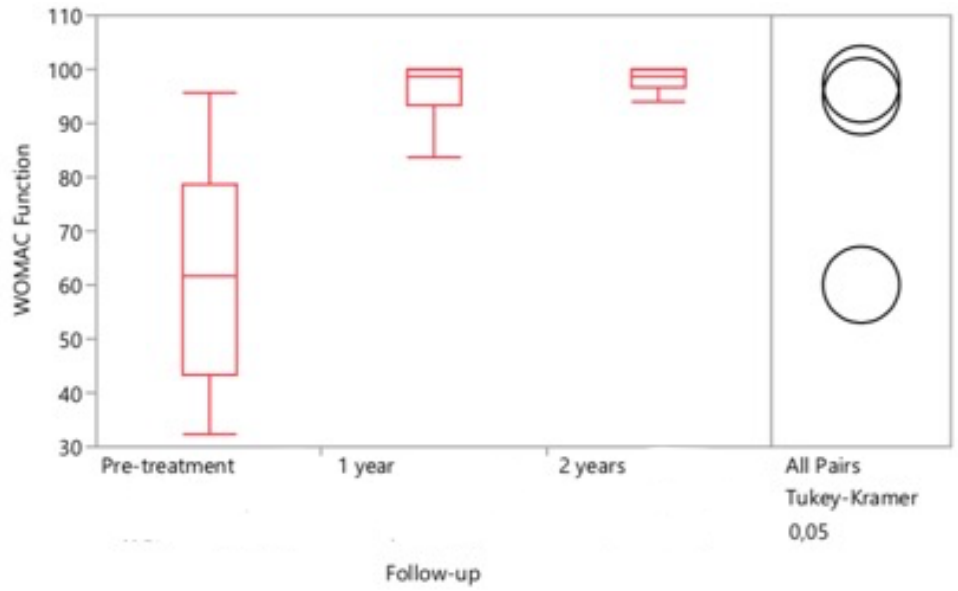



Figure 98: Chart demonstrating the WOMAC for function at the different time intervals

**Visual Analogue Pain Scale (VAS)**

The VAS for pain decreased significantly from 3.6 preoperatively to 0.9 at 2-year follow-up ($p<0.0001$). (Figure 99) No significant differences were seen between the 1-year and 2-year postoperative time intervals.

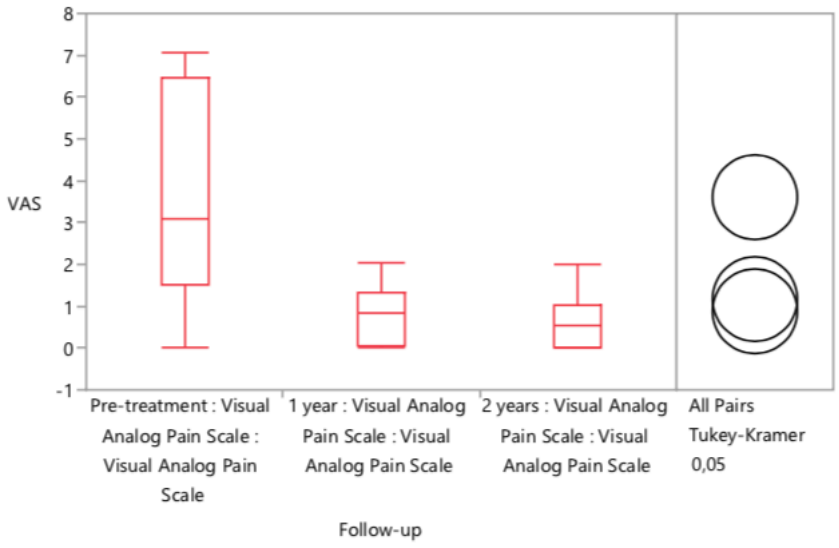



Figure 99: Chart demonstrating a significant decrease in pain scores from preoperatively to 2-year postoperatively.

**Veterans RAND 12 Item Health Survey (VR-12)**

The VR-12 physical score was 34.8 preoperatively and increased significantly to 54.0 at 2-year follow-up (p<0.0001). (Figure 100) The VR-12 mental score was 51.1 preoperatively and there was minimal change to 54.1 at 2-year follow-up (p=0.57). (Figure 101) No significant differences were seen between the 1-year and 2-year postoperative time intervals.

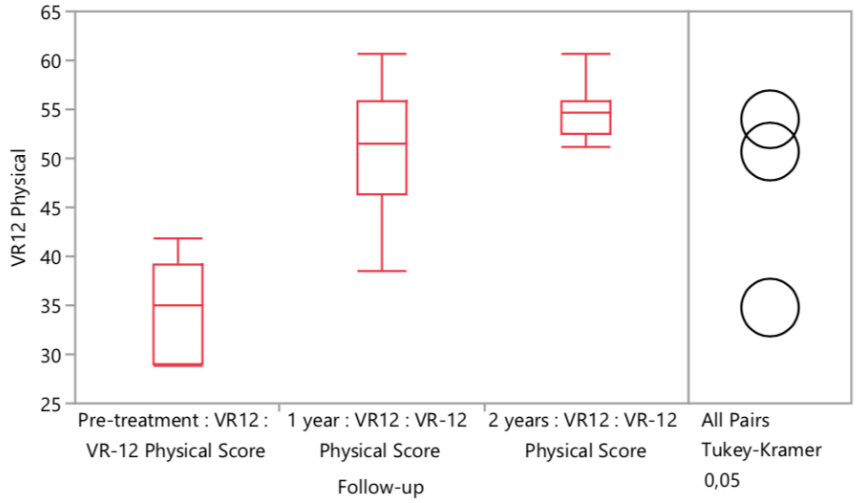



Figure 100: Chart demonstrating the VR-12 physical scores at the different time intervals

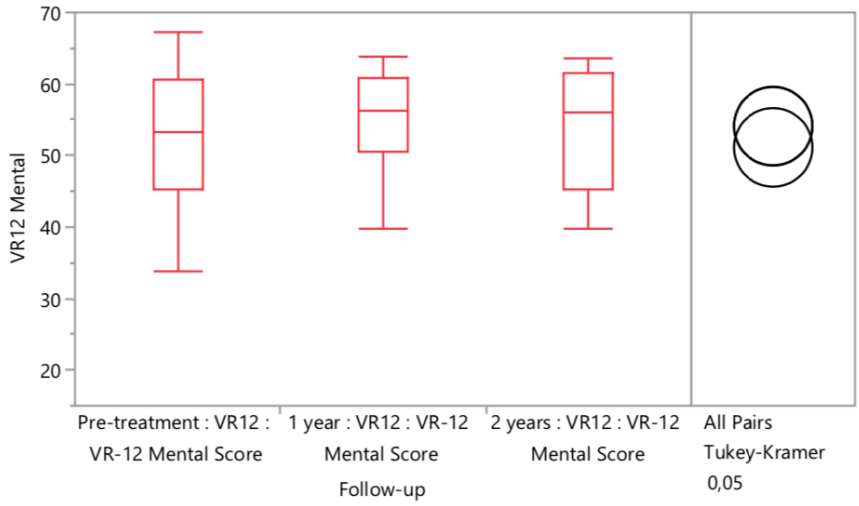



Figure 101: Chart demonstrating the VR-12 mental scores at the different time intervals

**Marx Activity Scale**

The Marx activity scale increased from 6.0 preoperatively to 7.9 at 2-year follow-up but this was not a statistically significant result (p=0.61). There was also very little change in the scores between 1-year and 2-years postoperatively. (Figure 102)

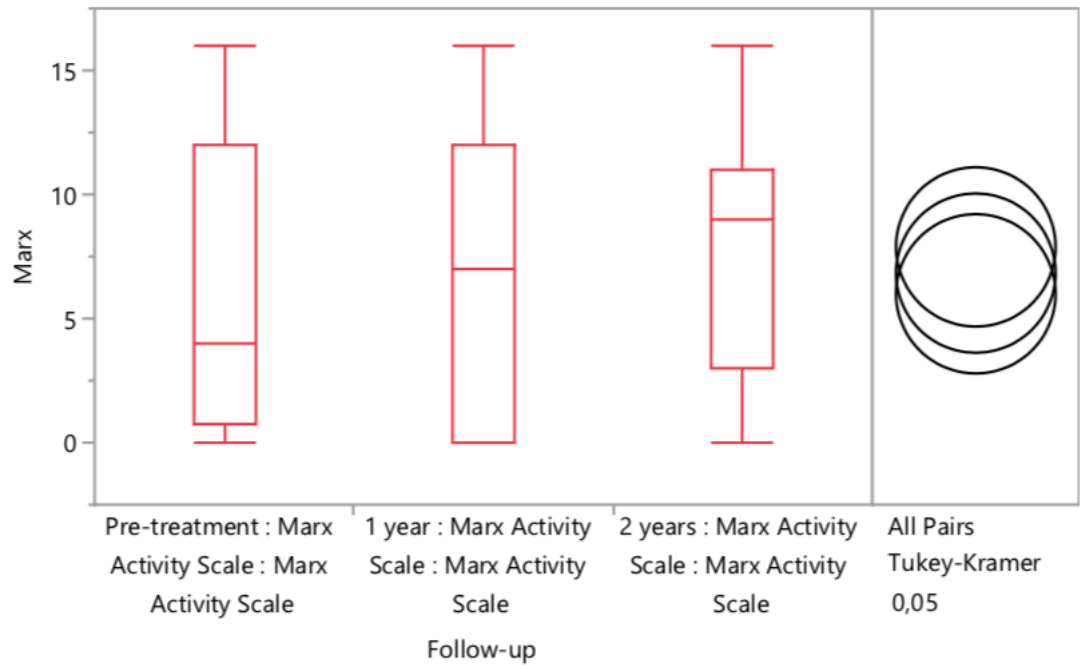



Figure 102: Chart demonstrating an overall increase in the Marx activity score following PLC repair

**Overall satisfaction**

As outlined in Table 18, the majority of patients were happy with their PLC repair with suture tape augmentation at 2-years. 100% of patients felt the surgery exceeded or met their expectations with regards to reducing pain as well as resuming normal functions of daily living. 95% of patients felt the surgery exceeded or met their expectations with regards to improving movement and strength of the knee. 84% of patients felt the surgery exceeded or met their expectations with regards to resuming normal sporting activities.

| | Pain (% patients) | Movement (% patients) | Function (% patients) | Sports (% patients) |
|---|---|---|---|---|
| **Exceeded expectations** | 56 | 67 | 67 | 56 |
| **Met expectations** | 44 | 28 | 33 | 28 |
| **Did not meet expectations** | - | 5 | - | 16 |
| **Not applicable** | - | - | - | - |

Table 18: This table demonstrates the overall satisfaction of patients at 2-year follow-up

## Medial Patellofemoral Ligament Repair

### Demographics

Between August 2011 and March 2017, 18 patients underwent MPFL repair with suture tape augmentation and were included in this study. These patients were prospectively followed up for a minimum of 2-years postoperatively. Indications for this procedure were patients who were suffering from recurrent patellar instability despite conservative treatment. Patients requiring any additional surgery such as a tibial tubercle osteotomy or trochleoplasty were excluded. 1 patient was lost to follow-up leaving 17 patients in the final analysis (94.4%).

Mean follow-up was 50.9 (+/- 20.8) months (range, 24-91 months). The mean age at the time of surgery was 21.6 (+/-11.3) years (range, 13-50). 8 patients were male and 9 patients were female.

No complications such as recurrent subluxation/dislocations, patellar fractures or tightness requiring release were reported in the patients included in this study.

### Knee Injury and Osteoarthritis Outcome Score (KOOS)

All sections of the KOOS demonstrated significant improvements at 2-year follow-up as outlined in Figure 103.

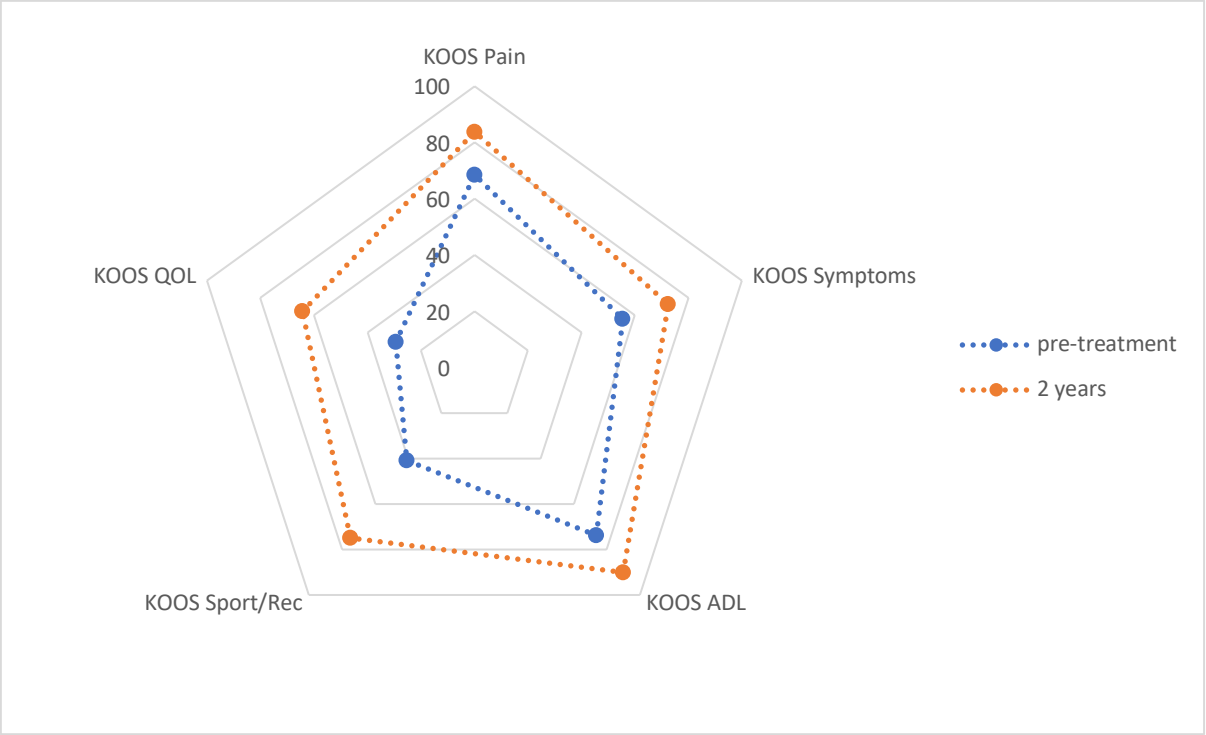



Figure 103: Spider chart demonstrating significant improvements at 2-year follow-up in all sub-sections of the KOOS.

