Original Article

Combined Assessments of Patellar Tendon and Hamstring Tendon Parameters on Preoperative Magnetic Resonance Imaging Can Improve Predictability of Hamstring Tendon Autograft Diameter in the Setting of Anterior Cruciate Ligament Reconstruction

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Purpose: To evaluate whether preoperative magnetic resonance imaging (MRI) measurements of multiple tendon autograft sources could be used to improve estimates of intraoperative hamstring tendon autograft (HTA) diameter. **Methods:** Patients who underwent anterior cruciate ligament reconstruction with HTA at our institution were identified through electronic health records. Preoperative MRI tendon measurements of the patellar tendon (PT) length, PT width, PT thickness, quadriceps tendon thickness, semitendinosus tendon (ST) cross-sectional area (CSA), and gracilis tendon (GT) CSA were conducted by 2 independent evaluators using digital imaging measurement tools. **Results:** A total of 53 patients met the inclusion criteria, with a mean HTA diameter of 7.98 ± 0.7 mm. Height greater than 1.63 m, weight greater than 63.4 kg, PT length greater than 4.2 cm, PT thickness greater than 0.33 cm, ST CSA greater than 10.8 mm^2, and GT CSA greater than 6.3 mm^2 were associated with an HTA of 8 mm or greater ($P < .005$). Female sex was associated with an HTA of less than 8 mm ($P < .05$). PT length, PT thickness, and GT CSA were the strongest predictors of an HTA of 8 mm or greater and were combined into an additive logistic regression model: Score $= -23.24 + (1.68 \times$ PT length$) + (20.104 \times$ PT thickness$) + (1.48 \times$ GT CSA$)$. If the score was greater than 0.237, the HTA graft diameter was predicted to be 8 mm or greater with 83% specificity, 91% sensitivity, and 87% accuracy. **Conclusions:** By combining PT length and PT thickness measurements with GT CSA measurements in a logit function model, we were able to show improved overall specificity, sensitivity, and accuracy of estimated HTA diameters in our data set when compared with assessments of anthropometric, ST CSA, GT CSA, or combined ST-GT CSA measurements in isolation. **Clinical Relevance:** Preoperative MRI measurements may be used to screen whether a patient is likely to have an 8-mm graft in the setting of anterior cruciate ligament reconstruction with HTA and thus may help guide graft choice.

Autograft choice is a significant component of preoperative planning prior to anterior cruciate ligament reconstruction (ACLR) procedures; however, there is still considerable debate regarding the ideal graft choice. Quadrupled hamstring tendon autograft (HTA) ACLR grafts are the most commonly used graft type worldwide[1-3] and can allow for circumferential healing of the graft within the bone tunnels. HTAs are

also associated with less risk of postoperative chronic anterior knee pain than bone–patellar tendon–bone grafts while providing similar patient-reported outcomes.[4-9]

Despite the potential benefits of HTA, surgeons must be aware of the variability in tendon size that exists among patients as grafts measuring less than 8 mm in diameter have been associated with higher retear rates and poorer outcome scores, particularly in young patients.[10,11] In the event that a patient has a graft of less than 8 mm after hamstring tendon harvest, surgeons may elect to use specialized implants and techniques that allow for triple folding or even quadruple folding of the graft. Alternatively, surgeons may elect to augment the autograft with allograft tissue. Although augmentation can achieve an overall graft diameter greater than 8 mm, allograft augmentation has been associated with increased failure rates compared with equivalently sized HTA in some studies.[12-14] Thus, knowledge of patient factors that contribute to the estimation of intraoperative HTA diameter can help guide preoperative patient counseling as well as preoperative planning regarding allograft availability, appropriate instrumentation, and the corresponding implants.

