Original Article

Preoperative magnetic resonance imaging evaluation of semitendinosus tendon in anterior cruciate ligament reconstruction

Does this have an effect on graft choice?

Mutlu Cobanoglu, Ferit Tufan Ozgezmez, Imran Kurt Omurlu[1], Ilhan Ozkan, Sevki Oner Savk, Emre Cullu

Abstract

Background: Anterior cruciate ligament (ACL) reconstruction with ST autograft is sometimes unsuccessful because of harvested thin graft. Magnetic resonance imaging (MRI) can be a useful tool to evaluate the thickness of the graft. This study is performed to evaluate whether there is any correlation between diameters and cross-sectional area (CSA) of the semitendinosus tendon (ST) on the preoperative magnetic MRI and the diameter of the 4-stranded ST autograft in ACL reconstruction.

Materials and Methods: Seventy patients who underwent single-bundle ACL reconstruction with 4-stranded ST for full-thickness ACL ruptures were included in this study. Anteroposterior (AP) and mediolateral (ML) diameters of ST at the levels of the joint line (JL) and femoral physeal line (PL), and also CSA at these levels were measured on T2-weighted fat-suppressed MRI examinations. The data obtained were compared with intraoperatively measured diameters of 4-stranded ST autograft. Correlations between variables were evaluated using Spearman's rho. Receiver operating characteristic and area under the curve statistics were used to evaluate the cut-off value for the correlation between 4-stranded ST graft diameter of 8 mm and CSA (mm^2) on MRI.

Results: On MRI measurements, no correlation was found between AP diameters at the level of the JL and 4-stranded ST diameter ($P = 0.180$). However, correlations were found between diameter of 4-stranded ST and ML diameter at the level of JL ($P = 0.003$) and PL ($P = 0.002$), AP diameter at the level of the PL ($P = 0.009$), CSA at the level of the JL ($P < 0.001$) and at the level of PL ($P < 0.001$). Correlation between the diameter of 4-stranded ST and CSA at both levels was more significant than that between AP-ML diameters of ST and diameter of autograft. The cut-off value for the 8 mm diameter CSA of 4-stranded ST was 5.9 mm^2 at the JL and 8.99 mm^2 at the PL.

Conclusion: Preoperative MRI evaluation of CSA at the JL of the ST is a reliable parameter to predict graft size. Other graft alternatives should better be considered if the CSA of ST is <5.9 mm^2 at the level of the JL.

Key words: Anterior cruciate ligament, cross-sectional area of semitendinosus, graft diameter, semitendinosus tendon, semitendinosus diameter

MeSH terms: Anterior cruciate ligament, magnetic resonance imaging, autograft, sports injuries

Introduction

Anterior cruciate ligament (ACL) reconstruction is the commonly accepted treatment in ACL injuries in adults. The reconstruction can be performed with various techniques according to the preference and

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Access this article online	
Quick Response Code:	Website: www.ijoonline.com
	DOI: 10.4103/0019-5413.189612

How to cite this article: Cobanoglu M, Ozgezmez FT, Omurlu IK, Ozkan I, Savk SO, Cullu E. Preoperative magnetic resonance imaging evaluation of semitendinosus tendon in anterior cruciate ligament reconstruction: Does this have an effect on graft choice?. Indian J Orthop 2016;50:499-504.

experience of the surgeon. Regarding the success of ACL reconstruction, the major factor for hamstring autograft is the graft size.[1,2] As it is widely accepted opinion that hamstring tendon autograft should be at least 7 mm in diameter for a successful treatment.[2,3] In recent studies, the authors have indicated that the diameter of tendon equal to or more than 8 mm decreases the risk of graft failure.[2,4] However, the diameter of the hamstring graft can only be determined after folding the harvested autograft into 4-stranded.[5] This situation leads to interest in finding ways to predict graft diameter preoperatively. To predict the graft size, there are some studies about evaluation of the diameter of hamstring tendons preoperatively with magnetic resonance imaging (MRI), computed tomography (CT), and ultrasonography (USG).[1,6-10] In all studies about this subject, both gracilis tendon (GT) and semitendinosus tendon (ST) were used for ACL reconstruction.[1,6-10]

Some authors prefer both ST and GT to obtain 4-stranded autograft, whereas some of them prefer only ST in single-bundle ACL reconstruction.[7,11] This study is designed for single-bundle ACL reconstruction technique with 4-stranded ST autograft. The aim of the present study is to evaluate whether there is a correlation between the diameters, the cross-sectional area (CSA) of the ST on the preoperative MRI and the diameter of the 4-stranded ST autograft measured during the surgery.

