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# Five-Strand Hamstring Autograft Versus Quadruple Hamstring Autograft With Graft Diameters 8.0 Millimeters or More in Anterior Cruciate Ligament Reconstruction: Clinical Outcomes With a Minimum 2-Year Follow-Up

Rafael Calvo, M.D., David Figueroa, M.D., Francisco Figueroa, M.D., Alex Vaisman, M.D., Andrés Schmidt-Hebbel, M.D., Nelson Morales, M.D., and Guillermo Izquierdo, M.D.

**Purpose:** To compare the outcomes of 2 groups of patients undergoing anterior cruciate ligament (ACL) reconstruction: the first with a quadrupled semitendinosus gracilis (ST-G) autograft larger than 8 mm diameter and the second with a 5-strand ST-G autograft larger than 8 mm due to an insufficient diameter graft harvesting. **Methods:** This was a retrospective study with 70 patients divided into 2 groups. Inclusion criteria included ACL ruptures of less than 3 months, ST-G ACL reconstructions, and final (4-strand or 5-strand) graft size larger than 8 mm. Exclusion criteria included multiligament knee injuries, meniscal or chondral pathology, ACL re-ruptures, inflammatory joint disease, or other procedures in the knee. **Results:** Group A comprised 33 patients with a quadruple ST-G graft, and group B comprised 37 patients with an insufficient graft diameter (<8 mm) in which a 5-strand graft was used. Mean age in group A was 29.7 (range 17-52) years and in group B was 30.6 (range 13-53) years ( $P = .78$ ). Average follow-up in group A was 32.2 (range 24-48) months and in group B was 30.35 (range 24-48) months ( $P = .75$ ). Average graft diameter in group A was 8.5 mm (range 8-10) and in group B when the graft was measured as quadruple was 7.2 mm (range 6.5-7.5) and 9.2 mm (range 8-10) when it was converted to 5-strand ( $P = .00596$ ). Group A had 3 (9%) re-ruptures, and group B had 2 (5.4%) ( $P = .55$ ). The average postoperative Lysholm score in group A was 93.3 (range 71-100) and in group B was 97.1 (range 80-100) ( $P = .79$ ). Mean postoperative International Knee Documentation Committee in group A was 91 (range 75.9-100) and in group B was 96.8 (range 82-100) ( $P = .18$ ). **Conclusions:** In our study, the 5-strand hamstring autograft in ACL reconstruction was clinically comparable with the quadruple autograft larger than 8 mm. The differences in re-rupture and clinical outcomes were not statistically significant between the 2 groups, suggesting that it is a valid option when we have a graft of insufficient diameter. **Level of Evidence:** Level III, retrospective comparative study.

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Hamstring autografts frequently are used for anterior cruciate ligament (ACL) reconstruction,<sup>1</sup> and many surgeons prefer them to bone–patellar tendon–bone (BPTB) grafts to avoid complications of the extensor mechanism.<sup>2</sup> Even though biomechanical studies have shown a greater load to failure with a 4-strand hamstring autograft compared with BPTB grafts,<sup>3</sup> clinical results are equivalent.<sup>4</sup> A potential disadvantage of hamstring autograft for ACL reconstruction is the inherent variability in graft diameter compared with BPTB grafts. Bickel et al.<sup>5</sup> demonstrated a strong relationship between cross-sectional area and final graft size, and smaller hamstring graft sizes are prone to a greater rate of failure in biomechanical and clinical studies.<sup>6</sup>

Magnussen et al.<sup>7</sup> recently evaluated hamstring autograft diameter as a predictor for graft failure and its

need for revision. In a study of 256 patients with hamstring autograft ACL reconstruction, grafts larger than 8.5 mm had a 1.7% revision rate, and grafts between 8 and 8.5 mm and 7.5 and 8 mm had a revision rate of 6.5% and 6.2%, respectively. In the same study, grafts that ranged from 7 to 7.5 mm and 7 mm or less had a revision rate of 11.3% and 33%, respectively.

Considering surgeon concerns related to graft size in ACL surgery that uses hamstring autografts, multiples studies have attempted to predict graft size preoperatively. In a previous study by Calvo et al.,<sup>8</sup> weight and height of patients correlated positively with final length and diameter of the semitendinosus tendon (ST). Other studies have confirmed these variables as predictors of graft size, particularly in relation to height.<sup>9,10</sup> In addition to anthropometric data, preoperative imaging, especially magnetic resonance imaging (MRI) scan have been used to estimate the diameter of the tendons with variable success rate.<sup>5,11</sup>

Because of the greater revision rates related to small hamstring graft size achieved during surgery, some techniques have been developed to increase hamstring graft diameter. One of these converts a standard quadrupled hamstring graft into a 5-strand graft by creating 3 equal strands of the typically larger semitendinosus combined with a double-stranded gracilis.