Discordant results have been reported regarding the use of anthropometric assessments (height, weight, thigh length, and so on) and patient demographic characteristics to estimate intraoperative HTA diameter.[15-19] Among these parameters, height has been indicated as the strongest predictor of HTA diameter.[11,17,19-21] Many studies have been conducted using imaging modalities such as ultrasound and computed tomography in an effort to more accurately estimate HTA diameter; however, the results have been inconclusive.[22-25] Thus, preoperative magnetic resonance imaging (MRI) has received an increased amount of attention, and there is a growing body of evidence that suggests preoperative MRI features may be used to estimate intraoperative graft size.[22,26-32] A recent systematic review of 14 studies concluded that preoperative MRI assessment of both quadriceps tendon (QT) and bone–patellar tendon–bone autografts is highly correlated with intraoperative measurements of the graft diameter of these autograft tendon tissues.[33] Preoperative MRI studies are often performed in patients undergoing ACLR; thus, using these as a screening tool for estimating graft size would be both convenient and cost-effective. However, considerable variability and heterogeneity have been reported for measurements of HTAs either individually or together, with most studies indicating a moderate correlation between MRI and intraoperative assessments.[16,19,22,23,26-30,32-35] Thus, there remains an overall lack of strong preoperative HTA diameter predictors.[33]

The purpose of this study was to evaluate whether preoperative MRI measurements of multiple tendon autograft sources could be used to improve estimates of intraoperative HTA diameter. We hypothesized that including preoperative MRI measurements of additional knee tendons imaged on routine knee MRI in a predictive model would result in improved accuracy in estimating which patients will have HTAs of 8 mm or greater in diameter at the time of surgery.

Methods

The study was approved by the Institutional Review Board at the University of California, Los Angeles. We retrospectively reviewed the records of patients who underwent ACLR with HTA between January 2013 and May 2020. A list of all ACLRs performed at our institution in the study period was generated from our institution's electronic medical record system, and a review of individual medical records was then conducted to identify patients who satisfied our inclusion and exclusion criteria.

The inclusion criteria were defined as follows: (1) MRI-proven anterior cruciate ligament tear, (2) preoperative 3-T MRI performed at our institution, (3) ACLR performed at our institution, (4) age older than 12 years at the time of surgery, and (5) intraoperative HTA diameter measurement documented in the operative report using cylindrical sizing tubes with sizes rounded to the nearest 0.5 mm. Patients were excluded if there was any evidence or documentation of prior hamstring tendon harvest and if there was no intraoperative HTA diameter measurement recorded in the operative report.

All surgical procedures were performed by 1 of 7 orthopaedic surgeons with fellowship training in orthopaedic sports medicine. HTAs in this study consisted of both the gracilis tendon (GT) and semitendinosus tendon (ST) and were folded once over a cortical button suspension loop (i.e., doubled). For any HTAs augmented with an allograft, only the recorded unaugmented HTA diameter was used as the native-tissue HTA diameter for this study. In addition, patient demographic data collected at the time of surgery, including height, weight, body mass index (BMI), sex, and age, were included in the analysis.

Image Acquisition Parameters

All preoperative imaging was performed without intra-articular contrast on a high–field strength 3-T MRI system (Magnetom Vida or Skyra; Siemens, Erlangen, Germany) using manufacturer-supplied standard knee coils. Coronal fat-saturated proton density, sagittal proton density, sagittal T2-weighted fat-saturated, coronal T1-weighted, and axial fat-saturated T2-weighted images were obtained in all cases. The imaging parameters were as follows: field of

view, 140 mm; slice thickness, 3 mm with 0.6-mm gap (sagittal) or 0.3-mm gap (coronal) or 4 mm with 0.8-mm gap (axial); and matrix size, 384 (sagittal and coronal) or 320 (axial). Single acquisitions were used on all knees, which were positioned in knee extension. The acquired knee images were reviewed and analyzed on a picture archiving and communication system (PACS) (Centricity; GE Medical Systems, Milwaukee, WI).

The most recent preoperative MRI scan was used for all tendon measurements. Measurements included patellar tendon (PT) length, PT width, PT thickness, QT thickness, ST cross-sectional area (CSA), and GT CSA. The MRI measurements were performed by 2 orthopaedic surgeon evaluators to determine inter-rater reliability: One evaluator (IGM) had fellowship training in orthopaedic sports medicine, and the other evaluator (MT) was an orthopaedic surgery resident (postgraduate year 4). Both image evaluators were blinded to all collected patient data including intraoperative HTA measurements. The image evaluators conducted independent measurements and were blinded to each other's results. They received the same training and standardized instructions for conducting the measurements.

