



# The Use of Five-Strand Hamstring Autograft to Increase the Graft Size in Anterior Cruciate Ligament Reconstruction—A Prospective Cohort Study With Satisfactory Early Clinical Results

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**Objectives:** To report on the outcomes of using 5-strand hamstring autograft to increase the graft size for anterior cruciate ligament (ACL) reconstruction and to determine whether the clinical results are comparable to using conventional 4-strand graft **Methods:** A prospective cohort study of patients with arthroscopic-assisted single-bundle ACL reconstruction using hamstring autograft from January 2019 to June 2021. The patients were prospectively recruited to undergo ACL reconstruction with either 5-strand hamstring graft (group A) or 4-strand hamstring graft (group B) **Results:** In total, 45 patients were included into the study. The mean diameter of the final graft was  $8.9 \pm 0.6$  cm in the 5-strand group and  $7.5 \pm 0.8$  cm in the 4-strand group ( $P < .001$ ). Four-strand graft diameter measurements were taken intraoperatively in the 5-strand group before preparation of the 5-strand graft. The mean graft diameter of the 4-strand grafts was similar in both groups:  $7.3 \pm 0.3$  mm in group A and  $7.5 \pm 0.8$  mm in group B ( $P = .72$ ). There was no statistically significant difference between the 2 groups of patients in terms of the Lysholm score, Knee Injury and Osteoarthritis Outcome Score (KOOS) Symptoms, KOOS Pain, KOOS Activities of Daily Living, KOOS Sports and KOOS Quality of Life scores. There were no postoperative complications of wound infection in both groups of patients. There was one case of graft rupture (4.8%) in the 4-strand group, which required revision reconstruction with patellar tendon graft 9 months postoperatively. There was no case of graft rupture in the 5-strand group ( $P = .29$ ) **Conclusions:** The 5-strand hamstring graft technique provides a graft with significantly larger graft diameter than the quadrupled graft technique, with satisfactory short- to medium-term outcomes. The 5-strand graft is therefore a useful technique to increase the graft size when faced with the problem of small hamstring graft. **Level of Evidence:** Level II, prospective cohort study.

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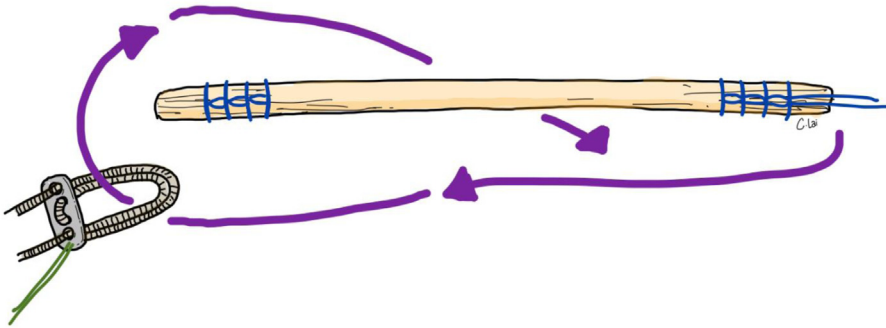
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Hamstring autograft is a popular choice of graft in anterior cruciate ligament (ACL) reconstruction because of its favourable biomechanical profile, ease of harvest, and positive clinical outcomes,<sup>1-4</sup> with results comparable to patellar tendon autografts.<sup>5,6</sup> However, variability exists in the population in terms of size of the hamstring and therefore the graft diameter. The difficulty in obtaining a hamstring graft with consistent and adequate diameter and length may adversely affect the surgical outcome. Multiple studies have demonstrated that an increase in the hamstring graft size is associated with a lower revision rate.<sup>7,8</sup> A retrospective review of the data in our regional institute revealed that a



**Fig 1.** Schematic diagram illustrating the technique of triple folding the semitendinosus tendon. After braiding both ends of the tendon, one end is tied to an ULTRABUTTON and the other end is lopped through the ULTRABUTTON to create and triple-folded semitendinosus tendon.

hamstring graft diameter of a minimum of 8.0 mm is associated with lower risk of graft failure.<sup>9</sup> In a significant proportion of our patients, particularly female Chinese patients with small body built, an 8.0-mm graft is difficult to achieve. Therefore, an alternative technique to increase the size of the hamstring graft is needed.

