

# Hamstring Autograft Size Can Be Predicted and Is a Potential Risk Factor for Anterior Cruciate Ligament Reconstruction Failure

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**Purpose:** The purposes of this systematic review were (1) to determine whether there is a minimum hamstring autograft size for anterior cruciate ligament (ACL) reconstruction that significantly decreases the risk of failure and (2) to evaluate the methods to accurately and reliably predict the size of hamstring grafts. **Methods:** We performed a systematic review of Level III and IV studies using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. All studies assessing failure of quadrupled-strand autograft hamstring ACL reconstruction as a function of graft diameter with at least 1 year of follow-up and those that assessed the use of imaging or anthropometric patient-specific factors to predict hamstring autograft size were included. **Results:** We identified 4 clinical studies that directly compared graft size and failure rate. These correlated with a 6.8 times greater relative risk of failure if the graft diameter was equal to or less than 8 mm ( $P = .008$ ). All 9 anthropometric-based prediction studies were able to significantly correlate at least 1 parameter with intraoperative graft size. Height was the most common correlation, with  $r = 0.45$  ( $P < .00001$ ). Five of 6 imaging-based prediction studies showed significant correlation, with  $r = 0.66$  ( $P < .00001$ ), between cross-sectional area and graft size. The most common method of imaging prediction was magnetic resonance imaging—derived cross-sectional area of both the semitendinosus and gracilis tendons. **Conclusions:** On the basis of the available evidence, ACL reconstruction with a quadrupled-strand hamstring autograft with a diameter equal to or larger than 8 mm decreases failure rates. In addition, grafts larger than 8 mm decrease failure rates in patients aged younger than 20 years, a group identified to be at increased risk of failure. Both patient height and magnetic resonance imaging—derived cross-sectional area of the hamstring tendons can be used preoperatively to reliably predict the hamstring autograft diameter. **Level of Evidence:** Level IV, systematic review of Level III and IV studies.

There are a variety of grafts commonly used for reconstruction of the torn anterior cruciate ligament. These include autograft options such as bone—patellar tendon—bone, quadriceps tendon, and hamstring tendon, as well as multiple allograft sources.<sup>1-4</sup> Quadrupled-strand semitendinosus and gracilis grafts have been shown to have similar biomechanical and clinical results to

central-third bone—patellar tendon—bone autografts and may decrease anterior knee donor-site morbidity.<sup>5-11</sup> Despite the success shown with the use of quadrupled-strand hamstring for anterior cruciate ligament reconstruction (ACLR), failures still remain a problem and our techniques to eliminate these continue to evolve.

Potential sources of failure in hamstring autograft ACLRs have traditionally focused on technical errors with graft fixation or tunnel malpositioning. Recently, graft diameter has received increased focus as a source of ACLR failure.<sup>11-14</sup> Hamstring tendons show significant variability in size, and biomechanical studies have correlated the cross-sectional area (CSA) of collagenous grafts with strain and strength. These data cause concern among surgeons that diminutive grafts may be at risk of failure and require augmentation.<sup>3,4,15-19</sup> The diameter that exactly defines a diminutive graft has been a matter of debate but has been most commonly cited as 7 mm.<sup>12,19</sup> In addition, the debate has fueled

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interest in methods to predict hamstring graft diameters preoperatively.

The most common methods to predict hamstring graft size are imaging (magnetic resonance imaging [MRI], computed tomography [CT], ultrasound) or anthropometrics plus patient-specific factors (height, weight, age, sex, thigh circumference, and so on). Imaging-based prediction typically involves the use of software-based standardized measurement methods to determine the CSA of the gracilis and semitendinosus tendons and subsequent conversion of CSA to graft diameter based on correlation analysis. Similarly, anthropometric-based prediction involves correlation of patient-specific factors and measurements individually or in combination to do the same.

We performed a systematic review of the literature to determine whether (1) outcomes studies support a “minimum”-diameter quadrupled-strand hamstring autograft for ACLR that will significantly decrease the risk of graft failure and (2) is it possible to accurately and reliably predict the size of hamstring grafts by either radiographic or patient-specific anthropometric methods.

