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## Original Article

# Pre-operative MRI measurements versus anthropometric data: Which is more accurate in predicting 4-stranded hamstring graft size in anterior cruciate ligament reconstruction?

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## ABSTRACT

**Background/objective:** Graft diameter has been shown to play an important role in anterior cruciate ligament (ACL) autograft failure rates. The roles of pre-operative MRI measurement of graft size and anthropometric data have been studied in the prediction of hamstring graft size. Pre-operative knowledge of hamstring graft diameter allows surgeons to perform better surgical planning and provides an opportunity to discuss with patients on alternative graft options such as allografts should the need arises. The purpose of this study was to compare the accuracy of pre-operative anthropometric data and MRI measurements in the prediction of 4-stranded hamstring autograft size in anterior cruciate ligament reconstruction.

**Method:** This was a cohort study involving 141 subjects (115 males and 26 females) who underwent a single bundle ACL reconstruction utilising a 4-stranded hamstring graft by a single surgeon from 2008 to 2012. Pre-operatively, the height, weight, body mass index (BMI), age, gender and smoking status was recorded. The MRI scans used for diagnosis were utilized to measure the gracilis (GT) and semitendinosus (ST) cross sectional area (CSA).

**Result:** We found the strongest correlation between Combined (ST + GT) CSA and intra-operative graft size ( $r = 0.596, p < 0.001$ ). This was followed by ST CSA ( $r = 0.570, p < 0.001$ ), Body surface area ( $r = 0.507, p < 0.001$ ), and GT CSA ( $r = 0.460, p < 0.001$ ). No significant correlation was found between 2 anthropometric data (Age and BMI). There was also no significant difference between different strengths of MRIs (1.5T vs 3.0T) in determining the intra-operative graft size ( $p = 0.438$ ).

**Conclusion:** We conclude that pre-operative MRI is superior to anthropometric variables in predicting the size of 4-stranded hamstring autografts used in ACL reconstruction.

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## Introduction

There is a high rate of recreational sports participation in our community.<sup>1</sup> Given this trend, sports-related injuries such as anterior cruciate ligament (ACL) injuries are prevalent. For individuals who are active in sports, reconstruction of a torn ACL is the current standard of care in order to return these athletes to their previous sporting level.

Multiple graft options are available for ACL reconstruction, each

with its own risks and benefits. Graft selection is often based on multiple factors including age, activity level, donor site morbidity and the individual surgeon's preference. There are 3 categories of ACL grafts, namely autografts, allografts and synthetic grafts. Autograft options include bone-patellar-tendon-bone (BPTB), quadriceps tendon and hamstring autografts. Commonly used allograft options include tibialis posterior tendon, Achilles tendon, tibialis anterior tendon, BPTB and peroneus longus tendon.

BPTB autograft is historically considered the gold standard in ACL reconstruction. Numerous authors have studied the outcomes of BPTB graft in ACL reconstruction since it was pioneered by Franke in 1969 and have reported good outcomes.<sup>2–4</sup> However, BPTB graft is associated with potential complications of knee pain while

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kneeling, anterior knee pain on walking, patella fracture, and patella tendon avulsion.<sup>5</sup>

In recent years, hamstring tendon autografts (semi-tendinosus and gracilis) have increased in popularity with more surgeons selecting it as their graft of choice for ACL reconstruction.<sup>6,7</sup> There are several reported benefits of utilizing a 4-stranded hamstring tendons autograft. Good functional outcomes as well as low re-rupture rates have been reported by several authors.<sup>8,9</sup> In addition, compared to BPTB autografts, the 4-stranded hamstring tendons autograft has lower and less significant donor site morbidity, with the avoidance of extensor mechanism disruption.<sup>10–12</sup>