Calculation of the CSA of both the ST and GT was performed on axial MRI sequences using the axial slice that included the widest portion of the distal femur (Fig 1A) according to the technique described by Grawe et al.[27] This image was magnified 4 times, and CSAs were measured using the elliptical region-of-interest tool in the PACS software (Centricity Enterprise Web, version 3.0; GE Medical Systems) (Fig 1B). This tool reports the CSA (in square centimeters) of the geometric object resulting from manual tracing of the area of interest on a selected image and is a feature included in most PACS software platforms. The tool itself is approved by the US Food and Drug Administration to compute areas in any plane or volume.[26]

The MRI measurement techniques for PT width, PT length, and PT thickness were adapted from the techniques previously described by Chang et al.[36] PT width was measured by identifying the point midway between the inferior pole of the patella and the tibial insertion of the PT on the sagittal view (Fig 1C). This midpoint (Fig 1C, intersection of white dashed line and anterior portion of PT) was cross-referenced to an axial view (the dashed line in Fig 1C designates the axial slice shown in Fig 1D, which was then used to quantify PT width). A point near the center of the tendon was defined, and the width was measured from this point to the medial and lateral borders separately. The sum of the widths was regarded as the true tendon width (Fig 1D). PT length was measured on the sagittal slice showing the most distal pole of the patella and tibial tubercle (Fig 2A). PT thickness was also measured on this sagittal slice at the tendon's midpoint between the

superior and inferior extents (Fig 2B). QT thickness was calculated on a sagittal view 25 mm proximal to the superior pole of the patella measured from anterior to posterior in a trajectory orthogonal to the orientation of the tendon fibers (Fig 2C). All measurements were performed using the same PACS software.

Statistical Analysis

Bivariate analysis was performed using height, weight, BMI, age, ST CSA, GT CSA, PT length, PT width, PT thickness, and QT thickness as predictors of an intraoperative HTA graft diameter of 8 mm or greater. The 3 best predictors were combined into a weighted, additive logistic regression model to determine a threshold score. Reliability statistics between the 2 image readers for all MRI measurements were evaluated using the coefficient of variation difference (CVD). Pearson correlation coefficients (r values) were calculated using the mean MRI tendon measurements obtained by each independent image evaluator as well as for each structure relative to intraoperative HTA diameter at the time of ACLR. The level of statistical significance was defined as $P < .05$.

Results

Application of the study inclusion and exclusion criteria identified 53 ACLRs at our institution, consisting of 26 male patients (49%) and 27 female patients (51%). The mean age ($\pm$ standard deviation) at the time of surgery was 23 ± 8.9 years. Of the patients, 23 (43.4%) were younger than 18 years at the time of surgery. The mean height, weight, and BMI were 1.7 ± 0.1 m, 74.4 ± 18.1 kg, and 25.5 ± 4.8, respectively.