## Methods

### Search Strategy

A written protocol was developed in adherence with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to conduct a systematic review of the available literature. The Medline, PubMed, Embase, and Cochrane Collaboration bibliographic electronic databases were searched for relevant studies.<sup>20</sup> The primary search terms were “anterior cruciate ligament” AND [diameter OR size] AND “hamstrings,” followed by secondary search terms of either “revision OR failure,” “predictor OR prediction OR predict,” or “CT OR MRI OR computer tomography.” Studies to answer the first research question had to be English-language studies published in peer-reviewed journals, with a primary aim of assessing revision or failure of hamstring grafts as a function of graft diameter. The second research question included studies that assessed the use of imaging or patient-specific factors and anthropometrics to predict hamstring graft size with a correlation analysis performed based on operative findings. For both queries, the follow-up period must have been no less than 1 year. Studies focused on ACLR using patellar tendon grafts or allografts and studies that did not evaluate graft diameter were excluded. No non-peer-reviewed journals, case reports, technique papers, or editorials were considered. Subsequently, the bibliographies of each article were reviewed to ensure that potential inclusive studies were not missed. A hand review of relevant journals for the prior 6 months (*The Journal of Bone and Joint Surgery*, *The Bone and Joint Journal*, *The*

*American Journal of Sports Medicine*, and *Arthroscopy*) was also performed.

### Study Selection

All studies that resulted from both the primary and secondary searches were first checked for duplicates and then screened by title, abstract, methods, and results. Each study was subjected to a staged screening process by each author. The results of these searches are listed in [Tables 1, 2, and 3](#), and a diagram of the methodology is presented in [Fig 1](#). These selected studies were then submitted for data extraction.

### Data Extraction

A standardized form was used to assist in data extraction. Any differences in the identified relevant data were reconciled by consensus agreement of the reviewers. Statistical univariate analysis and distributions were performed by JMP software (version 9.0.2 [2010]; SAS Institute, Cary, NC). Comprehensive Meta-Analysis software (version 2.2; Biostat, Englewood, NJ) was used to perform the cross-study analysis. Odds ratios and 95% confidence intervals were calculated for each study.

## Results

The initial search parameters yielded 200 results, of which 112 remained after the secondary searches. After the inclusion and exclusion criteria were applied, 19 studies were identified and analyzed in this systematic review. Four studies evaluated hamstring graft diameter as a function of outcome, 6 reviewed the use of diagnostic imaging to predict graft size, and 9 evaluated the use of anthropometrics and patient-specific factors to predict graft size. The details of the studies are shown in [Tables 1, 2, and 3](#), including type of study, level of evidence, sample size, length of follow-up, technique of fixation, and correlation analysis.

### Question 1: Effect of Graft Diameter on Outcome

Four studies, with a total of 913 patients, were identified that directly related clinical outcomes of hamstring autograft ACLR as a function of graft diameter and are listed in [Table 1](#). Reflecting a growing recent interest in this subject, all 4 studies were published within the past 2 years. Three were Level III retrospective studies, and 1 was a Level IV study. Reconstruction techniques varied, with 2 studies preferring transtibial and 2 preferring anatomic tunnel positioning. Fixation methods, however, were more uniform, with all 4 studies preferring an interference screw with or without a staple or washer on the tibial side and most using cortical button suspension fixation on the femoral side.

The primary outcome, failure, was defined similarly by Mariscalco et al.<sup>13</sup> and Magnussen et al.<sup>21</sup> as revision

