The role of preoperative magnetic resonance imaging in the prediction of triple hamstring tendon graft size in patients undergoing anterior cruciate ligament reconstruction: a prospective study

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Background
Hamstring tendon grafts are efficacious and safe options for the reconstruction of anterior cruciate ligament (ACL) tears. However, a minimum graft size of seven millimeters is required to enhance its outcomes. Therefore, it is crucial to seek an effective and noninvasive way to predict the graft size to properly choose the reconstruction method.
Patients and methods
We prospectively included the data of 93 cases undergoing ACL reconstruction using triple hamstring graft. The measured graft size was correlated with cross-sectional area (CSA) of gracilis (G) and semitendinosus (ST), measured by magnetic resonance imaging (MRI) before the operation.
Results
The measured CSA of G and ST had mean values of 7.07 (range, 4–10.3) and 11.35 millimeters (range, 7.8–17.6), respectively. The combined CSA ranged between 12 and 27.6 mm (mean = 18.41). The cutoff point that was correlated with a graft diameter greater than or equal to 8 was a combined CSA of 16.9 mm. A significant positive correlation was detected between graft diameter and patients' weight, height, G CSA, ST CSA, and combined CSA. The area under the curve was 0.8, 0.801, and 0.833 for G CSA, ST CSA, and combined CSA, respectively. Linear regression analysis showed the reliable ability of MRI parameters to predict graft diameter.
Conclusion
MRI has a reliable predictive ability for the hamstring graft size used in ACL reconstruction. Its application should be encouraged in the orthopedic setting for such patients.

Keywords:
anterior cruciate ligament reconstruction, graft size, magnetic resonance imaging

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Background

The anterior cruciate ligament (ACL) is one of the most important stabilizing ligaments of the knee joint, and it is frequently injured in athletes and trauma patients. Around 200 000 individuals suffer from ACL injury every year in the USA, and half of them require subsequent reconstruction [1,2].

There are multiple graft options for ACL reconstruction, and each option has its pros and cons. Graft options include synthetic, autografts, and allografts. Graft selection should be suited for every patient according to his/her age, activity status, donor site morbidity, and surgical expertise of the operating surgeon [3].

Recently, autografting using the hamstring tendons has gained popularity among orthopedic surgeons [4,5]. The use of triple hamstring autograft also has additional benefits, including better functional outcomes and lower rupture rates [6,7]. Despite the previous advantages, it has some limitations. The main one is the difficulty of changing the graft diameter during surgery, unlike the bone-patellar tendon-bone graft approach [8].

One should know that a minimum graft diameter of seven millimeters is required to decrease the risk of postoperative graft failure [9,10]. Hence, it is crucial to seek preoperative parameters to accurately predict the hamstring graft size in order to properly choose another grafting option if the expected size is not enough for the reconstruction procedure [3].

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A previous study has evaluated anthropometric body measures to predict graft size [11]. Other reports used preoperative radiological assessment, including computed tomography (CT) or magnetic resonance imaging (MRI) parameters for the same purpose [12-14]. Nonetheless, most of these have many limitations, including the small sample size.

Herein, we conducted this study to evaluate the cross-sectional area (CSA) of hamstring tendons, measured by MRI, and its correlation with the actual graft size during ACL reconstruction using a triple hamstring graft. Our primary outcome was to correlate the preoperative CSA of gracilis (G) and semitendinosus (ST) with the triple hamstring tendon graft and to find the cutoff CSA that is correlated to the 8 mm graft size. Our secondary outcome was to correlate the graft size to the patient anthropometric measures.

