Original Article

MRI Accurately Predicts Quadrupled Semitendinosus Autograft Size Using Posterior Hamstring Harvest for ACL Reconstruction

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Purpose: To determine the effectiveness of preoperative magnetic resonance imaging (MRI) measurements of the cross-sectional area (CSA) of the semitendinosus tendon in predicting the intraoperative quadrupled semitendinosus graft diameter of a posteriorly harvested hamstring autograft for anterior cruciate ligament (ACL) reconstruction. **Methods:** A retrospective review of patients who underwent ACL reconstruction with autograft using a posterior hamstring harvest was performed. Patient demographics and operative reports were reviewed, and measurements of the CSA of the semitendinosus on MRI were performed. Multiple linear regression was used to analyze the predictors for graft diameter. A P value $< .05$ was considered statistically significant. Interrater and intrarater reliability were calculated. **Results:** 280 patients were included. Patient height ($P < .0001$), and CSA of the semitendinosus ($P < .0001$) were significant predictors. Patients shorter than 63 inches had an average graft diameter of 7.89 mm compared to 8.69 mm for patients above 63 in ($P < .001$). The formula for the model is as follows: Graft diameter (mm^2) = 2.74 + .067·Height (in) + .00009 · Weight (lbs) + .0018 · Age (years) +.12·Gender (1 if M, 0 if F) + 8.56 · CSA (cm^2). The R^2 for the model (0.5620), was greater than models using only height (R^2 = .4092) or only CSA Semitendinosus (R^2 = .3932). None of the interaction terms between covariates (e.g., height, weight, age, gender) were significant. Age (P =.6400), weight (P = .9970), and gender (P = .6700) were not significant predictors. Both intraclass (ICC = 0.864, 95% CI=[0.791, 0.912]) and interclass correlation (ICC=0.827, 95% CI=[0.715, 0.894]) showed good reliability. **Conclusion:** CSA semitendinosus tendon and patient height independently perform similarly as predictors of graft diameter. When used together, CSA and height accurately predict the graft diameter. In particular, for patients under 63 in tall who demonstrated an average graft diameter below the minimum 8 mm, as suggested by the literature, this may be a useful tool for preoperative planning of patients intending to undergo ACL reconstruction with posterior hamstring harvest. **Level of Evidence:** Level III, diagnostic: retrospective cohort study.

The anterior cruciate ligament (ACL) is the most commonly injured ligament in the United States.[1] Accordingly, surgical reconstruction of the ACL is a common procedure, and the rate of this procedure has dramatically increased in the last few decades.[2,3] Fortunately, outcomes from ACL reconstruction are generally good, with a 2011 systematic review showing an 82% rate of return to sport after surgery.[4] However, a considerable amount of variability exists among orthopedic surgeons performing these procedures regarding preoperative planning and postoperative protocol, as well as graft type selection.[5] The decision of allograft or autograft has been the subject of several systematic reviews and meta-analyses[6-8] with additional discussion of radiated versus irradiated allograft.[7,8] Multiple autograft options have been touted as well as different methods of obtaining these grafts.

For hamstring autografts, harvest of the semitendinosus and possibly the gracilis tendon is traditionally performed through an anterior approach.[9,10] However, posterior hamstring harvest has been shown to be an effective, minimally invasive, and potentially advantageous technique.[9-11] Prodromos et al.[12] originally described the benefits of the technique in terms of improved patient-reported cosmesis, increased safety and efficacy of identifying and harvesting the desired tissue.[12]

Critical to the success of an anteriorly harvested or posteriorly harvested autograft, alike, is the an assurance of the diameter of the graft[13] given that

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inadequate graft diameter has been strongly associated with graft failure.[14] Magnussen et al.[15] have shown that hamstring grafts sized at less than 8 mm in diameter have an increased risk of retear.[15] Nuelle et al[11] compared their graft diameters using the posterior harvest technique to the Multicenter Orthopaedic Outcomes Network (MOON) data, as published by Mariscalco et al.[16] Although 49% of anteriorly harvested semitendinosus-only autografts had diameters greater than 8 mm,[16] 95% of posteriorly harvested semitendinosus-only autografts were 8 mm in diameter or greater.[11] Accordingly, we speculate this may represent a difference with respect to fiber loss during the harvesting process depending on the approach.

