Superior knee flexor strength at 2 years with all-inside short-graft anterior cruciate ligament reconstruction vs a conventional hamstring technique

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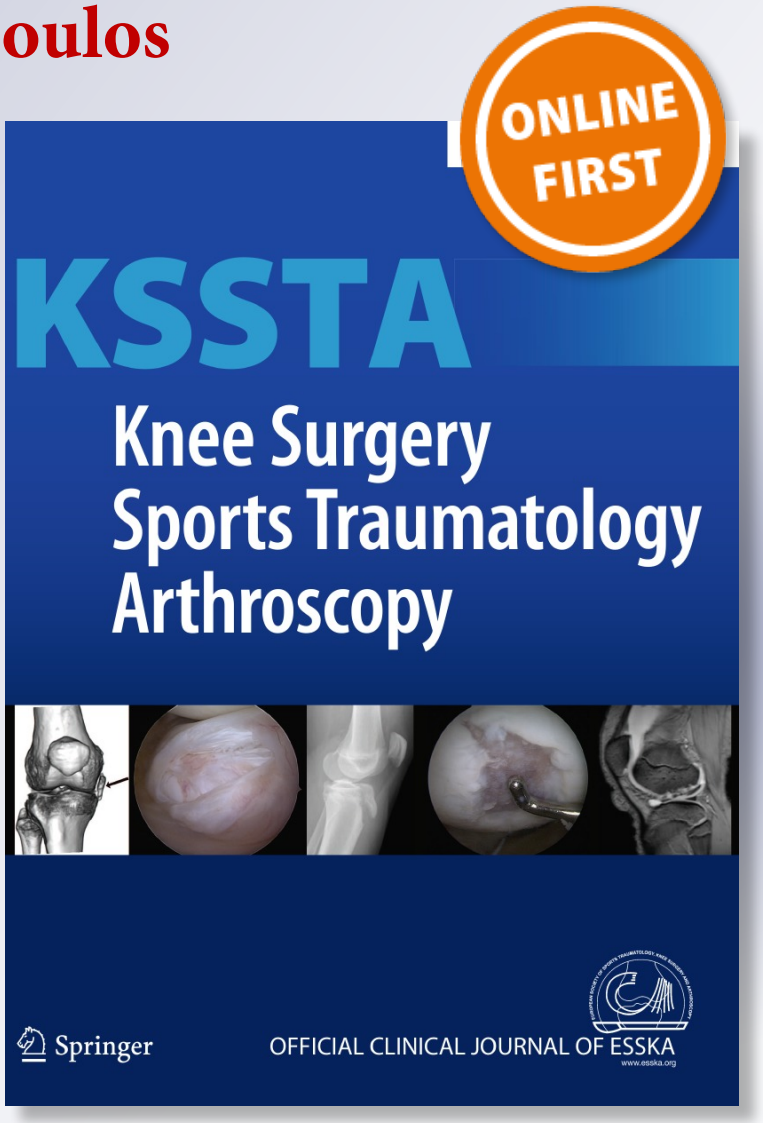

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Superior knee flexor strength at 2 years with all-inside short-graft anterior cruciate ligament reconstruction vs a conventional hamstring technique

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Abstract

Purpose To compare the "all-inside technique" for anterior cruciate ligament (ACL) reconstruction using a short, quadrupled semitendinosus tendon (ST4) autograft and suspensory cortical fixation on both the femoral and tibial side vs the "conventional technique" using a semitendinosus/gracilis (ST/G) autograft fixed with a suspensory device on the femoral side and with an interference screw on the tibial side, in terms of clinical and functional outcomes.

Methods A total of 90 patients were enrolled, randomised into two groups, and prospectively followed. Group A comprised 45 patients treated with the all-inside technique and Group B included 45 patients treated with the conventional ACL technique (55 males, 35 females; mean age 28.7 ± 11.3 years). Patients completed the Lysholm knee score, the International Knee Documentation Committee (IKDC) score, the Knee Injury and Osteoarthritis Score (KOOS), and the Knee Society Score (KSS) preoperatively and at 2 years postoperatively. Anterior tibial translation measurement (KT-1000 arthrometer) and isokinetic testing of the operative vs non-operative limb were also conducted and the limb symmetry index (LSI) was determined.

