Original Article

A Partial-Thickness Quadriceps Autograft Reliably Augments the Size of the Hamstring Graft During Anterior Cruciate Ligament Reconstruction

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Purpose: To measure the increase in diameter resulting from the augmentation of a hamstring autograft with a partial width rectus femoris tendon band in anterior cruciate ligament reconstruction. **Methods:** Thirty-three cadaveric knees were dissected to harvest semitendinosus and gracilis tendons (4S) along with a 6-mm wide tendon band from the rectus femoris. Harvesting was done according to the usual surgical techniques of both harvests. Measures of length and diameter in 4S and 4S augmented with the rectus femoris band (4S +Q) configurations were performed separately by 3 evaluators. **Results:** The quadriceps augmentation led to an average increase of 1.49 mm (95% confidence interval 1.03-1.95 mm) in diameter of the 4-strand hamstring grafts. The previously demonstrated threshold diameter of 8.5 mm was attained in only 30% of 4S grafts within this population in comparison with 88% when augmented with a quadriceps band. **Conclusions:** In conclusion, supplementing doubled hamstring graft (4S) with quadricipital tendon in anterior cruciate ligament reconstruction (ACLR) increases the graft diameter by an average of 1.49 mm. It has the physical potential to reliably augment hamstring grafts that measure 7.5 mm in diameter or more in order to obtain an 8.5 mm when necessitated. **Clinical Relevance:** Increased graft diameter is associated with a decreased risk of graft failure after ACLR. Because of this, it is important to identify methods to increase the size of grafts. This study investigates the use of a partial-width rectus femoris tendon band as an option to reliably augment graft sizes during ACLR.

Despite several advances in surgical techniques, the failure rate of anterior cruciate ligament (ACL) reconstruction generally varies between 5% and 25%.[1] Principal factors influencing these results are the definition of failure, the patient's age, the surgical techniques employed, the level of physical activity, and the size of grafts.[1-8]

One of the most frequently used ACL reconstruction grafts is an autograft composed of doubled semitendinosus and gracilis (4-strand hamstring graft, or 4S).[9,10] Biomechanical studies show an inversely proportional relationship between the graft's size and the risk of rerupture.[11] A large-scale clinical study relates a reduction in relative risk of almost 15% per 0.5-mm increase in graft diameter.[12,13] A correlation between graft size and failure rate is demonstrated in multiple studies, with cutoffs established at 8 or 8.5 mm of diameter. These results are in agreement with those of other researchers who found a greater failure rate[1,3,4,14] and lesser functional results[4] with grafts measuring 8 mm in diameter or less.

Different options can be considered when the harvested graft's diameter is inferior to the target value. The most frequently used, due to its simplicity and the fact that it doesn't increase morbidity, is to triple the graft to obtain 5 or 6 strands (5S or 6S).[15,16] However, in some situations, length could be unsatisfactory even after tripling the graft or the graft could, even tripled, maintain a smaller diameter than desired. In these cases, another supplementation technique might have to be added.

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The option of a hybrid allograft/autograft is associated with a greater failure rate and a lesser integration than a 4S graft of the same diameter.[17-19] In this context, one of the authors started using a partial width quadricipital tendon band (rectus femoris only) as a supplementation technique when a hamstring autograft has a diameter deemed unsatisfactory. Harvesting a quadricipital tendon band in ACL reconstruction is well-established and globally accepted as a principal graft.[20-29] However, Wilson et al.[30] are currently the only authors having described and tested the biomechanical characteristics of using quadricipital tendons (Q) as supplementation of a 4S graft. The advantage of this technique relies on the ability to maintain the full length of the 4S graft. Only an additional 3-cm incision is needed to harvest this additional graft.

It is desirable to be able to estimate the impact of harvesting a band of quadricipital tendon on the graft's total diameter to ensure a sufficient size after supplementation. The purpose of this study was to measure the increase in diameter resulting from the augmentation of a hamstring autograft with a partial width rectus femoris tendon band in ACL reconstruction. We hypothesized that this technique would reliably increase the diameter of the graft by more than 1 mm.

Methods

The cadaveric specimens used in this study are part of a larger project. The data from this study constitute only a part of all the data collected from the specimens dedicated to the larger project. The study protocol was approved by the local ethical committee.