The KOOS for pain was 68.5 preoperatively and increased significantly to 83.8 at 2-year follow-up (p=0.0054). The KOOS for symptoms was 55.5 preoperatively and increased significantly to 72.5 at 2-year follow-up (p=0.0018). The KOOS for ADLs was 73.8 preoperatively and increased significantly to 90.1 at 2-year follow-up (p=0.0006). The KOOS for Sport and Recreation was 40.9 preoperatively and increased significantly to 74.9 at 2-year follow-up (p<0.0001). The KOOS for Quality of Life was 29.4 preoperatively and increased significantly to 64.3 at 2-year follow-up (p<0.0001). No significant differences were seen between the 1-year and 2-year time intervals for any of the KOOS subsections. (Figures 104-108)

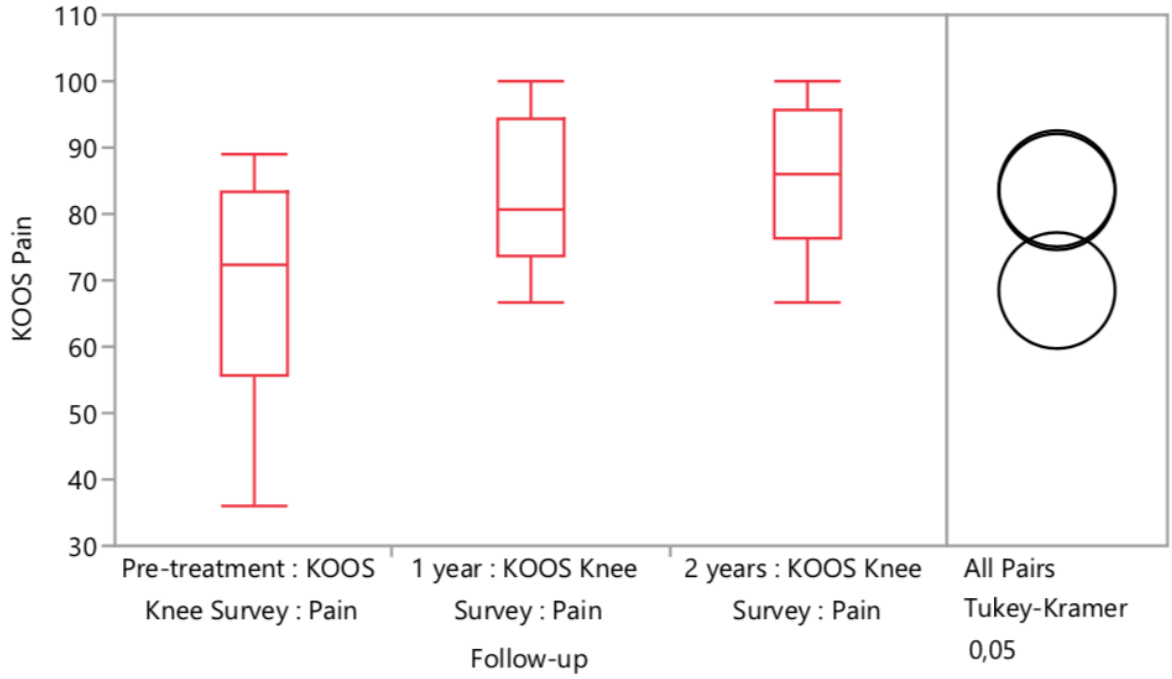



Figure 104: Chart demonstrating the KOOS for pain at the different time intervals

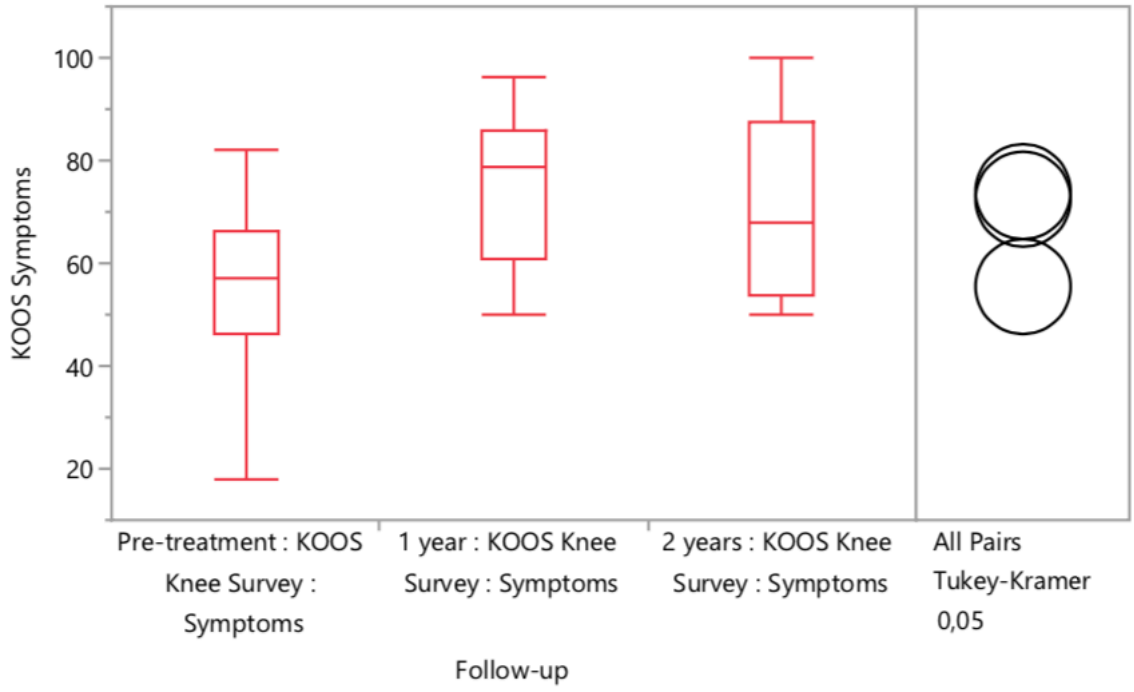



Figure 105: Chart demonstrating the KOOS for symptoms at the different time intervals

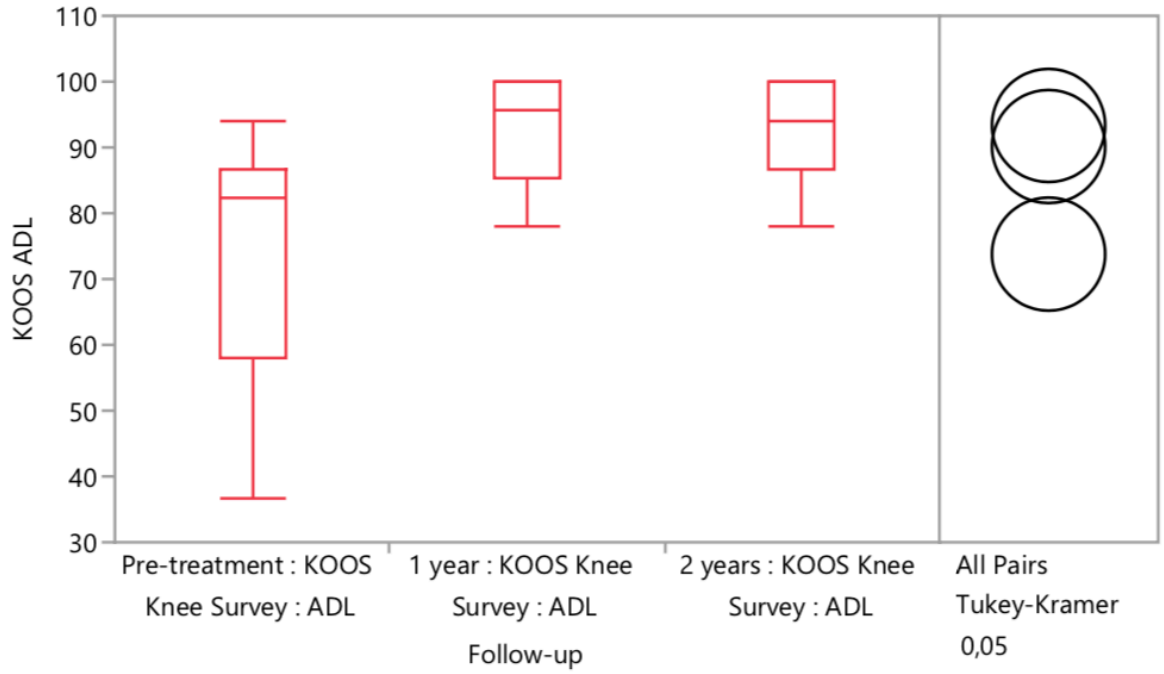



Figure 106: Chart demonstrating the KOOS for ADLs at the different time intervals

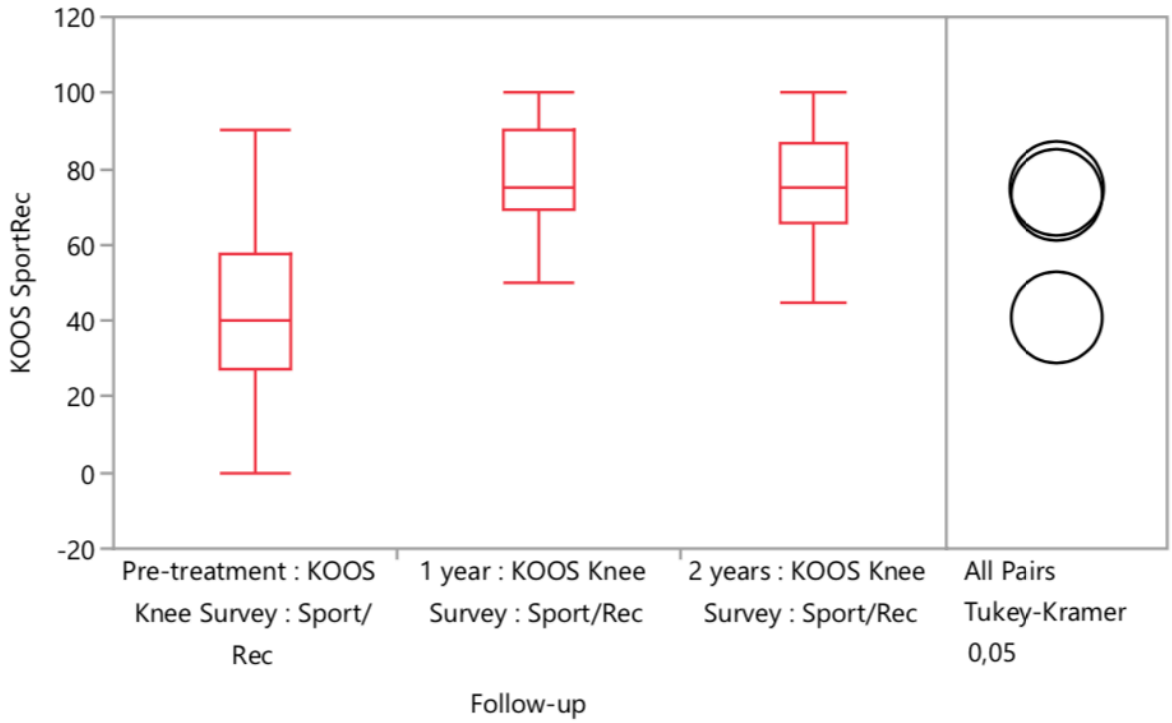



Figure 107: Chart demonstrating the KOOS for sport and recreation at the different time intervals

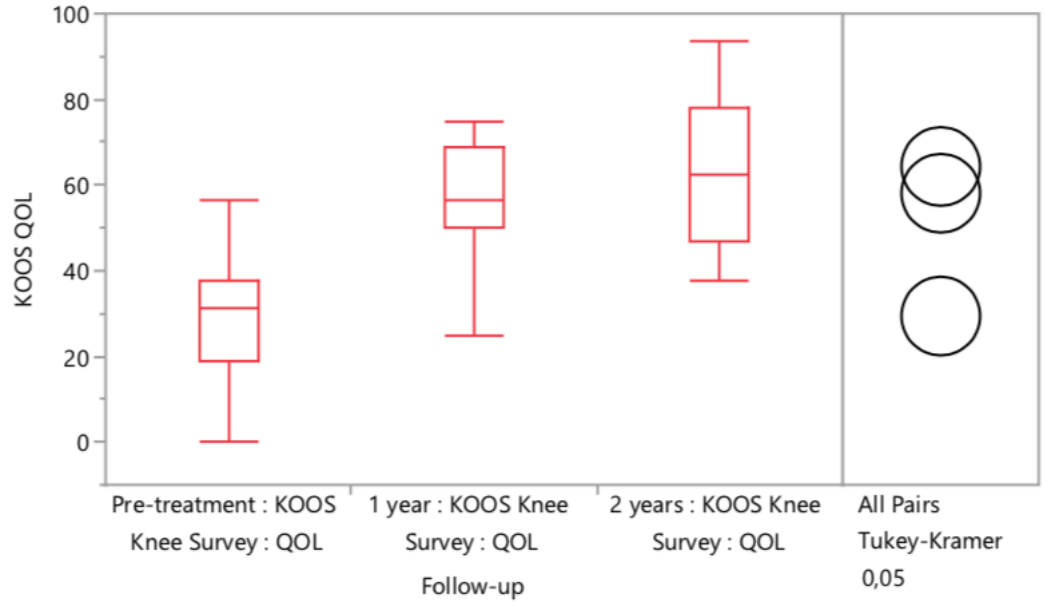



Figure 108: Chart demonstrating the KOOS for quality of life at the different time intervals

**Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)**

All sections of the WOMAC improved at 2-year follow-up as outlined in Figure 109.

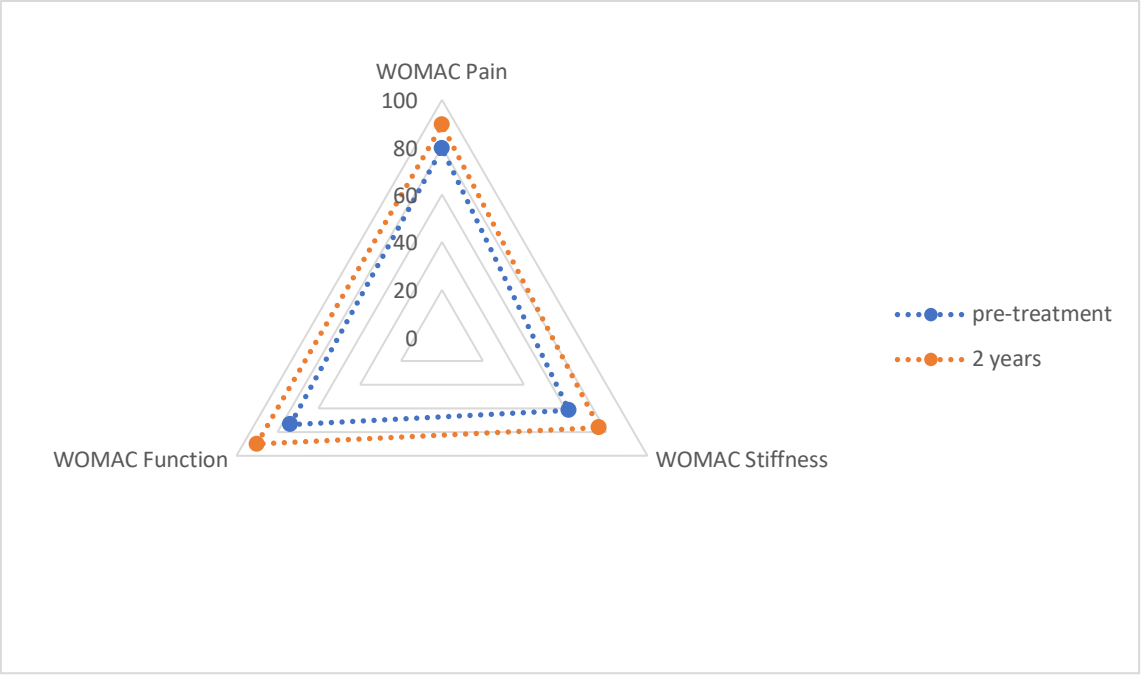



Figure 109: Spider chart demonstrating significant improvements at 2-year follow-up in all sub-sections of the WOMAC.