The mean intraoperatively measured HTA diameter of the folded (doubled over) GT and ST was 7.98 ± 0.7 mm prior to any augmentation. There were 18 grafts (34%) that measured less than 8 mm. The CVDs for tendon measurements between image readers were rated as very good (CVD < 10%) to good (CVD of 10% to <20%) (Table 1). Bivariate logistic regression analysis using demographic data and mean measurements between the 2 image readers showed that height greater than 1.63 m, weight greater than 63.4 kg, PT length greater than 4.2 cm, PT thickness greater than 0.33 cm, ST CSA greater than 10.8 mm^2, and GT CSA greater than 6.3 mm^2 were significantly associated with an HTA of 8 mm or greater ($P < .005$). Female sex was also significantly associated with an HTA graft of less than 8 mm ($P < .05$) on bivariate analysis. BMI, age, patellar tendon medial-lateral width, and QT thickness were not significant predictors of an HTA of less than 8 mm (Table 2). MRI measurements including the mean PT length, ST CSA, GT CSA, and combined ST-GT CSA were all significantly correlated with intraoperatively measured HTA diameter (Table 3).
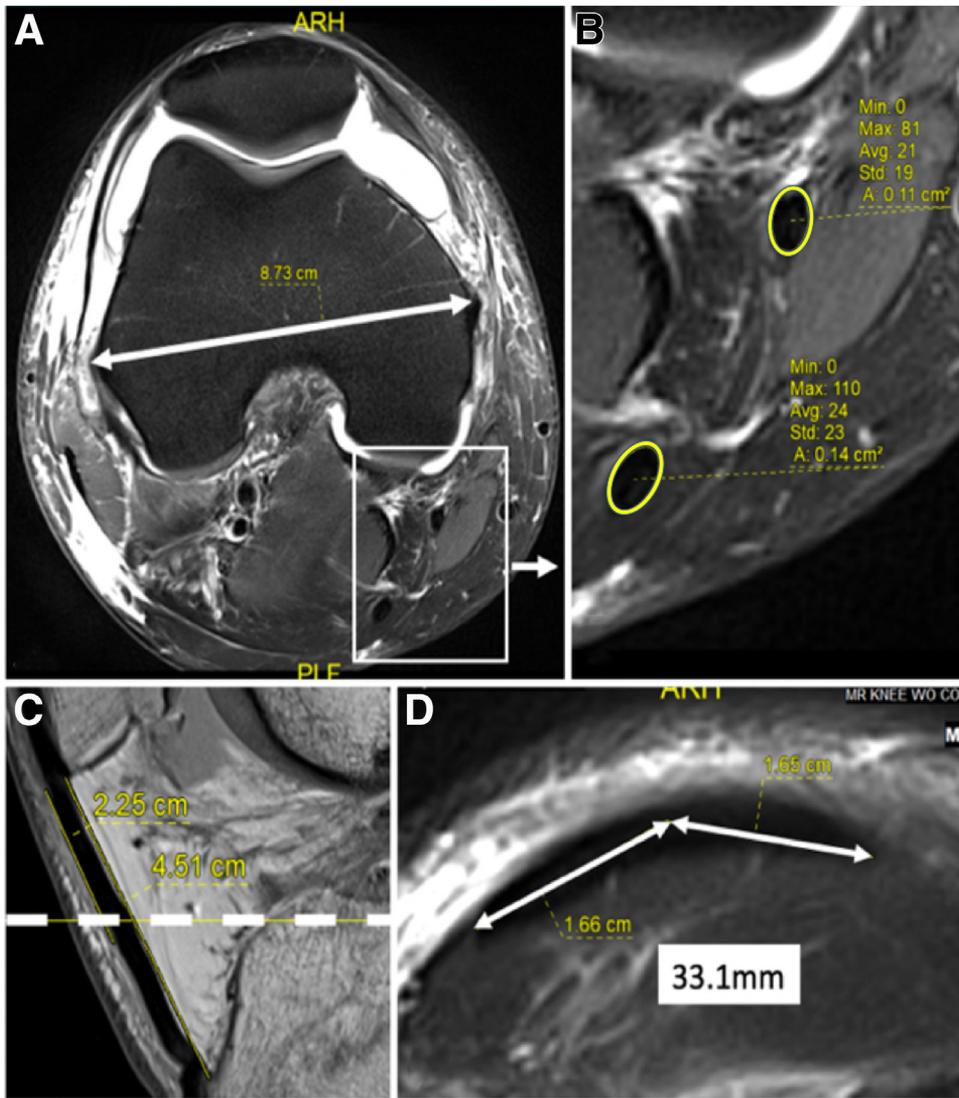
Fig 1. (A) Axial magnetic resonance imaging slice including widest portion of distal femur (white arrow). (B) Cross-sectional area measurements of semitendinosus tendon and gracilis tendon at 4× magnification (yellow ovals). (C) Sagittal magnetic resonance imaging view used to measure patellar tendon thickness, cross-referenced to axial view (dashed white line corresponds to the axial view plane in figure 1D). (D) Sum of measurements from center of patellar tendon to medial and lateral borders, giving true patellar tendon width (white arrows).

