Can Preoperative MRI Predict Intra-Operative Hamstring Graft Size In Double Bundle Anterior Cruciate Ligament Reconstruction?

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Research Article

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Abstract

Background: Hamstring tendon graft diameters < 8 mm are considered a risk factor for graft failure. There is a lack of data regarding the prediction of double-bundle (DB) hamstring graft diameter using magnetic resonance imaging (MRI). This study aimed to evaluate whether preoperative MRI can be a predictor of DB hamstring graft diameter and to determine the minimum hamstring tendon cross-sectional area (CSA) on MRI required to produce a hamstring graft equivalent to 8 mm of a single-bundle (SB) graft, in the case of a DB graft.

Methods: A retrospective study was performed on patients who underwent anterior cruciate ligament (ACL) reconstruction between 2017 and 2020. The inclusion criteria were (1) patients aged 20 years or older and (2) operation with DB reconstruction. The exclusion criteria were (1) multiple ligament injuries, (2) previous hamstring injury, and (3) patients who underwent revision surgery. The correlation between preoperative MRI CSA and anthropometric data and graft size was calculated, and the factors most associated with graft size were calculated using multiple regression analysis. The receiver operating characteristic (ROC) curve was also used to calculate the threshold for creating a thicker DB graft.

Results: Based on the inclusion and exclusion criteria, we selected 69 patients for this study. There was a positive correlation between intra-operative graft size and height ($r = 0.590$, $P < 0.001$), weight ($r = 0.485$, $P < 0.001$) and preoperative MRI semitendinosus tendon + gracilis tendon CSA ($r = 0.591$, $P < 0.001$). Multiple regression analysis showed that preoperative MRI CSA was the most influential factor on intra-operative graft size ($\beta = 0.366$, 95% CI 0.237-0.946, $P = 0.001$). Based on the ROC analysis, the optimal cut-off value of MRI CSA for determining the CSA of DB graft corresponding to an SB diameter of 8 mm was 19.1 mm^2 (sensitivity 96.3%, specificity 80.0%).

Conclusions: MRI CSA was found to be the most relevant factor for graft size. The ability to predict graft diameter by preoperative MRI is beneficial for surgical planning and graft selection and may reduce the risk of failure.

Level of Evidence: Level IV, case series

Introduction

Anterior cruciate ligament (ACL) tears are a common sports injury, with an estimated annual incidence of about 68.6 cases per 100,000 people. [1] Among the different options for grafts used to reconstruct the ACL, autologous hamstring tendons are most frequently used. When using hamstring tendons for reconstruction, a graft diameter < 8 mm is a significant risk factor for graft failure [2 - 4]. Hamstring graft diameters are often unpredictable because hamstring tendon size varies widely among individuals. Identifying patients in advance who are at risk of having an inadequate hamstring graft diameter can help surgeons in their graft selection. In our opinion, if such patients can be identified before surgery, then alternatives such as using patellar tendon bone or quadriceps tendon autografts can be discussed with them for preoperative planning. Previously, various studies have been conducted to predict hamstring graft size preoperatively. Height, weight, leg length, and thigh circumference have been reported to correlate with hamstring graft size strongly; however, these results were inconsistent [5 - 10].

Therefore, more direct methods of estimating hamstring graft size have been investigated using magnetic resonance imaging (MRI) [11 - 16], computed tomography (CT) [17], and ultrasound [18], with promising results. Of these modalities, routine preoperative MRI is beneficial considering the medical cost and patient burden. Several studies have predicted single-bundle (SB) hamstring graft diameter using MRI cross-sectional area (CSA) measurements, but none have predicted the double-bundle (DB) hamstring graft diameter.

This study primarily aimed to investigate the correlation between MRI CSA measurements of the hamstring tendon, anthropometric data (height, weight, and body mass index [BMI]), and DB hamstring graft diameter to determine whether MRI CSA measurements of the hamstring tendon can be used as a predictor of DB hamstring graft diameter. Additionally, this study aimed to investigate the minimum hamstring tendon CSA on MRI required to produce an equivalent 8-mm SB hamstring graft in the case of a DB graft. We hypothesised that MRI CSA measurements would be a stronger predictor of hamstring tendon size than anthropometric data.

