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***Abstract**

ABSTRACT

Purpose: This paper reports the outcomes of patients undergoing ACL reconstruction using a TransLateral single bundle, all-inside hamstring technique at a minimum of two years follow up.

Methods: The semitendinosus alone is harvested, quadrupled and attached in series to two adjustable suspensory fixation devices. Femoral and tibial sockets are produced using a retrograde drill. The graft is deployed, fixed and tensioned on both tibia and femur. Patients were evaluated preoperatively using the KOOS, Lysholm and Tegner scores and at 6, 12 and 24 months postoperatively. Objective assessment of knee laxity was performed using the KT-1000 along with goniometric measurement of range or motion.

Results: 108 patients, mean age 30.9 years (range 15 to 61) were included. Mean follow up 49.8 months (range 30-66). The mean increase in KOOS at two years was 30.3 points; Lysholm, 33.1 points; Tegner Activity scale, 2.0 levels. These were all statistically significant ($p<0.001$). Range of motion in the reconstructed knee approximated the uninjured knee by 12 months and was restored by two years. KT-1000 showed significant reduction in side-side difference to no more than 2.4 mm at all postoperative time points ($p<0.001$). Re-rupture rate in this series was 6.5%, all following episodes of significant additional postoperative trauma to the knee.

Conclusions: TransLateral all-inside ACL reconstruction demonstrates good medium term subjective and objective outcomes with a low complication and failure rate.

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Clinical Outcomes of Anatomic, All-Inside, Anterior Cruciate Ligament (ACL) Reconstruction

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Conflicts of interest: The senior author (AJW) works as a paid consultant for Arthrex. No financial incentive or reimbursement was received for this study. Other authors declare no conflicts of interest

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Purpose: This paper reports the outcomes of patients undergoing ACL reconstruction using a TransLateral single bundle, all-inside hamstring technique at a minimum of two years follow up.

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Keywords: ACL reconstruction, all-inside, outcomes, TransLateral

1. Introduction

Rupture of the anterior cruciate ligament (ACL) is a common injury with an incidence of 25-78 per 100,000 [1, 2]. It is estimated that there are 100,000 - 175,000 injuries per annum in the USA alone with a male preponderance [3, 4]. Around a third of patients undergo surgical reconstruction [2], with the reported operative incidence in the UK being 13.5 per 100,000 [5], and this therefore represents one of the most common orthopaedic procedures in sports medicine. Despite this, considerable controversy still exists regarding nearly all aspects of ACL surgery including graft selection, positioning, fixation, tensioning and postoperative rehabilitation protocols. The ultimate goal is to stabilise the knee without restricting range of motion, and prevent secondary damage within an unstable joint. An increased risk of degenerative arthritis persists, however, irrespective of whether reconstruction is undertaken or not [6, 7]. This has spurred ongoing research and consideration of alternative techniques in a bid to improve short and long term outcomes.

Traditional transtibial drilling remains commonplace for creation of the femoral tunnel. Femoral positioning is thus dictated by tibial tunnel placement which can lead to a high (i.e. towards the roof of the intercondylar notch) and deep (i.e. posteriorly along Blumensaat's line), non-anatomic position that fails to restore normal knee kinematics [8, 9]. Fu et al championed a move towards 'anatomic' ACL reconstruction which aims to place the graft within the native ACL footprint [10]. An accessory anteromedial (AM) portal has been used by some authors for independent drilling of the femoral tunnel to achieve such positioning [11] but this can prove technically demanding [12].

The TransLateral technique is a variation of the all-inside ACL reconstruction technique developed by the senior author. It utilises specifically designed instrumentation allowing navigation around the lateral femoral condyle and inside-to-out drilling to produce retrograde sockets. These can be positioned entirely at the surgeon's discretion. All-inside ACL reconstruction has been demonstrated to produce less pain and is bone conserving [13]. A detailed description of the technique has previously been published [14, 15]. This paper reports the medium term outcomes of a large consecutive series of patients undergoing ACL reconstruction using the TransLateral single bundle technique with a minimum follow up of two years.

