Correlation of intra-operative hamstring autograft size with pre-operative anthropometric and MRI measurements[☆]

Sally Corey^{a,*}, Terry Mueller^a, Christopher Hartness^b, Balakrishna M. Prasad^c

^a Department of Orthopaedic Surgery, Eisenhower Army Medical Center, 300 E Hospital Road, Fort Gordon, GA, 30905, Georgia

^b Department of Radiology, Eisenhower Army Medical Center, 300 E Hospital Road, Fort Gordon, GA, 30905, Georgia

^c Department of Clinical Investigations, 38705 Seventh Avenue, Fort Gordon, GA, 30905, Georgia

ARTICLE INFO

Keywords:

Hamstring autograft size
Anthropometric measurements
MRI measurements

ABSTRACT

The purpose of this study was to compare various pre-operative methods of estimating intra-operative hamstring autograft size. A retrospective review was completed on 74 patients who had an anterior cruciate ligament reconstruction performed using a quadruple-looped hamstring autograft from July 2007–April 2015 at a single institution. A positive correlation was observed between intra-operative graft size and pre-operative imaging using two methods of MRI measurements. Correlation existed between hamstring size and patient height and weight, but not age or BMI. Thus, pre-operative MRI and anthropometric measurements can be used to estimate intra-operative hamstring graft size.

1. Introduction

Anterior cruciate ligament (ACL) reconstruction is a common orthopaedic surgical procedure. Many graft choices exist to recreate the ACL, including the “hamstrings” (semitendinosus and gracilis tendons).^{1–3} The ideal size of ACL grafts has been reported as greater than 8 mm.^{4–6} Variability exists in the size of each individual's hamstring, making it difficult to obtain a graft of the ideal size at the time of harvest.⁷

Several methods exist to evaluate hamstring autograft sizes pre-operatively including anthropometric measurements^{8–20} and imaging measurements such as MRI, ultrasound, and CT.^{19,21–30} Anthropometric studies have yielded conflicting results in which measurements best predict hamstring graft sizes. Imaging studies have demonstrated a greater correlation between graft size and measurement methods, but have been performed using highly standardized methods and may not be as applicable in the true clinical setting, where more variability exists on imaging techniques and experience measuring images.

The purpose of this study was to compare anthropometric measurements to two different previously described methods of measuring MRI hamstring size to evaluate the optimal method of predicting intra-operative hamstring graft size. Our hypothesis is that MRI and anthropometric measurements will correlate with intra-operative hamstring graft size.

2. Methods

Institutional review board (IRB) approval was obtained prior to conducting this retrospective review. Patients with an ACL reconstruction performed using a quadruple-looped hamstring autograft from July 2007–April 2015 at a single US military institution were included. Operative reports were reviewed for intra-operative hamstring graft sizes. All grafts were created in the same manner. Semitendinosus and gracilis tendons were harvested and stitched together to create a four-strand grafts. Grafts were measured through a sequential cylindrical sizer (Arthrex®, Naples, FL, USA) in 0.5-mm increments.

Anthropometric and demographic data was collected to include age, gender, height, weight, BMI, and active duty status.

MRI scans were performed at various sites without a standardized method replicating the clinical setting of MRI procurement. MRI measurements were performed using two different methods. The method by Grawe et al., described using the widest portion of the distal femur on an axial image as a reference for determining which MRI sequence to measure the semitendinosus and gracilis. Zakko et al., described performing measurements on the MRI sequence, which shows the largest and most circular semitendinosus and gracilis tendons (Fig. 1). For both methods, observers were encouraged to magnify the images as needed and use a region of interest tool to determine the cross-sectional area of the tendons (IMPAX version 6.6.1.3525 2016, AGFA HealthCare,

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* Corresponding author. Dwight D. Eisenhower Army Medical Center, 300 E. Hospital Rd, Fort Gordon, GA, 30905, Georgia.

E-mail address: Sally.a.corey@mail.mil (S. Corey).

Fig. 1. Measurements of the same individual using the Grawe method (A) where the freeform region of interest tool is utilized to measure the semitendinosus and gracilis tendons at the widest portion of the distal femur. The Zakko method (B) uses the region of interest tool to measure the semitendinosus and gracilis tendons where they appear the largest and most circular.

Belgium). Measurements were initially performed using an ellipse region of interest tool; however due to poor inter-observer reliability, the freeform region of interest tool was utilized improving the inter-observer reliability. Measurements were performed independently by five different observers (two medical students with minimal experience reading MRI and using imaging software, a PGY-IV orthopaedic resident, a fellowship-trained orthopaedic staff, and a radiologist). All measurements were repeated a week later by each observer to assess intra-rater reliability.

