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Quadriceps augmentation of undersized hamstrings during ACL reconstruction

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A B S T R A C T

Background: Double hamstring autograft for anterior cruciate ligament (ACL) reconstruction is a well-established graft option; however, a major concern with this method arises when the prepared graft is too small. Resorting to allograft can be a solution to this problem, but some surgeons prefer to use autograft in particular situations and some patients may refuse allograft. We investigate the merits of using autogenous quadriceps tendons to augment the insufficient hamstrings and compare the autograft composite graft to a standard hamstrings graft of equal size.
Methods: Semitendinosus, gracilis, and quadriceps tendons were harvested from 10 matched pairs of human cadaver lower extremities. Within each pair, a routine hamstring ACL graft (control) consisting of the semitendinosus and gracilis tendons, and an quadriceps augmented hamstrings graft of equal size comprised of the semitendinosus and quadriceps tendons, were prepared. A freeze-clamp mount was used to biomechanically test each graft construct. Tensile failure load, displacement, energy absorbed, and stiffness were determined and statistically compared within each pair and mode of graft failure was established.
Results: No statistically significant differences were found between the quadriceps augmented hamstrings graft versus standard control grafts. Average values for peak failure load and graft displacement at the point of first failure were nearly identical. All ACL graft constructs failed at the mid-substance.
Conclusions: This study demonstrates no statistical difference in the biomechanical properties of an isolated hamstring ACL autograft versus a quadriceps augmented ACL autograft of equal size at time zero.
Clinical relevance: This is a potentially new and reliable method for quadriceps tendon autograft augmentation of hamstring autograft for ACL reconstruction.

1. Introduction

The use of autograft for anterior cruciate ligament (ACL) reconstruction has many well-established advantages, including faster incorporation and a lower cost [1–3]. The use of autograft has been shown to have lower postoperative failure and revision rates compared to allograft [4,5]. The double hamstring autograft is a popular option; however, achieving a harvested graft of adequate size is a major concern during the reconstruction procedure. Graft sizes below eight millimeters are associated with high failure rates [6–8], and alternative preparation techniques or graft augmentation is indicated. One option is supplementation with allograft, but this may be an issue if the patient refused consent for the allograft, or if autograft is the surgeon's preference for

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some young and/or athletic patients. Further, this option may also increase risk of re-tear, and has been shown to have inferior patient reported knee stability scores [9,10]. Another option is to use a tripled or quadrupled hamstring graft with suspensory fixation in both the femoral and tibial tunnels [11,12].

We have established an alternative salvage option. It involves augmentation of an undersized hamstring autograft with ipsilateral quadriceps tendon autograft. This technique was born out of necessity during an otherwise routine ACL reconstruction at our institution. Per preoperative planning, the intention was to use hamstrings autograft for the reconstruction. After harvesting the semitendinosus and gracilis tendons and graft preparation, it was found that the autograft was of insufficient width at 5.5 mm. The patient had refused allograft in their surgical consent, and the senior surgeon's preference was to use autograft given that the patient was a young and active individual. Intraoperatively, the decision was made to augment the hamstrings graft with quadriceps tendon. An anterior midline longitudinal incision was made and the quadriceps tendon was exposed. A one-centimeter wide and 0.5-mm thick section of the quadriceps tendon was harvested from the superior aspect of the patella as far proximally as the vastus medialis would allow. Standard graft preparation was completed and the quadriceps autograft section was attached to the hamstring autograft with suture (0 Ethibond) in a whipstitch configuration. The thickness of the graft, measured with a pull-through sizing block, increased from 5.5 mm before augmentation to 10 mm after augmentation with the quadriceps tendon. The ACL reconstruction was then completed in standard fashion using suspensory fixation on the femur and an interference screw on the tibial fixation.

To investigate whether this technique could be a reliable option in such a situation, it was necessary to determine if quadriceps tendon augmented autograft was comparable in biomechanical strength to hamstring grafts of equal size. The use of the quadriceps tendon as a primary autograft for ACL reconstruction is an established technique [13–15]. However, there are no current studies utilizing the quadriceps tendon as a supplementary augmentation of the undersized hamstring autograft in ACL reconstruction. The objective of this study was to compare the biomechanical properties of a quadriceps augmented hamstring autograft to a standard double hamstrings autograft.