PT length (in centimeters), PT thickness (in centimeters), and GT CSA (in square millimeters) were the strongest predictors and could be used in an additive logistic regression model to calculate a score for each individual's MRI measurements: Score = −23.24 + (1.68 × PT length) + (20.104 × PT thickness) + (1.48 × GT CSA). If the score resulting from the application of this model is greater than 0.237, then the HTA graft diameter is predicted to be 8 mm or greater with 83.3% specificity, 91.4% sensitivity, and 87.4% accuracy in our data set. If the score is less than 0.237, then the HTA graft diameter is predicted to be less than 8 mm with 83.3% specificity, 91.4% sensitivity, and 87.4% accuracy.

Discussion

This study shows that preoperative MRI measurements of potential autograft sources can be used to estimate intraoperative HTA diameter in the setting of ACLR. Furthermore, including multiple autograft tendon measurements in the predictive model improved the accuracy of intraoperative HTA diameter estimations in our data set. Specifically, we observed that PT length, PT thickness, and GT CSA were the strongest predictors of an intraoperative native graft diameter of 8 mm or greater.

There is a growing body of literature attempting to use preoperative MRI to predict intraoperative HTA diameter.[16,19,22,23,26-30,32-35] Most of these studies have used ST and GT CSA measurements and correlated these relative to HTA diameter, with results ranging from weak ($r = 0.16$) to strong ($r = 0.81$), and often, the sum of ST and GT has been reported as showing the strongest correlation (r values ranging from 0.42 to 0.93).[16,19,22,23,26-30,32-35] Our study found a moderate correlation with ST CSA ($r = 0.48$) and combined ST-
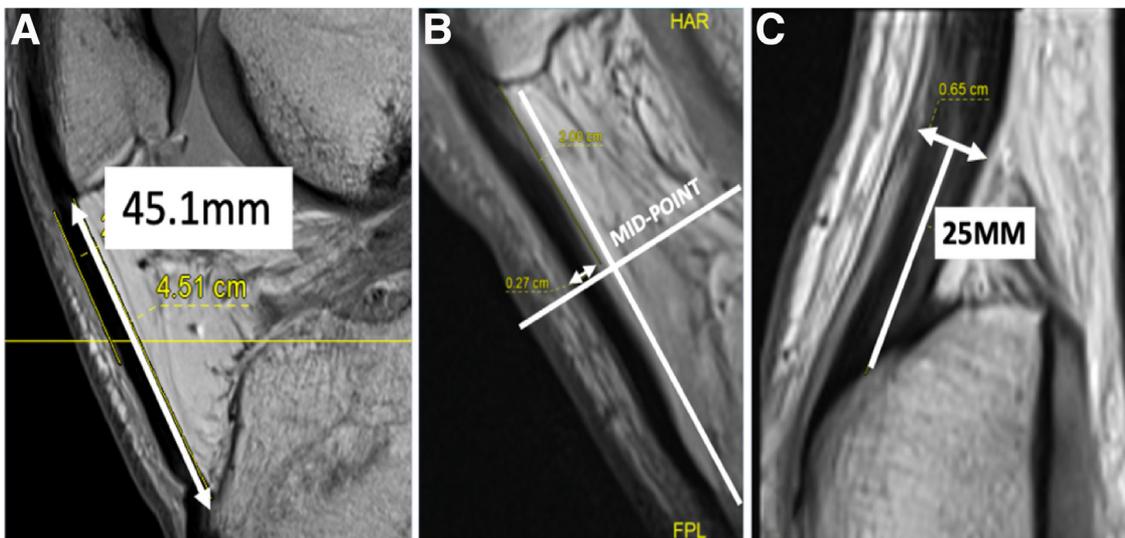
Fig 2. (A) Patellar tendon length measured on sagittal slice showing most distal pole of patella and tibial tubercle. (B) Patellar tendon thickness measured on sagittal slice at tendon's midpoint between superior and inferior extents. (C) Quadriceps tendon thickness calculated on sagittal view 25 mm proximal to superior pole of patella measured from anterior to posterior in trajectory orthogonal to orientation of tendon fibers.