2.1. Statistical analysis

Inter- and intra-rater reliabilities were assessed with intraclass correlation coefficients (ICC). Linear regression models were created to calculate correlation coefficients between intra-operative graft size and patient height, weight, age, BMI, and MRI measurements using the Grawe method and Zakko method. Linear trend analysis was performed to assess statistical significance of the correlations. Multivariable regression model was generated to determine differences in correlations based on gender, surgeon, and active duty status. Values of $p < 0.05$ were considered significant. A receiver operator characteristic curve (ROC) was developed for each variable with significant correlation to determine values associated with the greatest sensitivity and specificity corresponding to a graft size ≥ 8 mm. Power analysis was performed to ensure an adequate number of participants. Statistical analysis was performed using the Prism 6 program (Graphpad Software Inc. California, USA).

3. Results

A total of 74 patients (54 males and 20 females) were included in this study. A power analysis indicated an adequate number of participants for a power of greater than 80%. The average age was 24.6 years-old (range 15–45 years-old). Active duty service members comprised 58% of patients. The average graft size was 8.26 mm (range 7–10 mm).

The Grawe method of measurement had the greatest correlation to graft size, followed by the Zakko method of measurement, weight, and height. Age and BMI were not correlated to graft size (Table 1). Values which corresponded to a graft greater than 8 mm included a cross-sectional area of 20.97 mm² using the Grawe measurement method, 21.86 mm² using the Zakko method, 69.5 inches using height, and 184.5 pounds using weight (Table 2).

The ellipse region of interest tool was not utilized in this study because the ICC was 0.572 for the Grawe method and 0.391 for the Zakko method. Using the freeform region of interest tool, the intra-rater reliability for the Grawe method improved to an ICC of 0.853 and an inter-rater reliability of 0.736. The Zakko method had an ICC of 0.749 for intra-rater reliability and 0.660 for inter-rater reliability.

Table 1

Correlations between anthropometric and MRI measurements and intra-operative hamstring graft sizes.

	Average	Pearson correlation (r)	p value
Grawe method CSA	21.99 $\pm$ 4.3 mm ²	0.427	< 0.0001
Zakko method CSA	23.61 $\pm$ 4.2 mm ²	0.388	< 0.0001
Weight	182.62 $\pm$ 34 lbs	0.338	0.0036
Height	69.32 $\pm$ 3.86 in	0.314	0.0065
Age	24.6 $\pm$ 6.9 yrs	0.225	0.0538
BMI	26.6 $\pm$ 3.69	0.215	0.0655

Table 2

Sensitivity and specificity of cut-off measurement values corresponding to a graft ≥ 8 mm.

	Value	Sensitivity	Specificity
Grawe measurement	20.97 mm	70.59%	67.86%
Zakko measurement	21.86 mm	70.59%	71.43%
Height	69.5 in	64.71%	61.4%
Weight	184.5 lbs	76.47%	57.89%

Table 3

Pearson correlation values of anthropometric measurements compared to MRI measurements using both the Grawe and the Zakko methods.

	Grawe measurements	Zakko measurements
Height	$r = 0.393$, $p = 0.0006$	$r = 0.317$, $p = 0.0067$
Weight	$r = 0.430$, $p = 0.0002$	$r = 0.420$, $p = 0.0002$
BMI	$r = 0.270$, $p = 0.0216$	$r = 0.321$, $p = 0.0059$
Age	$r = 0.118$, $p = 0.3222$	$r = 0.143$, $p = 0.2302$

There was correlation between anthropometric measurements of height, weight, and BMI and MRI measurements of graft size (Table 3). There were no statistical significance between the linear regressions for different surgeons ($p = 0.089$ for the Grawe method and $p = 0.058$ for the Zakko), gender ($p = 0.808$ for Grawe and $p = 0.947$ for Zakko), or active duty status ($p = 0.895$ for Grawe and $p = 0.994$ for Zakko). The average graft size for active duty patients was 8.395 $\pm$ 0.128 mm and for civilian patients was 8.075 $\pm$ 0.143 mm, which was not statistically significant ($p = 0.103$). There was a statistical difference between gender in terms of graft size, age, height, BMI, and weight (Table 4).

4. Discussion

Multiple graft choices exist for anterior cruciate ligament reconstruction. The hamstring autograft has been shown to have comparable if not superior outcomes in comparison to other graft types in

Table 4

Average anthropometric measurements and graft sizes of males and females with statistical analysis of differences.