The specimens were prepared according to the usual technique for fresh corpse preservation, without embalming, by the technicians of the Medical Faculty's Anatomy Laboratory. A total of 34 cadaveric knees were dissected by one of the orthopaedic surgery senior residents to harvest the semitendinosus, gracilis, and quadriceps tendons while adhering to the usual surgical techniques. Of those 34, 33 samples were deemed usable in the study due to their quality, the absence of structural damage, and the absence of previous surgeries on those structures. The age and sex of the cadavers from which these samples were harvested have been tabulated (Table 1).

Harvesting of every tendon used was done by the same senior resident by using the instruments and surgical techniques typically employed in the authors' hospital. An oblique anteromedial incision is made near the insertion of the pes anserinus to the proximal tibia. Subcutaneous adipose tissues are dissected until the sartorius is seen, then incised longitudinally along the axis of its fibers. The gracilis tendon is then isolated and freed from its adherences before being harvested with the tendon harvester for cruciate ligament reconstruction (Conmed Linvatec, Aurora, OH). These steps are the same when harvesting the semitendinosus tendon. The remaining muscular fibers are cleaned from the tendons and the 2 tendons are freed in a subperiosteal manner from their tibial insertion, then set aside for ulterior measures. Harvesting of the quadriceps tendon band is done through a midline longitudinal incision reaching to the proximal pole of the patella. The subcutaneous adipose tissues are dissected until the quadriceps fascia is seen, then incised along the axis of its fibers with a 6-mm width in the central part of the tendon. The tendon band is then released from the patella with a depth of about 5 mm (thickness of the rectus femoris tendon) and this plane is dissected up proximally before being cut to a length of 9 cm. Each group of tendons from the same knee was identified with a code, then frozen until the day of the measurements.

Table 1. Demographic Characteristics

Number of samples	17 cadavers (33 samples)
Average age, y	76.2 ± 13.6
Body mass index	22.6 ± 4
Sex, men	52.9%

At the time of measuring, each group of tendons had been unfrozen at room temperature and kept humid with surgical sponges soaked with normal saline between each step. The 4S configuration was then prepared for each group of tendons folded on a polydioxanone suture, and the diameter measures were taken using ACL diameter measuring tubes (Conmed Linvatec), varying from 6.5 to 11.0 mm in diameter in intervals of 0.5 mm. The graft length was measured with a millimeter graduated ruler. The quadriceps tendon bands were then sutured at the center of the 4S grafts to produce grafts in a 4S+Q conformation (Fig 1), which were also measured with the Conmed measuring tubes.

Each measure was done individually by 3 evaluators and compiled by a research assistant. Each evaluator

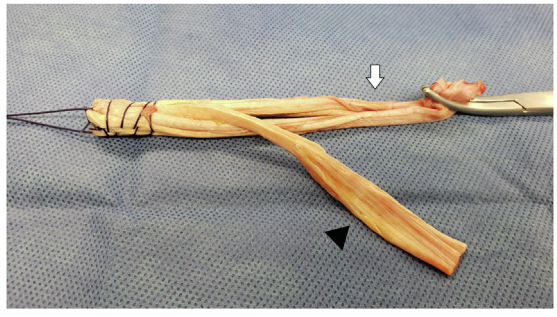

Fig 1. 4S+Q graft configuration.Four-strand hamstrings graft with quadriceps augmentation configuration. Black arrowhead: Quadricipital band. White arrow: Four-bundle hamstring graft.

Table 2. 4S and 4S+Q Graft Diameters

Diameter, mm	No. of 4S, %	No. of 4S+Q, %
7.0	9 (27.3%)	0 (0%)
7.5	6 (18.2%)	0 (0%)
8.0	8 (24.2%)	4 (12.1%)
8.5	9 (27.3%)	4 (12.1%)
9.0	1 (3.0%)	8 (24.2%)
9.5	0 (0%)	8 (24.2%)
10.0	0 (0%)	7 (21.2%)
10.5	0 (0%)	1 (3.0 %)
11.0	0 (0%)	1 (3.0%)

4S, 4-strand hamstring graft; 4S+Q, 4-strand hamstring graft with quadricipital tendon supplementation.

also re-evaluated 10 grafts, randomly assigned by the research coordinator, to establish intraobserver reliability. It is worth noting that the repeated measures were done in a blinded manner. Further analysis of the impact of the augmentation technique were performed using the median value obtained from the three evaluators, for each sample.

