Predicting Diameter Increase Using a Quadriceps Tendon Augmentation for Undersized Hamstring Grafts in ACL Reconstruction

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Abstract

Background The failure rate for ACL reconstruction varies between 5 to 25% depending on the population. Recent studies found a higher failure rate with grafts of 8 millimeters in diameter or less. Various options are described when the graft's diameter is inferior to the target value, but little literature helps us predict the final diameter during surgeries. Therefore, this study's goal is to describe a new technique supplementing a hamstring graft folded in half with a quadricipital tendon band of partial width and thickness (4S+Q), and to predict the final diameter.

Methods Thirty-three cadaveric knees were dissected in order to harvest semitendinosus and gracilis tendons (4S) along with a 6mm wide tendon band from the rectus femoris. Harvesting was done according to the usual surgical technique. Measures of length and diameter in 4S and 4S+Q configurations were performed separately by three evaluators.

Results The threshold diameter of 8,5 mm was attained in only 30% of 4S grafts within our population in comparison with 88% when augmented with a quadriceps band. The average diameter increase with the 4S+Q configuration was 1,49 mm. A threshold of 7,5 mm was established for the applicability of this augmentation technique considering that 93% of the grafts measuring 7,5 mm or more reached the 8,5mm target.

Conclusions The 4S+Q configuration offers a salvage option worth adding to one's arsenal, significantly increasing the graft's diameter. The width of the quadricipital tendon sample can be adjusted and will need further study.

1. Introduction

Despite several advances in surgical techniques, the failure rate of anterior cruciate ligament 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][2][3][4][5][6][7][8].

The usual reconstruction practice in our center is the autograft of doubled semitendinosus and gracilis (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]. These results are in agreement with those of other researchers who found a higher 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 in order to obtain 5 or 6 strands (5S or 6S)[15][16]. Although in some situations, length could be

unsatisfactory after tripling the graft or the graft could, even tripled, maintain a smaller diameter than desired and that another supplementation technique must be utilized.

The option of a hybrid allograft/autograft is associated with a higher failure rate and a lesser integration than a 4S graft of the same diameter[17][18][19]. In this context, we began to consider utilizing a partial width quadricipital tendon band (rectus femoris only) as supplementation of a tibial hamstring autograft with a diameter deemed unsatisfactory. The harvesting of quadricipital tendons in ACL reconstruction is well-established and globally accepted as a principal graft[20][21][22][23][24][25][26][27][28][29]. However, Wilson et al. are currently the only authors having described and tested the biomechanical characteristics of utilizing quadricipital tendons (Q) as supplementation of a 4S graft[30]. The advantage of this technique relies on the ability to maintain the full length of the 4S graft. Only an additional 3cm 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 in order to ensure a sufficient size after supplementation. The objective of this descriptive cadaveric study is therefore to identify the minimum diameter threshold for a 4S graft to benefit from the supplementation of a partial thickness quadriceps tendon with a 6mm width, in order to obtain a final 4S+Q graft diameter of 8.5mm or more.

2. Material And Methods

2.1. Ethics

This descriptive cadaveric study was elaborated within the context of a larger project aiming to create a decisional algorithm focused on the different options meant to increase the diameter of 4S grafts. The instruments, the evaluators and the specimens used are the same as another study encompassed in this larger project [31]. The protocol was approved by the "Comité d'éthique de la recherche du CIUSSS de l'Estrie-CHUS (Centre intégré universitaire de santé et de services sociaux de l'Estrie – Centre hospitalier universitaire de Sherbrooke).

2.2. Sample Size

Each usable cadaver, having previously been consented as a donor to science between January and March 2019, was 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 orthopedic surgery senior residents in order to harvest the semitendinosus, gracilis and quadriceps tendons while adhering to the usual surgical techniques. Of those 34, 33 samples were deemed usable in our 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).

2.3. Sample preparation

Harvesting of every tendon used was done by the same senior resident by using the instruments and surgical techniques typically employed in our center.

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, Ohio). These steps are the same when harvesting the semitendinosus tendon. The remaining muscular fibers are cleaned from the tendons and the two 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.

2.4. Measurements

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 PDS suture and the diameter measures were taken using *ACL diameter measuring tubes* (Conmed Linvatec, Aurora, Ohio), 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 in order to produce grafts in a 4S+Q conformation (figure 1), which were also measured with the Conmed measuring tubes. Each measure was done individually by three evaluators and compiled by a research assistant. Each evaluator also re-evaluated 10 grafts, randomly assigned by the research coordinator, in order 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.

2.5. Statistical calculations

Statistical calculations and analyses were done by a statistician with SPSS (v23.0.0 from IBM). 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.

3. 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 ($p=0,002$) and 0,959 ($p<0,001$) respectively.

The diameter measures used in the results for each sample constitute the median of the three evaluators. Within our population, 69,7% of grafts had a diameter inferior to 8,5mm with a 4S configuration (Table 2), whereas that ratio fell to 12,1% after supplementation with a 6mm band of rectus femoris tendon (Table 2).

Supplementation with a quadricipital tendon band saw an average increase of 1,49 [1,03 – 1,95] in diameter for grafts in 4S conformation (Table 3). After augmentation, 82,6% of grafts with a diameter of 7,0mm to 8,0 mm reached the target of 8,5mm, in comparison with 92,9% of those with a diameter of 7,5mm to 8,0mm.

4. Discussion

The results of our descriptive study indicate a significant increase of the diameter of a 4S graft when supplemented with a quadricipital tendon band. Starting a few years ago, the principal author of this document uses this 4S+Q supplementation technique as a backup option when the 4S graft diameter is insufficient and its length does not allow to triple de 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 7,5mm or more diameter that did not reach the target of 8,5mm 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.

