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Research Article

Investigating the magnetic resonance imaging cross-section area that best correlates with intraoperative hamstring autograft size

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ABSTRACT

Objective: This study aimed to find out the level of the gracilis and semitendinosus tendons that would provide the closest information about the size of the quadruple-stranded hamstring autograft using magnetic resonance images before anterior cruciate ligament reconstruction.

Methods: Ninety-six patients (44 males, 52 females) who underwent anterior cruciate ligament reconstruction with quadruple hamstring tendon autografts between January 2015 and March 2020 were retrospectively analyzed. The cross-sectional areas of the gracilis and the semitendinosus tendons at 6 different levels (pes anserinus insertion site, tibial tuberosity, fibular head, tibial plateau, and the proximal insertion sites of the anterior cruciate ligament and the medial collateral ligament were measured on the magnetic resonance images. In addition, the harvested hamstring tendons were measured together (quadrupled) using a standardized graft-sizing block.

Results: There was no significant difference between genders in terms of the tendon sizes measured in all levels using magnetic resonance images. There was a strong correlation between the graft size and the measurements made at the tibial plateau level ($P < .0001$, $r = 0.590$).

Conclusion: Intraoperative quadruple hamstring tendon sizes were most correlated with the magnetic resonance image measurements at the tibial plateau level. To use a hamstring autograft with a diameter of at least 8 mm for anterior cruciate ligament reconstruction, the total area of the 2 tendons should be at least 18.11 mm^2 in the magnetic resonance image measurements made at the tibial plateau level.

Level of Evidence: Level IV, Diagnostic Study

Introduction

The anterior cruciate ligament (ACL) is a ligament that consists of 2 bundles and is responsible for the anteroposterior and rotational stability of the knee.[1] Since injuries of the ACL are one of the most important sports injuries, the frequency of reconstruction surgeries is increasing.[2] Thousands of studies on ACL reconstruction exist in the literature; however, debates about the anatomical features and surgical techniques regarding the ligament continue.[3] Nevertheless, we know that the 2 most important factors for the success of the reconstruction are the accurate placement of the tunnels and the durability of the graft.[4,5]

The ideal graft to be used in reconstruction should have structural and biomechanical properties similar to the natural ACL, allow a safe and strong fixation, provide rapid biological healing in bone tunnels, and have little donor site morbidity.[6] Although autograft options such as bone-patellar tendon-bone, quadriceps tendon, iliotibial band, and allografts are available, quadruple hamstring autografts, which offer the highest tensile resistance, are the most preferred option today.[7]

In practice, a hamstring autograft with a thickness of at least 8 mm is recommended for a successful ACL reconstruction.[8] Knowing in advance that the size of the hamstring autograft is insufficient provides the surgeon with the opportunity to make changes in preoperative planning, such as considering the use of bone-tendon-bone autografts or allografts. Studies have suggested that the dimensions of the semitendinosus and gracilis tendons can be evaluated using MRI.[8,9] However, in almost all of these studies, MRI measurements were made at the level of the medial femoral condyle, whereas, it is known that the diameters of hamstring tendons vary along the course of the tendon.

In this study, we tried to determine the level of the gracilis and the semitendinosus tendons that would provide the closest information about the size of the quadruple hamstring autograft to be harvested and used during ACL reconstruction. We hypothesized that the measurements made from the tibial plateau level would give the best information about the intraoperative graft size. As far as we know, no study to date has reviewed this issue in the literature.

Materials and Methods

The approval for the study was obtained from the Ethics Committee of Bolu Abant İzzet Baysal University (2020/223). Written informed consent was

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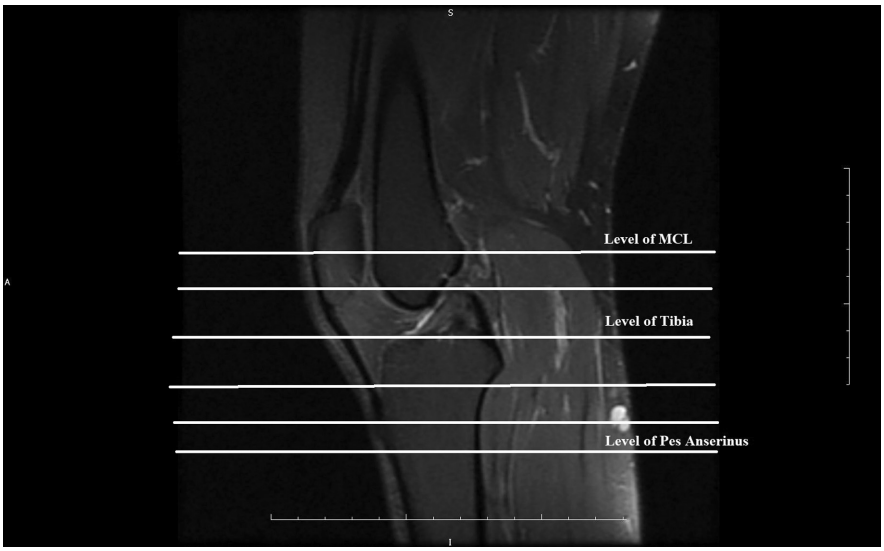