2. Methods

All patients presenting with a clinically unstable knee and a diagnosis of ACL deficiency were considered for surgical reconstruction using the all-inside TransLateral technique. This technique has been used by the senior author for all primary ACL reconstructions since December 2010. A prospectively maintained database was interrogated to identify all TransLateral ACL reconstructions performed between December 2010 and December 2015. Revision cases, multi-ligament reconstructions and cases using a graft other than quadrupled semitendinosus were excluded. Patients under the age of 15 who had not reached skeletal maturity were also excluded. Minimum follow-up was set at two years, leaving 108 eligible patients. All patients were operated on by either *(surgeons details removed to blind manuscript).*

2.1 TransLateral technique

The patient is positioned supine with the knee flexed to 90 degrees using a footrest and side support. A thigh tourniquet is inflated throughout. A modified anterolateral (AL) portal which is slightly lower and more medial than traditional placement is made. The AM portal is created under direct visualisation. A specially designed curved and calibrated radiofrequency probe is used for femoral preparation and marking.

Anatomical placement of the femoral socket was achieved using the validated measurement technique [16]. An inside-out drill (FlipCutter, Arthrex, Naples, FL) is used to create a retrograde socket of 20mm depth in the femur. A tibial socket is then produced with the FlipCutter, to 30-35mm in depth depending on graft length. Socket diameter is determined by the width of the graft.

The semitendinosus alone is harvested, quadrupled and attached to two cortical suspensory fixation devices. Grafts were routinely placed in compression tubes to reduce their external diameter and provide a tight interference fit with the bony sockets. The size of the retrograde femoral and tibial sockets is based on the post-compression diameter. In cases where the quadrupled tendon is deemed inadequate in width (generally under 7mm), the graft may be reinforced with a 2mm non-absorbable braided polyethylene tape (FibreTape, Arthrex, Naples, FL) running through its core, or a quadrupled semitendinosus and gracilis construct used. These cases have also been excluded from the reported cohort. The graft is placed into the knee via the AM portal and 'parachuted' into its femoral and tibial sockets respectively via pull-through sutures. The cortical buttons are flipped and the graft tensioned with the knee in extension. The knee is then cycled and the graft re-tensioned as required.

Standard rehabilitation entails immediate full weight bearing with the protection of crutches for two weeks. Full range of motion is encouraged. Closed chain activities are introduced early, open chain activities at 3 months, sport-specific training at 6 months, with a return to contact sport at 9-12 months. In patients who underwent additional chondral or meniscal surgery, the postoperative rehabilitation regime was adjusted accordingly.

All patients were fully informed and consented to the proposed surgical reconstruction technique. Clinical evaluation and recording of any complications was undertaken by the surgical team preoperatively and at 6 weeks, 3 months, 6 months, 1 year and 2 years postoperatively. Patients were also evaluated by a single research physiotherapist independently of the surgical team at 6 months, 1 year and 2 years via separate clinic appointments. Subjective assessment using the KOOS, Lysholm and Tegner activity scoring indices was undertaken at each of these time points. Objective assessment of knee laxity using the KT-1000, and goniometric measurement of knee range of motion was also recorded. Patients who failed to attend their research follow up were telephoned and asked to complete subjective scoring by junior members not directly related to the surgical team. In these instances range of motion data was used from the surgical clinical assessment. Objective parameters were available in over 85% of patients followed up.

Statistical analysis was performed using SPSS Version 22 (IBM 2013) and Microsoft Excel (2013). Descriptive statistics are used for demographic and operative data. Data was assessed for normality using a Shapiro-Wilk test. One way repeated measures ANOVA tests, with post-hoc Bonferroni correction are used for evaluating changes in scoring indices at postoperative time points. Paired student's t-tests are used to compare range of motion data and KT-1000 data. A p value of 0.05 for significance was set. Confidence intervals were set at 95%, and are represented as "95% CI".

3. Results

3.1 Demographics

A total of 108 patients (81 men, 27 women) underwent single bundle TransLateral ACL reconstruction. Mean age at time of operation was 30.9 years (range 15-61 years). All were physiologically young and active. There were 53 right-sided and 55 left-sided procedures. Mean follow up was 49.8 months (range 30-66 months).

3.2 Operative Procedures

Table 1 summarises the operative procedures undertaken. There were 61 cases (56.4%) involving additional meniscal surgery, of which 36 were meniscal repairs. All meniscal repairs in this series were achieved with an all inside suture device. In 8 cases (7.4%) additional chondral surgery was performed (3 cases of micro-fracture and 5 of chondroplasty). As some patients underwent both meniscal and chondral surgery, this left 45 patients (41.7%) undergoing ligament reconstruction alone.