Other techniques are described in these circumstances too. The other main source of supplementation described is allograft, which presents a higher failure rate than autografts, especially in younger patients[17][18][19]. 6S grafts are a good option if length is satisfactory. According to a study done in our center earlier this year[31], this method would allow an average increase in graft diameter of 1,35 mm and 95,8% of grafts measuring 7,5 mm in diameter or more would therefore reach 8,5 mm. The prerequisite for this technique, however, is that the semitendinosus tendon harvested must measure more than 270mm in order to have a minimal length of 90mm after preparation, which consists in optimal length, in our experience, for a satisfactory reparation with a tibial interference screw and femoral cortical suspension[32]. A 6S graft configuration or a quadrupled semi-tendinosus can also be used despite a length of less than 90 millimeters, but those options necessitate a tibial suspensory fixation, which entails altering the operating plan and having more fixation options on site.

Certain limitations are intrinsically linked with the study design employed. Among others, a study based on cadavers can diminish the clinical applicability of its results. This potential bias, as well as the fact that our studied population is much older than the usual ACL reconstruction population, is lessened by comparing the average diameter increase between two configurations rather than the diameter as an absolute number. Moreover, we took care to use recent cadaveric samples, kept fresh and frozen only a short time before harvesting. We also slowly warmed the tendons at room temperature before any manipulation and kept them constantly hydrated between measures using surgical sponges soaked with a saline solution. The total number of samples (n=33) directly limits the numbers per group and might therefore influence the external validity of the experiment. However, that three evaluators performed each measure independently and with excellent inter and intraobserver reliability contributes in countering this effect on external validity.

Several questions, such as the complications associated with the technique as well as the real clinical benefit, are beyond the scope of this project. We realize that adding a second harvesting site adds potential complications. Based on our experience, the two main potential complications following the harvest of a quadriceps tendon band - namely some pain and the post-operative strength of the extensor mechanism[33] - do not seem to be major stakes in the recuperation of patients benefiting from this supplementation. Existing literature demonstrates significantly less anterior knee pain [34][35][23][28][36] and less kneeling pain[37][34][23][28] after harvesting quadriceps tendons when compared with patellar tendon, even when it is harvested with the patellar bone and in its entire thickness. Though it remains to be demonstrated in a subsequent study, we believe that with a quadriceps 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[38].

This descriptive study backs the use of quadriceps 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.

The diameter obtained with a 6 mm band of rectus femoris did not reach 8.5mm or more for all 4S grafts. Therefore, future work could evaluate the use of rectus femoris bands of greater widths, the 6S or even the 6S+Q configurations for the smaller sizes of 4S grafts.

Greater characterization of side effects related to this technique is also necessary before any wide-range application.

We must also not underestimate the risks associated with too great an increase of the graft diameter. In fact, an oversized graft in a tight femoral notch could also increase the risk of failure from repeated impingements on the roof of this notch during extension. *Fu et Al.* pronounce this same warning when they propose to estimate with MRI the diameter of the native ACL and attempt to reproduce it[39]. In this context, it will be interesting to continue to evaluate increases in graft diameter according to different

configurations or supplementations in order to be able to predictably choose from a complete quiver of options to obtain the right graft size for the right patient.

5. Conclusion

In conclusion, a minimum graft diameter of 8.5mm is reached with initial 4S graft of 7.5mm or more in 92.6% in this sample. Supplementing doubled hamstring graft (4S) with quadriceps tendon in ACL reconstruction is an option to be added to our arsenal, which increases the graft diameter by an average of 1,49 millimeters. More descriptive, biomechanical and clinical studies are necessary in order to establish with greater certainty where exactly this option resides within a future decisional algorithm based around graft diameter and length.

Declarations

Ethics approval and consent to participate:

The study protocol was approved by the “Comité d’éthique de la recherche du CIUSSS de l’Estrie-CHUS (Centre intégré universitaire de santé et de services sociaux de l’Estrie – Centre hospitalier universitaire de Sherbrooke). Final approval was obtained on march 13th, 2019 with the study number 2019-3057.

Consent for cadavers use was obtained by the director of the Laboratoire d’anatomie, Centre de simulation PRACCISS de la faculté de médecine et des sciences de la sante de l’Université de Sherbrooke.

Consent for publication :

Not applicable

Availability of data and materials:

The datasets generated and analysed during the current study are not publicly available but are available from the corresponding author on reasonable request.

Competing interests:

YBG, KAL and KL have no competing interest to declare regarding this research project.

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Authors’ contributions:

YBG contributed to data collection, analyses, interpretation and was a major contributor in writing the manuscript.

KAL, SB, FB and FV contributed to protocol conception, data collection, analyses, interpretation and manuscript writing.

KL contributed to conception, statistical analyses, interpretation and manuscript revision.

All authors read and approved the final manuscript.

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Soumission n.d.

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Tables

Table 1
Demographic characteristics

Number of samples	17 cadavers (33 samples)
Average age	76.2 ± 13.6 years
BMI	22.6 ± 4 kg/m ²
Sex	52.9% men

Table 2
4S and 4S+Q graft diameters

Diameter (mm)	n 4S (%)	n 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%)

Due to technical limitations, table 1 is only available as a download in the Supplemental Files section.

Figures

Figure 1

4S+Q graft configuration

Black arrowhead : quadricipital band. White arrow : Four bundle hamstring graft

Supplementary Files

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- [Table3.jpg](#)