The WOMAC for pain was 79.4 preoperatively and increased to 89.4 at 2-year follow-up, however, this was not significant (p=0.0657). The WOMAC for stiffness was 61.8 preoperatively and increased to 76.5 at 2-year follow-up but this was also not significant (p=0.0656). However, the WOMAC for function did increase significantly from 73.8 preoperatively to 90.1 at 2-year follow-up (p=0.0006). No significant differences were seen between the different postoperative time intervals for any of the WOMAC subsections. (Figures 110-112)

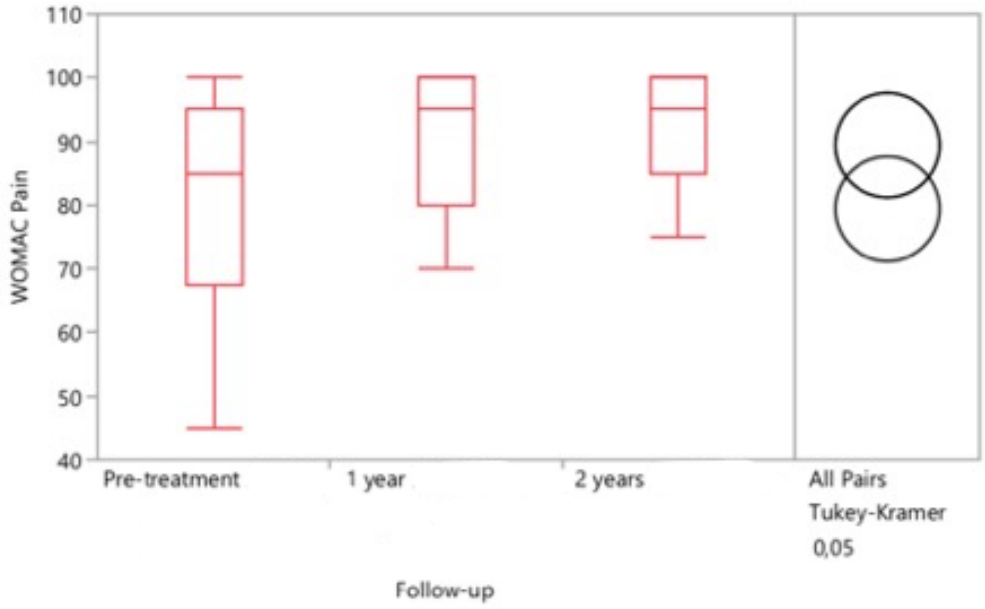



Figure 110: Chart demonstrating the WOMAC for pain at the different time intervals

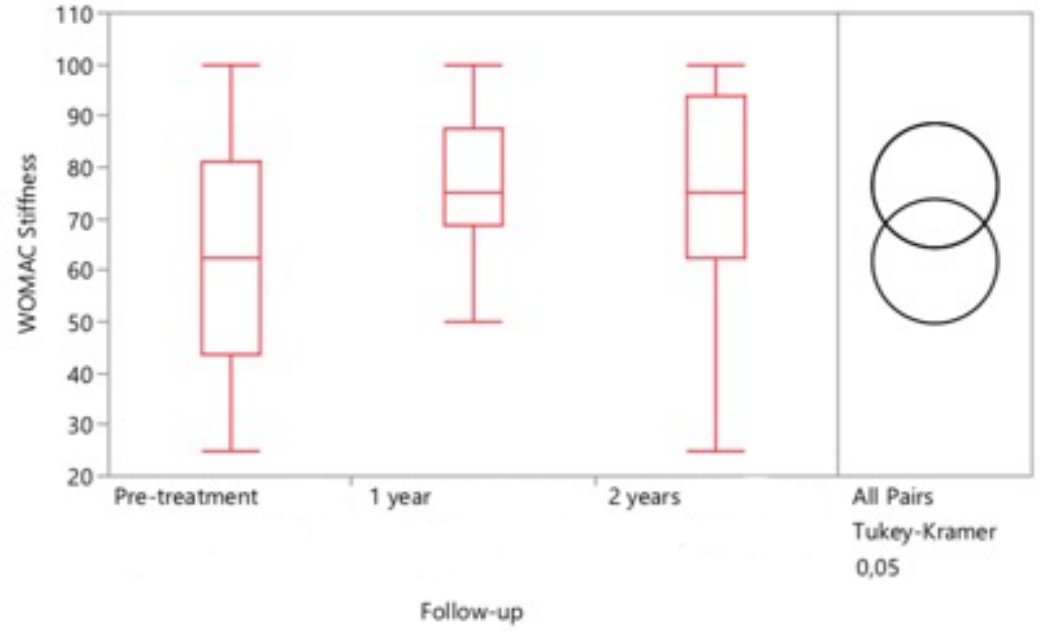



Figure 111: Chart demonstrating the WOMAC for stiffness at the different time intervals

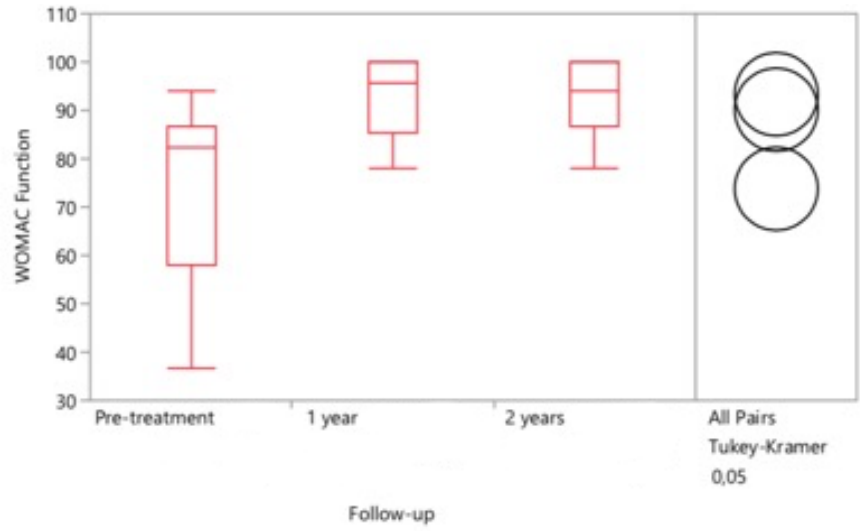



Figure 112: Chart demonstrating the WOMAC for function at the different time intervals

**Visual Analogue Pain Scale (VAS)**

The VAS for pain decreased significantly from 2.9 preoperatively to 1.3 at 2-year follow-up (p=0.025). (Figure 113) No significant differences were seen between the 1-year and 2-year postoperative time intervals.

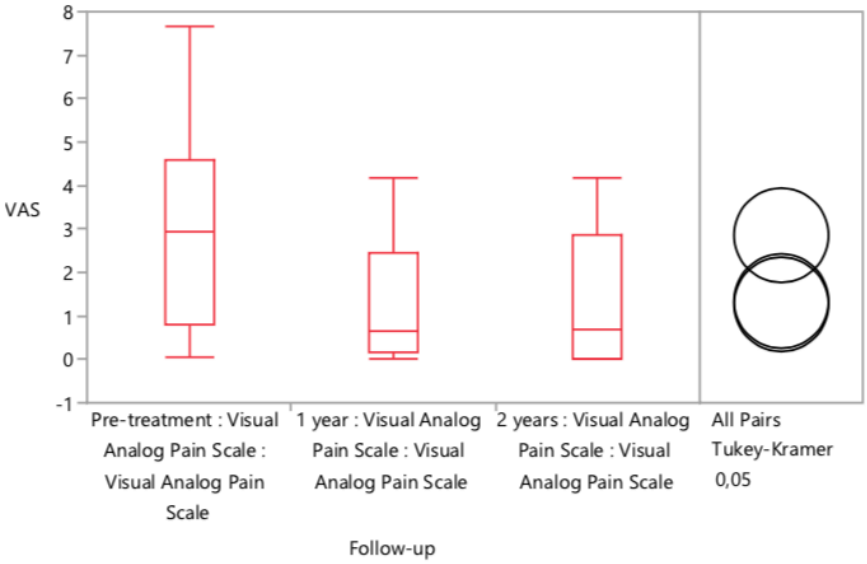



Figure 113: Chart demonstrating a significant decrease in pain scores from preoperatively to 2-year postoperatively.

**Veterans RAND 12 Item Health Survey (VR-12)**

The VR-12 physical score was 37.3 preoperatively and increased significantly to 51.1 at 2-year follow-up (p<0.0001). (Figure 114) The VR-12 mental score was 54.5 preoperatively and there was minimal change to 58.5 at 2-year follow-up (p=0.16). (Figure 115) No significant differences were seen between the 1-year and 2-year postoperative time intervals.

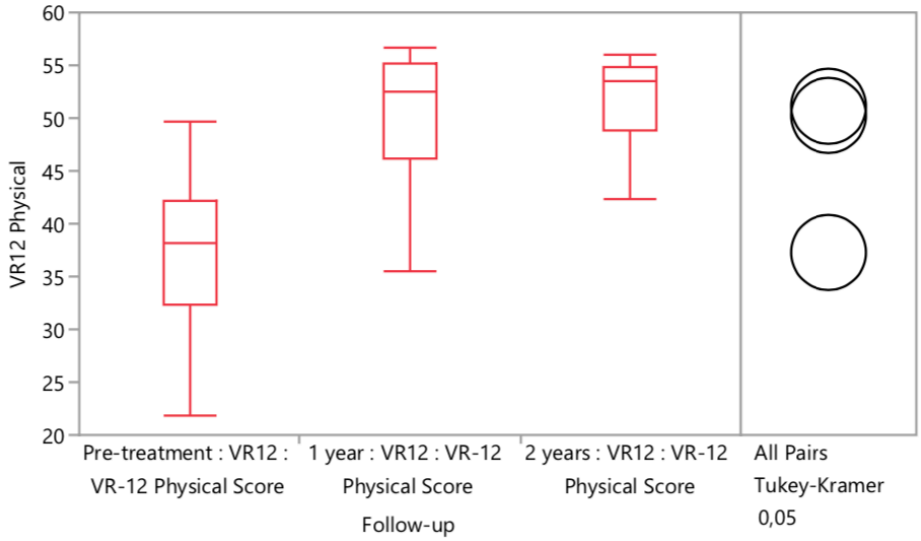



Figure 114: Chart demonstrating the VR-12 physical scores at the different time intervals

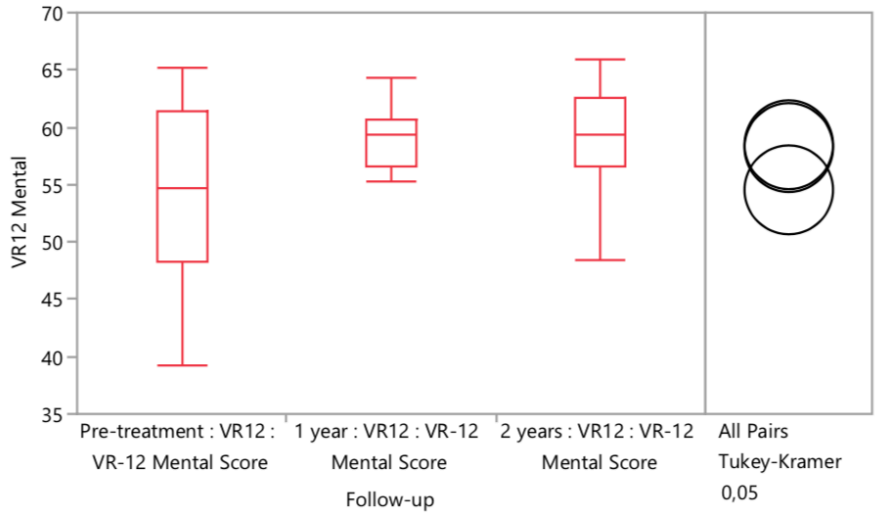



Figure 115: Chart demonstrating the VR-12 mental scores at the different time intervals

**Marx Activity Scale**

There was minimal change in the Marx activity scale which went from 10.3 preoperatively to 9.3 at 2-year follow-up but this was not a statistically significant result (p=0.83). There was also very little change in the scores between 1-year and 2-years postoperatively. (Figure 116)

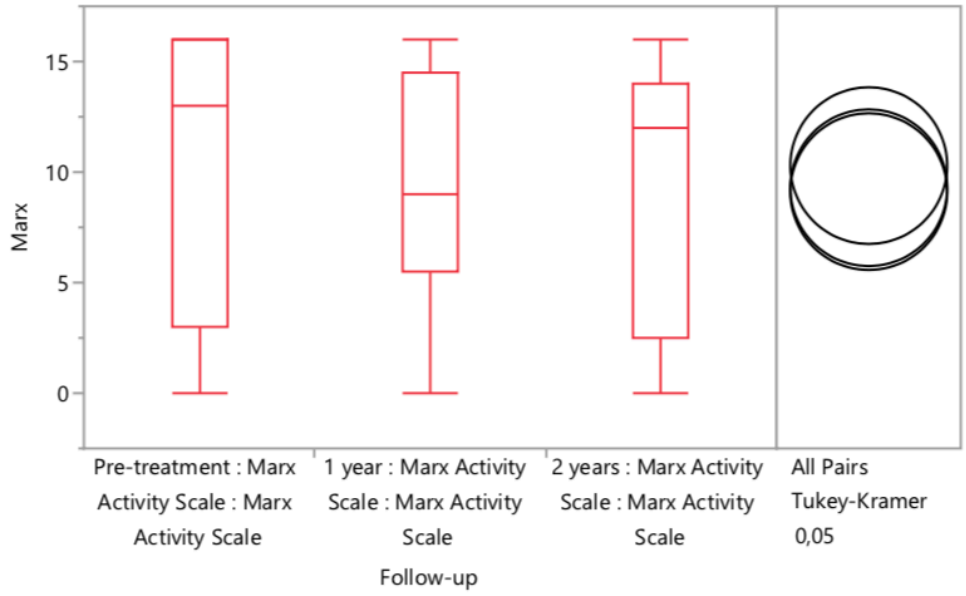



Figure 116: Chart demonstrating minimal change in the Marx activity score at 1 year and 2 years postoperatively

**Overall satisfaction**

As outlined in Table 19, the majority of patients were happy with their MPFL repair with suture tape augmentation at 2-years. 88% of patients felt the surgery exceeded or met their expectations with regards to reducing pain as well as resuming normal functions of daily living. 75% of patients felt the surgery exceeded or met their expectations with regards to improving movement and strength of the knee. 63% of patients felt the surgery exceeded or met their expectations with regards to resuming normal sporting activities.

| | **Pain (% patients)** | **Movement (% patients)** | **Function (% patients)** | **Sports (% patients)** |
|---|---|---|---|---|
| **Exceeded expectations** | 38 | 44 | 38 | 38 |
| **Met expectations** | 50 | 31 | 50 | 25 |
| **Did not meet expectations** | 12 | 25 | 12 | 25 |
| **Not applicable** | - | - | - | 12 |

Table 19: This table demonstrates the overall satisfaction of patients at 2-year follow-up

# Chapter 4 – Discussion

## Anterior Cruciate Ligament

The most important findings of this study were the excellent patient-reported outcome measures in 82.4% of patients undergoing ACL repair with suture tape augmentation for acute proximal ACL ruptures. There were significant improvements in all aspects of the KOOS and WOMAC scores ($p<0.0001$) as well as a significant reduction in the VAS for pain ($p<0.0001$) and a significant increase in the VR-12 physical score ($p<0.0001$). These patients have avoided the need for ACL reconstruction and its associated graft site morbidity and loss of proprioceptive fibres from the native ACL. These outcomes are better than the failure rates of 25-53% associated with primary repairs of the ACL in the 1970s and 1980s which was one of the reasons behind ACL reconstruction becoming the gold standard surgical option for ACL ruptures. [48,51,113] This outcome is also similar to that described for meniscal repair surgery where more than 80% of patients do not require further surgery. [55] Importantly, the tunnels associated with this technique in this study are situated in the same position as the larger tunnels used for hamstring or patellar tendon autografts in ACL reconstruction. As a result, the 6 failures of our ACL repair technique have had a routine primary ACL reconstruction using autograft without compromise of the knee joint and the additional complications associated with revision surgery. [109] Reassuringly, there was no evidence of synovitis, erosions or cyst formation on further imaging or at the time of revision surgery. This addresses a major concern and highlights the difference between the internal bracing technique used in this study and traditional synthetic grafts. [170] Survival rates are similar to the 5-year outcomes of the dynamic intraligamentary stabilization ACL repair technique (80%), albeit that was a much smaller cohort. [44] Likewise, we have shown similar results to the recent paper by Gagliardi et al which showed an 81.8% survival rate with ACL repair with suture tape augmentation in adolescents with a mean age of 13. [59]

Our finding of increased failure rates in young and more active patients are not surprising given these findings have been reported in registry data for several years in relation to ACL reconstructions. [4,5,50,60,90,116,158,186] However, we found 42.9% of patients aged 25 or under suffered from a re-rupture therefore these patients should not be undergoing ACL repair alone and either require an additional augmentation procedure to provide rotational stability or should undergo ACL reconstruction with or without suture tape augmentation which has been recently described in the literature. Additionally, the overall decrease in the Marx activity scale postoperatively has previously been reported for patients undergoing ACL reconstruction. [128,164] However, our findings of a 38.5% failure rate in those with a Marx Activity level greater than 14 is significant therefore the appropriateness of ACL repair in isolation should be assessed for this patient population as for the younger patients. Interestingly we also found that the patients who underwent revision surgery returned to their previous level of activity at 5 years which indicates that the revision surgery is certainly not as troublesome as revision following ACL reconstruction.