Despite these benefits, the hamstring tendon grafts have some limitations. One such limitation is being the difficulty in altering the diameter of the hamstring tendon intra-operatively, as compared to BPTB graft diameter. Studies have shown that a minimum hamstring graft size of 7.0 mm is recommended to reduce the rate of graft failure.<sup>13,14</sup> The use of anthropometric data of the patient to assess the graft diameter has been explored. Thomas et al. examined 121 patients (108 males, 18 females) who underwent ACL reconstruction and found that height ( $r = 0.38$ ,  $p < 0.001$ ), and weight ( $r = 0.29$ ,  $p < 0.001$ ) have the strongest correlation with hamstring graft diameter for both males and females. Body mass index (BMI) did not correlate with graft diameter in their study.<sup>15</sup> One of the criticisms of this study is that the confidence intervals are too large for accurate clinical use. In the literature, a few studies have also used imaging techniques to predict hamstring graft diameter. Most of the authors used MRI, except for Yasumoto et al. who used computed tomography (CT) scans.<sup>16</sup> These studies have their limitations, one of which is the relatively small sample size.<sup>17,18</sup>

To our knowledge, there is currently limited data, which directly compare the two techniques in a head-to-head fashion.<sup>19</sup> The purpose of this study is to determine whether preoperative MRI measurement of hamstring tendon cross-sectional area or preoperative anthropometric data such as height, weight, body mass index (BMI), body surface area (BSA), age, gender as well as smoking status is more accurate in determining intra-operative graft diameter and length.

## Methods

Institutional Review Board (IRB) approval was obtained for the conduct of this study. This is a retrospective cohort study involving 141 patients (115 males and 26 females) who underwent a single bundle ACL reconstruction utilizing a 4-stranded hamstring graft by a single surgeon (senior surgeon) from 2008 to 2012. Inclusion criterion for the study was an MRI proven, acute and complete ACL tear. Exclusion criteria included partial ACL tears, previous ACL reconstruction on the ipsilateral limb, multi-ligamentous knee injury and previous hamstring injuries or surgery. Pre-operatively, the height, weight, body mass index (BMI), body surface area (BSA), age, gender and smoking status were recorded. BSA is calculated using the Mosteller Formula;  $BSA (m^2) = [Height (cm) \times Weight (kg)/3600]^{1/2}$ .

The two hamstring tendons were harvested from each patient in a similar manner using vertical incisions and a closed-loop hamstring harvester. Both tendons were prepared and trimmed for a 4-stranded single bundle technique. The graft preparation was performed by the second surgeon under the direct supervision of the senior author in all cases. The tendon ends were whipped stitched using Ethibond 2 sutures and tubularized with Vicryl 2–0. The ends of the prepared graft were used to measure the functional length of the 4-stranded graft. The graft was measured sequentially using commercially available sizing cylinders with 0.5 mm increments. To ensure consistency of a tight fitting graft, the senior

surgeon will check the graft diameter personally prior to implantation. Endobutton CL loop (Smith & Nephew) was used for femoral fixation and Biosure screw was used for tibia fixation.

An MRI of each patient was performed using either 3.0 T or 1.5 T units with an 8-channel knee coil. 1.5 T MRI scanner was used in 91 patients while 3.0 T MRI scanner was used in 50 patients. Proton density (PD) axial images were used for the measurements. All the measurements were evaluated by a fellowship-trained musculoskeletal radiologist. We utilised the technique reported by Bickel et al.<sup>18</sup> A coronal proton density weighted image was used to identify the physeal scar. The cross-sectional area measurements of the gracilis tendon and semitendinosus tendon were taken at the level of physeal scar using a corresponding axial proton density cut. This cut produces a more tubular cross section of the tendon for measurement. The axial images were magnified where the gracilis tendon and semitendinosus tendon could best be seen to outline each tendon. The radiologist would manually trace each tendon's outline using General Electric Healthcare area measurement tool, after which the software automatically calculates the cross-sectional area in  $mm^2$  (Fig. 4). Combined cross sectional area was taken as the sum of gracilis tendon and semitendinosus tendon cross sectional area measurements. The reporting radiologist was blinded to the intra-operative measurements of the hamstrings on these patients.

Continuous variables were presented as mean (standard deviation) or median (interquartile range) after assessing normality. Frequency (percentage) was calculated for categorical variables.

Correlation coefficients (Pearson  $r$ ) were used to determine the relationship between graft diameter and predictor variables, pre-operative anthropometric data and MRI measurements. Higher correlation coefficients indicate stronger relationships between the variables.