The purpose of this study is to compare the clinical outcomes 2 groups of patients undergoing ACL reconstruction: the first with a quadrupled semitendinosus gracilis (ST-G) autograft larger than 8 mm diameters and the second with a 5-strand ST-G autograft larger than 8 mm diameters as the result of an insufficient diameter graft harvesting. Our hypothesis is that the 5-strand ST-G autograft provides a statically significant larger diameter graft, with similar clinical results.

## Methods

We conducted a retrospective review of patients with MRI-diagnosed ACL ruptures and clinical instability who underwent ACL reconstruction from January 2012 to December 2013. The ethics committee of our Clínica Alemana approved the study, and all patients provided written informed consent to participate.

The inclusion criteria were the following: MRI-diagnosed ACL ruptures with clinical instability, ACL ruptures of less than 3 months since injury, ST-G ACL reconstructions, final (4-strand or 5-strand) graft size larger than 8 mm. We limited the inclusion of patients with surgeries completed more than 3 months previously because we wanted to limit any confounding factors and make the groups as homogenous as possible. The exclusion criteria were the following: multiligament knee injuries, meniscal or chondral pathology, ACL re-ruptures, inflammatory joint disease, or other procedures needed in the knee.

MRI evaluation of ACL ruptures was done with a 1.5-Tesla MRI. The sequences evaluated were coronal proton density with fat saturation, coronal T1, and sagittal T1 and T2. One experienced musculoskeletal staff radiologist assessed and reviewed the images.

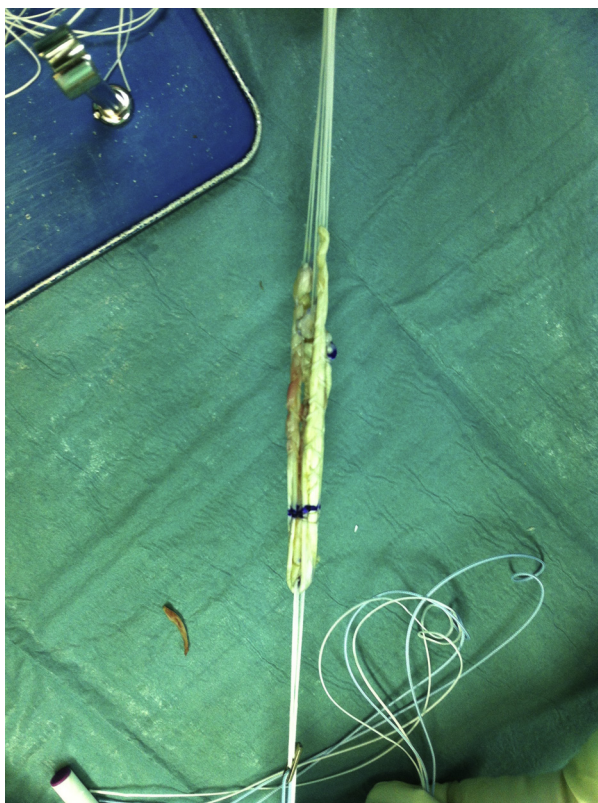
After application of the inclusion and exclusion criteria, the patients undergoing total 5-strand hamstring ACL reconstruction who fulfilled these criteria were selected. Once this group was identified, matched controls were obtained via the same database. All control patients underwent primary ACL reconstruction with a quadrupled hamstring autograft. Two knee orthopaedic surgeons with 25 and 27 years of experience (R.C., D.F.) performed every ACL reconstruction.

Patients were divided into 2 groups according to the technique of ST-G graft preparation: group A underwent a quadruple ST-G graft (standard technique; Fig 1), and group B had patients with insufficient diameter and a ST graft length of more than 21 cm, and therefore a 5-strand graft was created with 3 equal strands of the ST combined with a double-stranded gracilis (Fig 2). Insufficient diameter graft was considered for every quadrupled graft less than 8 mm based on the study by Magnussen et al.<sup>7</sup>

All patients underwent preoperative physical therapy emphasized in obtaining full range of motion and quadriceps strengthening. The patients were discharged from the hospital 2 days after surgery and followed in the outpatient clinic weekly until 1 month, monthly until 6 months, and yearly thereafter. Every patient underwent a MRI at the 6-month follow up to assess the maturation and integration of the graft. Return to sport was allowed from the 6-month follow up.