Materials and Methods

Eigthy two patients who underwent ACL reconstruction between March 2011 and November 2014 were retrospectively reviewed from medical records. The patients who underwent single-bundle ACL reconstruction with 4-stranded ST graft were included in this study. Patient with multiple ligament knee injuries, revision ACL reconstruction, hamstring tendon injury, double-bundle reconstruction, and single-bundle ACL reconstruction with ST and GT autograft were excluded. Three of the 82 patients who underwent double-bundle ACL reconstruction and one who underwent revision ACL reconstruction, one with multiple ligament injuries treated with allograft and seven of 82 patients whose preoperative MRIs were not found on picture archiving and communication system (PACS), were excluded. The study population consisted of 70 cases who underwent anatomical single-bundle ACL reconstruction using only 4-stranded ST autografts. All patients underwent routine MRI examinations using 1.5-T unit MRI device (Philips Electronics NV, USA) preoperatively. Anteroposterior (AP) and mediolateral (ML) diameters and CSA of ST at the level of the joint line (JL) and femoral physeal line (PL) were evaluated on axial T2-weighted fat-suppressed MRI examinations. Measurements were performed on PACS computerized system under ×10 magnification by the person blinded to the intraoperative measured graft diameters. To determine ST at the level of the JL, posterior horn of the medial meniscus was tagged with three-dimensional (3D) cursor on the sagittal image, and ST on the axial image corresponding to the same section was determined [Figure 1]. To determine ST at the level of the femoral PL, femoral PL was tagged with 3D cursor on the sagittal section and ST on the axial image corresponding to the same section was determined [Figure 1]. Maximum AP and ML diameters were measured on axial MRI images. The CSA measurement was evaluated manually tracing the tendon with the free hand tool. Measurements of diameter and CSA were performed at the outermost border of the hypointense region of the tendon [Figure 2]. Data obtained from MRI were compared with intraoperatively measured diameter of 4-stranded ST autograft tendon. All surgeries were performed by arthroscopic methods. The graft was harvested through anteromedial incision. Soft tissue remnants of the graft were removed and its length was adjusted to at least 6 cm after folding as 4-stranded. Then diameters of grafts were measured using cylindrical caliber gauges (from 5 to 11 mm with increment by 0.5 mm). For the purpose of standardization, diameters were measured and evaluated from the unsutured femoral part of the graft. The length of the graft was adjusted so as to leave at least 1.5 cm

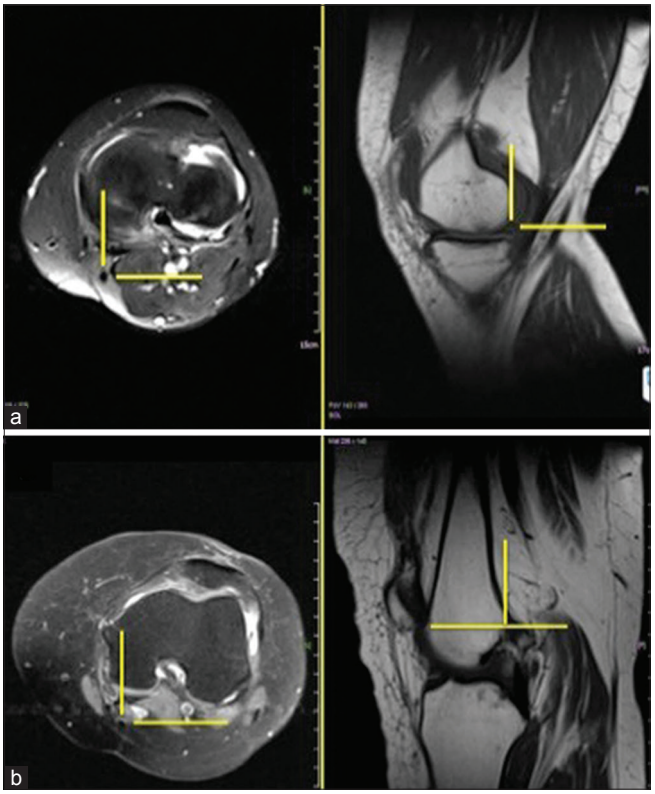

Figure 1: MRI axial and sagittal views T2W fat suppressed showing (a) Semitendinosus tendon, marked at the level of the joint line, (b) Semitendinosus tendon, marked at the level of physeal line