Patients and methods

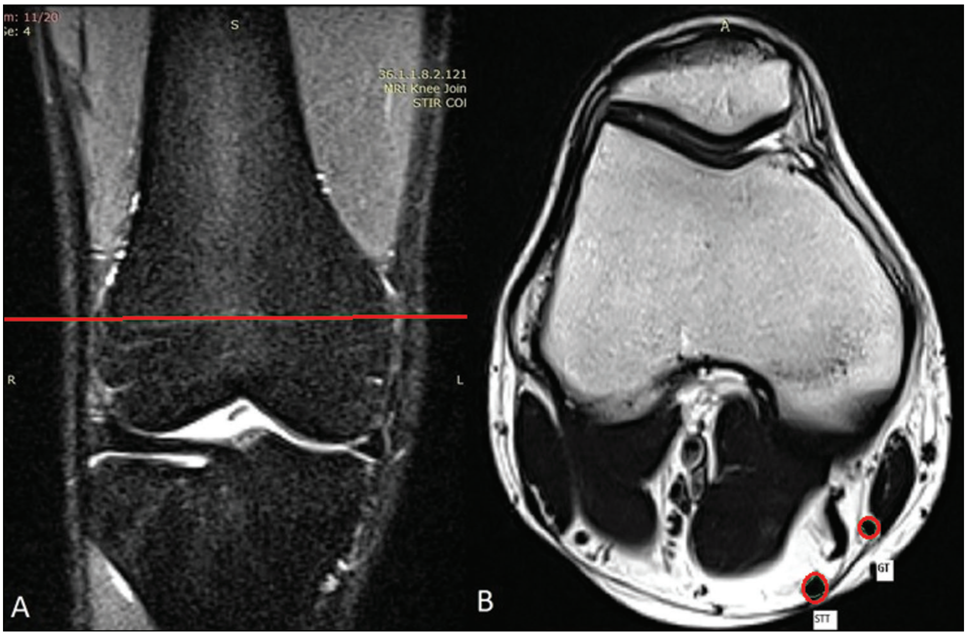
The current prospective study was conducted at the author's institute after approval of the ethical and scientific committee of the related medical school. The study included the skeletally mature patients diagnosed with ACL complete tears who were operated upon in our orthopedic surgery department between March 2022 and March 2023 (a total of 93 patients were included). The exclusion criteria were partial tears, associated ligamentous knee injury, associated injury to the hamstring muscles, or previous ipsilateral ACL operations.

Before the operation, all patients received the standard preoperative history taking, clinical assessment, as well as routine preoperative laboratory investigations. The diagnosis of ACL tear was confirmed based on history, clinical examination and knee MRI findings. MRI was done via a 1.5 T machine (Philips, Netherlands), and a coronal image was used to locate the physical scar, followed by axial images to measure the CSA of both G and semitendinosus (ST) tendons at the same level. The measurements were done at the same physical scar level, as it provides more tubular CSA of the required tendons. Magnification of the MRI images was done in the same region, followed by outlining each tendon. The CSA was automatically calculated for each tendon, and they were added to each other to estimate the combined CSA. (Fig. 1) These measurements were calculated by a single consultant of diagnostic radiology.

The main preoperative variables collected were age, sex, weight, height, body mass index (BMI), G CSA, ST CSA, and combined CSA.

All patients underwent ACL reconstruction by a single surgeon using the triple hamstring grafts. The tendons of both G and ST muscles were harvested through vertical incisions using an open-loop hamstring harvester. These tendons were prepared and trimmed for the triple single bundle technique. The tendon ends were stitched with Ethibond sutures, and they were then tabularized by vicryl 2–0 sutures. Both the diameter and length of the graft were measured

Figure 1



Coronal STIR (A), line representing plane of physical scar. (B) Axial T2 at same plane with cross-sectional area of Gracilis tendon (GT) and Semitendinosus tendon (STT) measured.

Table 1 General patient criteria

	Mean and SD	Median	Range	IQR
Age (y)	25.11 ± 5.138	24.00	16.0, 39.0	22.00, 29.00
Sex				
Male	76.3% (71)			
Female	23.7% (22)			
Height (cm)	171.67 ± 7.240	171.00	156.0, 187.0	166.00, 178.00
Weight (kg)	74.16 ± 10.140	73.90	53.1, 96.3	67.35, 81.00
BMI (kg/m^2)	25.16 ± 2.986	25.44	19.1, 29.8	22.96, 27.87

prior to implantation. For the reconstruction process, femoral fixation was done via endobutton adjustable loop, whereas tibial fixation was done via interference screw.

The collected data were tabulated and analyzed via the SPSS software. Categorical data were expressed as numbers and percentages, whereas numerical data were expressed as mean (with standard deviation) and median (with range and interquartile range). A correlation was done to detect the relation between graft diameter and the collected variable, while Receiver operating characteristic was done to measure the ability of MRI parameters to predict graft diameter. A *P* value less than 0.05 was considered significant.