The initial rehabilitation protocol consisted of immediate postoperative rest (until 6 hours from the surgery) and continuous passive movement twice daily from the first postoperative day. Early weight bearing as tolerated with 2 crutches; isometric quadriceps exercises and manual patellar mobilization were performed. The steps of the rehabilitation are described in Table 1.

The primary outcome evaluated was the re-rupture rate in both groups. The secondary outcomes evaluated were graft diameter difference between quadrupled and 5-strand in grafts smaller than 8 mm (when quadrupled), postoperative Lysholm score,<sup>12</sup> postoperative International Knee Documentation Committee (IKDC) score,<sup>13</sup> and anterior laxity measured with a KT-1000 arthrometer (MEDmetric Corporation, San Diego, CA) by an experienced physiotherapist. Lysholm score, IKDC score, and KT-1000 were measured at the end of the follow-up in both groups. Clinical scores were collected by an orthopaedic surgeon (F.F.) who was blind to the procedure performed (4-strand or 5-strand) at the outpatient clinic.



**Fig 1.** Standard quadruple semitendinosus gracilis graft.

### Surgical Technique

All patients had an ACL reconstruction performed with independent femoral tunnel drilling. The femoral socket was drilled from outside-in with a Flipcutter (Arthrex, Naples, FL). The tibial tunnel was made with a cannulated drill. Both tunnels were made according to the graft diameter. Tight Rope (Arthrex) was used for femoral fixation, and tibial fixation was performed with a 35-mm long biocomposite interference screw in every case (Arthrex).

Graft size was measured with the Arthrex sizing block that allows measuring differences of 0.5 mm in graft diameter. When the graft was considered insufficient and long enough (21 cm at least), an equal 3-strand ST was created with the technique described in Figures 2 and 3. We did a previous biomechanical study analyzing different ways of tripling the ST (unpublished data). A circular configuration (Fig 4A), S configuration (Fig 4B), and a partial quadruple configuration (Fig 4C) were tested. We concluded that the partial quadruple configuration had biomechanical advantages compared with the other 2 configurations; thus, finally we decided to use it in our practice. This technique consists in first preparing both ends of the ST graft with Fiberwire (Arthrex). The next step consists of tripling itself creating 3 equal strands, which are then sutured with Fiberwire under tension from pulling the 2 previous sutures. Five millimeters of the thinner end of the ST graft are passed

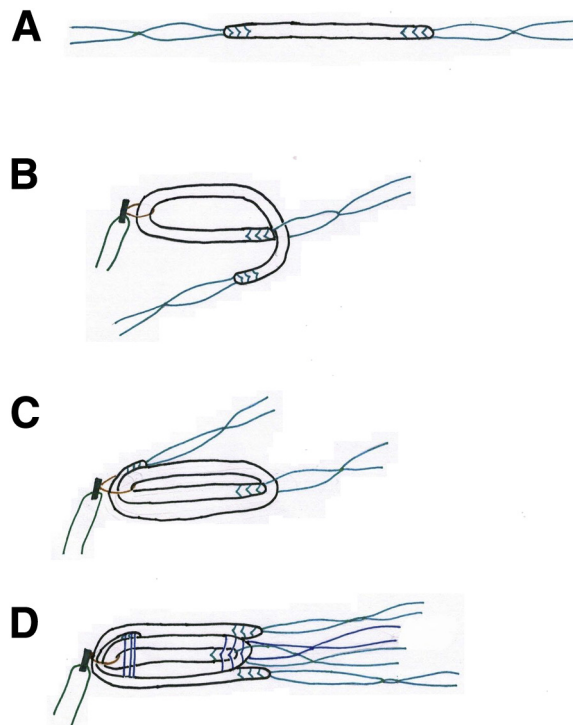
over the tripled graft obtaining the partial quadruple final configuration. Finally, the gracilis graft is doubled over the triple ST and sutured in the apex of the graft with absorbable suture (Monocryl, Ethicon, Somerville, NJ).

The minimum ST length needed to create an equal 3-strand graft was 21 cm (final length of at least 7 cm to have 20 mm of graft inside the femoral tunnel); this was an indispensable condition to use this technique. It was achieved in all patients and allowed safe tibial fixation with an interference screw, but this could change in populations with taller patients (needing a longer ST graft to perform the technique).