Nevertheless, the patients in this study underwent an isolated ACL repair with suture tape augmentation between 2011-2014 which is around the time when the anterolateral ligament (ALL) was being rediscovered. [28] We now know that many of the patients in this cohort, in particular those who suffered from a re-rupture who could be deemed high risk patients may have had an additional ALL repair with suture tape augmentation performed to provide rotational stability. Our results add to the current literature suggesting that a combined ACL and ALL procedure is the treatment of choice for high risk patients. [138] Indeed, the recent STABILITY trial demonstrated a statistically significant reduction in graft rupture from 11% to 4% with the addition of a lateral extra-articular tenodesis to a single-bundle hamstring autograft ACL reconstruction. [64]

There are several limitations associated with this study, namely the lack of clinical testing and radiological assessment at 5 years. Furthermore, the mean age in this cohort was 37.8 years and it could be these older patients have not put the extra demand on the ACL that a younger patient often does. In addition, no comparisons

can be made to ACL reconstruction procedures as there was no randomisation and all of the patients within the inclusion criteria underwent ACL repair with suture tape augmentation.

Nonetheless, further clinical studies are necessary with larger patient numbers and longer follow-up as well as studies with a higher level of evidence such as a randomized controlled trial between ACL reconstruction and ACL repair. This would further assess the encouraging early results of ACL repair with internal bracing.

**Anterolateral Ligament**

The main finding in this study was the encouraging 2-year follow-up results of this technique of combined ACL and ALL repair with suture tape augmentation. There were significant improvements in all aspects of the KOOS and WOMAC scores ($p<0.0001$) as well as a significant reduction in the VAS for pain ($p<0.0001$) and a significant increase in the VR-12 physical score ($p<0.0001$). These 2-year follow-up PROMs are comparable to the MOON Knee Group of 1592 patients who underwent ACL reconstruction. [163] 2 patients suffered from a re-rupture (5.3%) and both of these were significant trauma therefore unavoidable. The ACL survival rate of 94.7% is similar to other ALL reconstruction techniques that have recently been published. [138]

Indeed, Helito et al described better results in an ACL and ALL reconstruction group versus an isolated ACL reconstruction group in patients who were treated for a chronic ACL lesion. The ACL and ALL group had a positive pivot shift test in 9.1% and no re-ruptures versus 35.3% and 7.3% respectively in the isolated ACL group at two years post-surgery [71]. Additionally, Helito et al described their findings in patients with ligamentous hyperlaxity and also demonstrated a lower failure rate with combined ACL and ALL reconstruction compared to ACL reconstruction alone, (21.7% v 7.3%) [72] More recently, the STABILITY trial demonstrated a statistically significant reduction in graft rupture from 11% to 4% with the addition of a lateral extra-articular tenodesis to a single-bundle hamstring autograft ACL reconstruction. [64] Good clinical outcomes have also been revealed with combined autograft procedures in high risk groups including professional athletes and it has also been shown to protect medial meniscal repairs with a significantly lower rate of failure when compared to isolated ACL reconstructions. [138,161,162] All of these papers in the literature are similar to our re-rupture rate of 5.3%. On the other hand, these techniques have some issues as demonstrated in a recent anatomical paper which reported that there is a 70% chance of tunnel convergence with a combined ACL reconstruction and lateral extra-articular tenodesis. [87] The technique we have described avoids this complication as small tunnels are used for

the ACL repair and bone anchors are used for the percutaneous ALL internal brace augmentation.

ACL repair and ALL internal brace augmentation was indicated in 43 patients during the timeframe of this study. As illustrated in Figure 45, this was 21% of the total number of cases and 118 patients (58%) were suitable overall for ACL repair in the cohort of 203 patients. Van der List et al identified patients who were suitable for primary ACL repair and noted that 44% of their large cohort of 361 patients had repairable ACL tears. [175] Additionally, the same group identified patients who were suitable for primary ACL repair on magnetic resonance imaging and demonstrated 16% of their patients had type I tears and 27% had type II tears which were suitable for ACL repair. [176] On the other hand, Achtnich et al reported the incidence of proximal ACL tears to be only 10%. [2] The experience of the senior author in primary repair and the number of tertiary referrals at the time of this study could account for our higher proportion of ACL repairs. Although, Grontvedt et al did report that 71% of their patients had proximal third tears amenable to repair. [68]

There are several limitations associated with this study including the lack of clinical testing and radiological assessment at two years. Furthermore, no comparisons can be made to ACL reconstruction procedures or isolated ACL repair procedures as all of the patients within the inclusion criteria underwent this combined procedure. Clinical studies are necessary with larger patient numbers and longer follow-up with objective clinical measurements and imaging, and concurrent cohorts to allow comparisons to further assess the encouraging early results of this combined ACL and ALL internal brace augmentation technique.

The findings of this combined ACL repair and ALL augmentation technique in addition to our isolated ACL repair outcomes suggest that younger patients, patients with a high level of sporting activity and those with a Grade 3 pivot shift or associated Segond fracture should have an additional ALL procedure to provide rotational stability. We would also suggest that patients requiring ACL reconstruction have internal bracing with suture tape augmentation as this has

recently been shown to be biomechanically superior in the literature. [13,155] Therefore, the senior authors suggested treatment algorithm for ACL ruptures based on these findings is outlined in Figure 116.

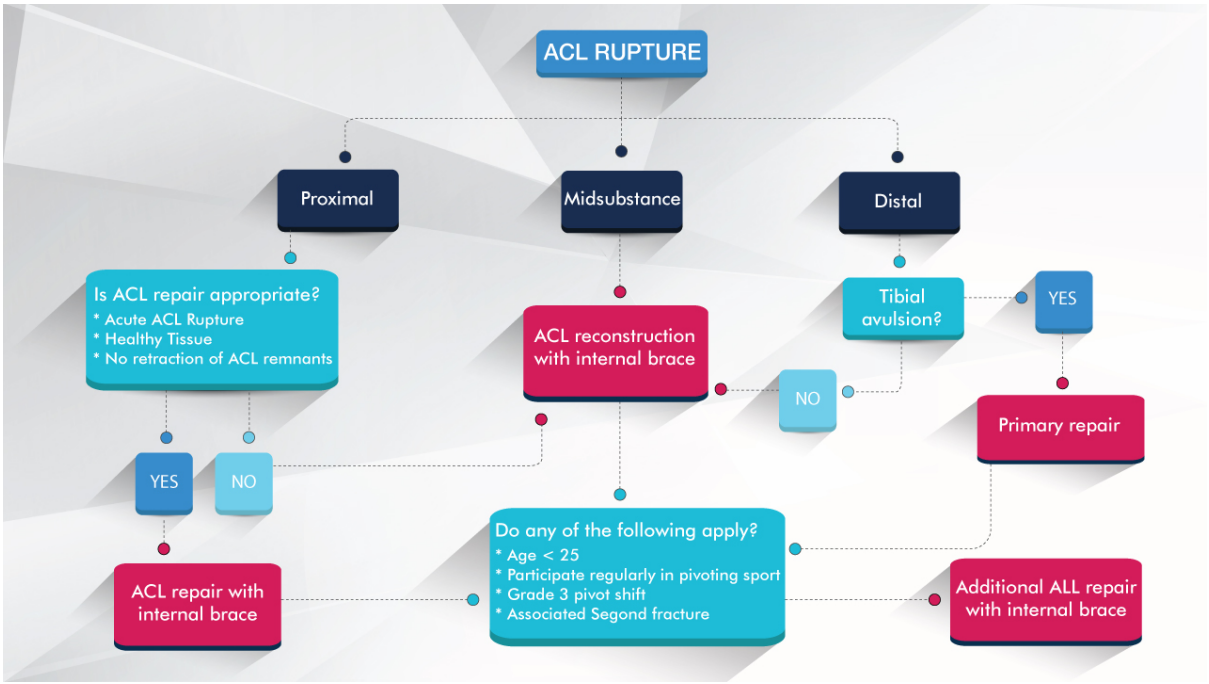



Figure 117: Flowchart demonstrating the senior authors recommended treatment for ACL ruptures with internal bracing

**Posterior Cruciate Ligament**

The main finding in this study was the encouraging 2-year follow-up results of this technique of PCL repair with suture tape augmentation. There were significant improvements in all aspects of the KOOS and WOMAC scores as well as a significant reduction in the VAS for pain and a significant increase in the VR-12 physical score ($p<0.005$). Only 1 patient suffered from a re-rupture and subsequently underwent a PCL reconstruction with no complications reported thereafter. Similar to our ACL studies, the tunnels associated with this PCL repair technique are situated in the same position as the larger tunnels used for autografts or allografts in PCL reconstruction. As a result, the revision surgery is routine without compromise of the knee joint and the additional complications associated with revision surgery. [109] As with our ACL work, there was no evidence of synovitis, erosions or cyst formation on further imaging or at the time of revision surgery. This addresses a major concern and highlights the difference between the internal bracing technique used in these studies and traditional synthetic grafts. [170]

The results we have described are substantially better than historical papers that investigated the clinical outcomes of PCL repairs. Hughston et al[82] found good objective results in only 65% of the 20 patients they had available for follow-up. However, only 55% of these patients had proximal PCL tears and all of the patients were part of a multiligament injury. On the other hand, the subjective results were reported as good in 90% of patients. Strand et al [166] indicated 51% of the patients in their study had posterior instability postoperatively but they also reported good or excellent subjective outcomes in 81% of patients. Pournaras et al [135] found that 100% of the 20 cases in their study had posterior instability postoperatively. Our results are comparable to traditional PCL reconstruction techniques as described in the systematic reviews by Chahla et al [24], Belk et al [17] and Del Buono et al [35]. Although, these studies reported objective clinical testing as well as using the IKDC, Lysholm and Tegner scores as PROMs. On the other hand, we did find that the KOOS postoperative scores were substantially lower than for the ACL repair and combined ACL and ALL repair techniques we have described. In particular, the KOOS for sport and recreation was 69.6 in comparison

to 87.8 and 82.8 for ACL repair and combined ACL and ALL repair respectively. Likewise, quality of life was 54.2 with PCL repair and 78 and 74.3 for ACL repair and combined ACL and ALL repair respectively. Furthermore, the overall satisfaction questionnaire demonstrates 29% of patients were not happy with regards to return to sporting activity.

There are several limitations associated with this study, namely the lack of clinical testing and radiological assessment at 2 years. Furthermore, the mean age in this cohort was 37.2 years and it could be these older patients have not put the extra demand on the PCL that a younger patient often does. Moreover, a number of these patients have torn their PCL as part of a multiligament injury though this is similar to the figures described in historic PCL literature and it is known that most PCL injuries are associated with multiligament injuries to the knee. Nonetheless, we did not find any differences between the isolated PCL group and the multiligament group. In addition, no comparisons can be made to PCL reconstruction procedures as there was no randomisation and all of the patients within the inclusion criteria underwent PCL repair with suture tape augmentation.

This study indicates PCL repair with suture tape augmentation is an alternative operative treatment to traditional PCL reconstruction techniques in appropriate cases. However, further clinical studies are necessary with larger patient numbers and longer follow-up as well as studies with a higher level of evidence to further assess these encouraging early results of PCL repair with internal bracing.

**Medial Collateral Ligament**

This study demonstrates encouraging 2-year follow-up results of this technique of MCL repair with suture tape augmentation in isolation or as part of a multiligament knee injury. There were significant improvements in all aspects of the KOOS and WOMAC scores as well as a significant reduction in the VAS for pain and a significant increase in the VR-12 physical score ($p<0.05$). 2 patients underwent further surgery on the same knee (5.6%), one was an ACL reconstruction for a re-rupture and the other patient suffered from a PCL rupture and underwent a PCL reconstruction using allograft. In addition, one patient reinjured his MCL which was managed conservatively with physiotherapy and he has had no issues since then. DeLong et al [37] reported a failure rate of 6.1% in their systematic review which is similar to our ipsilateral secondary surgery rate, however, no patient required any further surgery on the MCL in our study. Our patient-reported outcome measures are also similar to this systematic review which evaluated 355 knees that underwent primary MCL repair. In addition, another systemic review of 275 patients undergoing MCL reconstruction demonstrated similar results to our study in terms of outcomes and failure rates. [178] However, the PROMS used were similar to the PCL population with IKDC scores and the Lysholm and Tegner knee activity scores. The rates of isolated MCL surgery versus MCL surgery as part of a multiligament injury are also similar to our study. 83.3% of patients in the systematic review were part of a multiligament injury which is comparable to our 88.9%.

Moreover, it has been reported that the majority of concomitant MCL injuries occur with anterior cruciate ligament (ACL) injuries which is similar to our cohort as all of the multiligament cases involved the ACL (88.9%). [67] Interestingly, staged procedures are often indicated as combined reconstructions of the ACL and MCL have often been associated with increased arthrofibrosis. [67] There were no suggestions in our cohort of multiligament injuries involving the ACL and MCL that this were the case. No manipulations under anaesthetic were required and the WOMAC for stiffness demonstrated significant improvements in terms of stiffness. This may be accounted for by the fact that the internal brace acts as a secondary

stabilizer during the early postoperative stages which promotes natural healing but also allows early mobilization. On the other hand, the satisfaction questionnaire did demonstrate that 13% of patient felt the surgery did not meet their expectation with regards to movement and 19% felt it didn't meet their expectation with regards to returning to sporting activity. Interestingly the change in Marx activity in this study was minimal going from 9.8 preoperatively to 9.4 at years which wasn't significant (p=0.43).

Of course, excellent outcomes have been demonstrated with non-surgical treatment of grade I and II injuries of the MCL. [112] In addition, non-surgical management of grade III injuries has been successful in returning patients to high risk sporting activity such as football. [45,85] Therefore, it could be considered that the majority of patients with MCL injuries do not require any operation. With the majority of instances being associated with a multiligament injury, the senior author would advocate repair with internal brace augmentation to allow earlier mobilisation and rehabilitation and return to sporting activity. Indeed, with Grade III MCL injuries, the risk of concomitant ligament injuries is 80% of which 95% is the ACL. [54] There is no clear consensus in the literature with regards to combined ACL and MCL injuries, however, it would appear that the majority would advocate ACL reconstruction or repair and protecting the MCL with delayed surgery if there is persistent valgus laxity. [67]

There are several limitations associated with this study, namely the lack of clinical testing and radiological assessment at 2 years. The majority of MCL repairs were part of a multiligament injury though this is similar to the figures described in historic MCL literature and it is known that most MCL injuries treated operatively are associated with multiligament injuries to the knee. Nonetheless, we did not find any differences between the isolated MCL group and the multiligament group. In addition, no comparisons can be made to MCL reconstruction procedures as there was no randomisation and all of the patients within the inclusion criteria underwent MCL repair with suture tape augmentation.

Therefore, MCL repair with suture tape augmentation is an alternative operative treatment to traditional MCL reconstruction techniques in appropriate cases. Based upon the literature, non-operative management should be considered in the majority of cases. However, additional studies with higher levels of evidence are required to reinforce this. In particular, studies assessing non-operative management versus MCL repair with suture tape augmentation would be of benefit.