3.3 Operative Time

Mean tourniquet time was 69.9 minutes (range 40-121 minutes) before tourniquet deflation after surgical dressings were applied. This includes the learning curve for both surgeons for the TransLateral technique, as well as time spent addressing simultaneous meniscal or chondral pathology. Excluding outliers, in patients undergoing ligament reconstruction alone, the mean tourniquet time was 58.6 minutes (95% CI 53.8-63.4).

3.4 ACL Graft Size and Positioning

All patients underwent quadrupled semitendinosus grafts. The mean graft diameter was 8.5mm pre-compression and 8.2mm post-compression. The mean graft length was 66.2mm (range 58-73mm). Grafts longer than 68mm are typically shortened to this length, as additional length is not required. Anatomic placement of the graft within the femoral footprint using the direct measurement technique was used in all cases.

3.5 Subjective scoring results

Patients without preoperative data were excluded. Data capture rates for subjective scoring parameters were 93.5% at 6 month follow up, 86% at one year and 85.1% at two years follow up. The outcome scores for the KOOS, Lysholm and Tegner activity scales are shown in table 2 and are graphically depicted in figure 1. The data was assessed to be normally distributed by the Shapiro-Wilk test. A one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in scores over the course of the two year follow up period. Post hoc analysis with a Bonferroni adjustment revealed that there were significant increases in all three scoring indices at all time points postoperatively (p<0.001) with a mean increase at two years in KOOS of 30.5 points, Lysholm of 33.2 points, and Tegner activity index of 2.0 levels Incremental increases in postoperative scores up to one year were statistically significant. No significant difference existed between one year and two year results considering the KOOS and Lysholm scores, but the corresponding Tegner scores were different (p=0.03). These results are summarised in table 3.

3.6 Range of Motion

Comparison of range of motion has been split into extension range and flexion range, and these are summarised in table 4. Negative values indicate extension past neutral. Preoperative ***extension*** was not significantly different between the injured and uninjured knee (uninjured knee -1.1 degrees, injured knee -1.2 degrees, p=0.94). Postoperatively, the extension range on the operated knee was reduced to 0.04 degrees at 6 months, which reached statistical significance (p=0.011), but this reverted to no significant difference compared to the uninjured knee at one year and two year follow up (1 year, -1.4 degrees p= 0.766; and 2 years, -1.2 degrees, p=0.969).

Preoperative ***flexion*** was significantly different between the injured and uninjured knee (uninjured knee 141.6 degrees, injured knee 130.4 degrees, p<0.001). The flexion range increased significantly when comparing the injured knee between preoperative and postoperative status at all time points (p<0.001 for all), but remained reduced compared to the normal knee at 6 month and 1 year follow up (6 months, 136.3 degrees, p<0.001; 1 year, 137.9 degrees, p=0.004). By two years follow up, flexion range was normalised and not statistically different between the ACL reconstructed knee and the uninjured knee (range 139.0 degrees, p=0.149 at 2 years).

3.7 KT-1000 Data

Data capture rates for objective scoring, are: 82.4% (89 patients) at preoperative assessment, 78.7% (85 patients) at 6 month follow up, 85.2% (92 patients) at one year and 81.5% (88 patients) at two years follow up. Anteroposterior laxity in the uninjured (normal) knee was recorded at a mean of 5.4 mm using the maximum manual tension method on the KT-1000 instrument. The injured knee had a mean of 10.0 mm laxity preoperatively giving a side-to-side difference of 4.6 mm. Side-to-side differences improved to 2.4mm at 6 months, 1.8mm at 1 year and 2.2 mm at 2 years. The reduction in knee laxity was statistically significant for all time points ($p<0.001$). This data is represented in table 5 with confidence intervals.

3.8 Complications

These are summarised in table 6. There was an overall complication rate of 9.3% (10 cases) including graft failure, postoperative bleeding and superficial infection. There were no cases of deep infection or venous thromboembolism. Seven reconstructions (6.5%) failed, all of which were due to significant further episodes of postoperative trauma: three at 4-6 months postoperatively, and the remainder after one year.

4. Discussion

4.1 Technical Advantages

Conventional techniques such as transtibial drilling tend to put the graft in a non-anatomic position with the graft anterior on the femur and posterior on the tibia. This results in a relatively vertical position, contributing to persistent rotational laxity postoperatively [17-19]. Clinical kinematic evaluation corroborates this in the dynamic state [9]. Lateral placement of the femoral tunnel has been shown to be biomechanically superior to traditional high and deep positions [8]. Although such 'anatomic' positioning has not translated into improved clinical outcomes thus far, the TransLateral technique facilitates accurate femoral socket placement by offering an unobstructed view of the lateral femoral condyle from the medial portal, while working from the lateral side.