Statistical calculations and analyses were done by a statistician with SPSS (version 23.0.0 from IBM Corp., Armonk, NY). Descriptive statistics were used for the calculation of means, medians, proportions, and confidence intervals. Inter- and intraobserver reliability of graft diameter measures was evaluated with the help of Kendall's coefficient of concordance, which allows evaluation of the concordance of discrete ordinal measures.

Results

The demographic characteristics of the studied cadavers can be found in Table 1. Intraobserver reliability, calculated for 4S+Q grafts, and interobserver reliability, calculated for all the measures in all configurations, are both excellent, with concordances of 0.976 ($P = .002$) and 0.959 ($P < .001$) respectively.

The diameter measures used in the results for each sample constitute the median of the three evaluators.

Table 3. Diameter Increase with 4S+Q Graft Augmentation

4S Diameter	Mean Increase (95% CI)	Percentage of Specimens of at Least 8.5 mm After Augmentation in 4S+Q		
7	1.50 (1.14-1.87)	66.67%	82,6%	92,9%
7.5	1.33 (0.92-1.65)	83.33%		
8	1.38 (1.14-1.62)	100.00%		
8.5	1.56 (1.26-1.86)	100.00%		
9	1.0	100.00%		
Global	1.49 (1.03-1.95)	100.00%		

4S+Q, 4-strand hamstring graft with quadricipital tendon supplementation; CI, confidence interval.

Within this population, 69.7% of grafts had a diameter inferior to 8.5 mm with a 4S configuration (Table 2), whereas that ratio fell to 12.1% after supplementation with a 6-mm band of rectus femoris tendon (Table 2).

Supplementation with a quadricipital tendon band saw an average increase of 1.49 (95% confidence interval 1.03-1.95) in diameter for grafts in 4S conformation (Table 3). After augmentation, 82.6% of grafts with a diameter of 7 mm to 8 mm reached the target of 8.5 mm, in comparison with 92.9% of those with a diameter of 7.5 mm to 8 mm.

Discussion

The results of this descriptive study confirm a significant increase, of more than 1 mm, of the diameter of a 4S graft when supplemented with a quadricipital tendon band. Starting a few years ago, the senior author of this document used this 4S+Q supplementation technique as a backup option when the 4S graft diameter was insufficient, and its length did not allow to triple the hamstring tendons in a 6S configuration while using the same tibial fixation. Being part of a larger project aimed at creating a decisional algorithm for graft selection according to diameter and length, this study focuses on better establishing the boundaries and criteria for the use of this type of supplementation. It states that 92.86% of grafts with a 7.5 mm or more diameter that did not reach the target of 8.5 mm in diameter with a 4S conformation did so with a 4S+Q conformation with the advantage of maintaining the full length of the doubled hamstring graft.

We realize that adding a second harvesting site adds potential complications. Based on our experience, the 2 main potential complications following the harvest of a quadriceps tendon band—namely some pain and the postoperative strength of the extensor mechanism[31]—do not seem to be major stakes in the recuperation of patients benefiting from this supplementation. Existing literature demonstrates significantly less anterior knee pain[23,28,32-34] and less kneeling pain[23,28,32,35] after harvesting quadricipital tendons when compared with patellar tendon, even when it is harvested with the patellar bone and in its entire thickness. Although it remains to be demonstrated in a subsequent study, we believe that with a quadricipital tendon harvesting technique of partial thickness only, of reduced width and without any bone block, these complications are even rarer. Also, new minimally invasive harvesting techniques could further reduce these potential complications.[36]

This descriptive study backs the use of quadricipital tendon supplementation described by Wilson et al.[30] and constitutes only the second study on the matter. In this sense, it contributes in establishing the foundations necessary to the elaboration of further clinical projects.

Limitations

The fact that this study is based on cadavers and that the mean age of the donors doesn't represent the usual ACL tear population can diminish the clinical applicability of its results. The absolute diameter of the tendons used can differ from the one in our aimed population because of age and preservation process. The total number of samples (n = 33) directly limits the numbers per group and might therefore influence the external validity of the experiment. Several questions, such as the complications associated with the technique as well as the real clinical benefit, have not been evaluated at all and are beyond the scope of this project.

Conclusions

In conclusion, supplementing doubled hamstring graft (4S) with quadricipital tendon in ACL reconstruction increases the graft diameter by an average of 1.49 mm. It has the physical potential to reliably augment hamstring grafts that measure 7.5 mm in diameter or more in order to obtain an 8.5 mm when necessitated.

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