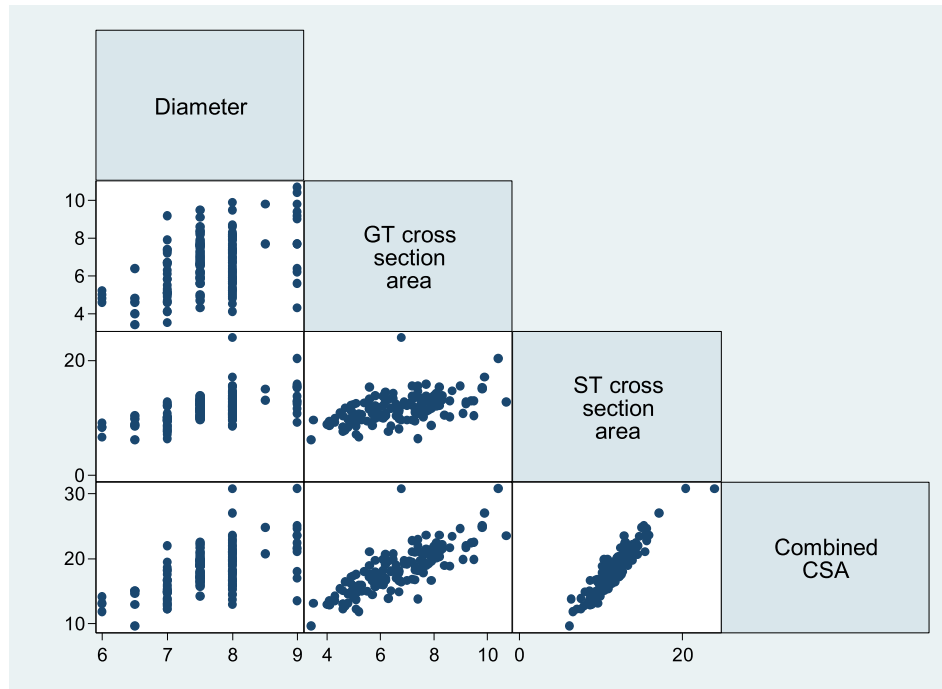
Receiver operating characteristic (ROC) analysis was done to determine a possible cut-off value for MRI cross sectional area to discriminate a graft diameter ( $\geq 7$  mm and  $\geq 8$  mm). Sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) were calculated to evaluate the utility of MRI cross sectional area measurements in accurately identifying sufficient graft diameter. All P values were two-sided, and values  $< 0.05$  were reported as statistically significant. Statistical analysis was performed using STATA v.13.0 (StataCorp, College Station, Texas, USA).

## Results

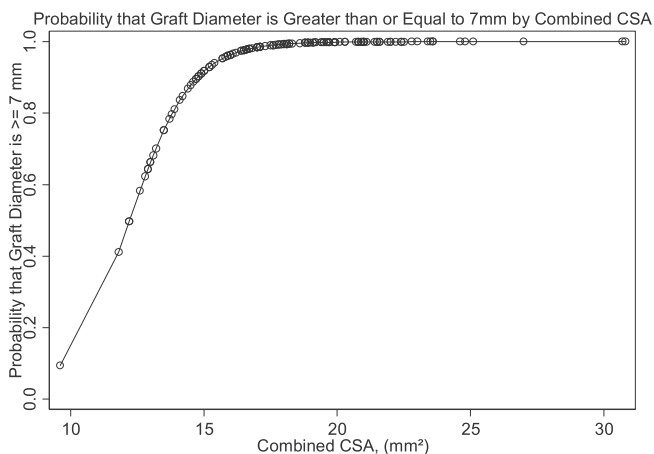
The mean graft diameter was 7.65 mm (6–9 mm) and the mean length was 12.43 cm (9–15 cm) (Table 1). The graft diameter and functional length was significantly smaller in females than in males. ( $p < 0.05$ ).