	Males	Females	p value
Graft size	8.476 ± 0.1086 mm	7.700 ± 0.1423 mm	p = 0.0002
Age	25.71 ± 0.8569 years	21.60 ± 1.624 years	p = 0.0204
Height	70.61 ± 0.3912 inches	65.46 ± 0.8368 inches	p < 0.0001
Weight	194.5 ± 3.729 pounds	148.6 ± 5.019 pounds	p < 0.0001
BMI	27.38 ± 0.4339	24.41 ± 0.8967	p = 0.0015

the young athletic population.^{1–3} Success of the graft may correlate to its size. Although the ideal graft size for each individual patient has yet to be determined, grafts larger than 8 mm in diameter have lower rates of revision and are preferred to smaller grafts.^{4–6,19,31} Hamstring autograft size is variable.⁷ Although many methods of predicting hamstring graft size exist,^{8–20,22–29} the best method has yet to be determined. Our study supports our hypothesis that pre-operative anthropometric and MRI measurements can correlate to intra-operative hamstring graft size. We find the Grawe method of MRI measurements has the best correlation to hamstring autograft size, and intra- and inter-rater reliability.

Several studies describe using pre-operative imaging to predict hamstring graft size including CT scans,²⁹ ultrasound,²³ and MRI.^{21,24–28,30} MRI are easy to assess because they are routinely performed for patients with ACL disruptions. Studies by Grawe et al.,²⁴ and Zakko et al.,³⁰ reported high correlation between MRI measurements and hamstring grafts greater than 8 mm, as well as excellent inter- and intra-rater reliability. Our goal was to compare these two methods of hamstring measurements. Our experience using both methods of MRI measurement was comparable to the studies by Grawe et al.,²⁴ and Zakko et al.³⁰ in that they both had a significant correlation to intra-operative graft size and are reliable. The Grawe method of measurement had a greater correlation coefficient and greater reliability; however a graft size of 21.86 mm² using the Zakko method had a greater specificity and equal sensitivity than using the cut-off of 20.97 mm² with the Grawe method.

One disadvantage of using imaging studies to predict hamstring graft size is that it relies on interpretation of the images. Previous studies have indicated reliability of using MRI imaging measurements as high as an ICC of 0.993.²⁴ Our study did not have inter- and intra-rater reliability values as high as previous studies, but did have “substantial” to “almost perfect” reliability even with medical students performing measurements.³² Our study supports that both methods of measurement are reliable even when performed by individuals with minimal experience in reading MRIs and using the imaging software.

An advantage of using anthropometric measurements, is that it eliminates any image interpretation variability and are easily obtained in a clinical setting. Unfortunately, most studies on the correlation of anthropometric data and hamstring graft size report variable outcomes. While some studies advocate that the correlation between weight and graft size is the most significant,^{14,18,20} most report height as the most accurate predictor of graft size.^{8,9,11–13,15–17} While the results of our study support that anthropometric data does correlate with intra-operative graft size, the correlation is not as great as MRI measurement methods.

Many authors attribute that variability of anthropometric data in predicting graft size to gender differences.^{9,12–18} We found that while females do have smaller hamstring grafts, they are also smaller in stature; thus the linear correlation between hamstring graft size and anthropometric values is the same for men and women. In addition, we found no difference in graft size between active duty military and civilians.

Difficulty in defining the optimal method of predicting hamstring graft size, may arise from the fact that different surgeons may use different methods of harvesting grafts. Although Dwyer et al.,³³ found

excellent inter- and intra-rater reliability for harvesting and measuring hamstring grafts in cylindrical sizes similarly to our method; Cruz et al.,³⁴ reports as much as 1 mm graft size variability depending on when the graft was measured during the graft preparation. We found no significant difference between surgeons in terms of graft size and correlation to pre-operative measurements. To our knowledge, this is the first study to compare the correlation of hamstring graft size to pre-operative measurements between different surgeons.

To our knowledge this is the only study to directly compare anthropometric measurements to MRI measurements in determining hamstring autograft size. Although Leiter et al.,²⁶ described success in combining anthropometric and MRI measurements to correlate with hamstring autograft size, they used special computer programs and software to conduct their study. Our study used commonly used imaging software.

One of the weaknesses of this study is that it is retrospective and relies on the accuracy of operative records in describing hamstring graft size. We also performed this in a clinical setting without standardization of MRI scans or hamstring harvest technique, which may affect the variability in our results; however this represents a realistic application of anthropometric and MRI measurement techniques in the clinical setting.

We also attempted to find a correlation between active duty status and hamstring graft size, which we hoped would describe our patients' activity level. Similar to other studies, we did not find a correlation,^{13,14,17} but we did not look at specific active duty military occupational specialty codes or patient reported activity assessments, which may better correlate with activity level.

5. Conclusion

Pre-operative anthropometric and MRI measurements do correlate with ultimate hamstring autograft size. The Grawe method of measurement was the most accurate and reliable method of determining intra-operative hamstring graft size in this study.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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