Several techniques have been described to increase the size of the hamstring graft,<sup>10,11</sup> one of which is the 5-strand hamstring graft preparation technique, in which the longer semitendinosus tendon is tripled with the shorter gracilis tendon doubled to produce a 5-strand graft configuration.<sup>12</sup> The purpose of the study was to report on the outcomes of using 5-strand hamstring autograft to increase the graft size for ACL reconstruction and whether the clinical results are comparable with that of using conventional 4-strand graft. We hypothesized that 5-strand hamstring graft would provide a graft with significantly larger diameter than the conventional quadrupled hamstring graft, with comparable clinical outcomes.

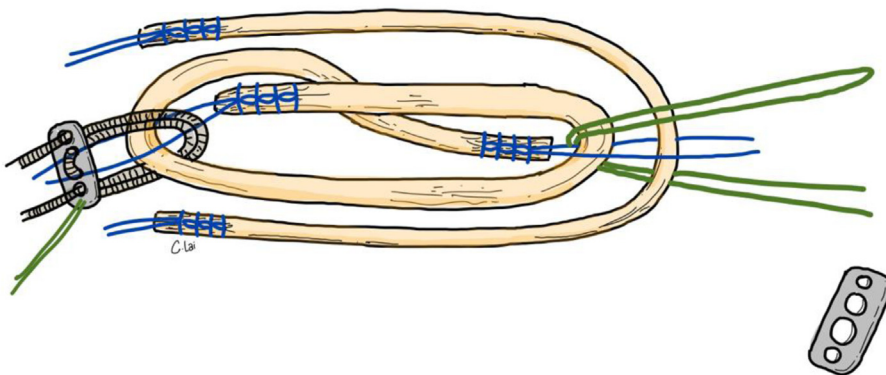
## Methods

The study design was approved by the local institutional review board. Between January 2019 and June 2021, patients who underwent arthroscopic-assisted single-bundle ACL reconstruction using hamstring autograft in our institution were prospectively recruited into our study. The indications for surgery were

patients with clinical evidence of ACL injuries from physical examinations confirmed with magnetic resonance imaging to be a complete tear.

The inclusion criteria were as follows: patients aged 18-45 years, symptoms and physical examinations consistent with ACL deficiency and magnetic resonance imaging indicating ACL injury, no contralateral ACL injury, no previous surgery done to the operated knee, and no other concomitant ligament injuries in the operated knee that require surgical management. Patients with their ACL reconstructed as part of the multiligamentous injuries, revision ACL surgeries, or concomitant lateral tenodesis were excluded.

The patients were prospectively recruited to undergo ACL reconstruction with either 5-strand hamstring graft (group A) or 4-strand hamstring graft (group B). Recruited patients were assessed preoperatively on the day before the surgery using multiple objective and subjective tests. Patient's sex, age at surgery, preinjury Tegner Activity Score, body height, body weight, and body mass index were recorded. The pivot shift test was performed and graded according to the International Knee Documentation Committee form as 0 (absent), 1+ (glide), 2+ (clunk), and 3+ (gross). The Lachmann test was performed and graded to the International Knee Documentation Committee form as 1+ (<5 mm), 2+ (5-10 mm), and 3+ (>10 mm). The assessors were blinded to the patient's grouping allocations.



**Fig 2.** Schematic diagram demonstrating the technique of preparing the 5-strand graft. After preparing the triple-folded semitendinosus tendon, the gracilis tendon is wrapped around on top of it.