The TransLateral technique also facilitates an 'all-inside' approach to ACL reconstruction which minimises morbidity. A recent level-one randomised controlled trial reviewing all-inside surgery for ACL reconstruction showed less postoperative pain and analgesic requirements at one month compared to traditional reconstruction techniques [20]. This has been corroborated by longer term studies demonstrating lower visual analogue pain scores at multiple time points up to 24 months follow up [13]. As short, blind-ending sockets are created rather than tunnels for the graft, the procedure is also bone conserving. Histological evidence in a canine model has demonstrated improved tendon-to-bone healing of the graft, especially at the aperture, when using bony sockets rather than interference screw fixation in tunnels [21].

Additionally, excellent early fixation is achieved through the use of the cortical suspensory devices. Adjustable-loop graft suspension constructs have now been shown to be equivalent to fixed-loop systems in clinical practice, with no higher incidence of loosening or failure [22]. There were no cases of hardware failure in our cohort.

The TransLateral all-inside procedure is reproducible and can be performed in under an hour once the learning curve is negotiated. The senior author has also successfully used the technique in the revision setting.

4.2 Single Hamstring Harvest

There are several advantages of using a quadrupled semitendinosus graft for the ACL reconstruction. Firstly, as the semitendinosus is thicker than the gracilis, a quadrupled graft is consequently thicker than a traditional 'four strand hamstring' graft which effectively contains a doubled semitendinosus and doubled gracilis. This was demonstrated by a mean graft diameter in this series of 8.5 mm. This is larger than multiple previously reported series where the mean graft diameter is typically under 8mm [23-25]. Historical in vitro and animal models have previously demonstrated that graft diameter can influence graft strength and anteroposterior stability of the reconstructed knee [26, 27]. In four strand hamstring reconstructions, graft strength is a function of the diameter [28] and a 1-2mm increase in width may dramatically influence strength [29]. A recent systematic review identified that an autologous hamstring graft diameter of less than 8mm corresponded to a 6.8 fold greater relative risk of failure [30].

Secondly, this technique leaves the gracilis available for use for additional ligament reconstructions and is therefore invaluable in the multiple-ligament injured knee. Lastly, the hamstring tendons are considered a secondary medial stabiliser of the knee [31] [32]. An anatomical study by Mochizuki et al demonstrating a number of aponeurotic connections from the muscles fusing with the deep fascia seem to support this view. Similarly, several studies have demonstrated that harvesting both semitendinosus and gracilis results in a lower peak torque in internal rotation than harvesting semitendinosus alone with a statistically significant difference in the ratio of internal versus external rotation torque between the two groups [32-34]. This is likely to have an effect on dynamic rotational stability. Furthermore, there is level 1 evidence from a prospective randomised controlled study demonstrating that single hamstring harvest results in decreased morbidity and improved residual knee flexion strength [35]. Preservation of the gracilis may therefore contribute to postoperative knee stability, particularly in a knee with medial laxity that does not warrant formal medial collateral ligament reconstruction.

4.3 Subjective Outcomes

The KOOS is validated as an ACL functional outcome parameter [36], as are the Lysholm score and Tegner activity scale [37]. All patients made gains in all scoring indices which were clinically significant. Repeated measures ANOVA tests showed that there was a statistically significant increase in all scoring indices at all postoperative time points compared against preoperative status. Increases in scores were not significantly different between one year and two years, however, suggesting a plateauing of the treatment effect one year after surgical intervention. Longer term follow up at five years and five yearly thereafter is planned. Absolute scores at final review in our series are in a similar range to that reported in the literature. A systematic review of ACL outcomes reported scores at 10 years follow up of 91.7±11.2 for the Lysholm index and a mean Tegner score of 5.1 [38, 39].

4.4 Objective Outcomes

Previous studies have identified several factors that contribute to reduced postoperative range of motion including limited preoperative range, typical lateral femoral condyle bone bruising on MRI scanning, female sex and surgery within 45 days of injury [40]. Patients in this series exclusively where operated upon well after 6 weeks following injury. No significant differences were identified according to gender. Our range of motion data does demonstrate a very minor loss of full extension in all operated knees at 6 months, which improves by 1 year and is maintained thereafter. ACL-injured knees have a significant reduction in full flexion preoperatively, and this improves slowly postoperatively, taking two years before returning to a comparable level to the uninjured knee.