Figure 1. The six different levels used in cross-sectional area measurements.

obtained from all participants who participated in this study. Ninety-six patients (44 males, 52 females) who underwent ACL reconstruction with quadruple hamstring autograft tendons between January 2015 and March 2020 were retrospectively analyzed.

The inclusion criteria were MRI findings indicating an acute total ACL rupture and patients with clinical complaints. Patients who had had previous knee surgeries or acute partial ACL injuries, used other autograft options, had multiligamentous laxity, and those with acute or chronic hamstring injuries were excluded from the study.

The study was conducted in a single center. All patients were operated on by the same experienced surgeon with single-bundle arthroscopic ACL reconstruction using quadruple hamstring autografts. Cortical buttons, screws, and staples were used for graft fixation. The MRIs were reviewed by a radiologist who had 6 years of clinical experience and an orthopedic surgeon who had taken a 6-hour course about the measurement of the gracilis and the semitendinosus tendons. The surgeon and the radiologist took the measurements together to provide a common technique and view. The measurements were repeated 3 times for each level and their average was taken. Cross-sectional area (CSA) measurements were taken in square millimeters at 6 different levels (Figure 1).

Since the study was designed retrospectively, the tendon diameters could not be measured individually, but rather the total graft diameter could be obtained during the operation. This may be a deficiency; however, we believe that the findings in the current study are important in terms of surgical practice.

HIGHLIGHTS

- Hamstring grafts are commonly used for ACL reconstruction. Previous studies on measurements of the semitendinosus and gracilis tendons were mostly made at the level of the medial femoral condyle. This study aimed to find the optimal level of the tendons on magnetic resonance imaging, that would provide the closest information about the size of the autograft.
- Both the gracilis and semitendinosus graft sizes werestrongly correlated with their respective measurements at the tibial plateau level. To harvest an autograft with a diameter of at least 8mm, the total area of the two tendons should be at least 18.11mm^2 in the MRI measurements made at the tibial plateau level.
- The results from this study indicate that the measurements of the hamstring tendons at the tibial plateau level are more compatible with the intraoperative graft size and that it may be useful for the preoperative planning of the graft to be used.

Preoperative magnetic resonance image measurements

Radiological evaluation of the knees was performed using a 1.5T MRI device (MAGNETOM Symphony; Siemens AG, Munich, Germany). A knee coil was used to obtain signals. After "localizer," the following images of the knee joint were obtained for each patient: proton density-weighted (PD-weighted) sagittal and axial fast spin-echo (SE) images (TR [Repetition Time]: 2940, TE [Echo Time]: 40, slice thickness: 4 mm and TR: 3140, TE: 33, slice thickness: 4 mm, respectively), sagittal T1-weighted fast SE image (TR: 760, TE: 9, slice thickness: 4 mm), and coronal T2-weighted, fat-saturated fast SE image (TR: 4360, TE: 81, slice thickness: 4 mm).

The CSAs of the gracilis and the semitendinosus tendons were measured using the NIH Image and ImageJ software (Figure 2). The ImageJ software was used to convert the irregular non-round surface into diameter. Axial fat-saturated, PD-weighted images and 6 different levels were selected for the measurements from the preoperative MRIs. The measurements were performed at the following levels: pes anserinus insertion site, tibial tuberosity, fibular head, tibial plateau, and the proximal insertion sites of the ACL and the medial collateral ligament (MCL). The axial images were correlated with the coronal and sagittal images to find the correct level for measurement.

Intraoperative measurements

The tibial tuberosity was entered about 1 cm to harvest hamstring autografts. Then, the semitendinosus and the gracilis tendons were released from their attachment to the tibia. After the hamstring autograft, tendons were smoothly released proximally using a graft harvesting device and debrided. After the semitendinosus and the gracilis tendons were folded together (quadruple-stranded), the total graft size was measured using a standardized graft-sizing block. The diameter of the graft was measured as the largest diameter that could pass through the smallest hole of the instrument. Graft diameters were measured before and after suturing to ensure accuracy. Intraoperative measurements of the hamstring tendon were made by 2 researchers during surgery, and the appropriate diameter was decided by consensus. The surgical team was not informed about the preoperative MRI measurements in any of the cases until the end of the study.