**Table 1.** Clinical Outcomes Studies

Study	Study Design, Time Frame	Study Population	Level of Evidence	Graft Type	Technique	Fixation	Primary Outcome (Failure)	Failure Rate	Failure Rate per Graft Diameter	Failure Rate Per Age and Graft Diameter	
										Older	Younger
Magnussen et al. <sup>21</sup> (2012)	Retrospective comparative study, 14 mo (range, 6-47 mo)	N = 256 (120 female, 136 male) Mean age, 25.0 yr (range, 11-52 yr)	III	4-stranded ST + GT	Transtibial or AMP by surgeon preference	Femur: cortical button Tibia: IS + staple or washer	Revision because of subjective instability or positive Lachman or pivot-shift findings	7.0% (18 of 256)	Graft >8 mm: 1.7% (1 of 58) Graft ≤8 mm: 8.6% (17 of 198)	Age >20 yr Graft >8 mm: 0% (0 of 36) Graft ≤8 mm: 1.0% (1 of 101)	Age ≤20 yr Graft >8 mm: 4.5% (1 of 22) Graft ≤8 mm: 16.5% (16 of 97)
Park et al. <sup>14</sup> (2013)	Prospective case series, 53.9 mo (range, 24-71 mo)	N = 296 (246 female, 64 male) Mean age, 29.8 yr (range, 14-61 yr)	IV	4-stranded ST + GT	Transtibial	Femur: cross pins Tibia: IS + staple or washer	IKDC grade C or D or revision	4.0% (12 of 296)	Graft ≥8 mm: 0% (0 of 65) Graft <8 mm: 5.2% (12 of 231)	NR	NR
Kamien et al. <sup>22</sup> (2013)	Cohort study, ≥24 mo	N = 98 (NR)	III	4-stranded ST + GT	Transtibial	Femur: cortical button Tibia: IS	Positive Lachman or pivot-shift findings, 5 mm on KT-1000 (MEDmetric, San Diego, CA) assessment, or revision	15.3% (15 of 98)	NS at 7 mm or 8 mm	Age >25 yr 6.0% (3 of 50)	Age ≤25 yr 25% (12 of 48)
Mariscalco et al. <sup>13</sup> (2013)	Retrospective comparative study (MOON database), ≥24 mo	N = 263 (119 female, 144 male) Mean age, 25.6 yr (range, 13-58 yr)	III	4-stranded ST + GT or 4-stranded ST	Transtibial or AMP by surgeon preference	Femur: cortical button Tibia: IS or IS + staple or washer	Revision for any reason	5.3% (14 of 263)	Graft >8 mm: 0% (0 of 64) Graft ≤8 mm: 7.0% (14 of 199)	Age >18 yr Graft >8 mm: 0% (0 of 47) Graft ≤8 mm: 0.8% (1 of 131)	Age ≤18 yr Graft >8 mm: 0% (0 of 14) Graft ≤8 mm: 18.3% (13 of 71)

AMP, anteromedial portal; GT, gracilis tendon; IKDC, International Knee Documentation Committee; IS, interference screw; MOON, Multicenter Orthopaedic Outcomes Network; NR, not reported; NS, not significant; ST, semitendinosus tendon.

**Table 2.** Imaging-Based Prediction Studies

Study	Study Design	Study Population	Imaging Type	Protocol Used	CSA of GT + ST
Hamada et al. <sup>24</sup> (1998)	Retrospective	N = 79 (38 female, 41 male) Mean age, 23 yr	1.5-T MRI	1 level, pixel counting	$r = 0.697, P < .0001$
Yasumoto et al. <sup>25</sup> (2006)	Retrospective	N = 28 (13 female, 15 male)	CT	1 level, 3D reconstruction, ellipse tool	NS
Bickel et al. <sup>23</sup> (2008)	Retrospective	N = 26 (14 female, 12 male) Mean age, 15.9 yr	1.5-T MRI	1 level, ROI tool	$r = 0.641, P < .001$
Wernecke et al. <sup>26</sup> (2011)	Prospective	N = 34 (9 female, 25 male) Mean age, 30 yr	1.5-T MRI	1 level, ROI tool	$r = 0.53, P = .001$
Beyzadeoglu et al. <sup>27</sup> (2012)	Prospective	N = 51 (7 female, 44 male) Mean age, 30.5 yr	3.0-T MRI	2 levels, 2× magnification, ROI tool	$r = 0.419, P = .002$
Erquicia et al. <sup>28</sup> (2013)	Prospective	N = 33 (8 female, 25 male) Mean age, 32 yr	3.0-T MRI and US—linear	MRI: 1 level, 2× or 4×, ROI and pixel counting US: ellipse tool	MRI 4×: $r = 0.86, P < .001$ US: $r = 0.506, P = .03$

GT, gracilis tendon; NS, not significant; ROI, region of interest; ST, semitendinosus tendon; 3D, 3-dimensional; US, ultrasound.

because of subjective instability or positive Lachman or positive pivot-shift findings. Kamien et al.<sup>22</sup> and Park et al.,<sup>14</sup> however, defined failure as increased laxity on postoperative examinations and poor International Knee Documentation Committee scores, respectively, with or without revision. The overall failure rate in the study of Kamien et al.,<sup>22</sup> 15.3%, was more than twice that in the other studies and most likely reflects the alternative definition of failure. This was also the only study to not find a correlation between graft diameter and outcome. The raw data from this study were not included in the published article, preventing its incorporation in the cross-study analysis. Park et al. found that grafts smaller than 8 mm had increased failure rates, whereas Magnussen et al. and Mariscalco et al. found that grafts larger than or equal to 8 mm had increased failure rates (Table 1).