2. Materials and methods

A matched-pair biomechanical study was performed using human cadaveric specimens to test the null hypothesis that there was no difference in the initial graft strength between a standard double hamstrings autograft and hamstring autograft augmented with quadriceps autograft. An a priori power analysis based on results of a pilot study indicated that a sample size of 20 specimens (10 matched graft pairs) would be required to detect a statistically significant difference in failure load with a two-tailed paired t-test with a mean difference of 500 N, common standard deviation of 750 N, at 80% power and alpha set at 0.05.

2.1. Specimen preparation

The semitendinosus, gracilis, and quadriceps tendons were harvested from 10 matched pairs of human cadaver lower extremities (six female, four male; mean age 73.8 years, range: 49–84 years) and randomized by laterality into two groups. For the control group, the semitendinosus and gracilis tendons were prepared in a routine fashion used for a double hamstring autograft ACL reconstruction technique. Each hamstring graft was sized to the largest allowable for each specimen using a pull-through graft-sizing block.

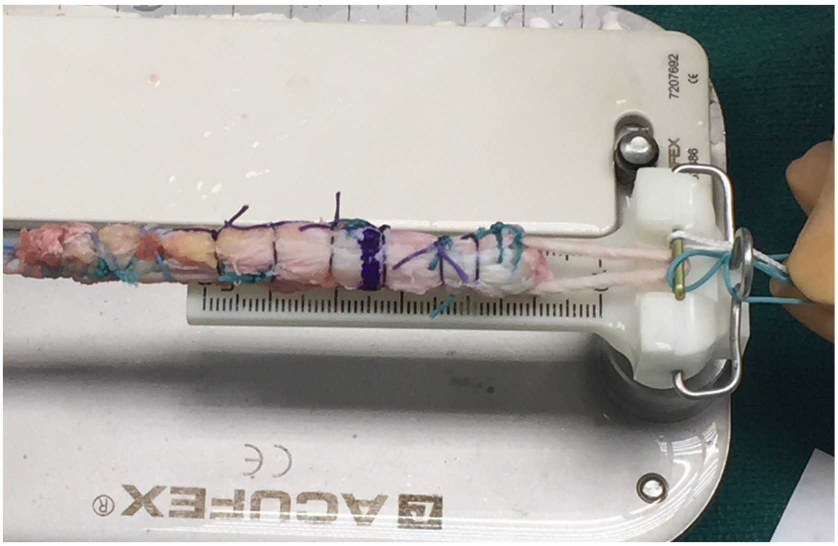

Figure 1. Hamstring autograft after augmentation with quadriceps.

The thickness of the control grafts were between eight and 10.5 mm. The experimental group was prepared from the contralateral extremity of the same specimen. In this group, the semitendinosus tendon was augmented with the quadriceps tendon. Owing to a natural limit to the length of quadriceps graft due to the abrupt transition from quadriceps tendon to muscle, the average length harvested was roughly 10 cm. This length was kept consistent in each matched pair. The sectioned quadriceps portion was looped over the top of the semitendinosus graft and trimmed down to match the thickness of its paired hamstrings graft using the pull-through sizing block. Thus, the sizes control grafts and the augmented grafts were equal thickness within in each matched pair, but differed between the specimens secondary to natural variability. All grafts were then augmented with suture (0 Ethibond, X424H) mid-substance in an uninterrupted running weave (Figure 1).

2.2. Biomechanical testing

Each ACL graft specimen was looped around a four-millimeter steel rod that rotated freely within a yoke mounted to the actuator of an MTS 858 Mini-Bionix materials testing system (MTS Corp., Eden Prairie, MN) to simulate suspensory fixation on the femoral side of ACL reconstruction. The loose end of the graft was secured within a freeze clamp mounted to the MTS load cell (Figure 2). For the grafts augmented with quadriceps, only one limb of the quadriceps tendon could be secured in the freeze clamp secondary to insufficient length. The working length of the graft from the top of the clamp to the rod was constant for each