**Fig 3.** Intraoperative graft measurement using the graft sizing cylinder with 0.5-mm increments.

### Surgical Technique

The patient was placed in a supine position with pneumatic tourniquet around the ipsilateral thigh. Standard anterolateral and anteromedial portals were established to assess the ACL tear and to look for other concomitant intra-articular injuries. A longitudinal skin incision was made over the anteromedial aspect of the tibial surface. The pes anserinus was incised to identify the gracilis and semitendinosus, which were then released from their tibial insertions. The tendons were whipstitched with nonabsorbable sutures (Ti-Cron Braided Polyester Sutures; Medtronic, Minneapolis,

MN) and harvested using a tendon stripper. After the residual muscle remnants were removed, the other ends of the tendons were whipstitched with Ti-Cron sutures. The tendon lengths were measured. Graft diameter was measured using the graft sizing cylinder in 0.5mm increments. The graft diameter was defined as the smallest-sized cylinder through which the graft could pass through smoothly.

### Five-Strand Group

Preliminary measurements of the gracilis and semitendinosus tendons were performed. A minimum length of 240-mm semitendinosus and 160-mm gracilis tendons was required before proceeding with the preparation of 5-strand graft, to obtain a 5-strand graft with a minimum length of 80 mm, with at least 30-mm graft inside the femoral socket, 25 mm of graft inside the joint, and 25-mm graft inside the tibial socket. If the minimum length of semitendinosus and gracilis could not be achieved, 4-strand grafts would be prepared and used. Those patients would still be included in the 5-strand group as part of the intention to treat analysis.

To prepare a 5-strand graft, one end of the semitendinosus tendon was tied to an ULTRABUTTON (Smith & Nephew, Andover, MA), with the other end looping through the ULTRABUTTON to create 3 equal segments (Fig 1). The graft was then wrapped by a doubled-up gracilis tendon with its midportion tied to the free end of the semitendinosus tendon (Fig 2) to create a 5-strand graft. The diameter of the 5-strand graft was measured using the graft sizing cylinder (Fig 3). Both ends of the graft were reinforced with nonabsorbable sutures using the SPEEDTRAP System (DePuy Synthes, Raynham, MA), with the mid-portion of the graft further reinforced with 2-0 VICRYL sutures (Ethicon, a Johnson & Johnson Company, Somerville, NJ) (Fig 4).

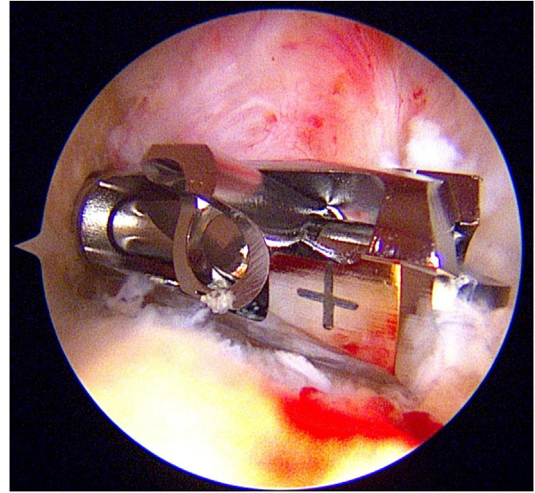
The femoral tunnel was drilled at the anatomical footprint with the knee in hyperflexion to create a femoral socket. The tibial tunnel was drilled using the ACUFEX TRUNAV retrograde drill (Smith & Nephew,



**Fig 4.** Intraoperative photo of the final 5-strand hamstring graft.



**Fig 5.** Intraoperative photo showing the preparation of the tibial socket using the retrograde drill. The patient is positioned supine with the knee flexed to 90°. A guide pin is inserted through the anteromedial wound of the tibia. The retrograde is then inserted through the guide pin and retrograde drilling of the tibial socket is performed under direct arthroscopic visualization.



**Fig 6.** Arthroscopic view with the cutting blade being deployed for preparing the tibial socket.

Andover, MA) (Figs 5 and 6). The graft was pulled up the femoral socket through the anteromedial portal and retrieved down the tibial socket (Figs 7 and 8). An “all-inside reconstruction” was achieved with the femoral fixation using the ULTRABUTTON, and the tibial fixation using the ENDOBUTTON (Smith & Nephew), by tying the graft sutures over an ENDOBUTTON (Fig 9). Anteroposterior view of a postoperative radiograph of a patient in the 5-strand group showing suspensory graft fixation over both the femoral and tibial sides (Fig 10).