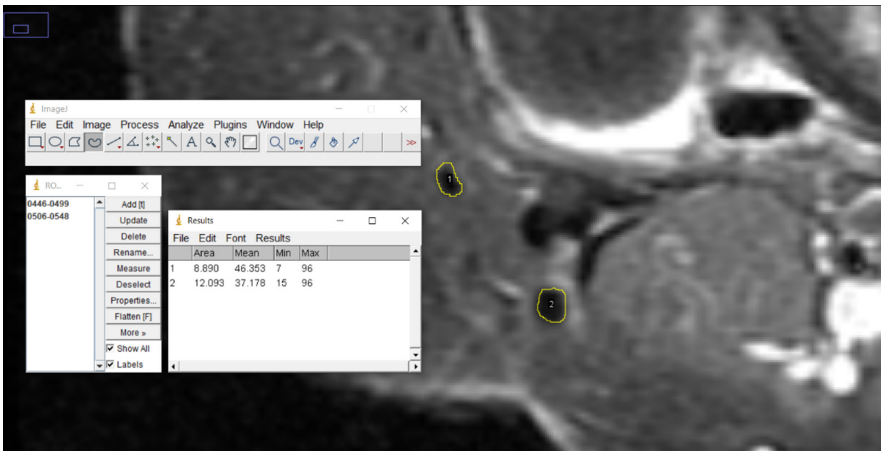

Figure 2. Axial proton density-weighted MRI of the knee analyzed at 300% magnificationusing the ImageJ software. At the level of the proximal MCL insertion site, the cross-sectional area measurements of the gracilis (1) and the semitendinosus (2) tendons were 8.890 mm² and 12.093 mm², respectively.

Statistical analysis

The data obtained in this study were analyzed using the IBM Statistical Package for Social Sciences (SPSS) Statistics v.22 software IBM SPSS Corp., Armonk, NY, USA. The normality of the variables was tested with the Shapiro–Wilk test. Spearman's correlation analysis was used according to the results of the normality test. In the evaluation of the correlation coefficient, r=0-0.24 was considered as "poor," r=0.25-0.49 as "moderate," r=0.50-0.74 as "strong," and r=0.75-1.0 as "very strong" correlation. Nonparametric tests were used for variables without normal distribution. We used a receiver operating characteristic (ROC) curve analysis to calculate the cut-off values needed to provide at least 8 mm graft size. Continuous data without normal distribution were analyzed using the Mann–Whitney U test. Quantitative data were expressed as mean, standard deviation, and minimum and maximum values. The confidence interval was 95%, and P values less than .05 were considered statistically significant.

Table 1. The graft size distribution by gender (n=96)

	Gender		
Graft size	Male	Female	Total
7 mm	9 (9.4%)	9 (9.4%)	18 (18.8%)
8 mm	25 (26.0%)	20 (20.8%)	45 (46.9%)
9 mm	7 (7.3%)	18 (18.8%)	25 (26.0%)
10 mm	3 (3.1%)	5 (5.2%)	8 (8.3%)

Results

The operations were performed on the right side in 45.8% of the patients and on the left side in 54.2%. The mean age of the patients was 23.8 years (range: 18-40 years). The mean graft diameter of female patients was 8.09 mm, while the mean graft diameter of male patients was 8.36 mm. There was no correlation between the graft size and gender or age. None of the patients had a quadruple-stranded graft less than 7 mm diameter intraoperatively. Four different graft sizes were used in the patients: 7, 8, 9, and 10 mm.

The graft size distribution by gender is given in Table 1. There was no significant difference between the genders in terms of the tendon sizes measured in all regions using MRI (P > .05).

(A) **The measurements made on the gracilis tendon (Table 2):**
There was a strong correlation between the graft size and the measurements made at the tibial plateau level (P < .0001, r=0.505). No correlation was observed between the graft size and the measurements performed at other levels.