There was a strong correlation among the studies when a meta-analysis was performed for the group, with a 6.8 times greater relative risk of failure for grafts equal to or less than 8 mm in diameter ( $P = .008$ ). Magnussen et al.<sup>21</sup> and Mariscalco et al.<sup>13</sup> performed a second analysis combining the effects of both age and graft size on failure rate. These results showed that young patients (aged <18 years or <20 years) had higher failure rates when compared with older patients (Table 1). However, when young patients underwent reconstruction with grafts larger than 8 mm, failure rates were reduced. A reduction in failure rate from 16.5% to 4.5% was identified by Magnussen et al. and from 18.3% to 0% by Mariscalco et al.

### Question 2, Part 1: Imaging-Based Prediction

We identified 6 studies that used imaging (MRI in 5 and CT in 1) to predict and correlate hamstring graft size, with a total of 251 patients. All but 1 study showed a significant correlation with intraoperative measured graft diameters (Table 2). The majority of studies were either prospective or retrospective case series with MRI.

In addition, all used similar methods of predicting graft diameter based on the combined CSA of the semitendinosus and gracilis tendons, which is summarized in Table 4. This was performed at similar locations along the knee joint and was obtained by software analysis with a region-of-interest tool based on the initial protocol developed by Bickel et al.<sup>23</sup> Other than the earliest attempt to predict graft diameter by Yasumoto et al.<sup>25</sup> in 1997, the only study based on CT, all 5 subsequent studies found significant Pearson correlation coefficients between CSA and intraoperative graft diameter.<sup>23-28</sup>

The sample size of most of the imaging studies was under half that of the average anthropometric study (42 patients v 124 patients). The study by Erquicia et al.<sup>28</sup> investigated both ultrasound- and MRI-based prediction and found that both can correlate significantly with intraoperative graft diameter. MRI-based prediction showed higher correlation than ultrasound, however (0.86 v 0.51). When the findings were taken as a group, imaging-based prediction of anterior cruciate ligament hamstring graft diameters showed a high correlation of 0.66 ( $P < .00001$ ). Two of the studies provided linear regression equations or graphs comparing CSA with graft diameter and were used to create the average CSA-to-graft diameter conversion shown in Table 5.<sup>23,28</sup>

### Question 2, Part 2: Prediction Based on Anthropometrics and Patient-Specific Factors

We identified 9 studies that have attempted to predict hamstring graft size in patients undergoing ACLR preoperatively based on anthropometric measurements and patient-specific characteristics. A total of 1,369 patients—551 female and 818 male patients—were evaluated. Commonly evaluated traits included sex, age, activity level, height, weight, body mass index, leg length, and thigh circumference (Table 3). These studies had larger sample sizes on average and included