All the MRI based measurements showed moderate positive correlations with the intraoperative graft diameter (Fig. 1). The combined cross sectional area has the moderate correlations with the graft diameter ( $r = 0.596$ ). Some of the anthropometric data (BSA, Height and Weight) also showed moderate correlation. There was weak correlation for BMI and very weak correlation for age with graft diameter ( $r = 0.256$  and  $0.062$ , respectively) (Table 2). Hamstring graft length correlated poorly to all the pre-operative measured variables. Using a multiple regression model, there were no significant findings in our series.

Based on the ROC analysis, MRI cut-off value of Combined cross sectional area for the minimum desired intra-operative graft size of 7 mm and 8 mm are  $15.2 mm^2$  and  $17.9 mm^2$  (Figs. 2 and 3) AUC was found to be 0.92 for the graft size of at least 7 mm, which indicates excellent discrimination while AUC for graft size of at least 8 mm was found to be 0.73, which shows fair discrimination (Fig. 3).



**Fig. 1.** To compare the accuracy of pre-operative MRI measurement and anthropometric data in the prediction of 4-stranded hamstring autograft size in anterior cruciate ligament reconstruction. GT - Gracilis Tendon , ST - Semitendinosus tendon, CSA – Cross-sectional area.



**Fig. 2.** Logistic regression model to determine the probability of obtaining a graft of sufficient size. CSA – Cross-sectional area.

Using the logistic regression model, the probability of correctly classifying patients with sufficient graft size (at least 7 mm) is 85.1% giving a sensitivity of 84.1%. For those whose true graft diameter was equal or more than 7 mm, the specificity was 100%. The positive predictive value was 111 of 111 (100%), while the negative predictive value was 9 of 30 (30%) (Fig. 2). The odds of having a graft diameter of 7 mm or greater are 2.4 times greater for every one unit increase in combined cross sectional area ( $\text{mm}^2$ ) ( $p = 0.001$ ).

Multiple regression models yielded the following equation,

$$\text{Graft diameter} = 0.109 \times \text{Combined cross sectional area} + 5.656$$

Using multivariate linear regression model, the use of 1.5 T or 3.0 T MRI scanner to measure the combined cross sectional area does not appear to affect the intra-operative graft diameter

( $p > 0.438$ ).

## Discussion

4-stranded hamstring graft is one of the most common graft choices for ACL reconstruction given their comparable biomechanical strength and low donor site morbidity.<sup>20</sup> Graft diameter is one of the important factors in the outcome of ACL reconstruction. To reduce the risk of graft failure, a minimum graft diameter of 7 mm has been suggested in biomechanical studies.<sup>11,12</sup> Some recent clinical evidence however, has shown that a minimum graft diameter of 8 mm is needed for better outcomes.<sup>14,21–23</sup> but all these studies were in Caucasian populations who are in general taller and heavier. Magnussen et al. retrospectively reviewed 256 patients who underwent ACL reconstruction and found that the rate of revision surgery increases with smaller graft diameter; More than 8 mm: 1.7%, 8 mm–7.5 mm: 6.5%, 7.5 mm–7 mm: 9.4% and 7 mm or less: 13.6%.<sup>14</sup>

Many authors have tried to predict the graft diameter using anthropometric data, as these are readily available. However, there have been conflicting results. While some authors found height to have strong correlation with graft diameter, others found weight or a combination of height and weight to have a stronger correlation.<sup>14,24</sup>

MRI has been used to predict the hamstring graft size with some success. It has been shown that cross sectional area of semitendinosus tendon and gracilis tendon on MRI have strong correlations with the graft diameter. However, many of these studies have relatively small sample sizes; ranging from 26 patients to 79 patients.<sup>17,18</sup> Thus, it is difficult to draw a generalised conclusion from these studies.<sup>14,15</sup>

In our study, we reviewed a consecutive series of ACL reconstructions by a single surgeon from 2008 to 2012 and identified 141 patients who had a primary single bundle ACL reconstruction using a 4-stranded hamstring graft. Our study showed that