Materials And Methods

We performed a retrospective study on the patients who underwent ACL reconstruction at our institution between 2017 and 2020. The patients included in the study were aged 20 years or older, had undergone preoperative MRI and DB reconstruction (anteromedial bundle [AM] 4-stranded semitendinosus tendon [ST], posterolateral bundle [PL] 4-stranded gracilis tendon [GT]), and had their hamstring graft diameter measured intraoperatively. The exclusion criteria were patients with multiple ligament injuries, previous hamstring injuries, and those who underwent revision surgery. This study was approved by the Ethics Committee of Toho University, Ohashi Medical Center (No. H21099_H20039).

MRI measurements

MRI CSA measurements were performed using the region of interest tool, the PACS software (Synapse5 version 5.4.001, FUJIFILM Medical Systems, USA, Inc), by two readers (two experienced orthopaedic surgeons performed the measurements without knowing the graft diameter). The CSA was measured at 4× magnification with an axial fat-saturated proton density image. The axial slice level was measured at the medial femoral epicondyle [12] and cross-referenced using coronal images. The PACS region of interest tool has been approved by the US Food and Drug Administration for accurately measuring area [15].

Intra-operative measurements

Grafts of the GTs and STs were successfully harvested using a tendon stripper (Smith and Nephew. Inc. Memphis, TN, USA) in all knees and were not severed. The soft tissue was removed, and the AM bundle 4-stranded ST was used as the AM bundle, while the 4-stranded GT was used as the PL bundle. A graft sizing block (Smith and Nephew. Inc. Memphis, TN, USA) with holes in 0.5 mm increments was used to measure the diameter of the AM and PL bundles.

Statistical Analysis

All data are presented as mean $\pm$ standard deviations. The inter-observer reliability of the CSA measurement was calculated using the intraclass correlation coefficient (ICC) with two measurers. Based on the 95% confidence interval of the ICC estimate, a less than 0.5 was designated as poor reliability, 0.5 to

0.75 as moderate reliability, 0.75 to 0.9 as good reliability, and 0.90 or more as excellent reliability [19]. Correlation between the intra-operative graft size (AM+PL bundle CSA) and each item was performed using Pearson's correlation test, and multiple regression analysis was used to calculate the factors most associated with the intra-operative graft size (AM+PL bundle CSA). The area under the curve (AUC) of the receiver operating characteristic (ROC) curve of the tendon CSA measurement was used to determine the threshold for predicting the DB (total AM and PL bundle) CSA equivalent to the CSA ($8 \text{ mm} \approx 50.2 \text{ mm}^2$) of an 8 mm diameter SB. Post hoc power analysis of the correlations between the MRI CSA and each item resulted in $\alpha = 0.05$ with a power of more than 80 %. P -value < 0.05 was considered statistically significant. The IBM SPSS statistics 24.0 (SPSS Inc. IBM Company, Chicago, IL, USA) and EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan), a graphic user interface for R (R Foundation for Statistical Computing, Vienna, Austria), were used to perform the statistical analysis [20].

Results

Demographic data

A total of 161 patients who underwent ACL reconstruction at our institution between 2017 and 2020 were reviewed. After applying the exclusion criteria, 69 patients (41 males and 27 females) were included in the study. The mean age was 34.2 ± 9.0 years, the mean height was 169.3 ± 9.6 cm, and the mean weight was 67.0 ± 11.1 kg (Table 1).

Inter-observer reliability

The inter-observer reliability of the CSA of ST and GT on MRI was 0.80 (95% CI 0.70-0.87) and 0.85 (95% CI 0.76-0.90), respectively.

Correlation of each category to intra-operative graft size

There was a positive correlation between intra-operative graft size (AM+PL bundle CSA) and height ($r = 0.590$, $P < 0.001$), weight ($r = 0.485$, $P < 0.001$), and preoperative MRI ST+GT CSA ($r = 0.591$, $P < 0.001$). However, there was no correlation with BMI ($r = 0.108$, $P = 0.377$) (Table 2).