Knee laxity measurements were performed using the validated KT-1000 [41] at maximal manual tension by the same research physiotherapist at all time points. Taking paired knee measurements rather than individual readings are recommended [42]. The side-to-side difference in a normal population is less than 3mm in 97% of patients without injury to the knee [43]. Maximal manual tension has been shown to be the most reliable method in identifying differences between injured and uninjured knees. In this series the results show a mean side-to-side differences of under 3mm at all postoperative time points, with a maximum difference of 2.4 mm.

4.5 Complications

The incidence of ACL failure in our cohort was 6.5%. All were attributable to defined episodes of postoperative trauma: three patients with football injuries between one and two years; one patient involved in a motorbike accident at six months; and the remaining three with falls within the domestic environment. There were no episodes of deep infection. The overall complication incidence of 9.3% and complication profile is similar to that reported in the literature [5, 44].

4.6 Limitations

The data completion rate fell to 85.1% at two year follow up, which could have influenced the results. Patients were recalled separately for research clinic follow ups with a physiotherapist independent of the surgical team. While this improves the objectivity of the scoring and collection of robust kinematic and goniometric data, it also increases the follow up burden on the patient which has likely contributed to the difficulties in maintaining research follow up. This data completion rate compares favourably against registry data, however. A non-response analysis on the Swedish Knee Ligament Register showed a response rate of only 52% [45].

5. Conclusion

The TransLateral ACL reconstruction technique has demonstrated good short to medium term outcomes with a low overall complication rate, and graft failure rate of 6.5%. The technique is reproducible and allows the surgeon complete flexibility in their choice of tibial and femoral graft positioning. The use of sockets rather than tunnels is bone preserving, and isolated harvesting of the semitendinosus allows greater flexibility in multi-ligament reconstruction scenarios, while minimising harvest morbidity. Whether such improvements translate to longer term benefits in the clinical setting remains to be seen.

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Tables and figures

Table 1: Operative procedures undertaken

Surgical Procedure	Number	Percent	Variation	
ACL reconstruction	108	100		
ACL with no additional procedure	45	41.7		
Chondral surgery	8	7.4		
			Microfracture	*3*
			Chondroplasty	*5*
Meniscal surgery	66	56.4		
			Repair	*36*
			Debridement	*30*

Table 2: Subjective scoring outcomes

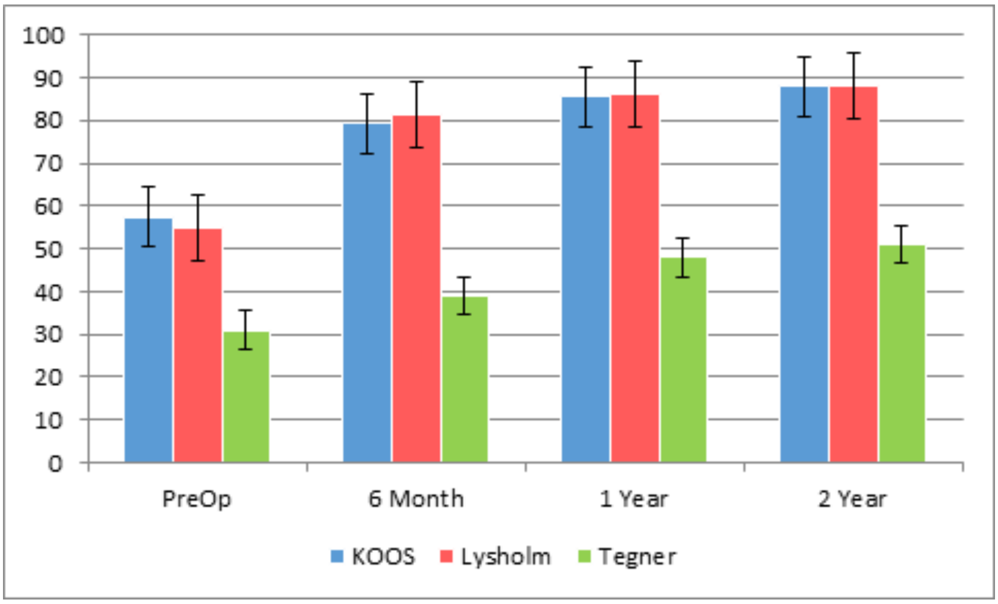
Score	Preop	6 Months	1 Year	2 Year	Change (2yrs)
KOOS	57.4	79.4	85.5	87.9	+ 30.5
Lysholm	54.9	81.4	86.3	88.1	+33.2
Tegner	3.1	3.9	4.8	5.1	+ 2.0

a) Pre and postoperative subjective scores calculated as a mean of *all* scores available. KOOS (Knee injury and osteoarthritis outcome score) is out of 100, Lysholm score out of 100, Tegner activity scale out of ten. Higher scores indicate better function.