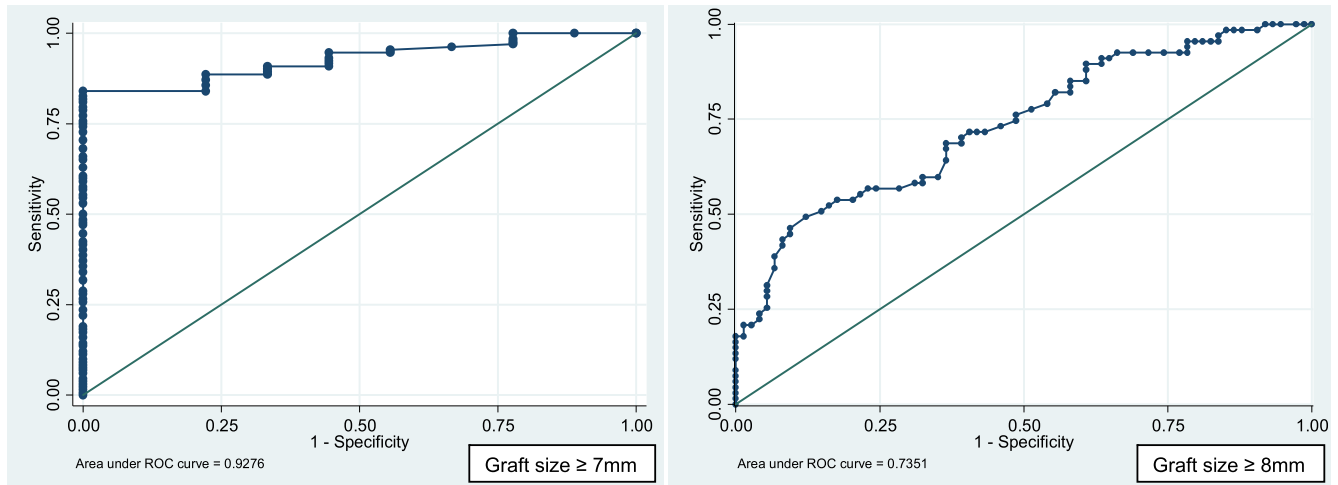


Fig. 3. Receiver Operating Characteristic Curve analysis of Graft size diameter  $\geq 7$  mm &  $\geq 8$  mm.

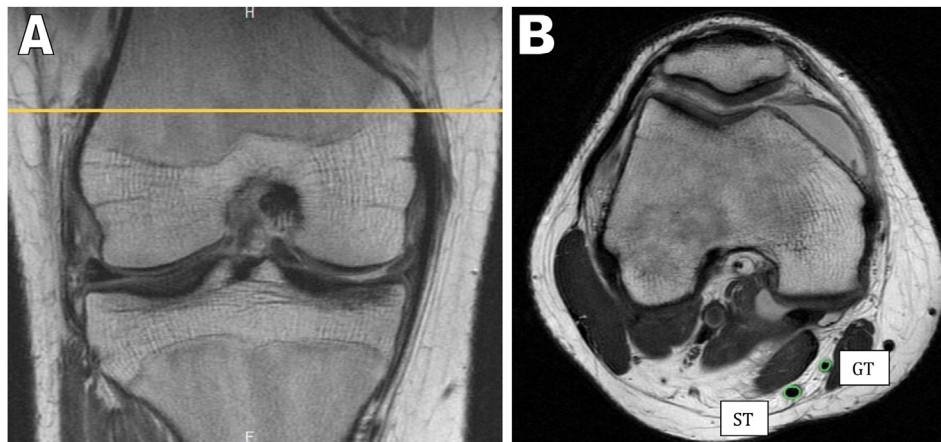


Fig. 4. Proton density-weighted (A) coronal and (B) axial magnetic resonance imaging of a knee. The cross sectional area of the gracilis tendon (GT) and semitendinosus tendon (ST) were measured at the level of physeal scar.

Table 1  
Demographic details.