#### Four-Strand Group

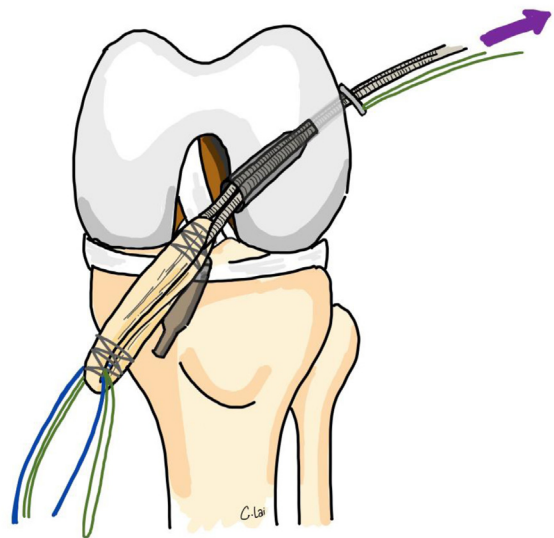
After harvesting the gracilis and semitendinosus tendons, the ends were whipstitched with nonabsorbable sutures. The gracilis and semitendinosus were looped around a nonabsorbable suture (ETHIBOND No. 5) to form a quadrupled hamstring graft, which was further reinforced with 2-0 VICRYL sutures. Similar to the 5-strand group, the femoral tunnel was drilled at the anatomical footprint with the knee in hyperflexion. The tibial side was drilled through the entire length of the tunnel. The graft was pulled up the tibial and femoral tunnels in a retrograde manner. Fixation was achieved over the femoral tunnel with the ENDOBUTTON. Tibial fixation was achieved with a bioabsorbable interference screw (BIOSURE REGENESORB, Smith & Nephew).

All surgeries and intraoperative measurements were performed by the same surgical team, with specialist surgeons. The preoperative and postoperative clinical data were collected using the hospital’s electronic patient’s management system.

#### Postoperative Rehabilitation Protocol

All patients received the same ACL reconstruction rehabilitation protocol per our institutional protocol, with early weight-bearing and range of motion exercises. Patients who had undergone further meniscal repair were instructed to avoid knee flexion beyond 90° during the first postoperative 6 weeks.

All patients were followed up at postoperative 2 weeks, 6 weeks, 3 months, 6 months, and 9 months at our outpatient clinic. Surgical complications including wound infection and graft re-rupture were recorded. To minimize the potential bias, the postoperative assessors were blinded to the patient’s grouping allocation.



**Fig 7.** Schematic diagram demonstrating the graft passage. Through the anteromedial portal, the graft is pulled proximally up the femoral socket.



**Fig 8.** Schematic diagram demonstrating the graft passage. Once secured inside the femoral socket, the other end of the graft is looped through the passing suture over the tibial socket. Through the anteromedial portal, the graft is pulled down the tibial socket, which is subsequently fixed with an ENDOBUTTON.

### Statistical Analysis

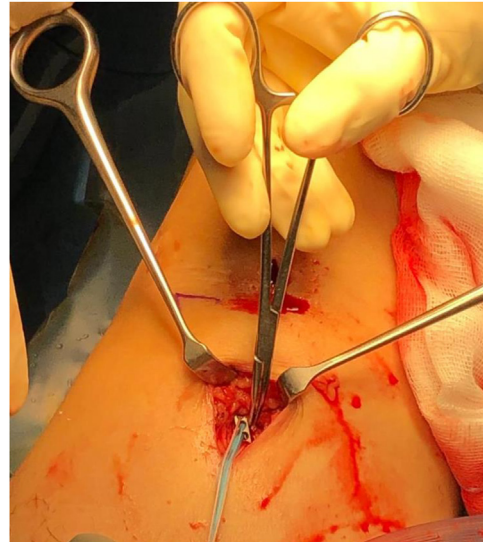
Means  $\pm$  standard deviation values are presented when applicable. Mann–Whitney *U* tests was used to compare the quantitative variables in the patient’s demographics and outcomes measured. The Pearson  $\chi^2$  test was used for categorical variables.