Results At 24 months, the Lysholm, IKDC, KOOS, and KSS scores between the two groups were similar (n.s.). Anterior tibial translation between the operative and non-operative knee was also similar among the two groups (n.s.). Patients of Group A had significantly higher mean LSIs in terms of flexor peak torque (1.0 ± 0.1 vs 0.9 ± 0.1; $p < 0.001$), time-to-peak (0.9 ± 0.1 vs 0.8 ± 0.1; $p < 0.001$) and total work (0.9 ± 0.1 vs 0.8 ± 0.1; $p < 0.001$) at 180°/s, and significantly better mean LSI for isometric flexor/extensor ratio at 90° (1.1 ± 0.3 vs 0.8 ± 0.2; $p < 0.001$).

Conclusion The all-inside ACL reconstruction with an ST4 autograft and cortical button fixation on both ends is a viable alternative to the conventional technique. It affords preservation of knee flexor strength, which is of advantage, especially when treating athletes with ACL injury.

Level of evidence I.

Keywords Anterior cruciate ligament reconstruction · All-inside · Cortical button fixation · Short graft

Introduction

Anterior cruciate ligament (ACL) reconstruction is a commonly performed orthopaedic procedure, with an estimated number of 130,000 procedures performed annually in the United States [8, 25]. Despite technical advances, there is ongoing debate over the optimal graft and type of fixation. While a bone-patellar tendon-bone autologous graft is considered the gold standard [10, 14, 28], associated disadvantages, including anterior knee pain, quadriceps muscle weakness and patellar tendinitis [1, 29, 30], have led to the widespread use of hamstring tendon autografts, in the form

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of a semitendinosus/gracilis tendon (ST/G) graft or an ST graft.

In this context, Lubowitz et al. [22] introduced an all-inside technique for ACL reconstruction, using a quadrupled semitendinosus tendon (ST4) autograft and suspensory cortical fixation with buttons on both the femoral and tibial side. With the use of retrograde drilling, bone sockets are created instead of tunnels [24], resulting in bone preservation for future revision surgery. Moreover, smaller incisions and diminished violation of bone cortices and periosteum may be associated with reduced postoperative pain [3, 23].

Although the initial reports comparing this technique with the traditional approaches have shown at least equivalent outcomes [3, 23, 25], other investigators have published less encouraging findings [6].

The purpose of this work was to compare subjective, and clinical and functional outcomes after a minimum of 2-year follow-up in patients treated with ACL reconstruction using: (a) an all-inside technique with an ST4 autograft and suspensory fixation on both the femoral and tibial sides; and (b) the conventional technique with an ST/G autograft fixed with a suspensory device on the femoral side and interference screw fixation on the tibial side. It was hypothesized that the all-inside technique with a short, ST4 autograft is associated with better patient-reported, clinical and functional outcomes at 2 years. To our knowledge, this is the first prospective, randomised-controlled study comparing both subjective and objective outcomes of the two aforementioned techniques.

Materials and methods

To quantify the differences between the two methods, a statistical comparison has been introduced. A prospective, randomised clinical study was conducted, including patients with ACL injury that underwent ACL reconstruction in the Orthopaedics and Sports Orthopaedics Clinic, Metropolitan Hospital, N. Faliro, Greece, between 2015 and 2016. Inclusion criteria were isolated first-time ACL ruptures without concomitant meniscal, chondral, or other ligamentous injuries in skeletally mature patients with no history of previous surgery or trauma to the injured knee. Patients with failed ACL reconstructions and/or with a history of injury/surgery to the contralateral knee were excluded from the study. Patients were randomised into one of the following two groups: those treated with an all-inside ACL reconstruction technique with an autologous ST4 graft and suspensory graft fixation on both the femoral and tibial side (Group A); and those treated with ACL reconstruction using an autologous ST/G graft and suspensory fixation on the femoral side and interference screw fixation on the tibial side (Group B).