**Posterolateral Corner**

This study demonstrates encouraging 2-year follow-up results of this technique of PLC repair with suture tape augmentation. The majority (89.5%) of these patients were part of a multiligament injury with most of these associated with an injury to the ACL in keeping with the literature. [102] There were significant improvements in all aspects of the KOOS and WOMAC scores as well as a significant reduction in the VAS for pain and a significant increase in the VR-12 physical score ($p<0.0001$). Furthermore, no complications were reported.

These results are substantially better than the historic PLC repair techniques that reported high failure rates with minimum 2-year follow-up [105,165] Stannard et al reported a failure rate of 37% with PLC repairs in comparison to 9% with PLC reconstruction. The majority of their patients (77%) were also multiligament cases. [165] Similarly, Levy et al reported a 40% failure rate with PLC repair compared to 6% in the PLC reconstruction group. [105] There were no PLC repair failures in this study and no re-ruptures of the ACL or PCL in the multiligament cases. We propose that the additional support of the suture tape augmentation during the healing phase has led to these improved results.

Interestingly, the Marx activity scale was only 6.0 preoperatively in this cohort and it increased to 7.9 at 2-years. This preoperative score was considerably lower than the other cohorts we have discussed with 12.4, 13.3, 8.7 and 9.8 for the ACL, ALL, PCL and MCL respectively. It is unclear why this is lower than the other cohorts but it could account for the fact there were no complications following PLC repair as the patients have not put the extra demand on the PLC that a more active patient would have.

There are several limitations associated with this study, namely the lack of clinical testing and radiological assessment at 2 years. Moreover, a number of these PLC injuries are part of a multiligament injury though this is similar to the figures described in historic PLC literature and it is known that most PLC injuries are associated with multiligament injuries to the knee. Nonetheless, we did not find

any differences between the isolated PCL group and the multiligament group. In addition, no comparisons can be made to PLC reconstruction procedures as there was no randomisation and all of the patients within the inclusion criteria underwent PCL repair with suture tape augmentation.

Therefore, PLC repair with suture tape augmentation is an alternative operative treatment to traditional PLC reconstruction techniques in appropriate cases. However, further clinical studies are necessary with a higher level of evidence to further assess these encouraging early results of PLC repair with internal bracing.

**Medial Patellofemoral Ligament**

This study demonstrates encouraging 2-year follow-up results of this technique of MPFL repair with suture tape augmentation. There were significant improvements in all aspects of the KOOS scores and the WOMAC function score as well as a significant reduction in the VAS for pain and a significant increase in the VR-12 physical score ($p<0.05$). On the other hand, the WOMAC scores for pain and stiffness did not improve significantly at 2-years. In addition, only 63% of patients felt MPFL repair with internal bracing met their expectation with regards to return to sporting activity. Moreover, 25% felt the surgery did not meet their expectation with regards to movement and strength of the knee at 2 years. This could be related to excessive tension which would result in postoperative irritation and may lead to quadriceps inhibition as we have mentioned in Table 11 of the surgical techniques section when discussing the pitfalls of MPFL repair with suture tape augmentation. No complications such as recurrent subluxation/dislocations, patellar fractures or tightness requiring release were noted in this cohort.

The absence of recurrent subluxations or dislocation in our cohort are superior to historic literature which revealed high failure rates with MPFL repair. [10,22] Arendt et al [10] described an MPFL repair technique using suture anchors to fix the MPFL to its origin on the femur. They retrospectively reviewed 55 knees in 48 patients with a minimum follow-up of 2-years. 46% of patients suffered from recurrent patellar dislocations with 13 patients undertaking a further stabilization procedure. Camp et al [22] described the outcomes of 27 patients undergoing MPFL repair with either suture anchors or a medial reefing technique with a minimum 2-year follow-up. 28% of patients experienced a recurrent lateral patellar dislocation with 5 of these patients requiring further surgery. Hiemstra et al[76] recently analysed the postoperative redislocation rates in patients undergoing MPFL reconstruction or imbrication. They found a redislocation rate of 5.1% with reconstructions and 20.9% with MPFL imbrication. However, they describe this as a 79% success rate with imbrication as it a simple and less invasive procedure that does not interfere with any future surgical treatments. On the other hand, Dragoo et al [43] recently compared 24 patients at a mean follow-up of 51 months who

underwent MPFL reconstruction or MPFL repair using an algorithm-based approach. They found no differences between the 2 groups and only 1 patient in the MPFL repair group experienced a further dislocation. We would suggest the lack of failures in our cohort is due to the addition of the internal brace which allows the ligament to heal whilst allowing early mobilisation.

MPFL reconstruction is the most commonly performed surgical procedure but it has been associated with varying results in the literature. Several systematic reviews have been published analyzing the outcomes of this technique. The first review by Smith et al [157] looked at 8 studies with 186 MPFL reconstructions and found satisfactory clinical and radiological outcomes, however, they concluded that all of the papers had several methodological weaknesses. Fisher et al [56], Buckens et al [18], Mackay et al [115] and Tompkins et al [168] have since reported similar conclusions. Schneider et al [144] performed a systematic review and meta-analysis to look more specifically at return to sport following MPFL reconstructions. They reported encouraging results with 84.1% of patients returning to sports postoperatively with a low incidence of recurrent instability. Additionally, Lippacher et al demonstrated MPFL reconstruction can allow most patients to engage in regular sports postoperatively. However, they did show that only 53% returned to equal or higher levels of sport. On the other hand, Shah et al [148] reviewed 25 articles and found a complication rate of 26.1% with 26 patients requiring further surgery. The MPFL repair technique we have described with internal bracing has not demonstrated these high complication rates associated with MPFL reconstructions therefore could be a safe alternative.

There are several limitations associated with this study, namely the lack of clinical testing and radiological assessment at 2 years. Moreover, additional surgery such as tibial tubercle osteotomies or trochleoplasties were excluded from this study as they were not part of the SOS data. As a result, no comparisons can be made with these additional procedures and no comparisons can be made with MPFL reconstruction procedures as there was no randomisation and all of the patients within the inclusion criteria underwent MPFL repair with suture tape augmentation.

Therefore, MPFL repair with suture tape augmentation is an alternative operative treatment to traditional MPFL reconstruction techniques in appropriate cases. However, additions to the literature are required with a higher level of evidence to further assess these encouraging early results of MPFL repair with internal bracing.

## Conclusion

As far as we are aware, these are the first cohorts of patients with minimum 5-year outcomes of ACL repair with internal brace augmentation and patients with minimum 2-year outcomes undergoing a combined ACL repair and ALL repair, PCL repair, MCL repair, PLC repair or MPFL repair with internal brace augmentation. Encouraging results are confirmed in all of the ligaments around the knee. The mean KOOS and WOMAC scores increased significantly and the VAS score and VR-12 physical scores improved significantly in all of the groups. 6 patients had an ACL re-rupture (17.6%) after isolated ACL repair. These patients were found to be younger and have higher initial Marx activity scores than the rest of the cohort. A combined ACL and ALL repair with internal brace augmentation in these higher risk patients reduced the ACL re-rupture rate to 5.3%. As a result, a treatment algorithm for ACL ruptures and the requirements for additional ALL rotational support is produced. PCL repair, MCL repair, PLC repair and MPFL repair all demonstrate encouraging early follow-up results.

We are currently undertaking a number of other studies and have plans for several other projects. We have created a surgical technique video for a 'hybrid' ACL reconstruction with suture tape augmentation and will be looking to create a video involving nanoscope technology. In addition, we plan to look at the outcomes of these hybrid reconstructions as well as the outcomes of multiligament cases using internal bracing. We have biomechanical testing underway to compare ACL repair with internal brace augmentation with a cohort of ACL reconstructions including the assessment of hamstring strength and proprioception. Furthermore, we are comparing the rates of meniscal repair at the time of primary surgery and also looking at the rates of secondary surgery. Additionally, we are liasing with our radiology colleagues to assist with a number of projects including reviewing postoperative MRI scans, reviewing the preoperative scans of the patients in the ACL re-rupture group and assessing the relationship between MRI and arthroscopic findings. In the future (10 years postoperatively), we plan to evaluate the patients discussed in this thesis for signs of osteoarthritis.

In conclusion, it is indicated that internal bracing around the knee gives surgeons an alternative technique to traditional reconstructions and avoids the need for a graft thereby preventing donor site morbidity whilst also preserving the proprioceptive fibres of the ligament. Nonetheless, further clinical studies are necessary as outlined above with larger patient numbers and longer follow-up as well as studies with a higher level of evidence to further assess these encouraging early results of ligament repair with internal bracing around the knee.

# Bibliography


1. Acevedo J, Vora A. Anatomical reconstruction of the spring ligament complex: "internal brace" augmentation. *Foot Ankle Spec*. 2013;6(6):441-445.
2. Achtnich A, Herbst E, Forkel P, et al. Acute Proximal Anterior Cruciate Ligament Tears: Outcomes After Arthroscopic Suture Anchor Repair Versus Anatomic Single-Bundle Reconstruction. *Arthroscopy*. 2016;32(12):2562-2569.
3. Ajuied A, Wong F, Smith C, et al. Anterior cruciate ligament injury and radiologic progression of knee osteoarthritis: a systematic review and meta-analysis. *Am J Sports Med*. 2014;42(9):2242-2252.
4. Andernord D, Desai N, Björnsson H, et al. Predictors of contralateral anterior cruciate ligament reconstruction: a cohort study of 9061 patients with 5-year follow-up. *Am J Sports Med*. 2015;43(2):295-302.
5. Andernord D, Desai N, Björnsson H, et al. Patient predictors of early revision surgery after anterior cruciate ligament reconstruction: a cohort study of 16,930 patients with 2-year follow-up. *Am J Sports Med*. 2015;43(1):121-127.
6. Anderson MJ, Browning WM, Urband CE, Kluczynski MA, Bisson LJ. A Systematic Summary of Systematic Reviews on the Topic of the Anterior Cruciate Ligament. *Orthop J Sports Med*. 2016;4(3):2325967116634074.
7. Andersson C, Odensten M, Gillquist J. Knee function after surgical or nonsurgical treatment of acute rupture of the anterior cruciate ligament: a randomized study with a long-term follow-up period. *Clin Orthop Relat Res*. 1991(264):255-263.
8. Andrews K, Lu A, Mckean L, Ebraheim N. Review: Medial collateral ligament injuries. *J Orthop*. 2017;14(4):550-554.
9. Ardern CL, Taylor NF, Feller JA, Webster KE. Return-to-sport outcomes at 2 to 7 years after anterior cruciate ligament reconstruction surgery. *Am J Sports Med*. 2012;40(1):41-48.
10. Arendt EA, Moeller A, Agel J. Clinical outcomes of medial patellofemoral ligament repair in recurrent (chronic) lateral patella dislocations. *Knee Surg Sports Traumatol Arthrosc*. 2011;19(11):1909-1914.
11. Bachmaier S, DiFelice GS, Sonnery-Cottet B, et al. Treatment of Acute Proximal Anterior Cruciate Ligament Tears-Part 1: Gap Formation and Stabilization Potential of Repair Techniques. *Orthop J Sports Med*. 2020;8(1):2325967119897421.
12. Bachmaier S, DiFelice GS, Sonnery-Cottet B, et al. Treatment of Acute Proximal Anterior Cruciate Ligament Tears-Part 2: The Role of Internal Bracing on Gap Formation and Stabilization of Repair Techniques. *Orthop J Sports Med*. 2020;8(1):2325967119897423.
13. Bachmaier S, Smith PA, Bley J, Wijdicks CA. Independent Suture Tape Reinforcement of Small and Standard Diameter Grafts for Anterior Cruciate Ligament Reconstruction: A Biomechanical Full Construct Model. *Arthroscopy*. 2018;34(2):490-499.
14. Baker CL, Norwood LA, Hughston JC. Acute posterolateral rotatory instability of the knee. *J Bone Joint Surg Am*. 1983;65(5):614-618.

15. Barrett DS. Proprioception and function after anterior cruciate reconstruction. *J Bone Joint Surg Br*. 1991;73(5):833-837.
16. Barrett GR, Line LL, Shelton WR, Manning JO, Phelps R. The Dacron ligament prosthesis in anterior cruciate ligament reconstruction. A four-year review. *Am J Sports Med*. 1993;21(3):367-373.
17. Belk JW, Kraeutler MJ, Purcell JM, McCarty EC. Autograft Versus Allograft for Posterior Cruciate Ligament Reconstruction: An Updated Systematic Review and Meta-analysis. *Am J Sports Med*. 2017:363546517713164.
18. Buckens CF, Saris DB. Reconstruction of the medial patellofemoral ligament for treatment of patellofemoral instability: a systematic review. *Am J Sports Med*. 2010;38(1):181-188.
19. Butler DL, Noyes FR, Grood ES. Ligamentous restraints to anterior-posterior drawer in the human knee. A biomechanical study. *J Bone Joint Surg Am*. 1980;62(2):259-270.
20. Byrne PA, Hopper GP, Wilson WT, Mackay GM. Acromioclavicular Joint Stabilisation Using the Internal Brace Principle. *Surg Technol Int*. 2018;33.
21. Byrne PA, Hopper GP, Wilson WT, Mackay GM. Knotless Repair of Achilles Tendon Rupture in an Elite Athlete: Return to Competition in 18 Weeks. *J Foot Ankle Surg*. 2017;56(1):121-124.
22. Camp CL, Krych AJ, Dahm DL, Levy BA, Stuart MJ. Medial patellofemoral ligament repair for recurrent patellar dislocation. *Am J Sports Med*. 2010;38(11):2248-2254.
23. Caterine S, Litchfield R, Johnson M, Chronik B, Getgood A. A cadaveric study of the anterolateral ligament: re-introducing the lateral capsular ligament. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA*. 2015;23(11):3186-3195.
24. Chahla J, Moatshe G, Cinque ME, et al. Single-Bundle and Double-Bundle Posterior Cruciate Ligament Reconstructions: A Systematic Review and Meta-analysis of 441 Patients at a Minimum 2 Years' Follow-up. *Arthroscopy*. 2017;33(11):2066-2080.
25. Chahla J, Moatshe G, Dean CS, LaPrade RF. Posterolateral Corner of the Knee: Current Concepts. *Arch Bone Jt Surg*. 2016;4(2):97-103.
26. Chalmers PN, Mall NA, Moric M, et al. Does ACL reconstruction alter natural history?: A systematic literature review of long-term outcomes. *J Bone Joint Surg Am*. 2014;96(4):292-300.
27. Cinque ME, Chahla J, Kruckeberg BM, et al. Posteromedial Corner Knee Injuries: Diagnosis, Management, and Outcomes: A Critical Analysis Review. *JBJS Rev*. 2017;5(11):e4.
28. Claes S, Vereecke E, Maes M, et al. Anatomy of the anterolateral ligament of the knee. *Journal of anatomy*. 2013;223(4):321-328.
29. Co FH, Skinner HB, Cannon WD. Effect of reconstruction of the anterior cruciate ligament on proprioception of the knee and the heel strike transient. *J Orthop Res*. 1993;11(5):696-704.
30. Coetzee JC, Ellington JK, Ronan JA, Stone RM. Functional Results of Open Broström Ankle Ligament Repair Augmented With a Suture Tape. *Foot Ankle Int*. 2018;39(3):304-310.
31. Crossley KM, Bennell KL, Cowan SM, Green S. Analysis of outcome measures for persons with patellofemoral pain: which are reliable and valid? *Arch Phys Med Rehabil*. 2004;85(5):815-822.