Results

The age of the included patients ranged from 16 to 39 years (mean = 25.11), and most of them were men (76.3%). Regarding their anthropometric measures, their weight ranged between 53.1 and 96.3 kg (mean = 74.16), while their height ranged between 156 and 187 cm (mean = 171.67). Additionally, their BMI had a mean value of 25.16 kg/m^2 (range, 22.96–27.87) (Table 1).

The measured CSA of G and ST had mean values of 7.07 (range, 4–10.3) and 11.35 mm (range, 7.8–17.6), respectively. The combined CSA ranged between 12 and 27.6 mm (mean = 18.41). Graft length ranged between 8.6 and 10.3 cm (mean = 9.4), while its diameter ranged between 6.5 and 10.5 mm (mean = 8.2) (Table 2).

There was a significant negative correlation between the graft diameter and the female gender. Nonetheless, a significant positive correlation was detected between graft diameter and patients' weight, height, G CSA, ST CSA, and combined CSA (Table 3). Both age and BMI did not show a significant correlation with the graft diameter.

For the prediction of graft diameter more than or equal to 8 mm in diameter, the area under the curve was 0.8, 0.801, and 0.833 for G CSA, ST CSA, and combined CSA, respectively (P<0.001). The cutoff point that was correlated with a graft diameter greater than or equal to 8 was a combined CSA of 16.9 mm. The diagnostic parameters of each CSA are illustrated in Table 4 and Fig. 2.

Linear regression analysis showed the excellent ability of MRI parameters to predict graft diameter (P<0.001) (Table 5).

Table 2 Magnetic resonance imaging measurements in the current study

	Mean and SD	Median	Range
GT CSA	7.07 ± 1.620	7.00	4.0, 10.3
ST CSA	11.35 ± 2.184	10.90	7.8, 17.6
Combined CSA	18.41 ± 3.445	18.10	12.0, 27.6
Graft Length (cm)	9.4 ± 0.707	9.5	8.6,10.3
Graft Diameter (mm)	8.2 ± 0.863	8.50	6.5, 10.5

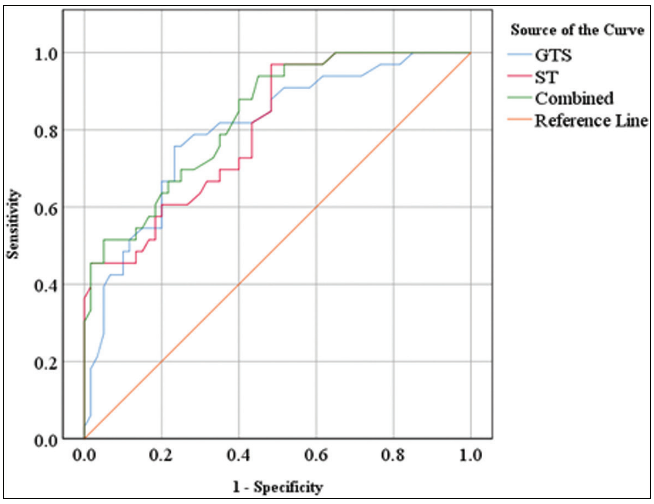
Table 3 Correlation between graft diameter and other clinical and radiological variables

Diameter	Correlation coefficient	*P*
Age	–0.153	0.142
Female gender	–0.414	**< 0.001**
Height	0.381	**< 0.001**
Weight	0.292	**0.005**
BMI	0.086	0.412
G CSA	0.574	**< 0.001**
ST CSA	0.644	**< 0.001**
Combined CSA	0.678	**< 0.001**

Table 4 Magnetic resonance imaging measurements in the prediction of graft diameter greater than or equal to 8 in the current study.

Graft diameter greater than or equal to 8	GT CSA	ST CSA	Combined CSA
AUC	0.800	0.801	0.833
95% CI of AUC	0.706, 0.893	0.711, 0.891	0.751, 0.915
P	**<0.001**	**<0.001**	**<0.001**
Cutoff point	7.45	10.25	16.9
Sensitivity	75.8%	97.0%	93.9%
Specificity	76.7%	51.7%	55.0%
PPV	64.1%	52.5%	53.4%
NPV	85.2%	96.9%	94.3%

Figure 2



Receiver operating characteristic curve analysis of graft size diameter greater than or equal to 8 mm.