Randomisation method, allocation concealment, and blinding

Randomisation into the two arms of the study was conducted with the block randomisation method. One of the authors (allocator) created a randomisation plan using randomly mixed block sizes of two, four, and six patients, to minimise allocation prediction. Next, the allocator prepared continuously numbered opaque sealed envelopes containing the corresponding allocation. These envelopes were handed over to the senior author, to be opened only after each patient enrollment. Patients with ACL injury who fulfilled the inclusion criteria were requested to provide informed consent for participation in the study. Next, each patient was scheduled for surgery; at that point, a consecutive opaque sealed envelope was opened, and the patient was allocated to one of the two groups. The allocation was not disclosed to the patients at any point; nonetheless, blinding of the outcome assessors was not feasible, as the surgical technique used was easily identifiable by the different skin incisions on the knee. Finally, the data analyst was blinded with respect to patient allocation, as the spreadsheet with raw data provided did not contain identifying terms.

Surgery

All patients were operated by the senior surgeon (PK), who commenced performing the all-inside technique in 2015. In patients of Group A, the semitendinosus tendon was harvested and a four-stranded graft (ST4) was prepared, attached to an ACL TightRope™ adjustable loop button system (Arthrex, Naples, FL) on either side. In patients of Group B, the semitendinosus and gracilis tendons were harvested and prepared to form a four-stranded ST/G graft attached to a Flipptack™ button system (Karl Storz, Tuttlingen, Germany) for femoral fixation on one side.

Graft fixation comprised suspensory fixation on both sides for patients of Group A; in patients of Group B, femoral fixation of the graft was obtained with a cortical button, whereas tibial fixation was achieved using a Megafix® absorbable interference screw (Karl Storz, Tuttlingen, Germany). Graft thickness on the femoral and the tibial side was measured and documented for patients of both groups.

Postoperative management and follow-up

Patients of both groups began quadriceps isometrics and range-of-motion on postoperative day 1. None of

the patients used a knee brace postoperatively. Immediate weight-bearing as tolerated was allowed. All patients were instructed with an identical rehabilitation protocol. Patients were seen for follow-up visits on weeks 1, 4, and 8, and on months 6, 12, and 24.

Outcome measures

Preoperatively, all patients underwent an extensive clinical, subjective, and objective evaluation. Anterior tibial translation of the operative knee was measured in mm by two different examiners (EK and EC) using a KT-1000™ arthrometer (MedMetric Corporation, San Diego, CA) and compared to the contralateral knee. Thus, two measurements per knee were obtained, and the average was calculated allowing for one decimal. The International Knee Documentation Committee (IKDC) grading system was used to allocate patients with regard to knee laxity into four categories. Patients also filled out questionnaires and underwent clinical examination by the same examiner (EC) to obtain the Lysholm knee score, the subjective IKDC score, the Knee Injury and Osteoarthritis Score (KOOS), and the Knee Society Score (KSS). At the 24-month visit, anterior tibial translation was reevaluated, and subjective scores were again obtained and compared to preoperative data. Measurements were performed by the examiners that carried out the corresponding preoperative evaluations, using the same methods.

Isokinetic testing of the operative limb was also conducted in both groups using a Biodex System 4 Pro™ Dynamometer (Biodex, Shirley, NY). Peak torques to body weight %, times to peak torque, and total work for both extensors and flexors were measured at 60°/s and 180°/s. In addition, isometric extensor and flexor peak torques to body weight % and isometric flexor/extensor ratios were determined at 90°. All measurements were performed for the operative and the non-operative limb in all patients by two examiners (EK and EC). The average values for each measurement were used to determine the limb symmetry index (LSI; operative/non-operative limb ratio), allowing for one decimal.

Informed consent was obtained from all patients and the study was officially approved by Metropolitan Hospital's Institutional Ethics Committee (ID# 2501101214).