32. Daggett M, Ockuly AC, Cullen M, et al. Femoral Origin of the Anterolateral Ligament: An Anatomic Analysis. *Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association*. 2015.
33. Dandy DJ, Flanagan JP, Steenmeyer V. Arthroscopy and the management of the ruptured anterior cruciate ligament. *Clin Orthop Relat Res*. 1982(167):43-49.
34. De Giacomo AF, Shin SS. Repair of the Thumb Ulnar Collateral Ligament With Suture Tape Augmentation. *Tech Hand Up Extrem Surg*. 2017;21(4):164-166.
35. Del Buono A, Radmilovic J, Gargano G, Gatto S, Maffulli N. Augmentation or reconstruction of PCL? A quantitative review. *Knee Surg Sports Traumatol Arthrosc*. 2013;21(5):1050-1063.
36. DeLee JC, Riley MB, Rockwood CA. Acute posterolateral rotatory instability of the knee. *Am J Sports Med*. 1983;11(4):199-207.
37. DeLong JM, Waterman BR. Surgical Repair of Medial Collateral Ligament and Posteromedial Corner Injuries of the Knee: A Systematic Review. *Arthroscopy*. 2015;31(11):2249-2255.e2245.
38. Difelice GS, Lissy M, Haynes P. Surgical technique: when to arthroscopically repair the torn posterior cruciate ligament. *Clin Orthop Relat Res*. 2012;470(3):861-868.
39. DiFelice GS, van der List JP. Clinical Outcomes of Arthroscopic Primary Repair of Proximal Anterior Cruciate Ligament Tears Are Maintained at Mid-term Follow-up. *Arthroscopy*. 2018;34(4):1085-1093.
40. DiFelice GS, van der List JP. Regarding "Acute Proximal Anterior Cruciate Ligament Tears: Outcomes After Arthroscopic Suture Anchor Repair Versus Anatomic Single-Bundle Reconstruction". *Arthroscopy*. 2017;33(4):693-694.
41. DiFelice GS, Villegas C, Taylor S. Anterior Cruciate Ligament Preservation: Early Results of a Novel Arthroscopic Technique for Suture Anchor Primary Anterior Cruciate Ligament Repair. *Arthroscopy*. 2015;31(11):2162-2171.
42. Dodds AL, Halewood C, Gupte CM, Williams A, Amis AA. The anterolateral ligament: Anatomy, length changes and association with the Segond fracture. *The bone & joint journal*. 2014;96-B(3):325-331.
43. Dragoo JL, Nguyen M, Gatewood CT, Taunton JD, Young S. Medial Patellofemoral Ligament Repair Versus Reconstruction for Recurrent Patellar Instability: Two-Year Results of an Algorithm-Based Approach. *Orthop J Sports Med*. 2017;5(3):2325967116689465.
44. Eggli S, Röder C, Perler G, Henle P. Five year results of the first ten ACL patients treated with dynamic intraligamentary stabilisation. *BMC Musculoskelet Disord*. 2016;17:105.
45. Ellsasser JC, Reynolds FC, Omohundro JR. The non-operative treatment of collateral ligament injuries of the knee in professional football players. An analysis of seventy-four injuries treated non-operatively and twenty-four injuries treated surgically. *J Bone Joint Surg Am*. 1974;56(6):1185-1190.
46. Elveos MM, Drogset JO, Engebretsen L, et al. Anterior Cruciate Ligament Reconstruction Using a Bone-Patellar Tendon-Bone Graft With and Without a Ligament Augmentation Device: A 25-Year Follow-up of a Prospective Randomized Controlled Trial. *Orthop J Sports Med*. 2018;6(11):2325967118808778.

47. Engebretsen L, Benum P, Fasting O, Mølster A, Strand T. A prospective, randomized study of three surgical techniques for treatment of acute ruptures of the anterior cruciate ligament. *Am J Sports Med*. 1990;18(6):585-590.
48. Engebretsen L, Benum P, Sundalsvoll S. Primary suture of the anterior cruciate ligament. A 6-year follow-up of 74 cases. *Acta Orthop Scand*. 1989;60(5):561-564.
49. England RL. Repair of the ligaments about the knee. *Orthop Clin North Am*. 1976;7(1):195-204.
50. Faunø P, Rahr-Wagner L, Lind M. Risk for Revision After Anterior Cruciate Ligament Reconstruction Is Higher Among Adolescents: Results From the Danish Registry of Knee Ligament Reconstruction. *Orthop J Sports Med*. 2014;2(10):2325967114552405.
51. Feagin JA, Curl WW. Isolated tear of the anterior cruciate ligament: 5-year follow-up study. *Am J Sports Med*. 1976;4(3):95-100.
52. Ferretti A, Monaco E, Fabbri M, Maestri B, De Carli A. Prevalence and Classification of Injuries of Anterolateral Complex in Acute Anterior Cruciate Ligament Tears. *Arthroscopy*. 2017;33(1):147-154.
53. Ferretti A, Monaco E, Redler A, et al. High Prevalence of Anterolateral Ligament Abnormalities on MRI in Knees With Acute Anterior Cruciate Ligament Injuries: A Case-Control Series From the SANTI Study Group. *Orthop J Sports Med*. 2019;7(6):2325967119852916.
54. Fetto JF, Marshall JL. Medial collateral ligament injuries of the knee: a rationale for treatment. *Clin Orthop Relat Res*. 1978(132):206-218.
55. Fillingham YA, Riboh JC, Erickson BJ, Bach BR, Yanke AB. Inside-Out Versus All-Inside Repair of Isolated Meniscal Tears: An Updated Systematic Review. *Am J Sports Med*. 2017;45(1):234-242.
56. Fisher B, Nyland J, Brand E, Curtin B. Medial patellofemoral ligament reconstruction for recurrent patellar dislocation: a systematic review including rehabilitation and return-to-sports efficacy. *Arthroscopy*. 2010;26(10):1384-1394.
57. Fridén T, Roberts D, Ageberg E, Waldén M, Zätterström R. Review of knee proprioception and the relation to extremity function after an anterior cruciate ligament rupture. *J Orthop Sports Phys Ther*. 2001;31(10):567-576.
58. Frobell RB, Roos HP, Roos EM, et al. Treatment for acute anterior cruciate ligament tear: five year outcome of randomised trial. *BMJ*. 2013;346:f232.
59. Gagliardi AG, Carry PM, Parikh HB, et al. ACL Repair With Suture Ligament Augmentation Is Associated With a High Failure Rate Among Adolescent Patients. *Am J Sports Med*. 2019;47(3):560-566.
60. Gans I, Retzky JS, Jones LC, Tanaka MJ. Epidemiology of Recurrent Anterior Cruciate Ligament Injuries in National Collegiate Athletic Association Sports: The Injury Surveillance Program, 2004-2014. *Orthop J Sports Med*. 2018;6(6):2325967118777823.
61. Gao F, Zhou J, He C, et al. A Morphologic and Quantitative Study of Mechanoreceptors in the Remnant Stump of the Human Anterior Cruciate Ligament. *Arthroscopy*. 2016;32(2):273-280.
62. Geeslin AG, LaPrade RF. Outcomes of treatment of acute grade-III isolated and combined posterolateral knee injuries: a prospective case series and surgical technique. *J Bone Joint Surg Am*. 2011;93(18):1672-1683.

63. Geeslin AG, Moulton SG, LaPrade RF. A Systematic Review of the Outcomes of Posterolateral Corner Knee Injuries, Part 1: Surgical Treatment of Acute Injuries. *Am J Sports Med*. 2016;44(5):1336-1342.
64. Getgood AMJ, Bryant DM, Litchfield R, et al. Lateral Extra-articular Tenodesis Reduces Failure of Hamstring Tendon Autograft Anterior Cruciate Ligament Reconstruction: 2-Year Outcomes From the STABILITY Study Randomized Clinical Trial. *Am J Sports Med*. 2020;48(2):285-297.
65. Gifstad T, Foss OA, Engebretsen L, et al. Lower risk of revision with patellar tendon autografts compared with hamstring autografts: a registry study based on 45,998 primary ACL reconstructions in Scandinavia. *Am J Sports Med*. 2014;42(10):2319-2328.
66. Gilmer BB, Crall T, DeLong J, et al. Biomechanical Analysis of Internal Bracing for Treatment of Medial Knee Injuries. *Orthopedics*. 2016;39(3):e532-537.
67. Grant JA, Tannenbaum E, Miller BS, Bedi A. Treatment of combined complete tears of the anterior cruciate and medial collateral ligaments. *Arthroscopy*. 2012;28(1):110-122.
68. Grøntvedt T, Engebretsen L, Benum P, et al. A prospective, randomized study of three operations for acute rupture of the anterior cruciate ligament. Five-year follow-up of one hundred and thirty-one patients. *J Bone Joint Surg Am*. 1996;78(2):159-168.
69. Harner CD, Vogrin TM, Höher J, Ma CB, Woo SL. Biomechanical analysis of a posterior cruciate ligament reconstruction. Deficiency of the posterolateral structures as a cause of graft failure. *Am J Sports Med*. 2000;28(1):32-39.
70. Hefti F, Müller W. [Current state of evaluation of knee ligament lesions. The new IKDC knee evaluation form ]. *Orthopade*. 1993;22(6):351-362.
71. Helito CP, Camargo DB, Sobrado MF, et al. Combined reconstruction of the anterolateral ligament in chronic ACL injuries leads to better clinical outcomes than isolated ACL reconstruction. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA*. 2018.
72. Helito CP, Sobrado MF, Giglio PN, et al. Combined Reconstruction of the Anterolateral Ligament in Patients With Anterior Cruciate Ligament Injury and Ligamentous Hyperlaxity Leads to Better Clinical Stability and a Lower Failure Rate Than Isolated Anterior Cruciate Ligament Reconstruction. *Arthroscopy*. 2019;35(9):2648-2654.
73. Henle P, Röder C, Perler G, Heitkemper S, Eggli S. Dynamic Intraligamentary Stabilization (DIS) for treatment of acute anterior cruciate ligament ruptures: case series experience of the first three years. *BMC Musculoskelet Disord*. 2015;16:27.
74. Heusdens CHW, Hopper GP, Dossche L, Mackay GM. Anterior Cruciate Ligament Repair Using Independent Suture Tape Reinforcement. *Arthrosc Tech*. 2018;7(7):e747-e753.
75. Hewison CE, Tran MN, Kaniki N, et al. Lateral Extra-articular Tenodesis Reduces Rotational Laxity When Combined With Anterior Cruciate Ligament Reconstruction: A Systematic Review of the Literature. *Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association*. 2015;31(10):2022-2034.

76. Hiemstra LA, Kerslake S, Kupfer N, Lafave M. Patellofemoral Stabilization: Postoperative Redislocation and Risk Factors Following Surgery. *Orthop J Sports Med*. 2019;7(6):2325967119852627.
77. Hirahara AM, Mackay G, Andersen WJ. Ultrasound-Guided Suture Tape Augmentation and Stabilization of the Medial Collateral Ligament. *Arthrosc Tech*. 2018;7(3):e205-e210.
78. Hoogeslag RAG, Brouwer RW, Boer BC, de Vries AJ, Huis In 't Veld R. Acute Anterior Cruciate Ligament Rupture: Repair or Reconstruction? Two-Year Results of a Randomized Controlled Clinical Trial. *Am J Sports Med*. 2019;47(3):567-577.
79. Hopper GP, Leach WJ, Rooney BP, Walker CR, Blyth MJ. Does degree of trochlear dysplasia and position of femoral tunnel influence outcome after medial patellofemoral ligament reconstruction? *Am J Sports Med*. 2014;42(3):716-722.
80. Hopper GP, Mackay GM. Achilles Tendon Repair Using the InternalBrace▫ Principle. *Surg Technol Int*. 2017;30:325-328.
81. Hughston JC. The importance of the posterior oblique ligament in repairs of acute tears of the medial ligaments in knees with and without an associated rupture of the anterior cruciate ligament. Results of long-term follow-up. *J Bone Joint Surg Am*. 1994;76(9):1328-1344.
82. Hughston JC, Bowden JA, Andrews JR, Norwood LA. Acute tears of the posterior cruciate ligament. Results of operative treatment. *J Bone Joint Surg Am*. 1980;62(3):438-450.
83. Ibrahim SA, Ghafar S, Salah M, et al. Surgical management of traumatic knee dislocation with posterolateral corner injury. *Arthroscopy*. 2013;29(4):733-741.
84. Iliadis DP, Bourlos DN, Mastrokalos DS, Chronopoulos E, Babis GC. LARS Artificial Ligament Versus ABC Purely Polyester Ligament for Anterior Cruciate Ligament Reconstruction. *Orthop J Sports Med*. 2016;4(6):2325967116653359.
85. Indelicato PA, Hermansdorfer J, Huegel M. Nonoperative management of complete tears of the medial collateral ligament of the knee in intercollegiate football players. *Clin Orthop Relat Res*. 1990(256):174-177.
86. Indelicato PA, Pascale MS, Huegel MO. Early experience with the GORE-TEX polytetrafluoroethylene anterior cruciate ligament prosthesis. *Am J Sports Med*. 1989;17(1):55-52.
87. Jaecker V, Ibe P, Endler CH, et al. High Risk of Tunnel Convergence in Combined Anterior Cruciate Ligament Reconstruction and Lateral Extra-articular Tenodesis. *Am J Sports Med*. 2019;47(9):2110-2115.
88. Jonkergouw A, van der List JP, DiFelice GS. Arthroscopic primary repair of proximal anterior cruciate ligament tears: outcomes of the first 56 consecutive patients and the role of additional internal bracing. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(1):21-28.
89. Jung YB, Jung HJ, Song KS, et al. Remnant posterior cruciate ligament-augmenting stent procedure for injuries in the acute or subacute stage. *Arthroscopy*. 2010;26(2):223-229.
90. Kaeding CC, Pedroza AD, Reinke EK, et al. Risk Factors and Predictors of Subsequent ACL Injury in Either Knee After ACL Reconstruction: Prospective Analysis of 2488 Primary ACL Reconstructions From the MOON Cohort. *Am J Sports Med*. 2015;43(7):1583-1590.

91. Kakar S, Greene RM. Scapholunate Ligament Internal Brace 360-Degree Tenodesis (SLITT) Procedure. *J Wrist Surg*. 2018;7(4):336-340.
92. Kannus P, Bergfeld J, Järvinen M, et al. Injuries to the posterior cruciate ligament of the knee. *Sports Med*. 1991;12(2):110-131.
93. Kennedy MI, Claes S, Fuso FA, et al. The Anterolateral Ligament: An Anatomic, Radiographic, and Biomechanical Analysis. *The American journal of sports medicine*. 2015;43(7):1606-1615.
94. Kohl S, Evangelopoulos DS, Kohlhof H, et al. Anterior crucial ligament rupture: self-healing through dynamic intraligamentary stabilization technique. *Knee Surg Sports Traumatol Arthrosc*. 2013;21(3):599-605.
95. Kohl S, Evangelopoulos DS, Schär MO, et al. Dynamic intraligamentary stabilisation: initial experience with treatment of acute ACL ruptures. *Bone Joint J*. 2016;98-B(6):793-798.
96. Konrath JM, Vertullo CJ, Kennedy BA, et al. Morphologic Characteristics and Strength of the Hamstring Muscles Remain Altered at 2 Years After Use of a Hamstring Tendon Graft in Anterior Cruciate Ligament Reconstruction. *Am J Sports Med*. 2016;44(10):2589-2598.
97. Kowalk DL, Duncan JA, McCue FC, Vaughan CL. Anterior cruciate ligament reconstruction and joint dynamics during stair climbing. *Med Sci Sports Exerc*. 1997;29(11):1406-1413.
98. LaPrade CM, Civitarese DM, Rasmussen MT, LaPrade RF. Emerging Updates on the Posterior Cruciate Ligament: A Review of the Current Literature. *Am J Sports Med*. 2015;43(12):3077-3092.
99. LaPrade RF, Ly TV, Wentorf FA, Engebretsen L. The posterolateral attachments of the knee: a qualitative and quantitative morphologic analysis of the fibular collateral ligament, popliteus tendon, popliteofibular ligament, and lateral gastrocnemius tendon. *Am J Sports Med*. 2003;31(6):854-860.
100. LaPrade RF, Muench C, Wentorf F, Lewis JL. The effect of injury to the posterolateral structures of the knee on force in a posterior cruciate ligament graft: a biomechanical study. *Am J Sports Med*. 2002;30(2):233-238.
101. LaPrade RF, Resig S, Wentorf F, Lewis JL. The effects of grade III posterolateral knee complex injuries on anterior cruciate ligament graft force. A biomechanical analysis. *Am J Sports Med*. 1999;27(4):469-475.
102. LaPrade RF, Terry GC. Injuries to the posterolateral aspect of the knee. Association of anatomic injury patterns with clinical instability. *Am J Sports Med*. 1997;25(4):433-438.
103. Lee DY, Park YJ. Single-Bundle versus Double-Bundle Posterior Cruciate Ligament Reconstruction: A Meta-Analysis of Randomized Controlled Trials. *Knee Surg Relat Res*. 2017;29(4):246-255.
104. Leiter JR, Gourlay R, McRae S, de Korompay N, MacDonald PB. Long-term follow-up of ACL reconstruction with hamstring autograft. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(5):1061-1069.
105. Levy BA, Dajani KA, Morgan JA, et al. Repair versus reconstruction of the fibular collateral ligament and posterolateral corner in the multiligament-injured knee. *Am J Sports Med*. 2010;38(4):804-809.
106. Levy BA, Dajani KA, Whelan DB, et al. Decision making in the multiligament-injured knee: an evidence-based systematic review. *Arthroscopy*. 2009;25(4):430-438.