With either approach, preoperative predictions of graft sizes are imperative to preoperative planning to maximize outcomes, and techniques have been well-reported in the literature. Namely, the use of preoperative magnetic resonance imaging (MRI) has been shown to be an effective tool in predicting the graft size of traditional ACL autografts.[17-23] However, the effectiveness of preoperative MRI in predicting autograft sizes using posterior hamstring harvest has not been evaluated. The purpose of this study is to determine the effectiveness of preoperative MRI measurements of the cross-sectional area (CSA) of the semitendinosus tendon in predicting the intraoperative graft diameter of a posteriorly harvested hamstring autograft for ACL reconstruction. It is hypothesized that MRI measurement of the CSA of the semitendinosus will accurately predict the intraoperative graft diameter.

Methods

Study Design and Patient Selection

This study was approved by the Lawrence Memorial Hospital health system (LMHealth) Institutional Review Board (IRB).

After seeking approval from the IRB, a retrospective review was performed. Operative reports were reviewed from a single surgeon from 2017 through April 2021 to identify all patients who had undergone primary ACL reconstruction with autograft semitendinosus using a posterior-approach hamstring harvest. Patients whose grafts were augmented with gracilis or who had hybrid grafts augmented with allograft were excluded. Chart review was then performed by a medical student to confirm the diagnosis and operation and to record patient demographics (preoperative height, preoperative weight, preoperative body mass index, patient age, date of birth, and gender). The graft diameter listed in the intraoperative report was recorded. Measurements of the CSA of the semitendinosus on standard preoperative MRI images on the PACS system were performed by the attending surgeon and a orthopedic sports medicine fellow and recorded along with the magnet strength. Multiple measurements were made to perform inter-rater and intrarater reliability calculations.

MRI Technique

All preoperative knee MRIs were reviewed. If available, the proton density (PD)-weighted images were chosen for the CSA measurement, and the CSA measurements were taken on axial images at the widest level of the femoral condyle, consistent with MRI technique described by Grawe et al.[18] and Wernicke et al.,[23] and as demonstrated in Fig 1, below which has been reproduced from Grawe et al.[18]

Surgical Technique

A standardized preoperative process and surgical prophylaxis were performed, according to hospital policy. Each patient underwent a physical exam under anesthesia and diagnostic arthroscopy. The semitendinosus tendon was then harvested through a posterior approach, according to the technique originally described by Prodromos et al[1,2] and further discussed by Nuelle et al.[11] and Khanna et al.[9] The quadrupled autograft was then prepared with the GraftLink system/technique (Arthrex, Naples, FL) and sized using the sterile graft sizer, as described by Nuelle et al.[11] If the graft was determined by the operating surgeon to be too small, it was augmented with a gracilis tendon or allograft at the surgeon's discretion. The limb was then exsanguinated, and the ACL reconstruction portion of

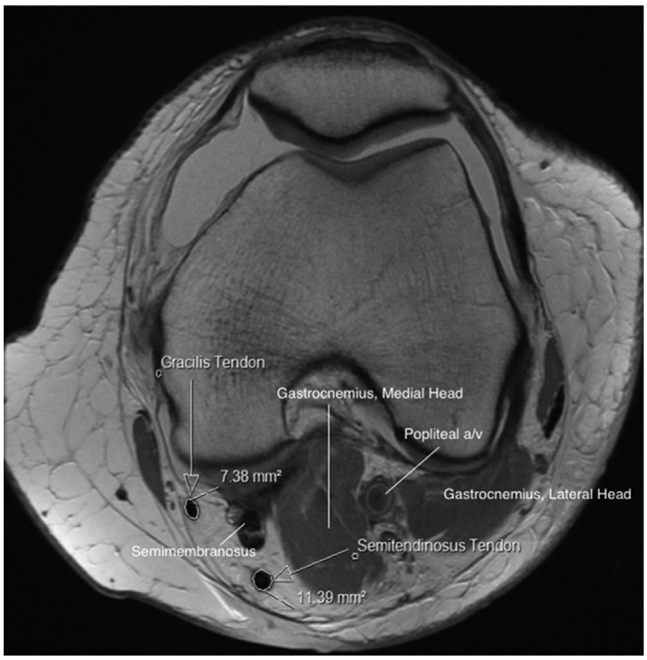

Fig 1. MRI axial image of a left knee demonstrating the technique used for measuring the cross-sectional area at the widest level of the femoral condyle (reproduced from Grawe et al.[18]).

the case began. Using standard technique, the surgeon drilled the femoral tunnel, and the graft was brought into the knee where it was affixed and tensioned using suspension, all inside technique. The knee was cycled, and the ACL graft retensioned multiple times prior to the initiation of closure. Closure then occurred followed by application of an ACE wrap, a TED hose, and knee immobilizer prior to the reversal of anesthesia.