Statistical analysis

At the stage of study design, power analysis was performed. At the 5% level of significance, with moderate-effect size (0.5) and sample sizes of 45 and 45, the power probability was estimated to be 78.6%. An intention-to-treat analysis was conducted to compare the effects of the different surgical techniques between the two groups. Descriptive statistics were used to report patient characteristics and frequencies; continuous variables are expressed as means and standard deviations, whereas categorical variables are expressed as absolute frequencies. A comparison of patient characteristics as well as outcome measures between the two groups at 24 months was conducted. Moreover, interobserver reliability for knee laxity and isokinetic testing measurements was conducted using the intraclass correlation coefficient (ICC with 95% CI). To determine the difference between the two sample means, the *t* test was used assuming the distribution of the study's patients which follow the normal distribution. The statistical analysis was performed with a commercially available software (SPSS v.18.0). Statistical significance was set at $p = 0.05$.

Results

During the study period, a total of 189 patients with ACL injury were evaluated. Of those, 90 patients were subsequently enrolled, with 45 patients initially randomised to each group. There was one patient of Group B that was lost to follow-up. Within the 2-year follow-up, there was also one ACL reconstruction failure in Group A (2.2%) and two ACL reconstruction failures in Group B (4.4%). This left 44 patients in Group A and 42 patients in Group B that completed the 24-month follow-up (Fig. 1). Patient demographics for both groups are summarised in Table 1. The use of quadrupled semitendinosus tendon resulted in a significantly higher mean (± SD) graft diameter compared to the ST/G graft, on both the femoral (8.2 ± 0.7 mm vs 7.7 ± 0.5 mm; $p < 0.001$) and the tibial side (8.3 ± 5.0 mm vs 7.7 ± 4.9 mm; $p < 0.001$).

Both groups showed a significant improvement in all subjective scores postoperatively (Table 2). However, between Group A and Group B, the mean (± SD) Lysholm knee scores (97.7 ± 2.1 vs 96.6 ± 2.2; n.s.), as well as the mean (± SD) subjective IKDC (83.6 ± 8.2 vs 78.5 ± 9.9; n.s.), mean (± SD) KOOS (95.3 ± 3.8 vs 95.8 ± 3.6; n.s.), and mean (± SD) KSS scores (83.9 ± 11.8 vs 96.6 ± 2.8; n.s.) were similar at 2 years.

Moreover, there was a significant improvement in laxity postoperatively, compared to preoperative measurements (Table 3). Nevertheless, no significant differences in anterior tibial translation between the operative and non-operative knee were found between the two groups (Table 3). Interobserver reliability for laxity measurements was excellent [ICC 0.93; 95% CI (0.85, 0.99)].

Isokinetic testing revealed that, compared to patients of Group B, patients of Group A had significantly higher mean LSIs in terms of flexor peak torque, flexor time to and flexor total work at 180°/s (Table 4). In addition, the mean LSI for isometric flexor/extensor ratio at 90° was higher in patients of Group A compared to Group B (Table 4). No