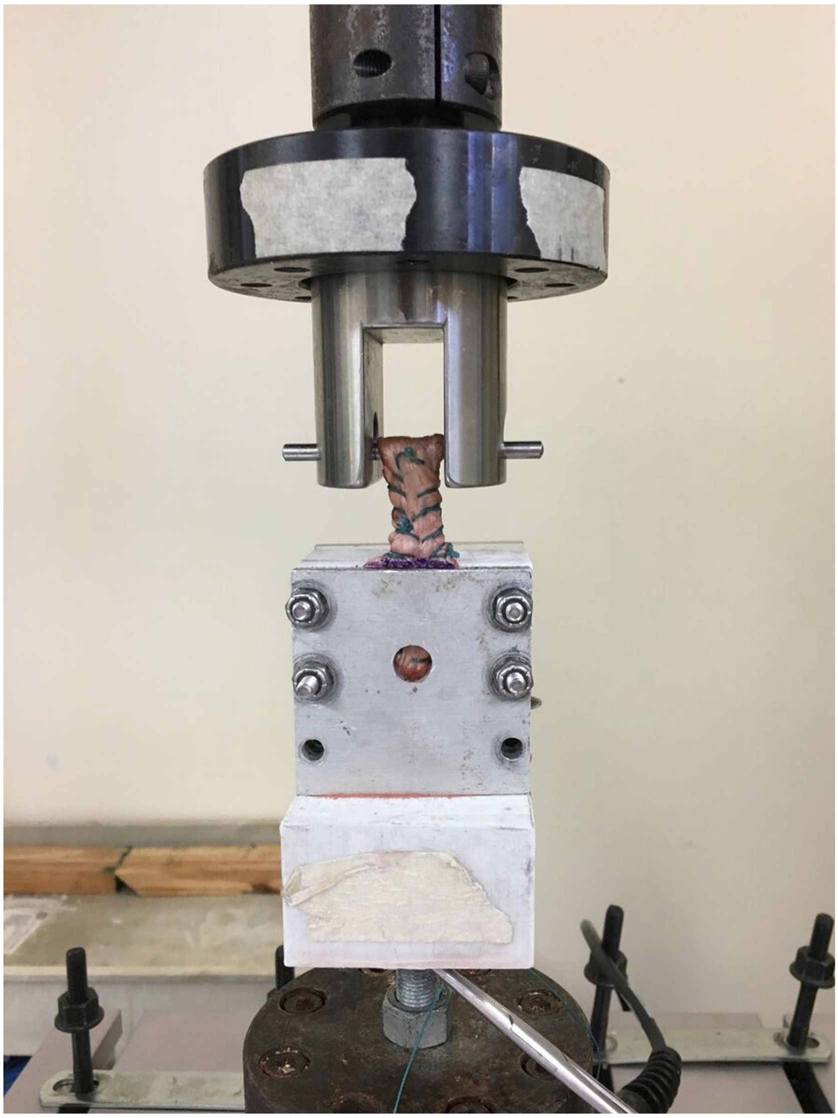

Figure 2. Biomechanical testing setup with quadriceps augmented graft construct.

specimen pair, yielding 30 mm. The rear bay of the clamp was loaded with dry ice and the clamping face tightened when the clamp temperature reached −15 °C. After 10 conditioning cycles at a 50 N load, each specimen was loaded to failure in tension at a rate of 3.0 mm/s. Load versus displacement curves were generated from which the first instance of failure and at the peak failure point were determined. The first failure load was defined as a drop in 10 N or greater, whereas the peak failure load was considered as the highest achieved load of each construct. Stiffness was calculated as the slope of the linear elastic region, between 200 N and 300 N, and energy absorbed was calculated from the area under the curve at the first and peak failure points. The mode of graft failure was also recorded. Paired t-tests were performed to detect differences in the above metrics between the two graft constructs.

3. Results

Results from the biomechanical failure testing are detailed in Table 1. There were no statistically significant differences between the two groups. The average values for double hamstrings versus augmented graft displacement at the point of first failure were nearly identical (6.82 ± 1.27 mm vs 6.86 ± 1.65 mm; $P = 0.94$), and similarly for first failure energy absorbed (3882.97 ± 1563.24 Nmm vs 3894.50 ± 1620.85 Nmm; $P = 0.99$), and for load at peak failure (1509.99 ± 436.78 N vs 1500.70 ± 371.24 N; $P = 0.97$). The displacement at peak failure showed the highest degree of difference between the two graft constructs, although not statistically significant (7.78 ± 1.75 mm vs 9.31 ± 1.73 mm; $P = 0.09$). All tendon graft constructs failed mid-substance, at the interface of the graft and the rod (Figure 3).