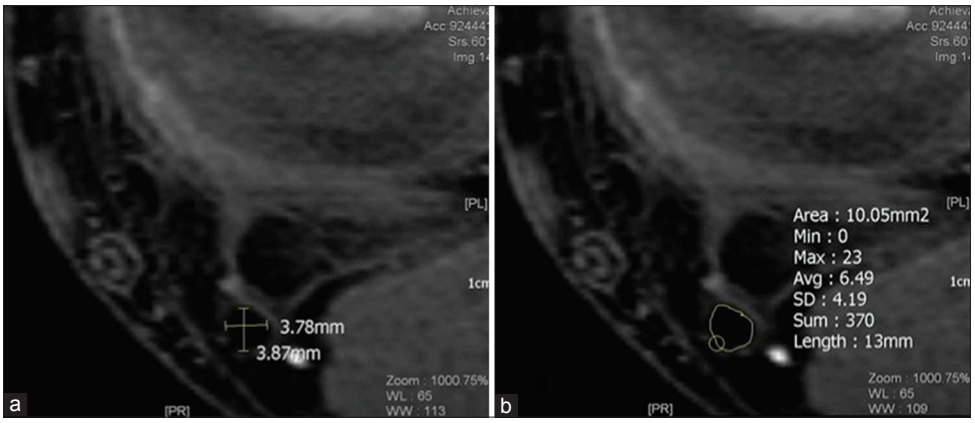

Figure 2: On T2-weighted fat-suppressed axial magnetic resonance imaging showing (a) Measurements of anteroposterior and mediolateral diameters of semitendinosus tendon at the level of the joint line. (b) Measurement of cross-sectional area of semitendinosus tendon at the level of the joint line (×10)

of the graft within the femoral tunnel. Endobutton was used for femoral fixation and screw and plate were used for tibial fixation. The study has been conducted in accordance with the principles of the Helsinki Declaration and approved by the local Institutional Review Board (2015/256).

Statistical analysis

A normal distribution of the quantitative data was checked using Kolmogorov–Smirnov test. Because the variable of the diameter of ST autograft did not show conformity to the normal distribution, correlations between variables were determined using Spearman's rho. Data are expressed as mean ± standard deviation. Receiver operating characteristic (ROC) method was used to determine the cut-off value for the correlation between 4-stranded ST graft diameter of 8 mm and CSA (mm^2) on MRI. All differences associated with a chance probability of 0.05 or less were considered statistically significant.

Results

The diameter of 4-stranded tendon graft was not <7 mm in the study. Mean preoperative MRI measurements and intraoperatively measured graft diameters are shown in Table 1.

There were significant correlation between 4-stranded tendon graft diameter and ML diameter measured at the level of the JL on MRI ($r = 0.345$, $P = 0.003$), between diameter of 4-stranded ST autograft and AP diameter at the level of the PL ($r = 0.309$, $P = 0.009$), between diameter of 4-stranded ST autograft and ML diameter at the level of the PL ($r = 0.360$, $P = 0.002$), between diameter of 4-stranded ST autograft and CSA at the level of JL ($r = 0.414$, $P < 0.001$), and between diameter of 4-stranded ST autograft and CSA at the level of PL ($r = 0.450$, $P > 0.001$). There was a positive moderate correlation between

Table 1: MRI and intraoperative measurements of 4-stranded ST grafts

Variables	Mean±SD (minimum-maximum)
4-stranded ST graft diameter (mm)	8.21±0.81 (7-10)
AP diameter at the level of the JL (mm)	4.07±0.89 (2.37-6.15)
ML diameter at the level of the JL (mm)	2.95±0.79 (1.09-6)
CSA at the level of the JL (mm^2)	7.38±0.9 (2.03-14.82)
AP diameter at the level of the PL (mm)	3.65±0.90 (1.62-6.79)
ML diameter at the level of the PL (mm)	3.80±0.86 (2-6.16)
CSA at the level of the PL (mm^2)	8.58±3.12 (3.32-17.76)