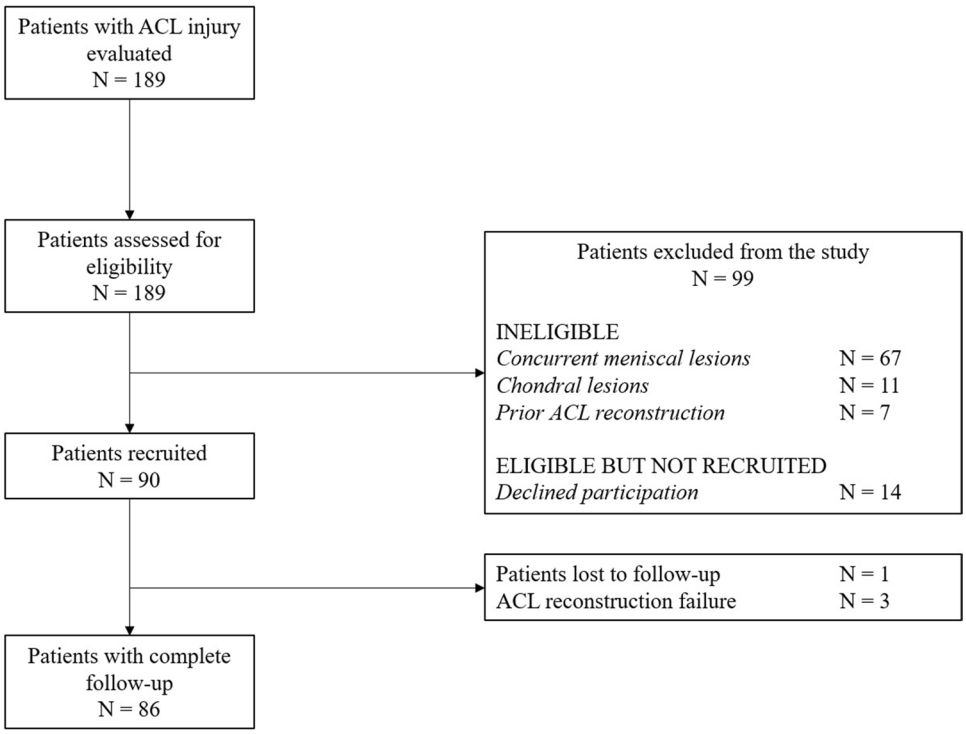

Fig. 1 Flowchart showing the process of recruiting patients with ACL injury

Table 1 Demographics of patients enrolled in the study

	Group A	Group B	*p* value
Gender			
Male	28 (62.2)	27 (60.0)	n.s.
Female	17 (37.8)	18 (40.0)	
Age (years)	27.6 ± 11.4	29.7 ± 11.0	n.s.
BMI (kg/m^2)	25.6 ± 2.8	24.8 ± 2.6	n.s.
Operative limb			
Left	21 (46.7)	22 (48.9)	n.s.
Right	24 (53.3)	23 (51.1)	

Categorical variables are expressed as *n* (%); continuous variables are expressed as mean ± SD

n.s. non-significant

other significant differences were noted for the remaining measurements (Table 4). Interobserver reliability for isokinetic testing measurements was also excellent [ICC 0.92; 95% CI (0.81, 0.97)].

Discussion

The most important finding of the present study was that ACL reconstruction with the all-inside technique using a short, ST4 autograft provided a better flexor muscle strength at 2 years, compared to the conventional technique with an ST/G autograft. In addition, the two techniques were associated with similar improvements in subjective scores and knee stability.

Arthroscopic ACL reconstruction is a widely performed surgical procedure. The all-inside technique with an ST4 autologous graft has been developed with the aim of minimising surgical trauma and donor side morbidity, enhancing

Table 2 Preoperative and postoperative patient-reported outcomes

	Group A			Group B		
	Preoperative	Postoperative	*p* value	Preoperative	Postoperative	*p* value
Lysholm knee score	45.6 ± 15.7	97.7 ± 2.1	< 0.001*	44.8 ± 17.5	96.6 ± 2.2	< 0.001*
IKDC score	41.9 ± 12.7	83.6 ± 8.2	< 0.001*	43.6 ± 14.0	78.5 ± 9.9	< 0.001*
KOOS	68.6 ± 6.6	95.3 ± 3.8	< 0.001*	65.9 ± 7.2	95.8 ± 3.6	< 0.001*
KSS	54.8 ± 15.6	83.9 ± 11.8	< 0.001*	58.4 ± 17.4	96.6 ± 2.8	< 0.001*

All variables are expressed as mean ± SD; statistically significant differences are marked with an asterisk

Table 3 Preoperative and postoperative laxity, as evaluated with the KT-1000™ arthrometer

	Preoperative	Postoperative	*p* value
Group A			
IKDC A	0 (0)	38 (83.4)	<0.001*
IKDC B	0 (0)	6 (16.6)	
IKDC C	12 (36.7)	0 (0)	
IKDC D	33 (73.3)	0 (0)	
Group B			
IKDC A	0 (0)	34 (80.9)	<0.001*
IKDC B	0 (0)	10 (19.1)	
IKDC C	14 (31.1)	0 (0)	
IKDC D	31 (68.9)	0 (0)	
p value	n.s.	n.s.	