Statistical Analysis

Two-way random effects interclass correlation was used to analyze the CSA measurements. Multiple linear regression was used to analyze the predictors for graft diameter. A P value <.05 was considered statistically significant.

Results

Of the 288 patients identified, 280 (97.2%) patients were included in this study. No patients were excluded because of incomplete records; 7 patients with hybrid grafts augmented by allograft and 1 patient with a graft augmented by gracilis tendon were excluded. Of the 280 patients included in the study, there were 132 female patients and 148 male patients. Patient ages ranged from 13 to 56 years old with an average age of 27 ± 10 at the time of the procedure. Average height was 68.4 ± 4.1 inches, and average weight was 175.83 ± 37.7 lbs. Patient body mass indices (BMI) (calculated from preoperative height and weight) was an average of 26.4 ± 4.8 kg/m^2 and ranged from 15.2 to 49.6 kg/m^2. Graft diameters ranged from 7 to 10.5 mm; the average was 8.64 ± 0.68 mm. CSA of the semitendinosus ranged from 0.08 to 0.25 cm^2 with an average of 0.14 ± 0.03 cm^2. Table 1 further provides information on mean patient demographics and CSA semitendinosus per graft diameters. Notably, smaller graft sizes (<8.0 mm) were only used without augmentation in female patients, whereas larger graft sizes (>9.0 mm) were almost exclusively obtained in male patients. Additionally, there appeared to be a natural cut-off in patient height for achieving an average graft diameter greater than the 8-mm cut-off, as supported by the literature. Patients shorter than 63 inches had an average graft diameter of 7.89 mm compared to 8.69 mm for patients above 63 inches ($P < .001$).

An increase of 1 inch in height was associated with an increase of 0.0679 mm (95% CI = [.0487, .0870]) in graft diameter. The R^2 value for the model using height alone is $R^2 = 0.4092$. For CSA of the semitendinosus, an increase in 0.01 cm^2 was associated with an increase of 0.086 mm (95% CI = [0.066772, 0.106186]) in graft diameter. The R^2 value for the model using CSA alone is $R^2 = 0.3932$. When height and CSA are used together to predict graft diameter, the adjusted R^2 for the model was $R^2 = 0.5620$. The formula for the model is as follows: Graft diameter = 2.74 + .067·height (inches) + .00009·weight (lbs) + .0018·Age (years) + .12·gender (1 if M, 0 if F) + 8.56·CSA (cm^2). None of the interaction terms between covariates (e.g., height, weight, age, gender) were significant. Height ($P < .0001$) and CSA of the semitendinosus ($P < .0001$) were statistically significant predictors of graft diameter. For the predictors of graft diameter, age ($P = .6400$), weight ($P = .9970$), and gender ($P = .6700$) were not significant.

Regarding inter-rater reliability for MRI CSA measurements, both intrarater (ICC = 0.864, 95% CI = [0.791, 0.912]) and interrater (ICC = 0.827, 95% CI = [0.715, 0.894]) showed good reliability.

Discussion

This study found that graft diameters for a posteriorly harvested hamstring tendon autograft can be reliably predicted. Patient height and CSA of the semitendinosus independently perform similarly when used alone to predict graft diameter ($R^2 = 0.3932$ and $R^2 = 0.4092$, respectively) but show a sizeable improvement when used together to predict the graft diameter ($R^2 = .5620$). Accordingly, these two variables can reliably predict the resulting graft diameter from a posteriorly harvested hamstring tendon for primary ACL reconstruction. This model may be particularly useful when considering graft options for patients less than 63 inches tall given that the average graft diameter for these patients was less than 8 mm ($P < .001$).