Variable	Male (N = 115)	Female (N = 26)	P value
Age, Mean(SD)	24.85 (6.13)	24.46 (9.09)	0.836
Height, Mean(SD)	173.39 (7.05)	161.19 (6.26)	<0.001
Weight, Mean(SD)	75.54 (15.73)	60.62 (11.47)	<0.001
BMI, Mean(SD)	25.00 (4.83)	23.35 (4.36)	0.111
BSA, Mean(SD)	1.89 (0.19)	1.63 (0.15)	<0.001
Smoker, N (%)	45 (39%)	2 (7.7%)	0.002
Diameter, Mean(SD)	7.79 (0.56)	7.00 (0.66)	<0.001
Length, Mean(SD)	12.58 (1.12)	11.73 (1.15)	0.001
GT* cross section area, Mean(SD)	6.77 (1.46)	5.78 (1.61)	0.003
ST* cross section area, Mean(SD)	12.00 (2.31)	9.54 (2.29)	<0.001
Combined CSA*, Mean(SD)	18.78 (3.26)	15.32 (3.52)	<0.001
Magnet, N (%)			0.030
1.5 T	79 (68.7%)	12 (46.2%)	
3.0 T	36 (31.3%)	14 (53.8%)	

GT - Gracillis Tendon, ST - Semitendinosus tendon, CSA - Cross-sectional area.

Table 2  
Correlation between MRI measurements, pre-operative anthropometric data and graft diameter.

Variable	Pearson Correlation Coefficient (r)	P value
GT* cross section area	0.460	<0.001
ST* cross section area	0.570	<0.001
Combined CSA	0.596	<0.001
Age	0.062	0.468
Height	0.496	<0.001
Weight	0.436	<0.001
BMI*	0.256	0.002
BSA*	0.507	<0.001

GT - Gracillis Tendon, ST - Semitendinosus tendon, BMI - Body Mass Index, BSA - Body Surface Area.

moderate positive correlation between Height/Weight and graft diameter ( $r = 0.496$  and  $0.436$ ).

Beyzadeoglu et al. used measurements at 2 levels to measure the cross-sectional area of semitendinosus tendon and gracilis tendon on 3.0 T MRI. They found cross-sectional areas of GT, ST and Combined cross sectional area to be 7.3 mm, 12.9 mm and 20.3 mm respectively.<sup>25</sup> The difference between our study and Beyzadeoglu et al. result might be due to the fact that tendons in the Asian

amongst all the parameters, semitendinosus and Combined cross sectional area have the strongest positive correlation with the intra-operative graft diameter ( $r = 0.570$  and  $r = 0.596$ ). BSA appears to have the strongest positive correlation among the anthropometric parameters ( $r = 0.507$ ). This was followed by a

population are smaller.<sup>25,26</sup>

The region of interest tool is a common and widely available tool used to quantify an area on MRI, such as combined surface area of the hamstring tendons. The freehand region of interest method has been reported to have low variability and moderate repeatability.<sup>27</sup> A variety of MRI strengths have been used to calculate the cross sectional area in different studies.<sup>14</sup> Factors such as the strength of an MRI can affect the signal to noise ratio (SNR).<sup>28</sup> The SNR will in turn affect accuracy in utilizing the region of interest tool. In our study, 2 different strengths of MRI were used. Using a multivariate linear regression model, we found that the strength of the MRI used to calculate cross sectional area did not significantly affect the intra-operative graft diameter ( $p > 0.438$ ).

This study has several limitations. As with many of the other studies, there is a relatively small sample size of female patients. This is an important consideration as height is a known predictor of graft size, and the female patients in our study are significantly shorter than their male counterparts. The area of interest tool that was used to measure the cross-sectional area of the hamstring tendon was read by a single radiologist due to the limited number of fellowship-trained radiologist available at our center. As a result, no intra-observer variability was tested in this study. In addition, for this tool to be more relevant in clinical practice, inter-observer variability should also be tested.

## Conclusion

The combined cross-sectional area of gracilis tendon and semitendinosus tendon, cross section of semitendinosus tendon as well as BSA showed strongest correlation with intraoperative hamstring graft size. Anthropometric variables such as height and weight only showed moderate correlation with intraoperative graft size. We conclude that pre-operative MRI based measurements are a better technique than anthropometric variables in predicting the actual hamstring graft size. This information will enable the surgeon to undertake better pre-operative planning and discuss with patients the preferred graft options.

## Declaration of competing interest

The authors declares that there is no conflict of interest.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.asmart.2020.05.004>.

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