Statistical analysis was performed with the  $\chi^2$  test to evaluate the main outcome (re-ruptures between groups) and Mann-Whitney *U* test to evaluate the secondary outcomes. Statistical significance was set for  $P < .05$ . Sample size was calculated to assess a minimal difference of 4% between groups in the primary outcome and at least 5 points in clinical scores<sup>14</sup> and to obtain a statistical power of 80%.

### Results

A total of 365 hamstring autograft ACL reconstructions were performed during the period

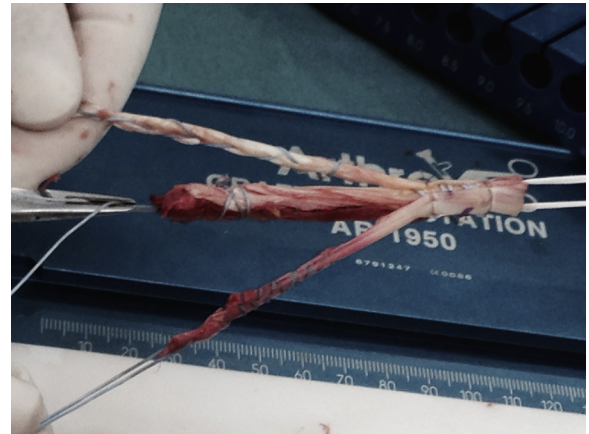


**Fig 2.** Diagram showing the 5-strand hamstring autograft technique. (A) ST graft is prepared at both ends with suture. (B) ST graft is tripled over itself. (C) A total of 5 mm of the thinner end of the ST graft is passed over the tripled graft obtaining the partial quadruple configuration. (D) Final 5-strand graft with doubled gracilis graft on the top. (ST, semitendinosus tendon.)

**Table 1.** Rehabilitation Protocol After Anterior Cruciate Ligament Reconstruction

|          | Immediate POP | First Day POP                                  | First Week POP   | Third Week POP   | Fourth Week POP  | Second Month POP  | Six- to Eight-Month POP |
|----------|---------------|--|--|--|--|---|-------------------------|
| Mobility | 0°-90° in PCM | 0° to 100°-120°                                | 0°-120°  | Complete   | Complete   | Complete  | Complete                |
| Walking  | —             | Assisted (2 crutches)                          | Assisted (2 crutches)                                    | Assisted (1 crutch)  | Free ROM   | Free  | Free                    |
| Therapy  | —             | Patellar mobilization<br>Quadriceps isometrics | Free ROM<br>Patellar mobilization<br>TENS<br>Cryotherapy | Free ROM<br>Patellar mobilization<br>Quadriceps strengthening<br>TENS<br>Cryotherapy | Free ROM<br>Patellar mobilization<br>Quadriceps strengthening<br>TENS<br>Cryotherapy<br>Stationary bicycle<br>Treadmill walk | —   | —                       |
| Gym      | —             | —  | —  | —  | —  | Stationary bicycle<br>Treadmill walk<br>Dumbbell work<br>Swimming<br>Soft jogging | —                       |
| Sports   | —             | —  | —  | —  | Swimming   | —   | Return to sports        |

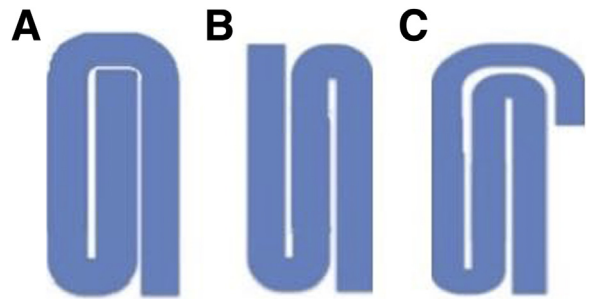
PCM, passive continuous motion; POP, postoperatively; ROM, range of motion; TENS, transcutaneous electrical nerve stimulation.