Table 5 Linear regression to assess magnetic resonance imaging measurements in the prediction of graft diameter in the current study

	R^2	B	95% CI	Constant	*P*
G CSA	32.9%	0.306	0.215, 0.396	5.547	< **0.001**
ST CSA	41.5%	0.254	0.191, 0.317	4.820	< **0.001**
Combined CSA	46.0%	0.170	0.131, 0.208	4.580	< **0.001**

Discussion

Although the triple hamstring tendon graft is an effective option for ACL reconstruction, the used graft should be at least seven millimeters thick to achieve the desired postoperative outcomes [15,16]. Other studies even recommended increasing that diameter to eight millimeters to obtain better outcomes [17-19].

Therefore, it is important to seek methods to predict the diameter of such tendons before the reconstruction procedure, especially since G and ST tendons have numerous anatomical variations [15,20]. It is necessary to identify patients with a high risk of graft insufficiency to take the needed precautions.

In the current study, age did not express a significant correlation with graft size (*P*=0.142). Treme and colleagues noted no significant correlation between age and graft size (*r*=0.15 – *P*>0.05) [21], which agrees with our results. On the other hand, other authors reported a significant negative correlation between the same two previous parameters (*r*=−0.16 – *P*=0.05) [22].

Our findings revealed that women tended to have a smaller graft size (*P*<0.001). Other authors also reported the association between the female gender and smaller graft sizes [22]. The same findings were also published by Ma *et al.* [23].

We noted a significant positive correlation between preoperative weight and graft size (*r*=0.292 – *P*=0.005). Schwartzberg *et al.* also found a significant positive correlation between patient weight and graft size (*r*=0.51 – *P*<0.001) [24]. Contrarily, Ma and colleagues denied any significant correlation between preoperative weight and graft size [23].

Our findings revealed the positive, significant correlation between patient height and graft size (*r*=0.381 – *P*<0.001). In line with our findings, Tuman and colleagues reported a significant positive correlation between the same two previous variables (*r*=0.36, *P*<0.001) [22]. Papastergiou and colleagues also reported the same findings [25].

We did not detect any positive correlation between BMI and graft size (*P*=0.412). Tuman and colleagues coincided with our findings, as they detected no significant correlation between the same two parameters (*P*>0.05) [22]. Contrarily, another study reported a significant positive correlation between BMI and graft diameter (*r*=0.62 – *P*<0.05) [21].

Our findings showed that preoperative MRI measurements were significantly correlated with intraoperative graft diameter measurements. MRI even expressed a higher correlation with graft size compared with the anthropometric measures. MRI had a strong sensitivity and moderate specificity to predict sufficient graft diameter (> 8 mm).

Thwin and colleagues agreed with our findings, as G, ST, and combined CSA had a significant positive correlation with the actual graft diameter (*P*<0.001). The sensitivity and specificity of MRI in detecting suitable grafts (7 mm or more) were 84.1% and 100%, respectively [3].

Moreover, Wernecke and colleagues reported the same findings as there was a significant positive correlation between preoperative MRI and intraoperative findings, including G CSA, ST CSA, and combined CSA (*P*=0.0006, 001, and 001, respectively) [26]. They reported a cutoff point only for the G CSA and ST CSA and not for the combined CSA for prediction of the 7 mm graft diameter.

Beyzadeoglu and colleagues also noticed a significant positive correlation between G CSA, ST, CSA and combined CSA measured by preoperative MRI and intraoperative graft size [27]. Erquicia and colleagues also confirmed the previous findings. The authors reported a 96.2% sensitivity and 100% specificity for identifying tendons with CSA more than 8 mm [28].

However, our study had a bigger sample size than all these reports. Moreover, we were able to find a cutoff point of the combined CSA of G and ST that allows us to be able to preoperatively predict if the triple graft diameter would exceed the golden 8 mm or not. If not, the surgeon should seek another graft option.

Our study had some limitations. Firstly, the included patients were gathered from a single orthopedic center. Additionally, inter-observer variability should have been assessed regarding MRI findings. The previous drawbacks should be well-covered in the upcoming studies.

In conclusion, MRI has a reliable predictive ability for the hamstring graft size used in ACL reconstruction. Its preoperative application should be encouraged in the orthopedic setting for such patients.

Acknowledgments

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Conflicts of interest

There are no conflicts of interest.

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