107. Leys T, Salmon L, Waller A, Linklater J, Pinczewski L. Clinical results and risk factors for reinjury 15 years after anterior cruciate ligament reconstruction: a prospective study of hamstring and patellar tendon grafts. *Am J Sports Med*. 2012;40(3):595-605.
108. Lie MM, Risberg MA, Storheim K, Engebretsen L, Øiestad BE. What's the rate of knee osteoarthritis 10 years after anterior cruciate ligament injury? An updated systematic review. *Br J Sports Med*. 2019;53(18):1162-1167.
109. Lind M, Menhert F, Pedersen AB. Incidence and outcome after revision anterior cruciate ligament reconstruction: results from the Danish registry for knee ligament reconstructions. *Am J Sports Med*. 2012;40(7):1551-1557.
110. Lohmander LS, Ostenberg A, Englund M, Roos H. High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players twelve years after anterior cruciate ligament injury. *Arthritis Rheum*. 2004;50(10):3145-3152.
111. Lubowitz JH, MacKay G, Gilmer B. Knee medial collateral ligament and posteromedial corner anatomic repair with internal bracing. *Arthrosc Tech*. 2014;3(4):e505-508.
112. Lundberg M, Messner K. Long-term prognosis of isolated partial medial collateral ligament ruptures. A ten-year clinical and radiographic evaluation of a prospectively observed group of patients. *Am J Sports Med*. 1996;24(2):160-163.
113. Lysholm J, Gillquist J, Liljedahl SO. Long-term results after early treatment of knee injuries. *Acta Orthop Scand*. 1982;53(1):109-118.
114. Mackay GM, Blyth MJ, Anthony I, Hopper GP, Ribbans WJ. A review of ligament augmentation with the InternalBrace™: the surgical principle is described for the lateral ankle ligament and ACL repair in particular, and a comprehensive review of other surgical applications and techniques is presented. *Surg Technol Int*. 2015;26:239-255.
115. Mackay ND, Smith NA, Parsons N, et al. Medial Patellofemoral Ligament Reconstruction for Patellar Dislocation: A Systematic Review. *Orthop J Sports Med*. 2014;2(8):2325967114544021.
116. Maletis GB, Chen J, Inacio MC, Funahashi TT. Age-Related Risk Factors for Revision Anterior Cruciate Ligament Reconstruction: A Cohort Study of 21,304 Patients From the Kaiser Permanente Anterior Cruciate Ligament Registry. *Am J Sports Med*. 2016;44(2):331-336.
117. Marx RG, Stump TJ, Jones EC, Wickiewicz TL, Warren RF. Development and evaluation of an activity rating scale for disorders of the knee. *Am J Sports Med*. 2001;29(2):213-218.
118. Matic GT, Magnussen RA, Kolovich GP, Flanigan DC. Return to activity after medial patellofemoral ligament repair or reconstruction. *Arthroscopy*. 2014;30(8):1018-1025.
119. McGee R, Daggett M, Jacks A, Hoang V, Theobald HA. Patellar Tendon Graft Anterior Cruciate Ligament Reconstruction Technique With Suture Tape Augmentation. *Arthrosc Tech*. 2019;8(4):e355-e361.
120. Mehl J, Otto A, Comer B, et al. Repair of the medial patellofemoral ligament with suture tape augmentation leads to similar primary contact pressures and joint kinematics like reconstruction with a tendon graft: a biomechanical comparison. *Knee Surg Sports Traumatol Arthrosc*. 2019.

121. Monaco E, Mazza D, Redler A, et al. Anterolateral Ligament Repair Augmented With Suture Tape in Acute Anterior Cruciate Ligament Reconstruction. *Arthrosc Tech*. 2019;8(4):e369-e373.
122. Moulton SG, Geeslin AG, LaPrade RF. A Systematic Review of the Outcomes of Posterolateral Corner Knee Injuries, Part 2: Surgical Treatment of Chronic Injuries. *Am J Sports Med*. 2016;44(6):1616-1623.
123. Murray IR, Chahla J, Frank RM, et al. Rogue stem cell clinics. *Bone Joint J*. 2020;102-B(2):148-154.
124. Murray MM, Flutie BM, Kalish LA, et al. The Bridge-Enhanced Anterior Cruciate Ligament Repair (BEAR) Procedure: An Early Feasibility Cohort Study. *Orthop J Sports Med*. 2016;4(11):2325967116672176.
125. Murray MM, Kalish LA, Fleming BC, et al. Bridge-Enhanced Anterior Cruciate Ligament Repair: Two-Year Results of a First-in-Human Study. *Orthop J Sports Med*. 2019;7(3):2325967118824356.
126. Murray MM, Spindler KP, Ballard P, et al. Enhanced histologic repair in a central wound in the anterior cruciate ligament with a collagen-platelet-rich plasma scaffold. *J Orthop Res*. 2007;25(8):1007-1017.
127. Newman SD, Atkinson HD, Willis-Owen CA. Anterior cruciate ligament reconstruction with the ligament augmentation and reconstruction system: a systematic review. *Int Orthop*. 2013;37(2):321-326.
128. Nwachukwu BU, Voleti PB, Chang B, et al. Comparative Influence of Sport Type on Outcome After Anterior Cruciate Ligament Reconstruction at Minimum 2-Year Follow-up. *Arthroscopy*. 2017;33(2):415-421.
129. Ornetti P, Dougados M, Paternotte S, Logeart I, Gossec L. Validation of a numerical rating scale to assess functional impairment in hip and knee osteoarthritis: comparison with the WOMAC function scale. *Ann Rheum Dis*. 2011;70(5):740-746.
130. Osti M, El Attal R, Doskar W, Höck P, Smekal V. High complication rate following dynamic intraligamentary stabilization for primary repair of the anterior cruciate ligament. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(1):29-36.
131. Parsons EM, Gee AO, Spiekerman C, Cavanagh PR. The biomechanical function of the anterolateral ligament of the knee. *The American journal of sports medicine*. 2015;43(3):669-674.
132. Paulos LE, Rosenberg TD, Grewe SR, Tearse DS, Beck CL. The GORE-TEX anterior cruciate ligament prosthesis. A long-term followup. *Am J Sports Med*. 1992;20(3):246-252.
133. Persson A, Fjeldsgaard K, Gjertsen JE, et al. Increased risk of revision with hamstring tendon grafts compared with patellar tendon grafts after anterior cruciate ligament reconstruction: a study of 12,643 patients from the Norwegian Cruciate Ligament Registry, 2004-2012. *Am J Sports Med*. 2014;42(2):285-291.
134. Poehling-Monaghan KL, Salem H, Ross KE, et al. Long-Term Outcomes in Anterior Cruciate Ligament Reconstruction: A Systematic Review of Patellar Tendon Versus Hamstring Autografts. *Orthop J Sports Med*. 2017;5(6):2325967117709735.
135. Pournaras J, Symeonides PP. The results of surgical repair of acute tears of the posterior cruciate ligament. *Clin Orthop Relat Res*. 1991(267):103-107.
136. Regauer M, Mackay G, Lange M, Kammerlander C, Böcker W. Syndesmotic. *World J Orthop*. 2017;8(4):301-309.

137. Roessler PP, Schuttler KF, Heyse TJ, Wirtz DC, Efe T. The anterolateral ligament (ALL) and its role in rotational extra-articular stability of the knee joint: a review of anatomy and surgical concepts. *Archives of orthopaedic and trauma surgery*. 2016;136(3):305-313.
138. Rosenstiel N, Praz C, Ouanezar H, et al. Combined Anterior Cruciate and Anterolateral Ligament Reconstruction in the Professional Athlete: Clinical Outcomes From the Scientific Anterior Cruciate Ligament Network International Study Group in a Series of 70 Patients With a Minimum Follow-Up of 2 Years. *Arthroscopy*. 2019;35(3):885-892.
139. Rothrauff BB, Jorge A, de Sa D, et al. Anatomic ACL reconstruction reduces risk of post-traumatic osteoarthritis: a systematic review with minimum 10-year follow-up. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(4):1072-1084.
140. Runer A, Birkmaier S, Pamminger M, et al. The anterolateral ligament of the knee: A dissection study. *The Knee*. 2016;23(1):8-12.
141. Salavati M, Akhbari B, Mohammadi F, Mazaheri M, Khorrami M. Knee injury and Osteoarthritis Outcome Score (KOOS); reliability and validity in competitive athletes after anterior cruciate ligament reconstruction. *Osteoarthritis Cartilage*. 2011;19(4):406-410.
142. Sanchez G, Ferrari MB, Sanchez A, et al. Proximal Patellar Tendon Repair: Internal Brace Technique With Unicortical Buttons and Suture Tape. *Arthrosc Tech*. 2017;6(2):e491-e497.
143. Schechinger SJ, Levy BA, Dajani KA, et al. Achilles tendon allograft reconstruction of the fibular collateral ligament and posterolateral corner. *Arthroscopy*. 2009;25(3):232-242.
144. Schneider DK, Grawe B, Magnussen RA, et al. Outcomes After Isolated Medial Patellofemoral Ligament Reconstruction for the Treatment of Recurrent Lateral Patellar Dislocations: A Systematic Review and Meta-analysis. *Am J Sports Med*. 2016;44(11):2993-3005.
145. Selim AJ, Rogers W, Fleishman JA, et al. Updated U.S. population standard for the Veterans RAND 12-item Health Survey (VR-12). *Qual Life Res*. 2009;18(1):43-52.
146. Seo JB, Heo K, Kim SJ, Jung JU, Yoo JS. Arthroscopic Acromioclavicular Fixation With Suture Tape Augmentation After Coracoclavicular Fixation With Dog Bone Button: Surgical Technique. *Arthrosc Tech*. 2018;7(11):e1197-e1203.
147. Setuain I, Izquierdo M, Idoate F, et al. Differential Effects of 2 Rehabilitation Programs Following Anterior Cruciate Ligament Reconstruction. *J Sport Rehabil*. 2017;26(6):544-555.
148. Shah JN, Howard JS, Flanigan DC, et al. A systematic review of complications and failures associated with medial patellofemoral ligament reconstruction for recurrent patellar dislocation. *Am J Sports Med*. 2012;40(8):1916-1923.
149. Sherman MF, Bonamo JR. Primary repair of the anterior cruciate ligament. *Clin Sports Med*. 1988;7(4):739-750.
150. Shon OJ, Park JW, Kim BJ. Current Concepts of Posterolateral Corner Injuries of the Knee. *Knee Surg Relat Res*. 2017;29(4):256-268.
151. Sinagra ZP, Kop A, Pabbruwe M, Parry J, Clark G. Foreign Body Reaction Associated With Artificial LARS Ligaments: A Retrieval Study. *Orthop J Sports Med*. 2018;6(12):2325967118811604.

152. Smith C, Ajuied A, Wong F, et al. The use of the ligament augmentation and reconstruction system (LARS) for posterior cruciate reconstruction. *Arthroscopy*. 2014;30(1):111-120.
153. Smith JO, Yasen SK, Palmer HC, et al. Paediatric ACL repair reinforced with temporary internal bracing. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(6):1845-1851.
154. Smith PA, Bley JA. Allograft Anterior Cruciate Ligament Reconstruction Utilizing Internal Brace Augmentation. *Arthrosc Tech*. 2016;5(5):e1143-e1147.
155. Smith PA, Bradley JP, Konicek J, Bley JA, Wijdicks CA. Independent Suture Tape Internal Brace Reinforcement of Bone-Patellar Tendon-Bone Allografts: Biomechanical Assessment in a Full-ACL Reconstruction Laboratory Model. *J Knee Surg*. 2019.
156. Smith TO, Postle K, Penny F, McNamara I, Mann CJ. Is reconstruction the best management strategy for anterior cruciate ligament rupture? A systematic review and meta-analysis comparing anterior cruciate ligament reconstruction versus non-operative treatment. *Knee*. 2014;21(2):462-470.
157. Smith TO, Walker J, Russell N. Outcomes of medial patellofemoral ligament reconstruction for patellar instability: a systematic review. *Knee Surg Sports Traumatol Arthrosc*. 2007;15(11):1301-1314.
158. Snaebjörnsson T, Svantesson E, Sundemo D, et al. Young age and high BMI are predictors of early revision surgery after primary anterior cruciate ligament reconstruction: a cohort study from the Swedish and Norwegian knee ligament registries based on 30,747 patients. *Knee Surg Sports Traumatol Arthrosc*. 2019.
159. Sommerfeldt M, Raheem A, Whittaker J, Hui C, Otto D. Recurrent Instability Episodes and Meniscal or Cartilage Damage After Anterior Cruciate Ligament Injury: A Systematic Review. *Orthop J Sports Med*. 2018;6(7):2325967118786507.
160. Sonnery-Cottet B, Lutz C, Daggett M, et al. The Involvement of the Anterolateral Ligament in Rotational Control of the Knee. *The American journal of sports medicine*. 2016.
161. Sonnery-Cottet B, Saithna A, Blakeney WG, et al. Anterolateral Ligament Reconstruction Protects the Repaired Medial Meniscus: A Comparative Study of 383 Anterior Cruciate Ligament Reconstructions From the SANTI Study Group With a Minimum Follow-up of 2 Years. *Am J Sports Med*. 2018;46(8):1819-1826.
162. Sonnery-Cottet B, Thaunat M, Freychet B, et al. Outcome of a Combined Anterior Cruciate Ligament and Anterolateral Ligament Reconstruction Technique With a Minimum 2-Year Follow-up. *The American journal of sports medicine*. 2015;43(7):1598-1605.
163. Spindler KP, Huston LJ, Chagin KM, et al. Ten-Year Outcomes and Risk Factors After Anterior Cruciate Ligament Reconstruction: A MOON Longitudinal Prospective Cohort Study. *Am J Sports Med*. 2018;46(4):815-825.
164. Spindler KP, Huston LJ, Wright RW, et al. The prognosis and predictors of sports function and activity at minimum 6 years after anterior cruciate ligament reconstruction: a population cohort study. *Am J Sports Med*. 2011;39(2):348-359.