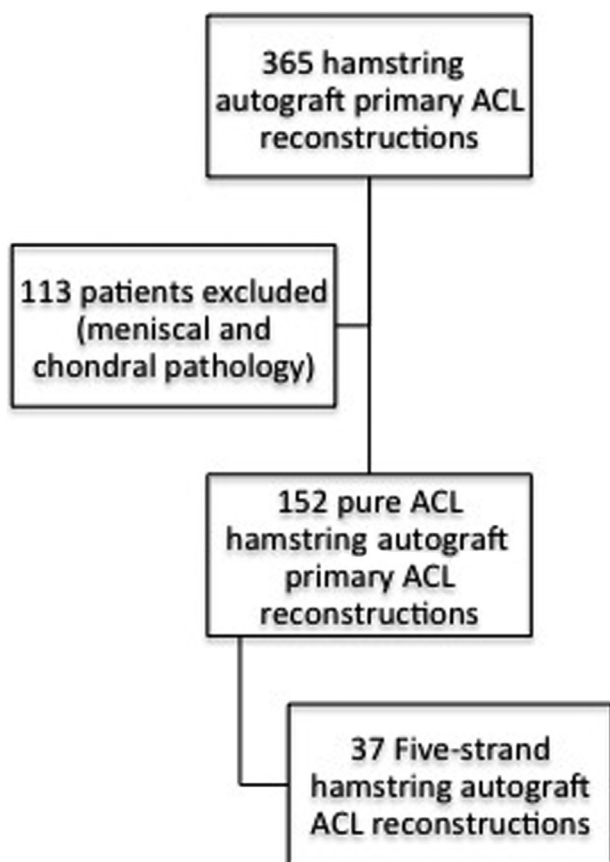
**Fig 3.** Five-strand autograft prepared for its use.

studied by our group. Application of the inclusion and exclusion criteria yielded a total of 152 patients who had ACL reconstructions with no meniscal or chondral pathology (213 patients were excluded for presenting meniscal and/or chondral lesions). Within this group, a total of 37 patients had a 5-strand hamstring ACL reconstruction because of an insufficient graft diameter (115 patients received quadrupled hamstring autograft ACL reconstructions) (Fig 5); 33 patients with quadrupled ACL reconstructions were selected as matched controls (the other 82 patients who received quadrupled hamstring autograft ACL reconstructions didn't match the 5-strand hamstring group).

Group A consisted of 33 patients (quadrupled ST-G) and group B of 37 patients (5-strand ST-G) (Table 2). Mean age was 29.7 (range 17-52) and 30.6 (range 13-53) years ( $P = .78$ ), and the average follow-up time was 32.2 (range 24-48) and 30.35 (range 24-48) months ( $P = .65$ ) for groups A and B, respectively. The average diameter of the graft in group A was 8.5 mm (range 8-10); in group B when the graft was measured as a quadruple graft the mean diameter was 7.2 mm (range 6.5-7.5) and 9.2 mm (range 8-10) when it was converted to a 5-strand graft. There were statistically significant differences between the graft diameters when the graft was 4-strand versus 5-strand in group B ( $P = .00596$ ).



**Fig 4.** Different configurations for tripling the semitendinosus tendon graft were tested. (A) Circular configuration. (B) S configuration. (C) Partial quadruple configuration.



**Fig 5.** Study flowchart. (ACL, anterior cruciate ligament.)

There were 5 MRI-diagnosed ACL re-ruptures, 3 in group A (9%) and 2 in group B (5.4%), with no statistically significant differences between groups ( $P = .55$ ). The preoperative mean Lysholm score was 61.8 (range 28-95) in group A and 59.1 (range 46-72) in group B ( $P = .75$ ); the average postoperative Lysholm score at final follow-up was 93.3 (range 71-100) in group A and 97.1 (range 80-100) in group B with no statistically significant differences between

both groups ( $P = .79$ ). The preoperative mean IKDC score was 63.1 (range 50-81.6) in group A and 61.02 (range 46-76) in group B ( $P = .62$ ). The mean postoperative IKDC score was 91 points (range 75.9-100) in group A and 96.8 points (range 82-100) points in group B with no statistically significant differences between groups ( $P = .18$ ). KT-1000 results were 1.5 mm (range 0-6) for group A and 2.1 mm (range 0-7) for group B with no statistically significant differences between groups ( $P = .2$ ).

## Discussion

This study demonstrated that combining a 3-strand ST graft with a doubled gracilis creates a 5-strand ST-G autograft with clinical results comparable with a quadruple ST-G for ACL reconstruction. This is a simple solution when a quadrupled hamstring graft with insufficient diameter is obtained. The final graft diameters in the 5-strand group were significantly wider than those found using the same grafts with the 4-strand technique (7.2 mm vs 9.2 mm,  $P = .00596$ ). It is important to mention that this technique requires a ST graft of at least 21 cm in length because if not the final graft length will be too short, a condition that will compromise graft length in the tunnels and will make interferential screw fixation impossible in the tibia.