(B) **The measurements made on the semitendinosus tendon (Table 2):**
There was a strong correlation between the graft size and the measurements performed at the proximal insertion site of the MCL and tibial plateau level (P < .0001, r=0.516 and P < .0001,

Table 2. Radiological measurements of the tendons by region and intraoperative graft size measurement

	Pes anserinus	Tibial tuberosity	Proximal fibula	Proximal tibial plateau	Proximal ACL	Proximal MCL
Gracilis tendon graft size						
7 mm	5.5±2.1 mm²	7.6±2.9 mm²	6.6±1.9 mm²	6.3±1.6 mm²	6.5±1.6 mm²	6.8±1.9 mm²
8 mm	7.4±2.1mm²	8.3±2.5 mm²	8.4±3.1 mm²	7.9±1.9 mm²	7.7±2.2 mm²	8.4±3.2 mm²
9 mm	7.0±3.3 mm²	8.2±5.2 mm²	8.0±3.2 mm²	9.1±2.2 mm²	8.0±3.3 mm²	8.3±2.6 mm²
10 mm	8.4±3.9 mm²	8.7±2.4 mm²	9.2±3.2 mm²	10.8±3.2 mm²	9.1±3.4 mm²	7.5±3.2 mm²
Semitendinosus tendon graft size						
7 mm	7.1±1.5 mm²	9.4±3.1 mm²	9.5±2.3 mm²	9.1±1.5 mm²	11.1±4.0mm²	10.6±2.6mm²
8 mm	9.7±3.2 mm²	11.0±3.5 mm²	10.8±3.6 mm²	11.2±1.9 mm²	12.2±2.6mm²	12.3±2.1mm²
9 mm	10.0±3.7 mm²	11.3±3.8mm²	11.6±3.3 mm²	12.4±3.3 mm²	13.8±3.1mm²	14.1±3.3 mm²
10 mm	10.3±5.0 mm²	10.5±6.0 mm²	11.2±3.9 mm²	14.2±1.5 mm²	12.2±2.6mm²	15.6±2.1mm²
Both (gracilis - semitendinosus) graft size						
7 mm	12.6±3.1 mm²	17.1±5.2 mm²	16.1±2.7mm²	15.4±2.5 mm²	17.5±4.4 mm²	17.4±3.9 mm²
8 mm	17.1±5.0 mm²	19.3±5.1 mm²	19.2±6.2 mm²	19.0±3.2 mm²	19.9±3.8 mm²	20.8±4.5 mm²
9 mm	17.0±6.3 mm²	19.6±7.7 mm²	19.6±5.2mm²	21.5±4.6 mm²	21.8±5.8 mm²	22.4±4.3 mm²
10 mm	18.7±7.7mm²	19.1±6.5 mm²	20.4±6.9 mm²	25.0±4.3 mm²	26.0±4.4 mm²	23.1±4.7 mm²

$r=0.502$, respectively). A moderate correlation was observed between the graft size and the measurements performed at the pes anserinus insertion site and the proximal insertion site of the ACL ($P=.006$, $r=0.278$ and $P < .0001$, $r=0.444$, respectively). No correlation was noted between the graft size and the measurements performed at the tibial tuberosity and the fibular head levels.

(C) **The measurement results obtained by collecting the measurements of both regions mentioned earlier (Table 2):**
There was a strong correlation between the graft size and the measurements performed at the tibial plateau level ($P < .0001$, $r=0.590$). A moderate correlation was observed between the graft size and the measurements performed at the pes anserinus insertion site and at proximal insertion sites of the ACL and the MCL ($P=.007$, $r=0.271$; $P < .0001$, $r=0.430$ and $P < .0001$, $r=0.370$, respectively). There was a weak correlation between the graft size and the measurements performed at the level of the fibular head ($P=.041$, $r=0.209$). No correlation was detected between the graft size and the measurement performed at the tibial tuberosity level.

Discussion

The most important finding of the study is that the intraoperative quadruple-stranded hamstring tendon sizes were most correlated with the MRI measurements at the tibial plateau level. As reported previously, preoperative MRI measurements can be used to predict the hamstring tendon size without an additional cost.[10,11] Studies on this subject have performed most of the measurements at the level of the medial femoral condyle. In the current study, the measurement at the tibial plateau level was found to be the most compatible one with intraoperative graft size.

Leiter et al[12] measured the diameters of the semitendinosus and gracilis grafts using a standardized graft-sizing block as a quadrupled-strand, as we did in our study. In addition, the authors concluded that graft diameters can be measured on preoperative MRIs to identify tendons that may be insufficient for ACL reconstruction.[12]

With its increased tensile strength and reduced donor site morbidity, hamstring autografts are more preferred in ACL reconstruction. However, the risk of harvesting an autograft smaller than the required diameter intraoperatively still exists. For this reason, it would be sensible to use a hamstring autograft with a thickness of at least 8 mm for ACL reconstruction.[9,13] Accordingly, predicting whether the thickness of the hamstring graft to be used for ACL reconstruction will be sufficient preoperatively will enable preparation for other graft options. Some anthropometric measurements have been shown to correlate with the size of the hamstring autographs. Especially the height[8,14,15] and thigh length[15,16] can serve in determining the hamstring graft diameter to be harvested before ACL reconstruction.