A minimum sample size of 40 patients was sufficient to detect an effective size of  $d = 0.92$  and a 2-sided alpha error of 5% with 80% statistical power (Fig 11). IBM SPSS, version 26 (IBM Corp., Armonk, NY). A *P* value of less than .05 was taken as statistically significant.

## Results

### Patient’s Demographics

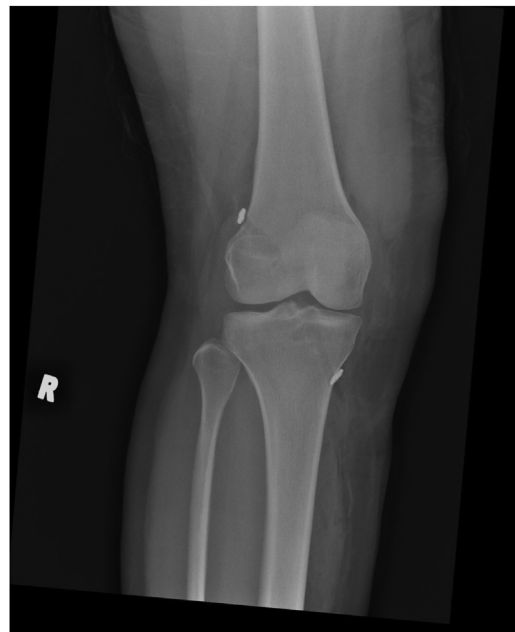
Between January 2019 and June 2021, a total of 45 patients were included into the study (Fig 12). In total, 24 patients received ACLR with a 5-strand graft (group A) and 21 patients with a 4-strand graft (group B). There were no statistical significances between the 2 groups in terms of age, sex, body height, body weight, body mass index, preinjury Tegner Activity Score, preoperative Lachmann’s and pivot shift tests results, or the presence of meniscal injury (Tables 1 and 2).



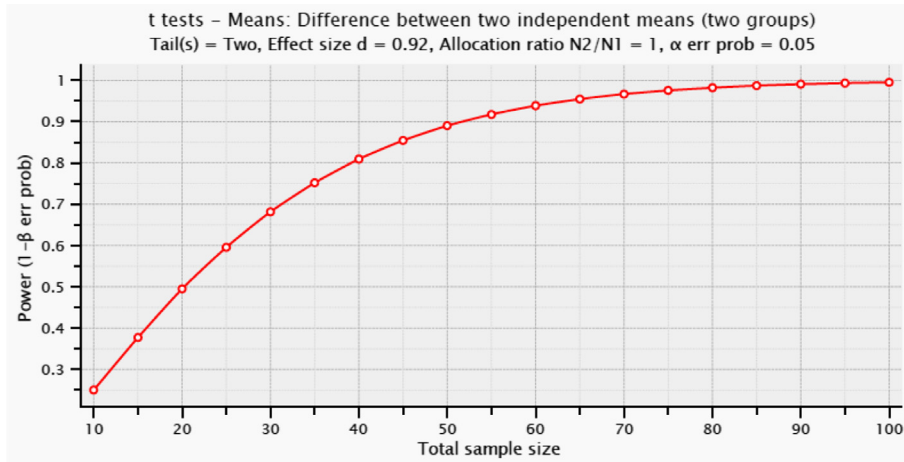
**Fig 9.** Intraoperative photo showing the tibial fixation of the graft by tying a sliding knot over an ENDOBUTTON at the anteromedial wound of the tibia.

### Graft Length and Diameter

The mean lengths of the semitendinosus tendon were  $24.7 \pm 1.7$  cm in the 5-strand group and  $24.9 \pm 2.0$  cm in the 4-strand group ( $P = .81$ ). The mean lengths of the gracilis tendon were  $21.7 \pm 5.0$  cm in the 5-strand group and  $21.1 \pm 1.4$  cm in the 4-strand group ( $P = .75$ ).



**Fig 10.** Postoperative radiograph of the knee using 5-strand graft with suspensory fixations over both the femoral and tibial sides.