The causes of ACL graft failure are multifactorial, and risk factors are more numerous than graft

Table 1. CSA and Mean Patient Demographics per Graft Diameter

Patient Demographics and CSA [Mean (SD)]	Graft Diameter <8.0 mm M	<8.0 mm F	8.0 mm M	8.0 mm F	8.5 mm M	8.5 mm F	9.0 mm M	9.0 mm F	>9.0 mm M	>9.0 mm F
N	1	19	15	55	37	38	46	15	49	5
Age (years)	40	26.96	27.3	25.14	25.59	24.73	28.40	30.41	28.42	29.70
Height (inches)	70	63.47	68.46	64.78	69.81	66.20	71.75	67.40	71.98	68.88
Weight (lb)	220	140.26	178.47	157.65	179.97	158.7	197.56	169.79	198.18	192.00
BMI	31.56	24.46	26.73	26.37	25.99	25.54	26.9	26.35	26.98	28.52
CSA Semi-T (cm^2)	0.12	0.107	0.134	0.122	0.142	0.13	0.159	0.141	0.172	0.148

diameter.[24,25] However, inadequate graft diameter has been consistently proven to be a critical risk factor in poor tensile strengths in biomechanical studies[26] and graft failure in clinical studies.[14,15,25] The graft diameter, which has shown to be reliably predictable preoperatively, is a critical consideration in preventing graft failure after ACL reconstruction.

Our findings are consistent with prior literature correlating CSA measurements on MRI with the size of grafts obtained through an anterior harvest. Reliability of MRI CSA measurements has been discussed rather extensively in the literature.[18,19,22,23] Grawe et al. reported from a study of 84 skeletally mature patients that, "increasing CSA correlated well with increasing overall diameter of the graft ($P < .001$)."[18] Hanna et al. reported from a study of 30 patients that routine preoperative MRI is particularly useful in determining patients below a cut-off graft diameter of 8 mm, a well-supported minimum to avoid graft failure.[19] Wernecke et al. suggested a cut-off of 17 mm^2 for the CSA of the semitendinosus for double-bundled autograft.[23] Finally, Leiter et al. created a model similar to the one proposed in this study, in which CSA and weight accurately predicted the diameter of a four-stranded graft.[22]

Despite its proven reliability in the literature and in this study, variability of MRI magnet strengths and measurement techniques may be an inherent limitation of MRI for this purpose.[22,27] However, Thwin et al. demonstrated that magnet strength did not significantly affect the measurements of the CSA ($P > .438$) and were, "superior to anthropometric variables," in predicting graft diameter in their study.[27] Additionally, the American Academy of Orthopedic Surgery (AAOS) practice guidelines strongly support the use of MRI in preoperative planning for ACL reconstruction, stating, "Strong evidence supports that the MRI can provide confirmation of ACL injury and assist in identifying concomitant knee pathology, such as other ligament, meniscal, or articular cartilage injury."[28] Accordingly, preoperative MRI should remain the standard of care. Patient height should also be readily available and can be used to confirm whether a patient may be of concern for a small graft. Using CSA in combination with patient height can assist in confirming adequate graft size for a shorter patient in whom an inadequate graft diameter would have been predicted when using a model that solely relied on height.

Limitations

Limitations to this study include those inherent to a retrospective study, a relatively small sample size, and a single surgeon treating the patients. While intraclass and interclass radiology review analysis shows good reliability, there may be variability in the measurements of the CSA. There was not a specific MRI protocol used, resulting in a heterogeneous sample of MRI techniques. Although this may have increased the range of CSA measurements, it also increased the generalizability of the study. Patient race or ethnicity was not collected or analyzed in this study, so it is also possible that there could be variation based on race or ethnicity that was not identified in this study.

Conclusions

Both CSA semitendinosus tendon and patient height independently perform well as predictors of graft diameter. When used together, CSA and height more accurately predict the graft diameter. In particular, for patients under 63 inches tall who demonstrated an average graft diameter below the minimum 8 mm, as suggested by the literature, this may be a useful tool for preoperative planning of patients intending to undergo ACL reconstruction with posterior hamstring harvest.

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Disclosure

The authors report the following potential conflicts of interest or sources of funding: E.H. reports stocks or stock options in Johnson & Johnson, outside the submitted work. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

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