Variables are expressed as *n* (%); statistically significant differences are marked with an asterisk

n.s. non-significant

Table 4 Isokinetic testing at 2 years after surgery

	Group A	Group B	*p* value
Extension at 60°/s			
Peak torque	0.9 ± 0.1	0.9 ± 0.1	n.s.
Time to peak	3.0 ± 14.2	0.9 ± 0.1	n.s.
Total work	0.9 ± 0.1	0.9 ± 0.1	n.s.
Extension at 180°/s			
Peak torque	0.9 ± 0.1	0.9 ± 0.1	n.s.
Time to peak	0.9 ± 0.1	0.9 ± 0.1	n.s.
Total work	0.9 ± 0.1	0.9 ± 0.1	n.s.
Flexion at 60°/s			
Peak torque	0.9 ± 0.1	0.9 ± 0.1	n.s.
Time to peak	0.9 ± 0.1	0.9 ± 0.1	n.s.
Total work	0.9 ± 0.1	0.8 ± 0.1	n.s.
Flexion at 180°/s			
Peak torque	1.0 ± 0.1	0.9 ± 0.1	<0.001*
Time to peak	0.9 ± 0.1	0.8 ± 0.1	<0.001*
Total work	0.9 ± 0.1	0.8 ± 0.1	<0.001*
Isometric measurements at 90°			
Extensor peak torque	0.9 ± 0.1	0.9 ± 0.1	n.s.
Flexor peak torque	0.9 ± 0.1	0.9 ± 0.1	n.s.
Flexor/extensor ratio	1.1 ± 0.3	0.8 ± 0.2	<0.001*

Measurements on both the operative and non-operative limbs were used to calculate the limb symmetry index (LSI)

The LSI for all measurements is presented as mean ± SD. Statistically significant differences are marked with an asterisk

n.s. non-significant

patient recovery, and preserving bone stock. Although hamstring tendon autografts have been extensively studied and compared with the "gold standard" bone-patellar tendon-bone graft, the evidence on the all-inside ST4 technique with suspensory fixation is limited. Therefore, the purpose of the study was to compare this technique with the conventional ACL reconstruction utilising full bone tunnels, ST/G graft, and interference screw fixation on the tibial side.

The use of the quadrupled semitendinosus tendon was found to provide grafts with significantly higher graft diameters on both the femoral and the tibial side compared to the ST/G graft. This was somewhat anticipated, as the technique encompasses a short graft which affords folding the ST tendon in four. On the other hand, the preparation of the double ST/G graft involves the use of the much thinner gracilis tendon, essentially leading to thinner grafts for the same semitendinosus tendon diameter. It should be noted that a minimum thickness of 8 mm and a minimum length of 28 mm are required for a short ST4 graft [16, 26]. It has been suggested that adequate graft thickness may be predicted based on specific anthropometric parameters, including height, thigh length, weight, and gender [12, 16, 33]. However, in case the thickness of the harvested ST tendon does not permit adequate graft thickness, the gracilis tendon should be also obtained. In the present series, there was never a need to proceed to gracilis harvest in patients undergoing all-inside ACL reconstruction. With the all-inside short-graft technique, larger drill diameter (due to increased graft thickness) is counterbalanced by drilling bone sockets rather than bone tunnels. In fact, with the use of bone sockets, a significant amount of bone is preserved, which may facilitate future revision surgery [4, 5]. The quantification of bone stock preservation is an interesting issue, which could be addressed in future investigations.

Patient-reported outcomes were similar between the two groups at 2 years. It should be noted, however, that the mean subjective IKDC scores for Group A and B in the present study were in the "good" and "fair" ranges, respectively, according to the stratification outlined by Hefti et al. [13]; nevertheless, these were not significantly different. However, the existing literature supports that subjective scores continue to improve after the second year from index procedure [2, 11]. Therefore, it is possible that the patients of the present study may experience continuing improvements in the long term.