The re-rupture rate of the grafts was not statistically significant when compared with patients operated with the standard quadruple technique using a graft diameter of 8 mm or more. The clinical results were comparable between groups, with no significant differences in Lysholm and IKDC scores, and no significant differences in anterior laxity was measured with the KT-1000 arthrometer.

Various cadaveric studies have shown a linear correlation between the cross-sectional area of the graft and failure in ACL reconstructions.<sup>15</sup> Magnussen et al.<sup>7</sup> confirmed this finding, reporting more failures in smaller diameter grafts in a clinical study.

**Table 2.** Summary of Demographic Factors and Clinical Outcomes in Anterior Cruciate Ligament Reconstructions with a Quadruple ST-G Autograft (Group A) and a 5-Strand ST-G Autograft (Group B)

|   | Group A<br>(Quadruple ST-G Graft) | Group B<br>(5-Strand ST-G Graft) | <i>P</i> Value |
|---|-----------------------------------|----------------------------------|----------------|
| No. of patients                                       | 33                                | 37                               |                |
| Mean age, yr (range)                                  | 29.7 (17-52)                      | 30.2 (13-53)                     | .78            |
| Mean follow-up, mo (range)                            | 32.2 (24-48)                      | 30.35 (24-48)                    | .65            |
| Mean graft diameter (quadrupled), mm (range)          | 8.5 (8-10)                        | 7.2 (6.5-7.5)                    |                |
| Mean graft diameter (5-strand), mm (range)            |                                   | 9.2 (8-10)                       |                |
| Re-ruptures, patients                                 | 3 (9%)                            | 2 (5.4%)                         | .55            |
| Mean preoperative Lysholm score, points (range)       | 61.8 (28-95)                      | 59.1 (46-72)                     | .95            |
| Mean Lysholm score at final follow-up, points (range) | 93.3 (71-100)                     | 97.1 (80-100)                    | .79            |
| Mean preoperative IKDC score, points (range)          | 63.1 (50-81.6)                    | 61.02 (46-76)                    | .62            |
| Mean IKDC score at final follow-up, points (range)    | 91 (75.9-100)                     | 96.8 (82-100)                    | .18            |
| Mean KT-1000 at final follow-up, mm (range)           | 1.45 (0-6)                        | 2.1 (0-7)                        | .20            |

IKDC, International Knee Documentation Committee; ST-G, semitendinosus-gracilis.

In addition to the 5-strand technique, other techniques have been described to address insufficient graft size; one of them is the use of an allograft augmentation technique to obtain a hybrid graft.<sup>16</sup> A recent retrospective study by Burrus et al.<sup>16</sup> described a failure rate of 13.8% for patients with ACL reconstructions with a hybrid graft versus 3.4% for patients reconstructed only with autograft. Therefore, the use of hybrid grafts is still in doubt as an augmentation technique for insufficient hamstring diameter, particularly in young and active patients.

Hamido et al.<sup>17</sup> also compared 27 patients with either short hamstring tendons (<15 cm length) or a small diameter harvested quadruple graft (less than 6 mm diameter) that were augmented with the Ligament Advanced Reinforcement System (LARS; Arc-Sur-Tille, France) artificial ligament with 45 patients with a quadruple graft with more than 8 mm of diameter. They found that KT-1000 examinations in the LARS group had significantly less anterior displacement than the quadruple group and better clinical scores at 5-year follow up. Although these findings are interesting, they should be taken with caution, especially considering recent evidence against the use of this kind of graft because of the high re-rupture rate.<sup>18,19</sup> Lavery et al.,<sup>20</sup> in a recent study, described their own technique to create a 5-strand hamstring graft when they had insufficient graft diameter but did not report outcomes.

The strengths of our study are that there are no confounding factors (meniscal or chondral pathology) that could alter clinical results, the presence of a control group, and that all ACL reconstructions were performed with the same surgical technique by the same team.

### Limitations

The main limitation of the study is the small number of patients included, as the need to triple the ST graft because of a graft of insufficient diameter (less than 8 mm) is not very common; however, the study has a sample size calculated with a power of 80%. Other limitations are the retrospective nature of the study and the lack of inter and intraobserver reliability because all the evaluations (MRI, K-1000, clinical scores) were performed by a single person (radiologist, physiotherapist, orthopaedic surgeon) at a single time.

### Conclusions

In our study, the 5-strand hamstring autograft in ACL reconstruction was clinically comparable with the quadruple autograft larger than 8 mm. The differences in re-rupture and clinical outcomes were not statistically significant between the 2 groups, suggesting that it is a valid option when we have a graft of insufficient diameter.

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