**Table 3.** Anthropometric-Based Prediction Studies

Study	Study Design	Study Population	Leg Length	Mass/Weight	Thigh Circumference/ Diameter	BMI	Height	Age	Sex	Activity Level
Treme et al. <sup>17</sup> (2008)	Prospective	N = 50 (21 female, 29 male) Mean age, 31.6 ± 13.6 yr	Female: $r = 0.14$ , $P = .10$ Male: $r = 0.07$ , $P = .16$	Female: $r = 0.11$ , $P = .13$ Male: $r = 0.35$ , $P = .001$	Female: $r = 0.25$ , $P = .021$ Male: $r = 0.34$ , $P = .001$	Female: $r = 0.10$ , $P = .18$ Male: $r = 0.41$ , $P < .001$	Female: $r = 0.04$ , $P = .40$ Male: $r = 0.008$ , $P = .65$	Female: $r = 0.13$ , $P = .1$ Male: $r = 0.22$ , $P = .01$	NA	Female: N Male: N
Tuman et al. <sup>18</sup> (2007)	Retrospective	N = 106 (55 female, 51 male) Mean age, 32.9 ± 13.0 yr	NR	Female: $r = -0.12$ , $P = .3$ Male: $r = 0.22$ , $P = .06$	NR	Female: $r = 0.13$ , $P = .19$ Male: $r = 0.13$ , $P = .19$	Female: $r = 0.40$ , $P < .001$ Male: $r = 0.17$ , $P = .11$	Female: $r = 0.24$ , $P = .04$ Male: $r = 0.15$ , $P = .15$	NA	NR
Stergios et al. <sup>29</sup> (2012)	Retrospective	N = 61 (16 female, 45 male) Mean age, 27.0 ± 7.7 yr	NR	Female: $r = 0.408$ Male: $r = 0.47$ , $P < .01$	NR	Female: $r = 0.391$ Male: $r = 0.295$ , $P < .05$	Female: $r = 0.227$ Male: $r = 0.368$ , $P < .05$	NR	NA	NR
Schwartzberg et al. <sup>30</sup> (2008)	Retrospective	N = 119 (65 female, 54 male) Mean age, 25 yr	$r = 0.4177$	$r = 0.5118$	$r = 0.3447$	NR	$r = 0.3903$	$r = -0.0437$	NR	NR
Ma et al. <sup>31</sup> (2010)	Retrospective	N = 536 (302 female, 234 male) Mean age, 24.1 ± 10 yr	NR	$P < .019$	NR	$P < .06$	$P < .0002$	$P < .06$	$P < .0047$	NR
Pinheiro et al. <sup>32</sup> (2011)	Prospective	N = 80 (15 female, 65 male) Mean age, 31.6 ± 9.4 yr	$r = 0.39$ , $P = .001$	$r = 0.36$ , $P = .001$	$r = 0.27$ , $P = .014$	N	$P = .001$	N	Y	N
Boisvert et al. <sup>33</sup> (2011)	Retrospective	N = 132 (64 female, 68 male) Mean age, 17.9 yr	NR	NR	NR	$R^2 = 0.12$ , $P < .0001$	$R^2 = 0.17$ , $P < .0001$	NR	NA	NR
Thomas et al. <sup>34</sup> (2013)	Retrospective	N = 121 (13 female, 108 male) Mean age, 32 yr	NR	$r = 0.29$ , $P < .01$	NR	$r = 0.08$ , $P = .38$	$r = 0.38$ , $P < .01$	NR	$r = -0.28$ , $P < .01$	NR
Celiktas et al. <sup>35</sup> (2013)	Prospective	N = 164 (164 male) Mean age, 29.2 ± 8.0 yr	N	$r = 0.245$ , $P = .002$	$r = 0.083$ , $P = .290$	$r = 0.028$ , $P = .727$	$r = 0.397$ , $P = .0001$	$r = -0.030$ , $P = .7$	NA	NR

BMI, body mass index; N, no; NA, not available; NR, non reported; Y, yes.