165. Stannard JP, Brown SL, Farris RC, McGwin G, Volgas DA. The posterolateral corner of the knee: repair versus reconstruction. *Am J Sports Med*. 2005;33(6):881-888.
166. Strand T, Mølster AO, Engesaeter LB, Raugstad TS, Alho A. Primary repair in posterior cruciate ligament injuries. *Acta Orthop Scand*. 1984;55(5):545-547.
167. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. *Clin Orthop Relat Res*. 1985(198):43-49.
168. Tompkins MA, Arendt EA. Patellar instability factors in isolated medial patellofemoral ligament reconstructions--what does the literature tell us? A systematic review. *Am J Sports Med*. 2015;43(9):2318-2327.
169. Trofa DP, Lombardi JM, Noticewala MS, Ahmad CS. Ulnar Collateral Ligament Repair With Suture Augmentation. *Arthrosc Tech*. 2018;7(1):e53-e56.
170. Tulloch SJ, Devitt BM, Norsworthy CJ, Mow C. Synovitis following anterior cruciate ligament reconstruction using the LARS device. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(8):2592-2598.
171. Urch E, DeGiacomo A, Photopoulos CD, Limpisvasti O, ElAttrache NS. Ulnar Collateral Ligament Repair With Suture Bridge Augmentation. *Arthrosc Tech*. 2018;7(3):e219-e223.
172. Van de Velde SK, Bingham JT, Gill TJ, Li G. Analysis of tibiofemoral cartilage deformation in the posterior cruciate ligament-deficient knee. *J Bone Joint Surg Am*. 2009;91(1):167-175.
173. van der List JP, DiFelice GS. Arthroscopic Primary Posterior Cruciate Ligament Repair With Suture Augmentation. *Arthrosc Tech*. 2017;6(5):e1685-e1690.
174. van der List JP, DiFelice GS. Primary Repair of the Medial Collateral Ligament With Internal Bracing. *Arthrosc Tech*. 2017;6(4):e933-e937.
175. van der List JP, Jonkergouw A, van Noort A, Kerkhoffs GMMJ, DiFelice GS. Identifying candidates for arthroscopic primary repair of the anterior cruciate ligament: A case-control study. *Knee*. 2019;26(3):619-627.
176. van der List JP, Mintz DN, DiFelice GS. The Location of Anterior Cruciate Ligament Tears: A Prevalence Study Using Magnetic Resonance Imaging. *Orthop J Sports Med*. 2017;5(6):2325967117709966.
177. Van Dyck P, Clockaerts S, Vanhoenacker FM, et al. Anterolateral ligament abnormalities in patients with acute anterior cruciate ligament rupture are associated with lateral meniscal and osseous injuries. *European radiology*. 2016.
178. Varelas AN, Erickson BJ, Cvetanovich GL, Bach BR. Medial Collateral Ligament Reconstruction in Patients With Medial Knee Instability: A Systematic Review. *Orthop J Sports Med*. 2017;5(5):2325967117703920.
179. Vavken P, Fleming BC, Mastrangelo AN, Machan JT, Murray MM. Biomechanical outcomes after bioenhanced anterior cruciate ligament repair and anterior cruciate ligament reconstruction are equal in a porcine model. *Arthroscopy*. 2012;28(5):672-680.
180. von Porat A, Roos EM, Roos H. High prevalence of osteoarthritis 14 years after an anterior cruciate ligament tear in male soccer players: a study of radiographic and patient relevant outcomes. *Ann Rheum Dis*. 2004;63(3):269-273.

181. Weaver JK, Derkash RS, Freeman JR, et al. Primary knee ligament repair--revisited. *Clin Orthop Relat Res*. 1985(199):185-191.
182. Wellsandt E, Failla MJ, Axe MJ, Snyder-Mackler L. Does Anterior Cruciate Ligament Reconstruction Improve Functional and Radiographic Outcomes Over Nonoperative Management 5 Years After Injury? *Am J Sports Med*. 2018;46(9):2103-2112.
183. Wheatley WB, Martinez AE, Sacks T, et al. Arthroscopic posterior cruciate ligament repair. *Arthroscopy*. 2002;18(7):695-702.
184. Wijdicks CA, Ewart DT, Nuckley DJ, et al. Structural properties of the primary medial knee ligaments. *Am J Sports Med*. 2010;38(8):1638-1646.
185. Xie X, Xiao Z, Li Q, et al. Increased incidence of osteoarthritis of knee joint after ACL reconstruction with bone-patellar tendon-bone autografts than hamstring autografts: a meta-analysis of 1,443 patients at a minimum of 5 years. *Eur J Orthop Surg Traumatol*. 2015;25(1):149-159.
186. Yabroudi MA, Björnsson H, Lynch AD, et al. Predictors of Revision Surgery After Primary Anterior Cruciate Ligament Reconstruction. *Orthop J Sports Med*. 2016;4(9):2325967116666039.
187. Yoon KH, Bae DK, Song SJ, Lim CT. Arthroscopic double-bundle augmentation of posterior cruciate ligament using split Achilles allograft. *Arthroscopy*. 2005;21(12):1436-1442.

# Appendices

## Appendix 1

**KOOS**

# KOOS KNEE SURVEY

Today's date: _____/_____/_____

Date of birth: _____/_____/_____

Name: _____

**INSTRUCTIONS:** This survey asks for your view about your knee. This information will help us keep track of how you feel about your knee and how well you are able to perform your usual activities.

Answer every question by ticking the appropriate box, only one box for each question. If you are unsure about how to answer a question, please give the best answer you can.

**Symptoms**

These questions should be answered thinking of your knee symptoms during the **last week**.

S1. Do you have swelling in your knee?

Never Rarely Sometimes Often Always

S2. Do you feel grinding, hear clicking or any other type of noise when your knee moves?

Never Rarely Sometimes Often Always

S3. Does your knee catch or hang up when moving?

Never Rarely Sometimes Often Always

S4. Can you straighten your knee fully?

Always Often Sometimes Rarely Never

S5. Can you bend your knee fully?

Always Often Sometimes Rarely Never

**Stiffness**

The following questions concern the amount of joint stiffness you have experienced during the **last week** in your knee. Stiffness is a sensation of restriction or slowness in the ease with which you move your knee joint.

S6. How severe is your knee joint stiffness after first wakening in the morning? None Mild Moderate Severe Extreme

S7. How severe is your knee stiffness after sitting, lying or resting **later in the day**? None Mild Moderate Severe Extreme

## Pain

P1. How often do you experience knee pain?

Never Monthly Weekly Daily Always

What amount of knee pain have you experienced the **last week** during the following activities?

P2. Twisting/pivoting on your knee

None Mild Moderate Severe Extreme

P3. Straightening knee fully

None Mild Moderate Severe Extreme

P4. Bending knee fully

None Mild Moderate Severe Extreme

P5. Walking on flat surface

None Mild Moderate Severe Extreme

P6. Going up or down stairs

None Mild Moderate Severe Extreme

P7. At night while in bed

None Mild Moderate Severe Extreme

P8. Sitting or lying

None Mild Moderate Severe Extreme

P9. Standing upright

None Mild Moderate Severe Extreme

## Function, daily living

The following questions concern your physical function. By this we mean your ability to move around and to look after yourself. For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A1. Descending stairs

None Mild Moderate Severe Extreme

A2. Ascending stairs

None Mild Moderate Severe Extreme

For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A3. Rising from sitting

None Mild Moderate Severe Extreme

A4. Standing

None Mild Moderate Severe Extreme

A5. Bending to floor/pick up an object

None Mild Moderate Severe Extreme

A6. Walking on flat surface

None Mild Moderate Severe Extreme

A7. Getting in/out of car

None Mild Moderate Severe Extreme

A8. Going shopping

None Mild Moderate Severe Extreme

A9. Putting on socks/stockings

None Mild Moderate Severe Extreme

A10. Rising from bed

None Mild Moderate Severe Extreme

A11. Taking off socks/stockings

None Mild Moderate Severe Extreme

A12. Lying in bed (turning over, maintaining knee position)

None Mild Moderate Severe Extreme

A13. Getting in/out of bath

None Mild Moderate Severe Extreme

A14. Sitting

None Mild Moderate Severe Extreme

A15. Getting on/off toilet

None Mild Moderate Severe Extreme

For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A16. Heavy domestic duties (moving heavy boxes, scrubbing floors, etc)

None Mild Moderate Severe Extreme

A17. Light domestic duties (cooking, dusting, etc)

None Mild Moderate Severe Extreme

**Function, sports and recreational activities**

The following questions concern your physical function when being active on a higher level. The questions should be answered thinking of what degree of difficulty you have experienced during the **last week** due to your knee.

SP1. Squatting

None Mild Moderate Severe Extreme

SP2. Running

None Mild Moderate Severe Extreme

SP3. Jumping

None Mild Moderate Severe Extreme

SP4. Twisting/pivoting on your injured knee

None Mild Moderate Severe Extreme

SP5. Kneeling

None Mild Moderate Severe Extreme

**Quality of Life**

Q1. How often are you aware of your knee problem?

Never Monthly Weekly Daily Constantly

Q2. Have you modified your life style to avoid potentially damaging activities to your knee?

Not at all Mildly Moderately Severely Totally

Q3. How much are you troubled with lack of confidence in your knee?

Not at all Mildly Moderately Severely Extremely

Q4. In general, how much difficulty do you have with your knee?

None Mild Moderate Severe Extreme

***Thank you very much for completing all the questions in this questionnaire.***

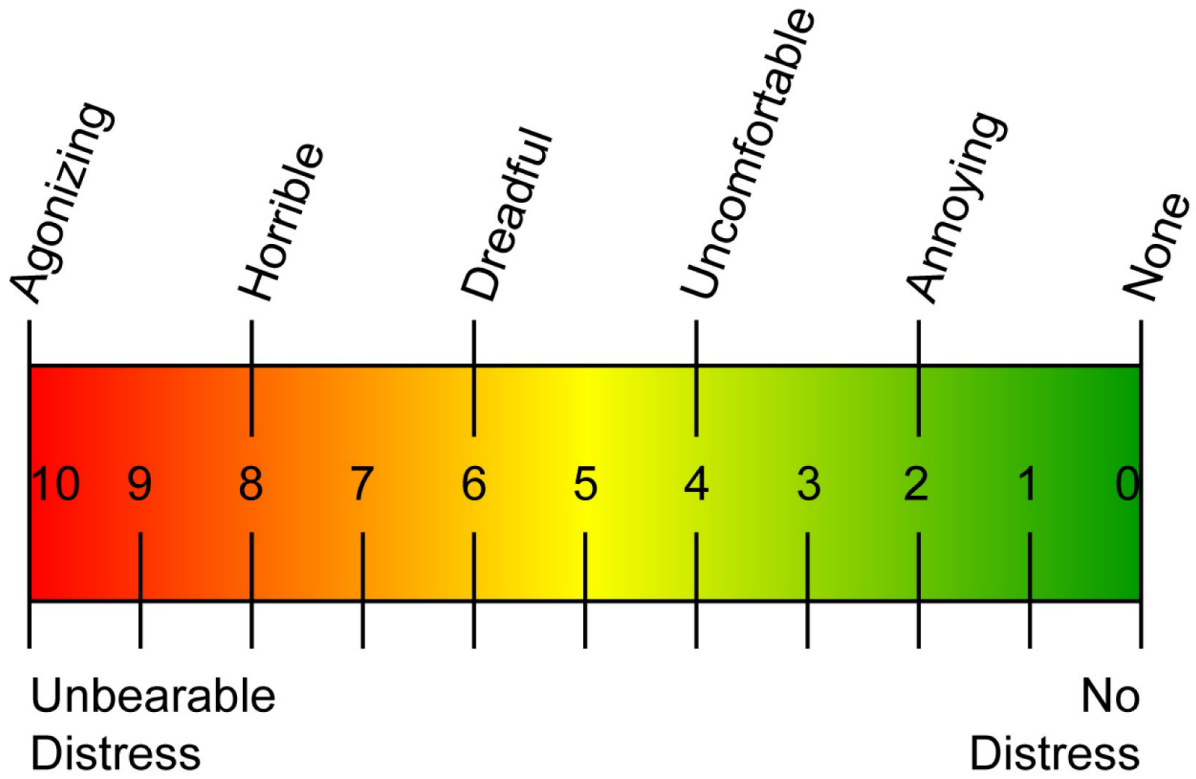
## Appendix 2

### WOMAC

The WOMAC (Western Ontario and McMaster Universities) Index of Osteoarthritis
Pain:
(1) walking
(2) stair climbing
(3) nocturnal
(4) rest
(5) weight bearing
Stiffness:
(1) morning stiffness
(2) stiffness occurring later in the day
Physical function:
(1) descending stairs
(2) ascending stairs
(3) rising from sitting
(4) standing
(5) bending to floor
(6) walking on flat
(7) getting in or out of car
(8) going shopping
(9) putting on socks
(10) rising from bed
(11) taking off socks
(12) lying in bed
(13) sitting
(14) sitting
(15) getting on or off toilet
(16) heavy domestic duties
(17) light domestic duties
Scoring and Interpretation
Points
none 0 slight 1 moderate 2 severe 3 extreme 4

**Appendix 3**

**VAS – Pain**




*Task* _____

*Date* _____ *Start* _____ *End* _____

## Appendix 4

## VR-12

### SF-12 Health Survey

This survey asks for your views about your health. This information will help keep track of how you feel and how well you are able to do your usual activities. **Answer each question by choosing just one answer**. If you are unsure how to answer a question, please give the best answer you can.

---

1. **In general, would you say your health is**:

□1 Excellent □2 Very good □3 Good □4 Fair □5 Poor

**The following questions are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?**

---

2. **Moderate activities** such as moving a table, pushing □1 □2 □3 a vacuum cleaner, bowling, or playing golf.

3. Climbing **several** flights of stairs. □1 □2

**During the past 4 weeks, have you had any of the following problems with your work or other regular**
**daily activities as a result of your physical health?**
**YES NO**

4. **Accomplished less** than you would like. □1 □2
5. Were limited in the **kind** of work or other activities. □1 □2

**During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?**
**YES NO**

6. **Accomplished less** than you would like. □1 □2 7. Did work or activities **less carefully than usual**. □1 □2

8. **During the past 4 weeks, how much did pain interfere with your normal work (including work outside the home and housework)?**

□1 Not at all □2 A little bit □3 Moderately □4 Quite a bit □5 Extremely **These questions are about how you have been feeling during the past 4 weeks.**
**For each question, please give the one answer that comes closest to the way you have been feeling. How much of the time during the past 4 weeks...**

**YES, YES, limited a lot a little**

**NO, not limited at all**

□3

---

All of the time

Most of the time

A good bit of the time

Some of the time

A little of the time

None of the time

9. Have you felt calm & peaceful? □1 □2 □3 □4 □5 □6

10. Did you have a lot of energy? □1 □2 □3 □4 □5 □6

11. Have you felt down-hearted and □1 □2 □3 □4 □5 □6

blue?

12. **During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting friends, relatives, etc.)?**

---

□1 All of the time □2 Most of the time □3 Some of the time □4 A little of the time □5 None of the time

---

Patient name: Date: PCS: MCS:

_____

_____ Visit type (circle one)

Preop 6 week 3 month 6 month 12 month 24 month Other:_____

**Appendix 5**

**Marx Activity Scale**

# MARX SCALE (ENGLISH VERSION)

Please indicate how often you performed each activity in your healthiest and most active state, in the past year. Kindly put a ( ) mark on the appropriate space after each item.

**Running**: running while playing a sport or jogging

0

1

2

3

4

**Cutting**: changing directions while running

0

1

2

3

4

**Deceleration**: coming to a quick stop while running

0

1

2

3

4

**Pivoting**: turning your body with your foot planted while playing sport; For example: skiing, skating, kicking, throwing, hitting a ball (golf, tennis, squash), etc.

0

1

2

3

4

## Appendix 6

### Satisfaction

Surgical Outcomes System

Name: _____ Date: _____

Knee Arthroscopy Standard Late Postoperative Form

How well did the treatment meet your expectations with regard to reducing your pain level?

- ☐ Did not meet expectations
- ☐ Met expectations
- ☐ Exceeded expectations

How well did the treatment meet your expectations with regard to an improvement in motion and strength of the affected joint?

- ☐ Did not meet expectations
- ☐ Met expectations
- ☐ Exceeded expectations

How well did the treatment meet your expectations with regard to you resuming normal functions for daily living?

- ☐ Did not meet expectations
- ☐ Met expectations
- ☐ Exceeded expectations

How well did the treatment meet your expectations with regard to resuming normal sporting activities?

- ☐ Did not meet expectations
- ☐ Met expectations
- ☐ Exceeded expectations