Multiple regression analysis

The factors most associated with intra-operative graft size (AM+PL bundle CSA) were calculated by multiple regression analysis and are shown in Table 3. The results showed that preoperative MRI CSA (ST+GT) was the most influential factor associated with intra-operative graft size AM+PL bundle CSA ($\beta = 0.366$, 95% CI 0.237 to 0.946, $P = 0.001$). The multiple regression model was statistically significant ($P < 0.001$).

Prediction of double bundle graft size using ROC analysis

Since preoperative MRI CSA (ST+GT) was found to be the most relevant factor for intra-operative graft size AM+PL bundle CSA, we determined the threshold for predicting graft size using MRI CSA. Based on the ROC analysis, the optimal cut-off value of MRI CSA for determining the cross-sectional area of DB graft

corresponding to an SB diameter of 8 mm was 19.1 mm², with a sensitivity of 96.3% and a specificity of 80.0%. The AUC was 0.919 (Fig 1).

Discussion

The main finding in this study was that the factor most associated with hamstring graft size in the multiple regression analysis was MRI (ST+GT) CSA. The second finding was that the cut-off value for predicting graft size equivalent to 8 mm or more in SB graft in the case of DB graft was found to be 19.1 mm² or more for MRI (ST+GT) CSA.

The rate of revision surgery after ACL reconstruction has been reported to be between 3.1% and 7.7% [21 - 22]. It has been reported that hamstring graft diameters of less than 8 mm are associated with a high risk of failure [2 - 4], and the ability to predict hamstring graft diameter with routine preoperative MRI is clinically vital. If the surgeon is aware of a high risk of failure before the operation, the surgeon can explain the risk to the patient and consider alternatives such as using other grafts. Several imaging techniques, such as MRI, ultrasound, and 3D CT, as well as anthropometric data, have been used in previous studies to predict hamstring graft diameter preoperatively [5 - 18]. Recently, routine preoperative MRI CSA has been used to predict the diameter of hamstring grafts preoperatively with good results [11 - 16]. Some previous studies have reported that height was most significantly associated with hamstring graft size [5 - 8, 10], but these studies did not take imaging data into account, and the results may vary from the present study. In this study, we performed a multiple regression analysis by taking anthropometric and imaging data into account and found that MRI CSA was the factor most associated with hamstring graft size. In addition, height, weight, and gender were not significantly associated with hamstring graft size. This finding supports the use of MRI CSA in predicting the size of the hamstring graft. Furthermore, if the size of the hamstring graft can be predicted by routine preoperative MRI, new tests are not essential, which is practical from the perspective of medical costs and patient burden. Hodges et al [12]. reported a cut-off value of 18 mm² for MRI CSA to create an 8-mm hamstring graft, and Hollnagel et al [14]. reported 17.5–18.8 mm². Although these reported cut-off values were based on SB grafts, the results were generally consistent with those obtained in this study with DB grafts [23 - 25]. Despite there being no advantage of DB over other grafts in ACL reconstruction, it has been reported to increase rotational stability [26-27]. The cut-off value for obtaining thicker DB grafts is a critical finding in this study. However, although the cut-off value for the total of the AM and PL bundle was found, the optimal size of each is still unknown.

Limitations

This study has some limitations. First, this study used DB grafts, and cut-off values were calculated. In SB grafts, a diameter of less than 8 mm is said to increase the risk of failure, but the corresponding diameter for DB grafts is still unknown. Graft size is likely a risk factor for failure as in SB grafts, but risk factors for failure in DB grafts should also be investigated in the future. Secondly, there was no standardised MRI protocol. This study was performed with retrospectively available MRI, and coils and imaging protocols may have been different. While consistent MRI protocols yield stronger correlations [18], studies that have taken measurements with non-standardised MRI have also yielded consistent results [12]. Finally, correlations with knee function, return to

sport, and objective measures such as range of motion and stability were not examined, as they were outside the scope of this study.

Conclusions

Preoperative MRI CSA was found to be the most relevant factor correlated with intra-operative hamstring graft size. MRI (ST+GT) CSA is a practical method with high sensitivity and specificity for predicting the appropriate DB hamstring graft size. The ability to predict graft diameter by preoperative MRI is beneficial for surgical planning and graft selection and may reduce the risk of failure.