Change in Score	6 Months	1 Year	2 Year
KOOS	23.7 (95% CI 20.4-27.0)	29.0 (95% CI 25.4-32.8)	30.8 (95% CI 26.6–34.9)
Lysholm	28.6 (95% CI 24.5-32.6)	32.4 (95% CI 28.4-36.4)	34 (95% CI 29.8-38.2)
Tegner	1.9 (95% CI 1.6-2.2)	2.2 (95% CI 1.8-2.6)	2.4 (95% CI 2.0-2.9)

b) Mean increase in scores against preoperative status. Calculated *only* from patients with sequential scores available. (95% Confidence interval shown).

Figure 1: Pre and postoperative subjective scoring outcomes



Mean pre and postoperative scores for the KOOS (Knee Outcomes in Osteoarthritis), Lysholm and Tegner Activity indices, with standard error bars shown. KOOS and Lysholm scores are out of 100. The Tegner Activity score is out of 10, but has been multiplied by 10 for graphical comparative purposes.

Table 3: One way repeated measures ANOVA analysis of subjective postoperative scoring change for whole cohort

KOOS	Preop	6 Months	1 Year	2 Years
Preop	-	<0.001	<0.001	<0.001
6 Months	<0.001	-	<0.001	<0.001
1 Year	<0.001	<0.001	-	0.139
2 Years	<0.001	<0.001	0.139	-

Lysholm	Preop	6 Months	1 Year	2 Years
Preop	-	<0.001	<0.001	<0.001
6 Months	<0.001	-	0.004	<0.001
1 Year	<0.001	0.004	-	0.236
2 Years	<0.001	<0.001	0.236	-

Tegner	Preop	6 Months	1 Year	2 Years
Preop	-	<0.001	<0.001	<0.001
6 Months	<0.001	-	<0.001	<0.001
1 Year	<0.001	<0.001	-	0.030
2 Years	<0.001	<0.001	0.030	-

KOOS (Knee injury and osteoarthritis outcome score), Lysholm score and Tegner activity scale shown. P values presented for comparison between different time points after Bonferroni correction. Preop = preoperative score; other scores at stated postoperative time points

Table 4: Range of motion data

Range of Motion		Extension (degrees)	P value	Flexion (degrees)	P Value
Non-operative knee		-1.1	-	141.6	-
Preoperative injured knee		-1.2	0.924	130.4	<0.001
Postoperative	6 months	0.04	0.011	136.3	<0.001
	1 year	-1.4	0.766	137.9	0.004
	2 years	-1.2	0.969	139.0	0.149

Extension and flexion values shown are in degrees. Negative values indicate hyperextension past the neutral point. P values shown are for independent sample student's t tests comparing the non-operative knee against the operated knee at different time points

Table 5: KT 1000 Data

Time point	KT 1000 side to side difference / mm
Preop	4.60 (4.0 – 5.2)
6 months	2.40 (1.8 – 3.0)
1 Year	1.80 (1.4 – 2.3)
2 Years	2.20 (1.7 – 2.6)

Mean side-to-side difference in mm between injured/reconstructed knee and non-injured knee shown at preoperative and postoperative time points (95% confidence intervals in parentheses).

Table 6: Complications

Complication		Number	Percent
ACL failure		7	6.5
Infection	Superficial	1	0.9
	Deep	0	0
Haemarthrosis		1	0.9
Superficial haematoma		1	0.9
Thromboembolism		0	0
TOTAL		**10**	**9.3**

*Ethics Committee Letter

Ethics

Independent ethics approval has not been sought, as this paper presents the results of a series of patients undergoing standard surgical intervention in our unit. All patients in our unit undergo prospectively determined clinical follow up with scoring and assessment by a physiotherapist. This study does not represent any additional intervention(s).