In the prospective study by Beyzadeoglu et al[10] conducted on 51 patients,[10] single-stage ACL reconstruction was performed by a single surgeon, similar to our study. After harvesting the hamstring grafts, the thickness of the gracilis and the semitendinosus tendons was measured separately as double-strand and quadruple-strand, using a graft-sizing block. In our study, measurements were made as quadruple-strand. In the study by Beyzadeoglu et al, the measurements were performed at 2 different levels. The first level was just below the muscle–tendon junction. The second level was at the joint line at the midpoint of the tendon. In our study, 6 different measurements were made. Patients with a gracilis CSA of less than 6.4 mm^2 and a semitendinosus CSA of less than 12 mm^2 using the MRI measurement technique were reported to be in the high-risk group for graft failure.[10] The authors also found a significant correlation between the CSA on the MRI and the intraoperative graft sizes.[10]

Despite the above information, it is more rational to also use other radiological measurements to estimate the intraoperative size of the hamstring autograft.[8] Erquicia et al[17] investigated the correlation between ultrasound (USG)/MRI measurements and intraoperative graft sizes and stated that MRI showed a higher correlation with the graft size than USG. Bickel et al[11] conducted a similar study on adolescent patients and used just below the physis or physeal scar level in their MRI measurements. The authors stated that if the combined CSA was greater than 18 mm^2, the probability of obtaining a sufficiently large graft during surgery was 88%. Wernecke et al[18] similarly examined 34 patients in their prospective study, using the level of the medial femoral epicondyle in their MRI measurements and suggested that preoperative MRI threshold values should be 10 and 17 mm^2 for the gracilis and the semitendinosus tendons, respectively.[18] Hollnagel et al[9] investigated the minimum CSA for the hamstring tendon needed to harvest an autograft with a thickness of at least 8 mm. The MRI evaluations were made by a radiologist at the level of the medial femoral condyle and joint line. The authors emphasized that preoperative MRI could be used to estimate the size of hamstring autografts for ACL reconstructions. In the study by Hamada et al.[13] the mean cutoff values for the total hamstring area were 18.8 and 17.5 mm^2 for the 1.5T and 3.0T MRI groups to obtain an 8 mm hamstring autograft. In the current study, 6 different levels were selected for measurements on preoperative MRIs: pes anserinus insertion site, tibial tuberosity, fibular head, tibial plateau, and the proximal insertion sites of the ACL and the MCL. Measurements on the tibial plateau level instead of the points commonly referenced in the literature were found to be more compatible with the intraoperative graft size. To obtain a hamstring autograft with a diameter of at least 8 mm intraoperatively, the cutoff value of the tendons according to the ROC curve analysis of the MRI measurements made at the level of the tibial plateau should be a minimum of 18.11 mm^2. The cutoff value could not be calculated for other graft sizes in our ROC curve analysis.

Our study had some limitations. The measurement of intraoperative graft size was performed using a standardized graft-sizing block for practical application. Therefore, the measurements may not be accurate and may affect the results. In addition, radiological measurements were performed by a radiologist who was experienced in musculoskeletal radiology. Therefore, intraobserver variability could not be evaluated. Another shortcoming was that the study had a retrospective design. However, this study was done meticulously in a well-documented archive system, and the obtained information will contribute to the literature.

In clinical practice, the size of hamstring autografts to be used in ACL reconstruction could be estimated using preoperative MRIs. This assessment can assist orthopedic surgeons to develop a better preoperative strategy, especially regarding graft selection. We observed that intraoperative quadruple hamstring tendon sizes were most correlated with the MRI measurements at the tibial plateau level. In addition, to use a hamstring autograft with a diameter of at least 8 mm for ACL reconstruction, the total area of the 2 tendons

should be at least 18.11 mm^2 in the MRI measurements made at the tibial plateau level.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Bolu Abant İzzet Baysal University (Approval No: 2020/223).

Informed Consent: Written informed consent was obtained from all participants who participated in this study.

Author Contributions: Concept - O.Y., K.E.Ö.; Design - T.A., E.A., H.G.; Supervision - T.A., K.E.Ö.; Materials - E.A., H.G.; Data Collection and/or Processing - E.A., O.Y., H.G.; Analysis and/or Interpretation - T.A., E.A., O.Y., H.G., K.E.Ö.; Literature Review - T.A., E.A.; Writing - T.A.; Critical Review - Y.E.K., K.E.Ö.

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