GT CSA ($r = 0.67$) and a stronger correlation with GT CSA ($r = 0.71$) in isolation. We found that PT length and PT thickness showed a significant correlation with HTA diameter in our data set. Although the correlation between tendon size and final HTA diameter is an important measure, it is of little practical value unless specific cutoff values are used to determine which patients are at risk of having a graft of insufficient size. In our study, we observed that the combination of PT length, PT thickness, and GT CSA offered the strongest predictive value for having an HTA of sufficient size when these 3 parameters were combined into an additive regression function to estimate the probability. In other studies, most investigators have reported the strongest correlation with the sum of ST and GT, but these studies did not include measurements of the PT and QT.[26-29,35] Our results do not necessarily disagree that the sum of ST and GT is a strong predictor but instead suggest that the combination of PT length, PT thickness, and GT CSA may be superior.

Both adult and pediatric populations were included in this study, with a mean age ($\pm$ standard deviation) at the time of surgery of 23 ± 8.9 years and 43% of patients younger than 18 years. It is unclear to what degree skeletal immaturity may confound results; however, we believe the age range of patients in this study was sufficiently broad, and age was considered as a variable in our statistical analysis. Furthermore, including a high proportion of pediatric patients may make this study more applicable to the pediatric population overall.

Anthropometric data have also shown conflicting findings when used to predict graft size. However, the most consistent parameter reported in most studies is height alone or height in combination with sex.[11,17,19,20] Other authors have reported that weight and thigh circumference have the greatest correlations.[21] Using a multiple regression analysis, Ma et al.[19] reported that height and male sex, but not age or weight, were significant predictors of increased graft diameter. In this study, height was a specific predictor only in male patients, whereas among female patients, none of the preoperative anthropometric measures were predictive of graft diameter.[19] Alternatively, Leiter et al.[35] analyzed

Table 1. Mean Tendon Measurements and Variation Between Image Evaluators

Variable	Mean for Rater 1	Mean for Rater 2	Mean Difference	CVD, %	Correlation
PT length	4.52 cm	4.5 cm	0.0158 cm	2.0	0.99
PTML width	2.81 cm	2.82 cm	−0.0058 cm	5.8	0.90
PT thickness	0.36 cm	0.36 cm	−0.0058 cm	10.9	0.88
QT thickness	0.79 cm	0.8 cm	−0.0104 cm	7.6	0.84
ST CSA	10.9 mm^2	10.7 mm^2	0.21 mm^2	13.2	0.65
GT CSA	7.1 mm^2	6.8 mm^2	0.30 mm^2	13.8	0.76

CSA, cross-sectional area; CVD, coefficient of variation difference; GT, gracilis tendon; PT, patellar tendon; PTML, patellar tendon medial-lateral; QT, quadriceps tendon; ST, semitendinosus tendon.

Table 2. Bivariate Analysis Using Demographic Data and Mean Tendon Measurements Based on Data Combined From Both Image Evaluators

Variable	n	Mean	SD	P Value	Threshold	Specificity, %	Sensitivity, %	Accuracy, %
Height								
Graft diameter ≥ 8 mm	35	1.74 m	0.10 m		1.63 m	80	72	76
Graft diameter < 8 mm	18	1.63 m	0.08 m	.0001				
Weight								
Graft diameter ≥ 8 mm	35	79.2 kg	18.4 kg		63.4 kg	89	56	72
Graft diameter < 8 mm	18	65.2 kg	13.7 kg	.0033				
BMI								
Graft diameter ≥ 8 mm	35	26.1	5.0		25.84	57	78	67
Graft diameter < 8 mm	18	24.6	4.4	.1562				
Age								
Graft diameter ≥ 8 mm	35	24.2 yr	9.4 yr		16.5 yr	74	50	62
Graft diameter < 8 mm	18	20.7 yr	7.5 yr	.1552				
PT length								
Graft diameter ≥ 8 mm	35	4.74 cm	0.56 cm		4.20 cm	86	67	76
Graft diameter < 8 mm	18	4.06 cm	0.48 cm	.0001				
PTML width								
Graft diameter ≥ 8 mm	35	2.89 cm	0.37 cm		2.74 cm	66	61	63
Graft diameter < 8 mm	18	2.68 cm	0.27 cm	.0685				
PT thickness								
Graft diameter ≥ 8 mm	35	0.381 cm	0.077 cm		0.333 cm	74	78	76
Graft diameter < 8 mm	18	0.313 cm	0.053 cm	.0008				
QT thickness								
Graft diameter ≥ 8 mm	35	0.798 cm	0.109 cm		0.813 cm	54	72	63
Graft diameter < 8 mm	18	0.773 cm	0.078 cm	.3284				
Semitendinosus CSA								
Graft diameter ≥ 8 mm	35	0.112 cm^2	0.014 cm^2		0.108 cm^2	63	83	73
Graft diameter < 8 mm	18	0.099 cm^2	0.014 cm^2	.0027				
Gracilis CSA								
Graft diameter ≥ 8 mm	35	0.074 cm^2	0.012 cm^2		0.063 cm^2	91	67	79
Graft diameter < 8 mm	18	0.060 cm^2	0.006 cm^2	<.0001				