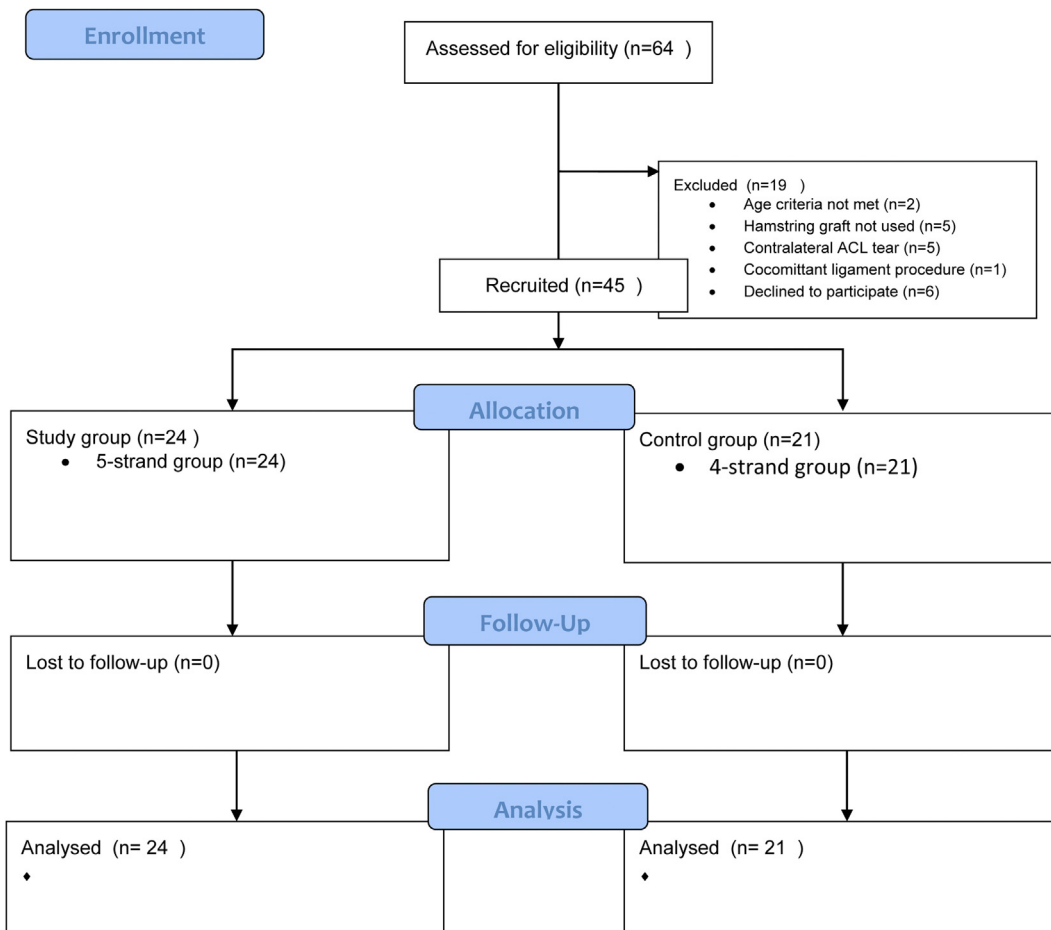


**Fig 11.** Power analysis for adequate sample size.

The mean diameter of the final graft was  $8.9 \pm 0.6$  cm in the 5-strand group and  $7.5 \pm 0.8$  cm in the 4-strand group ( $P < .001$ ) (Table 3). Four-strand graft diameter measurements were taken intraoperatively in the 5-strand group before preparation of the 5-strand graft.

The mean graft diameter of the 4-strand grafts was similar in both groups:  $7.3 \pm 0.3$  mm in group A and  $7.5 \pm 0.8$  mm in group B ( $P = .72$ ).