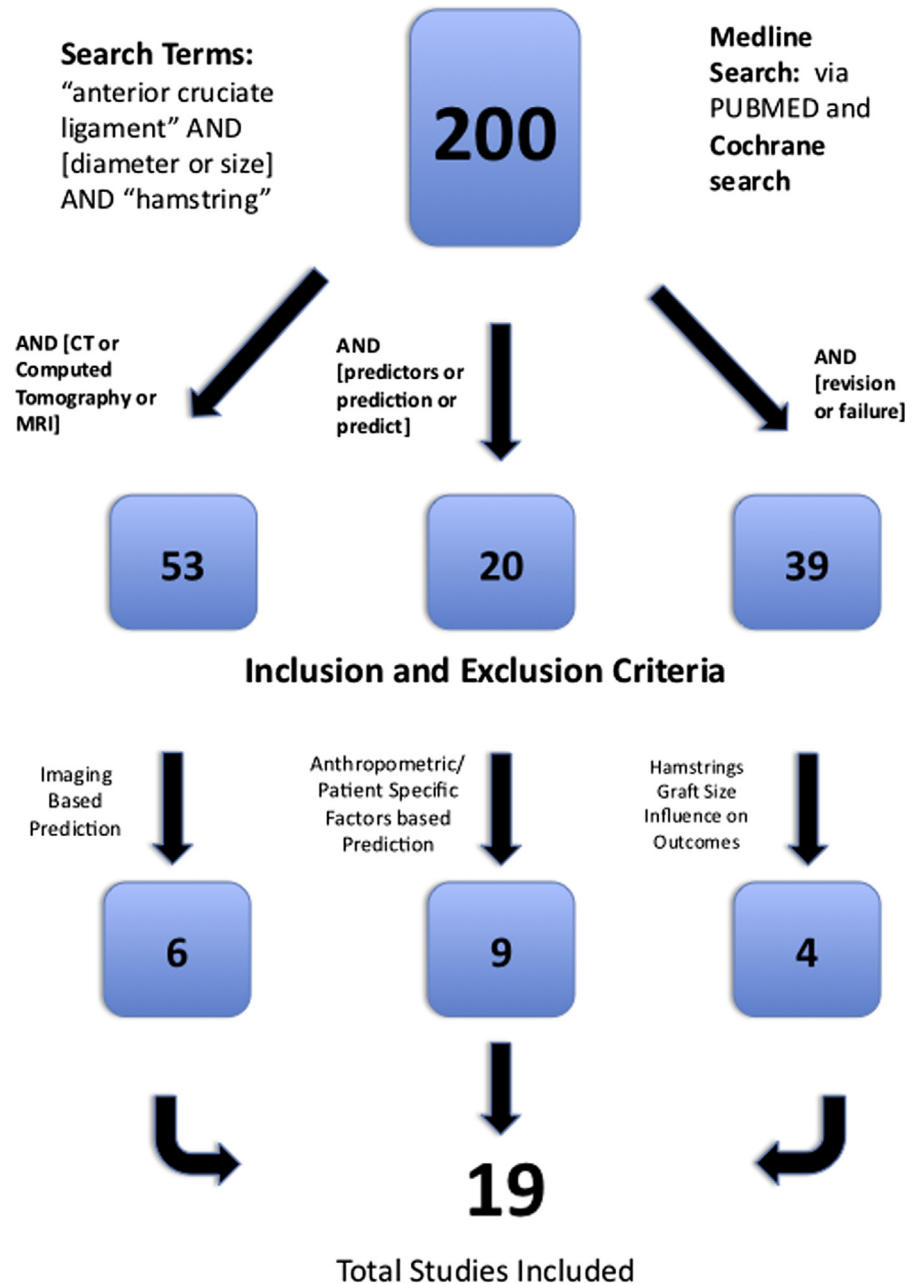


Fig 1. Search strategy and results.

substantially more heterogeneity in the data collection than that of the imaging studies. Three of the 9 studies separated most results by sex, and not all studies evaluated the same parameters. Furthermore, some studies combined parameters in correlation whereas some used parameters only individually.

Nearly all anthropometric studies were able to show significant correlation of at least 1 parameter studied, the most common being patient height. Cross-study analysis was more difficult than that of imaging-based prediction because of the heterogeneity of the data. To make analysis possible, we assessed the most commonly reported significant parameter, height, across

all studies and found an overall correlation of 0.45 ( $P < .00001$ ).<sup>17,18,29-35</sup> Five of the 9 studies provided linear regression equations correlating height to graft diameter. These were used to create the average height-to-diameter correlations shown in Table 5.<sup>17-19,34,35</sup>

#### Comparison of Imaging Prediction and Anthropometric-Based Prediction

The overall correlation for imaging-based studies ( $r = 0.66$ ) was higher than that of anthropometric-based prediction ( $r = 0.45$ ). However, sample sizes were much smaller in the imaging-based studies, and only 1 parameter was correlated for each, making assessment

**Table 4.** Method to Obtain Cross-Sectional Area From MRI Data (Based on Protocol Developed by Bickel et al.<sup>23</sup>)

Step 1: Using a coronal T1 sequence, find the widest part of the medial femoral epicondyle.
Step 2: At the corresponding level of an axial proton density sequence, use a freehand ROI tool to trace the circumference of the ST and GT.
Step 3: Apply the area function of the ROI tool to calculate the CSA of the ST and GT.

CSA, cross-sectional-area; GT, gracilis tendon; ROI, region of interest; ST, semitendinosus tendon.

simpler. No studies were identified that directly compared the 2 techniques in a head-to-head fashion. Combining all predictive studies, we found an overall correlation of  $r = 0.46$  ( $P < .00001$ ).

## Discussion

There are few studies in the published literature that have correlated outcomes of hamstring autograft ACLRs based on the size of the graft. This is the first systematic review that addresses failure of quadrupled-strand hamstring autograft ACLR with respect to size of the graft and the ability to preoperatively predict hamstring graft size. The use of hamstring autograft in ACLR necessitates a critical understanding of these factors to help identify and prevent implantation of a diminutive graft at risk of failure.<sup>11,13-15,19,36,37</sup>