Abbreviations

ACL: Anterior cruciate ligament

MRI: Magnetic resonance imaging

CT: Computed tomography

CSA: Cross-sectional area

BMI: Body mass index

SB: Single-bundle

DB: Double-bundle

AM: Anteromedial

PL: Posterolateral

GT: Gracilis tendon

ST: Semitendinosus tendon

ICC: Intraclass correlation coefficient

AUC: Area under the curve

ROC: Receiver operating characteristic

Declarations

Ethics approval and consent to participate

This study was approved by the institutional review board of Toho University Ohashi Medical Center (IRB No. H21099_H20039). As this was a retrospective study and all patient information was deidentified before analysis, the institutional review board of Toho University Ohashi Medical Center approved the study without the

need to obtain informed consent from the patients. All methods were performed in accordance with the Declaration of Helsinki.

Consent for publication

Not Applicable.

Availability of data and materials

All data analyzed during this study are included in this published article.

Competing interests

The authors declare that they have no competing interests.

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No funds were received in support of this study.

Authors' contributions

YS collected and analysed the data and drafted the manuscript. YM conceived of the study, participated in its design, collected and analysed the data and coordination and helped to draft the manuscript. KI and YM collected and analysed the data. HI contributed significantly to the writing and revised the manuscript. All authors read and approved the final manuscript.

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Tables

Table 1: Patient demographics and intra-operative and MRI measurements

Variables	Mean $\pm$ standard deviation
Male / Female	41 / 27
Mean age	34.2 $\pm$ 9.0
Height (cm)	169.3 $\pm$ 9.6
Weight (kg)	67.0 $\pm$ 11.1
BMI	24.0 $\pm$ 2.7
ST CSA (MRI)	13.9 $\pm$ 3.4
GT CSA (MRI)	8.5 $\pm$ 2.2
ST+GT CSA (MRI)	22.4 $\pm$ 4.9
AM CSA (intra-operative)	32 $\pm$ 5.3
PL CSA (intra-operative)	23.6 $\pm$ 4.0
AM+PL CSA (intra-operative)	55.6 $\pm$ 7.9

BMI, body mass index; ST, semitendinosus tendon; GT, gracilis tendon; CSA, cross-sectional area; MRI, magnetic resonance imaging; AM, anteromedial; PL, posterolateral

Table 2: Correlation between intra-operative graft size (AM+PL CSA) and, height, weight, BMI, and ST+GT CSA

Variables	R value	Confidence interval		<i>P</i> value
		Lower 95%	Upper 95%	
Height	0.590	0.411	0.725	< 0.001*
Weight	0.485	0.281	0.648	< 0.001*
BMI	0.108	-0.132	0.336	0.377
ST+GT CSA (MRI)	0.591	0.413	0.726	< 0.001*

BMI, body mass index; ST, semitendinosus tendon; GT, gracilis tendon; CSA, cross-sectional area; MRI, magnetic resonance imaging; AM, anteromedial; PL, posterolateral

Table 3: Multiple regression analysis for predictors of the dependent variable of intra-operative graft size (AM+PL CSA)

Adjusted R ²	0.448		Significance (<i>P</i> Value)		< 0.001*	
Variable	Unstandardised Coefficient	Standardised Coefficient	Confidence interval		<i>P</i> value	VIF
			Lower 95%	Upper 95%		
Intercept	22.41		-37.91	51.62	0.761	
Height	0.239	0.288	-0.019	0.497	0.069	2.988
Weight	-0.14	-0.020	-0.206	0.178	0.882	2.221
Gender	-2.863	-0.178	-0.759	1.869	0.231	2.684
ST+GT CSA (MRI)	0.591	0.366	0.237	0.946	0.001*	1.488

ST, semitendinosus tendon; GT, gracilis tendon; CSA, cross-sectional area; MRI, magnetic resonance imaging; AM, anteromedial; PL, posterolateral; VIF, variance inflation factor

Figures

Figure 1

The specificity (0.800) and sensitivity (0.963) of the receiver operating characteristic (ROC) curve are shown. The area under the curve (AUC) was 0.919. The optimal cut-off threshold for the balance of sensitivity and specificity was 19.1 mm².