The average increase in graft diameter with the use of 5-strand graft over the 4-strand graft in group A was 1.6



**Fig 12.** Study flowchart. (ACL, anterior cruciate ligament.)

**Table 1.** Comparison of Patient Demographics

	5-Strand Group (n = 24)	4-Strand Group (n = 21)	P Value
Age, y, mean ± SD	29.6 ± 8.7	27.7 ± 8.5	.44
Sex, n (%)			.53
Male	15 (62.5%)	15 (71.4%)	
Female	9 (37.5%)	6 (28.6%)	
Height, cm, mean ± SD	170 ± 10.2	172.5 ± 8.6	.45
Weight, kg mean ± SD	71.8 ± 12.2	70.2 ± 15.0	.6
BMI, mean ± SD	24.8 ± 3.9	23.4 ± 3.8	.17
Side of injury, n (%)			.58
Left	7 (29.2%)	12 (57.1%)	
Right	12 (57.1%)	12 (57.1%)	
Concomitant meniscal injury, n (%)			
Medial meniscus	6	5	.93
Lateral meniscus	11	10	.91
Tegner Activity Score	6.7 ± 0.7	6.6 ± 0.8	.52
Mean follow-up duration, mo	17.5 ± 2.34	17.4 ± 2.57	.89
Postoperative scores at latest follow-up			
Lysholm	89.2 ± 6.8	86.5 ± 6.7	.47
KOOS symptoms	86.9 +/- 15.4	82.7 +/- 18.4	.69
KOOS pain	91.2 ± 11.3	87.5 ± 12.2	.58
KOOS activities of daily living	95.6 ± 6.8	95.4 ± 4.1	.58
KOOS sports	87.5 ± 14.7	88.8 ± 6.3	.3
KOOS Quality of life	85.5 ± 13.5	85.9 ± 7.7	.87

BMI, body mass index; KOOS, Knee Injury and Osteoarthritis Outcome Score; SD, standard deviation.

± 0.4 mm. In the 5-strand group, 20 of 24 patients (83.3%) had graft diameters exceeding 8 mm, compared with 3 of 21 patients (14.3%) in the 4-strand group (Table 4).

With regards to the postoperative outcomes of the 5-strand group and the 4-strand group, there was no significant statistical difference in terms of the Lysholm score, Knee Injury and Osteoarthritis Outcome Score (KOOS) Symptoms, KOOS Pain, KOOS Activities of Daily Living, KOOS Sports, and KOOS Quality of Life scores (Table 1).

There were no postoperative complications of wound infection in both groups of patients. There was one case of graft rupture (4.8%) in the 4-strand group, which required revision reconstruction with patellar tendon graft 9 months postoperatively. There was no case of graft rupture in the 5-strand group (*P* = .29).

**Discussion**

The key finding of our study was that the 5-strand graft was able to provide a significantly larger graft diameter than the conventional 4-strand graft, with an average increase of 1.6 ± 0.4 mm in graft diameter, at the same time able to achieve clinical outcomes that are comparable with that of the 4-strand graft. In addition, the majority of the patients (83.3%) could achieve graft

**Table 2.** Preoperative Knee Laxity Assessment

	5-Strand Group (n = 24)	4-Strand Group (n = 21)	P Value
Lachmann, n (%)			.86
0			
1	3 (12.5%)	3 (14.3%)	
2	21 (87.5%)	18 (85.7%)	
3			
Pivot shift test, n (%)			.83
0			
1	4 (16.7%)	3 (14.3%)	
2	20 (83.3%)	18 (85.7%)	
3			

diameters of at least 8.5 mm in the 5-strand group, compared with 14.3% of patients in the 4-strand group.

There are numerous biomechanical and clinical studies that demonstrate the advantages of an increased hamstring graft diameter. The cut-off of 8.5 mm of graft diameter has been mentioned in multiple studies as the cut-off of graft diameter, below which is associated with a significant increase in the risk of graft failure and the need for revision ACL reconstruction.<sup>8,13-16</sup> Magnussen et al.<sup>8</sup> found that grafts of 8 mm or less in diameter were associated with significant increase in the rate of revision ACL surgery. Mariscalco et al.<sup>13</sup> published their findings of the Multicentre Orthopaedic Outcomes Network cohort study and found that the revision rate was 0% if graft diameter larger than 8.5 mm was used. Conte et al.<sup>14</sup> published a systematic review showing that the relative risk of graft failure was 6.8 times greater when graft diameter of less than 8.5 mm was used.