NOTE. If the predictor value is above the threshold, then the predicted graft diameter is 8 mm or greater with the associated specificity, sensitivity, and accuracy listed.

BMI, body mass index; CSA, cross-sectional area; PT, patellar tendon; PTML, patellar tendon medial-lateral; QT, quadriceps tendon; SD, standard deviation.

a combination of anthropometric data with preoperative MRI measurements and found that the strongest indicators of graft diameter in their data set were ST and GT CSA combined with weight. In our study, height and

Table 3. Pearson r Values for Mean Tendon Measurements Between Image Readers Compared With Intraoperatively Measured HTA Diameter

Measurement	r Value	P Value
PT length	0.56	.00006
PTML width	0.2	.15
PT thickness	0.36	.008
QT thickness	0.24	.08
CSA		
ST	0.48	.0003
GT	0.71	.0001
ST and GT	0.67	.0001

CSA, cross-sectional area; GT, gracilis tendon; HTA, hamstring tendon autograft; PT, patellar tendon; PTML, patellar tendon medial-lateral; QT, quadriceps tendon; ST, semitendinosus tendon.

weight were strong predictors of an HTA diameter of 8 mm greater, whereas female sex was a predictor of an inadequate graft diameter (<8 mm). Although we found height and sex to be significant predictors, anthropometric data underperformed in comparison to MRI measurements; thus, these parameters were not included in our additive logistic regression model. One reason our results may have differed from those of the previous investigations is that we had a larger proportion of skeletally immature patients, we used a different anatomic location on MRI (relative position of the cross-sectional image on which measurements were obtained), and all of our MRI measurements were conducted on 3-T magnetic resonance images at 4× magnification. Additionally, our study reported a multivariate analysis including PT length, PT thickness, and QT thickness, which have not been previously used in studies of predictive measurements for HTA diameter. Our results suggest that a broad range of tendon measurements may offer improved accuracy for predicting

sufficient HTA diameter when compared with a combination of anthropometric and ST or GT measurements.

In addition to studies of anthropometric data, a number of recent investigations have reported a correlation of preoperative MRI hamstring tendon measurements with intraoperative HTA diameter. Grawe et al.[27] stated that a combined ST-GT CSA larger than 22 mm^2 can be used as a minimum cutoff for a graft diameter of 8 mm with a sensitivity and specificity of 100%. Similarly, Hollnagel et al.[29] reported that a combined CSA of at least 18.3 mm^2 was sufficient to produce an 8-mm graft with a sensitivity of 57% and a specificity of 80% with 3-T MRI measurement at the medial femoral condyle. Unfortunately, neither study reported on what percentage of the cohort actually met the reported threshold values. In our study, ST CSA greater than 11.2 mm^2 and GT CSA greater than 6.3 mm^2 were predictors of an intraoperative HTA of 8 mm or greater with an accuracy of 73.1% and 79%, respectively. The variation in cutoff values between different studies could be attributed to the variability in sensitivity, specificity, and accuracy. Grawe et al., for example, reported a relatively higher cutoff value, but this was to achieve a sensitivity and specificity of 100%. Although a diagnostic test with such high accuracy will never be incorrect, it may be of little clinical utility if very few patients' measurements actually meet the requisite high cutoff value. In our cohort, we observed 20 patients (37.7%) who met the ST cutoff value and 38 patients (71.7%) who met the GT cutoff value. Our reported additive logistic regression model, when applied among our patients, resulted in a specificity of 83.3%, sensitivity of 91.4%, and accuracy of 87.4% in predicting a final HTA diameter of sufficient size.