Despite the historical cutoff for diminutive-sized hamstring grafts being 7 mm, a search of the literature did not identify any clinical study to qualify this size. Rather, it seems to have appeared anecdotally based on biomechanical analysis and to have been sequentially referenced.<sup>19,29,37</sup> On the basis of the available clinical studies, we have identified that quadrupled hamstring autografts of 8 mm or larger reduce failure rates of ACLRs. In addition, the studies by Magnussen et al.<sup>21</sup> and Mariscalco et al.<sup>13</sup> identified that large grafts, those greater than 8 mm in diameter, are especially protective in young patients (aged <20 years). This finding may represent a challenge to

**Table 5.** Average Correlation Between MRI Cross-Sectional Area and Patient Height With Graft Diameter

Predicted Graft Diameter (mm)	CSA of ST + GT (mm <sup>2</sup> ) on MRI	Patient Height (cm)
6.0	12.0	114
6.5	14.0	131
7.0	15.9	149
7.5	17.9	167
8.0	19.8	185
8.5	21.8	203
9.0	23.7	221
9.5	25.6	239
10.0	27.6	257

CSA, cross-sectional-area; GT, gracilis tendon; ST, semitendinosus tendon.

surgeons because hamstring grafts larger than 8 mm are uncommon, particularly in female patients and patients with shorter heights. To this end, there may be a role for methods to increase the diameter of the hamstring graft (as described in the section on our preferred method) or use a patellar tendon autograft in patients who have small hamstring grafts.

Both imaging and anthropometric patient-specific methods have been shown to be accurate and consistent in predicting hamstring graft diameter. Five of the 6 imaging studies that we identified were able to show significant linear correlation analysis between predicted graft diameters and intraoperative diameters, with a overall strong correlation ( $r = 0.66$ ).<sup>19,23,26,27</sup> All used similar methodology with MRI and a region-of-interest tool to calculate CSA (Table 4). Because most surgeons currently obtain an MRI study of the knee before ACLR and many software packages contain tools to measure CSA, this method of prediction may be added to routine preoperative planning with a small addition in protocol.

Anthropometric data are similarly useful for hamstring graft size prediction. All 9 anthropometric studies identified were successfully able to obtain significant linear correlations between predicted and intraoperative sizes.<sup>17,18,29,31-35</sup> Height was the most common predictor of larger grafts. Overall, the quality of the correlations with graft diameter obtained by any parameter in these studies was weaker than that of the correlations obtained by MRI CSA. An advantage of this method is the ease of collection of patient-specific factors and anthropometric measurements in the office setting.

The small sample sizes of the imaging-based studies, the heterogeneity of the patient-specific anthropometric studies, and the lack of a direct comparison of the 2 methods in a single head-to-head study limit our ability to make a definitive statement on which is more reliable. Thus both graft size—prediction methods are useful tools for the surgeon to identify patients at risk of small-sized grafts and prepare accordingly.

## Our Preferred Technique

In the event of a diminutive hamstring autograft harvest, various options are available. Augmentation with soft-tissue allograft is a possibility, although some patients may object to the use of cadaveric tissue and there is increasing evidence of high failure rates, particularly in young patients.<sup>38</sup> Use of bone—patellar tendon—bone autograft is another option but may not be acceptable to the patient or surgeon because of donor-site morbidity, pre-existing patellar tendon disease, or an occupation or sport that requires a significant amount of kneeling. Another option is the use of a 5-strand graft technique. This creates 3 strands from the longer and more robust semitendinosus tendon and uses a doubled-over gracilis tendon. Cortical suspension

provides fixation on the femoral side, and a screw and sheath are used for graft fixation on the tibial side.<sup>39</sup>

### Limitations

This systematic review has several limitations. The level of evidence of retrieved studies was poor, with no Level I or II studies identified. Furthermore, the sample sizes in most studies were small, particularly the studies with MRI prediction of graft size, which ranged from 26 to 79 patients.<sup>23-28</sup> The authors' definitions of failure in the outcomes studies also varied, and not all authors provided the data necessary for inclusion in the cross-study analysis.<sup>11,13,14,21</sup>

### Conclusions

On the basis of the evidence obtained in this systematic review, ACLR with a quadrupled-strand hamstring autograft with a diameter equal to or larger than 8 mm decreases failure rates. Grafts larger than 8 mm were found to provide a protective effect in patients aged younger than 20 years, a group identified to be at increased risk of failure. Both anthropometric parameters, such as patient height, and imaging parameters, such as the CSA of the hamstring tendons on MRI, can be used preoperatively to reliably predict the hamstring autograft diameter. This study provides a platform by which further investigation including prospective, randomized data can be obtained to further strengthen these recommendations.

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