Most of the aforementioned studies were conducted in North American and European countries. Asian patients are known to exhibit significant differences in terms of body build, and hence there exists a difference in the knee anthropometry between White and Asian patients. Ho et al.<sup>17</sup> published their data on Singaporean patients showing that the mean quadrupled hamstring graft diameters were less than 8 mm, whereas Xie et al.<sup>18</sup> revealed the mean quadrupled graft diameter to be 7.5 mm. Tang et al.<sup>9</sup> reported that close to 85% of patients failed to have a graft diameter of at least 8.5 mm using the quadrupled technique, and a graft diameter of less than 8.5 mm was associated with a significant increase in the graft failure rate. Because of that, there existed a need to improve the

**Table 3.** Mean Graft Diameter Between the 2 Groups

	5-Strand Group (n = 24)	4-Strand Group (n = 21)	P Value
Mean graft diameter (final)	8.9 ± 0.6	7.5 ± 0.8	<.001
Mean graft diameter (4-strand)	7.3 ± 0.3	7.5 ± 0.8	0.72

**Table 4.** Number of Patients Per Graft Size in Each Group: Graft Size

	6 mm	6.5 mm	7 mm	7.5 mm	8 mm	8.5 mm	9 mm	9.5 mm	10 mm
5-strand group (n = 24)					5	3	10	3	3
4-strand group (n = 21)	1		10	2	5	1	2		

surgical outcomes by methods to increase the graft diameter.

The 5-strand graft has been reported as a mean to increase the graft diameter when faced with inadequate 4-strand graft.<sup>10,11</sup> The 5-strand technique has the advantage of increasing the graft diameter and at the same time also able to create a graft with adequate length for ACL reconstruction. In our study, we used an “all-inside” technique to create the femoral and tibial “sockets.” Instead of drilling through the tibia to create a tibial “tunnel,” we used a retrograde drill to create a tibial socket so that a shorter amount of graft is required on the tibial side, therefore solving the problem of shorter graft lengths using the 5-strand technique. The 5-strand technique is, in particular, useful for Asian patients, in whom smaller graft sizes are commonly encountered.<sup>19,20</sup>

There have been limited clinical studies on the use of 5-strand hamstring graft and the clinical outcomes. Krishna et al.<sup>21</sup> conducted a similar study demonstrating similar clinical outcomes between the 5-strand and 4-strand hamstring grafts, with comparable functional scores and postoperative complications.

### Limitations

Different limitations can be attributed to this study. First, intra- and interobserver variability may inevitably arise during the intraoperative graft measurements. In addition, the measurements were performed using graft sizing cylinders with 0.5-mm increments. This may result in upsizing or downsizing the graft diameters to the nearest 0.5 mm. Second, the intraoperative graft measurements were done by surgeons who were not blinded to the group allocation. This may result in bias in the outcomes measurement. Third, although it was a prospective study, the grouping allocations were performed by individual surgeon’s preference and therefore there was a lack of randomization in our study. Furthermore, we were only able to report a minimum of 9 months of clinical outcomes for some cases. This may not be adequate for study involving ACL reconstruction. In addition, comparison should be made between patients with 5-strand graft all-inside technique and patients with 4-strand graft all-inside technique instead of 4-strand graft with complete tibial tunnel technique. This would have eliminated the uncertainty of whether the clinical results were due to the increased graft size or different tibial fixation technique. Last but not least, we were only able to report the significant increase in the graft size and the early to medium term

outcomes in terms of surgical complications with the 5-strand technique. Further studies with larger sample size and long-term results are needed in the future in order to determine whether the use of 5-strand graft would lead to superior clinical outcomes compared to conventional 4-strand graft in ACL reconstruction.

### Conclusions

The 5-strand hamstring graft technique provides a graft with significantly larger graft diameter than the quadrupled graft technique, with satisfactory short- to medium-term outcomes. The 5-strand graft is therefore a useful technique to increase the graft size when faced with the problem of small hamstring graft.

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