Making direct comparisons between studies is challenging for a number of reasons, such as differing CSA measurement techniques and the lack of standardization of imaging protocols. Different studies use different radiographic landmarks when measuring hamstring tendon CSA or diameter. These variable landmarks include an axial slice at the level of or just below the distal femoral physeal scar or 3 cm proximal to the articular surface. In our experience, defining the exact portion of the articular surface on which to base measurements, as well as identifying the relatively nonlinear appearance of the physeal scar or, in the setting of skeletally immature patients, the physis itself, was less reproducible in pilot studies. Therefore, in this study, we elected to use the axial slice that included the widest portion of the distal femur because it was highly reproducible between our observers and, at this level, the ST and GT have a more tubular appearance, making them more conducive to outlining with image analysis tools that are included with most available PACS software platforms. To improve the accuracy of our imaging assessments, MRI images were magnified 4 times their original size. Measurements conducted at this level of magnification have been shown to provide higher correlation with final HTA diameter.[33] However, other authors have suggested 2× magnification as optimal, suggesting that at 2× magnification, only the true tendon tissue may be measured, minimizing the chance of measuring adjacent muscle, vincula, or other soft tissues.[27]

Previous studies have shown ST CSA to have a stronger correlation with HTA diameter than GT CSA, which is in contrast to the findings of our study.[16,19,22,23,26-30,32-35] A possible explanation is that MRI CSA measurements may capture accessory band tissue, which will ultimately be removed from the final HTA.[37,38] The ST may have more abundant accessory band tissue than the GT, and the ST accessory bands often originate 10 cm proximally from the insertion site.[37] This would confound the correlation between ST MRI measurements and final HTA diameter to a greater degree than GT measurements. Another contributing factor is that the ST makes up a larger proportion of the final HTA than the GT, explaining why it has been more correlative with HTA in previous studies. In the clinical experience of the senior author (TJK), the GT tends to have a more variable size from one patient to the next. This was noted in our cohort, showing more variation in GT CSA measurements than in ST CSA measurements. Although the ST makes up a larger proportion of the final graft, the contributions of the GT may be more significant in achieving a graft of sufficient size owing to increased variability in the size of the GT in the population as observed among our patients.

Limitations

Our study has some noteworthy limitations. As with any retrospective study, there is concern for possible selection bias. Other limitations include the fact that we only used 3-T MRI studies in this investigation because this may limit the translation of our results to patients undergoing MRI on 1.5-T or lower—field strength machines, as well as the inherent relative inaccuracy and subjectivity associated with graft sizing. Most grafts are not uniform in diameter, and most commercially produced sizing guides are only available in 0.5-mm increments, which means there is a degree of rounding up of the graft diameter value, which may negatively impact correlations with the anatomic structures measured on MRI. In addition, there are variations in hamstring tendon harvesting technique, as well as variations in the methods of shaping, suturing, and tensioning the final graft construct, among the different surgeons, which could lead to different measurements of intraoperative HTA diameter. Our predictive model has not been validated in a prospective study or in a larger sample of patients, which are major limitations of our study and set the stage for future work. Despite these shortcomings, we find the initial characterization of this easily applicable approach (adding PT length and

thickness measurements to GT CSA) exciting. The reported results for estimating HTA diameter in the literature thus far are highly variable, and the approach described in this study has great potential to help improve estimations of HTA diameter in the future.

Conclusions

By combining PT length and PT thickness measurements with GT CSA measurements in a logit function model, we were able to show improved overall specificity, sensitivity, and accuracy of estimated HTA diameters in our data set when compared with assessments of anthropometric, ST CSA, GT CSA, or combined ST-GT CSA measurements in isolation.

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