4. Discussion

This study introduces an alternative option for autograft augmentation in ACL reconstruction when a hamstring autograft is undersized and neither the patient nor the surgeon want to resort to allograft. While this clinical scenario may be rare, there are few options the surgeon can consider for recovering the procedure. Supplementation of the hamstring autograft with autogenous quadriceps tendon can increase the undersized graft to a more appropriate size for implantation, during the same procedure. This quadriceps augmentation would certainly not be considered as a primary graft option for ACL reconstruction, but in the case of salvaging an undersized graft and completing the procedure, it may be viable. This technique may provide several clinical advantages. First, the surgeon does not need to modify the ACL reconstruction technique once the graft augmentation is complete. Such would be the case if the surgeon opted to resort to bone tendon bone patellar tendon autograft. Second, the graft can be harvested from the ipsilateral extremity that is already draped for the procedure. Finally, this technique confers the known advantages of using autograft. The results of this biomechanical study suggest that the time zero augmented graft tensile properties are statistically no different than those of its standard double-hamstring counterpart. In this pairwise comparative study, the null hypothesis could not be rejected, given that no statistical differences were found between the two autograft types. Each ACL graft prepared using the augmented technique had its matched control consisting of a routine double hamstring graft, an established and frequently utilized ACL graft-preparation technique. The matched experimental design allowed all variables other than graft type to be minimized; furthermore, all specimens were subjected to the same number of freeze/thaw cycles, prepared in the same manner, and ultimately tested under the same protocol.

There are many clinical and biomechanical considerations to address with the introduction of a new surgical augmentation to a standard procedure. The first potential limitation to consider is the addition of sutures in each of the grafts. This was necessary to attach the quadriceps to the semitendinosus. If the harvested quadriceps is long enough, the attachment to the hamstring graft with sutures would not be necessary. However, the length of the quadriceps is usually too short to allow for this. A longer quadriceps tendon graft can be obtained, but this would likely necessitate a large iatrogenic suprapatellar arthrotomy and/or potentially lead to a significant postoperative quadriceps weakness. To reduce variability between groups, suture was also incorporated into the semitendinosus and gracilis grafts using the same amount, manner, and type of sutures. The biomechanical literature offers little insight into the effect of additional sutures on graft performance. Hoher et al. found that uniform suturing of the tendon graft increases ultimate failure load, but this suture augmentation was specific to the intratunnel portion of the graft [16]. On the contrary, additional sutures may decrease the strength of grafts as a result of microdamage during the preparation process, but this has not been borne out in the literature. Nonetheless, the intention of this study was not to test for suture type/technique/degree of effect on graft strength, so graft preparation for each group was the same.

Table 1
Biomechanical comparison of ACL grafts: Native semitendinosus-gracilis graft versus quadriceps-augmented graft. Average (standard deviation).

	Semitendinosus-gracilis graft	Quadriceps-augmented graft	*P* value
First failure displacement (mm)	6.82 (1.27)	6.86 (1.65)	0.94
First failure load (N)	1369.92 (389.38)	1218.54 (356.72)	0.41
First failure energy absorbed (Nmm)	3882.97 (1563.24)	3894.50 (1620.85)	0.99
Peak failure load displacement (mm)	7.78 (1.75)	9.31 (1.73)	0.09
Peak failure load (N)	1509.99 (436.78)	1500.70 (371.24)	0.97
Peak failure load energy absorbed (Nmm)	5435.37 (2680.41)	6892.62 (1934.53)	0.27
Stiffness (N/mm)	225.64 (48.59)	207.54 (32.96)	0.46