Similarly, no differences were found in anterior tibial translation between the two groups. The previous studies on the use of the ST4 graft for ACL reconstruction have reported excellent results in terms of residual laxity, with the mean difference in anterior tibial translation between the operative and non-operative knee ranging below 3 mm [7, 9, 11, 19, 20, 27, 32]. On the other hand, in their recent series, Bressy et al. [6] found a significant residual laxity and attributed this finding to the use of adjustable loop cortical button. The present study's results, however, do not support this hypothesis. Of note, all previous studies are quite

heterogenous; patients with meniscal injuries were included in some and excluded in others. In the present study, patients with meniscal lesions requiring repair or meniscectomy were excluded, as it is known that at least certain types may contribute to persistent laxity after ACL reconstruction [31].

One theoretical advantage of the use of an ST4 graft is preservation of the gracilis tendon, which may be associated with improved function, especially in activities requiring knee flexion. Flexion weakness is an acknowledged issue after ACL reconstruction with hamstring tendon grafts [17, 18, 34]. Interestingly, the present study showed that, at 2 year postoperatively, patients treated with ACL reconstruction with an ST4 graft had significantly better flexor isokinetic measurements at 180°/s than patients treated with an ST/G graft; at lower angular velocities; however, no difference was noted. These findings suggest that the ST4 graft may offer some benefit in patients involved in sports that require rapid knee flexion, including soccer, dynamic sports, etc [15]. It was also found that isometric flexor/extensor ratio at 90° was higher in patients treated with an ST4 graft, which further supports enhanced postoperative flexor function with this technique. Further investigation is warranted to identify whether this difference tapers after the second postoperative year.

The present study had certain limitations that need to be acknowledged. First, blinding of the surgeon and the outcome assessors was not possible due to the different surgical techniques employed and different surgical scars which revealed the technique employed. In addition, whereas patients were also blinded with respect to the surgical technique, it is probable that some might have identified it by means of incision type and information retrieved from the internet. On the other hand, the data analyst was provided with data blinded in terms of surgical technique. Another limitation is that, while all surgeries were performed by the senior surgeon, the study period includes his learning curve on the all-inside technique. Therefore, the study's results may have been affected by technical flaws related to accommodation to the technique. Nevertheless, the technique's learning curve is rather shallow for a high-volume surgeon [21]; thus, its effect on the study's results is probably minimal. Moreover, while patients were given the same rehabilitation protocol, this was employed by different rehabilitation professionals and variations cannot be excluded. However, every effort was made to maintain regular communication with both the patients and rehabilitation teams during the postoperative period, to minimise discrepancies.

The findings of the present study may be of value in everyday practice. Considering the superior flexor strength at 2 years, which was the sole observed difference compared to the conventional technique, the all-inside ACL reconstruction with a short ST4 autograft should be strongly considered in the athletic patient population. Certainly, the surgeon should take into account other factors, as well, including graft diameter and availability, previous surgeries, somatometric characteristics, etc. However, these high-demand patients will benefit from preserving the gracilis tendon, when feasible.

Conclusion

The all-inside ACL reconstruction with a short ST4 graft and suspensory cortical fixation on the distal femur and proximal tibia is a viable and easy to adopt technique, yielding excellent results at 2 years. In addition, it provides an advantage over ACL reconstruction with an ST/G graft in terms of improved knee flexion strength at higher angular velocities.

Author contributions PK conceived and designed the study, performed all surgeries, and helped to draft the manuscript. EK and EC performed data collection. DK performed the statistical analysis. GT performed the randomisation and drafted the manuscript. All authors have read and approved the final manuscript.

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Compliance with ethical standards

Conflict of Interest The authors have no conflicts of interest in relation with this study.

Ethical approval The study was approved by the Institutional Ethics Committee, Metropolitan Hospital, ID number: 2501101214.

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