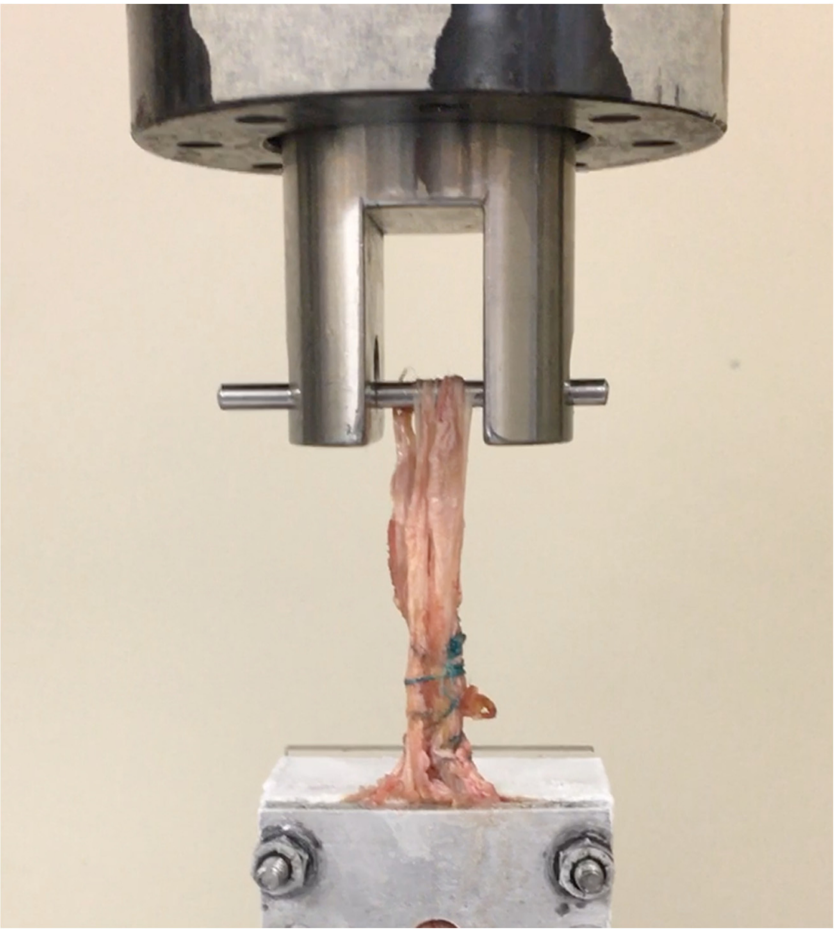

Figure 3. Mid-substance failure of graft construct.

When comparing the results of this biomechanical study to similar studies, the peak failure loads were less than the failure loads typically reported for double hamstring graft [17,18]. This may have been due to cadaveric tendon quality, initial tendon harvesting/storage techniques, or differences in soft-tissue mounting and loading techniques between studies. However, since this was a matched pair comparative study, all grafts were subjected to the same harvesting, preparation, and testing protocols. Graft preparation and testing was done in a timely fashion to minimize the variability of freeze–thaw cycle between specimens. As stated above, ultimate tensile strength was not the intention of the study, but rather comparison of tensile strength to a known and widely accepted control (double hamstring).

Another clinical consideration of this technique is donor site morbidity. As previously mentioned in the clinical scenario, we utilized a longitudinal incision proximal to the patellar to obtain the quadriceps graft. This particular morbidity can be reduced by using minimally invasive techniques and quadriceps-specific harvesting equipment [19–21]. Potential postoperative quadriceps weakness is another possibility, though controversial; some evidence suggests that patients recover with equivalent or superior activity without changes in extensor strength [22,23].

This study has limitations, primarily related to the ex vivo nature of the testing. Even while maintaining constant conditions in clamping and testing protocols, the experimental setup does not completely replicate the anatomical or physiological conditions present after an ACL reconstruction. However, our testing protocols and conditions are very similar to many of the commonly cited studies that have reported graft strength. Cyclic fatigue strength or long-term post-rehabilitation stability of the grafts were not considered in this study, as it focused primarily on the initial failure strength of the graft constructs. Augmenting the grafts with sutures may have induced microdamage, producing failure points within the graft, although all grafts in each group were augmented equally. Cadaveric specimens have inherent variability in age and quality, thus the matched-pair study design was applied to minimize these potential effects. Finally, this biomechanical study was designed to compare a quadriceps supplemented hamstring autograft to an accepted standard double hamstrings autograft, to determine if this technique is a viable salvage solution to an undersized hamstring autograft. While it may not represent a routine clinical procedure, it is certainly a possible situation that a surgeon may encounter during ACL reconstruction.

5. Conclusions

In conclusion, as a salvage option for undersized hamstring autograft in ACL reconstruction, quadriceps autograft augmentation of double hamstring autograft showed comparable biomechanical behavior to double hamstring autgraft controls. More biomechanical and clinical studies are warranted to further explore this treatment option.

Ethical statement

This manuscript represents original and honest work that has no prior or duplicate submissions or publications. All authors made significant contributions to the study in design, data collection, analysis, interpretation or preparation of the final version of the manuscript. The submitted version has been read and approved by all authors. There was no outside funding for this study.

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