AP=Anteroposterior, ML=Mediolateral, CSA=Cross-sectional area, PL=Physeal line, JL=Joint line, MRI=Magnetic resonance imaging, ST=Semitendinosus tendon, SD=Standard deviation

4-stranded ST diameter and CSA at both level of the PL and level of the JL of ST on MRI [Table 2]. And there was a positive poor correlation between 4-stranded ST diameter and ML at both level of the PL and level of the JL and AP diameter at the level of the PL of ST on MRI [Table 2].

According to ROC analysis, area under the curve value for CSA measured at the JL and PL were 0.786 and 0.741, respectively. The cut-off value for the measurement of CSA calculated at the JL corresponding to 8 mm diameter of 4-stranded ST graft was 5.9 mm^2 with 75% sensitivity and 77.8% specificity. This cut-off value was 8.99 mm^2 at the PL with 93.75% sensitivity and 51.85% specificity [Table 3 and Figure 3].

Mean CSA of ST at the level of the JL for the diameters of ST autograft equal to and bigger than 8 mm and less than 8 mm were 8.01 ± 2.95 mm^2 and 5.29 ± 1.69 mm^2, respectively. When the area at the JL was ≥6.5 mm^2, graft diameter was ≥8 mm with 75% sensitivity, 66.7% specificity, 40% positive predictive value (PPV), and 90% negative predictive value (NPV).

Mean CSA at the level of the PL for the diameters of ST autograft equal to and bigger than 8 mm and less than 8 mm

Table 2: Correlation between intraoperatively measured 4-stranded ST graft diameter and MRI measurements

MRI measurements	Diameter of ST autograft	
	r	**P*
AP diameter at the level of the JL	0.162	0.180
ML diameter at the level of the JL	0.345	0.003
CSA at the level of the JL	0.414	<0.001
AP diameter at the level of the PL	0.309	0.009
ML diameter at the level of the PL	0.360	0.002
CSA at the level of the PL	0.450	<0.001

**P*<0.05 statistically significant. AP=Anteroposterior, ML=Mediolateral, CSA=Cross-sectional area, PL=Physeal line, JL=Joint line, ST=Semitendinosus tendon, MRI=Magnetic resonance imaging

Table 3: Minimum CSA corresponding to 8 mm diameter of 4-stranded ST

CSA	Cut-off (mm^2)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	AUC	*P*
JL	5.9	75	77.8	50	91.3	0.786	<0.001
PL	8.99	93.75	51.85	36.6	96.6	0.741	0.001

PPV=Positive predictive value, NPV=Negative predictive value, CSA=Cross-sectional area, PL=Physeal line, JL=Joint line, AUC=Area under curve, ST=Semitendinosus tendon

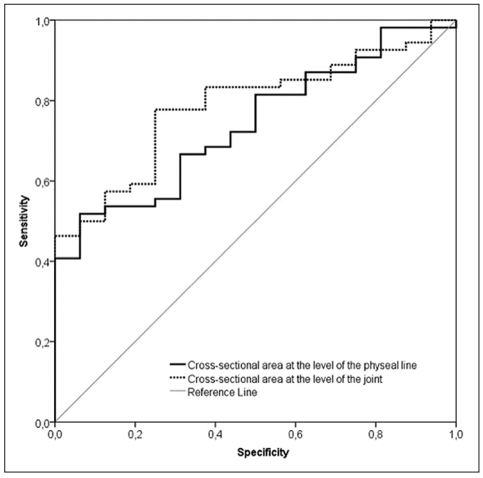

Figure 3: Receiver operating characteristic analysis

were 9.15 ± 3.19 mm^2 and 6.69 ± 1.98 mm^2, respectively. When CSA of the ST at the physeal level was ≥7.5 mm^2, graft diameter was ≥8 mm with 62.5% sensitivity, 66.7% specificity, 35.7% PPV, and 85.7% NPV.

Discussion

ACL injuries have increased in young individuals because of intensive sportive activities. If the level of activity remains the same in cases who underwent ACL reconstructions, they will be more prone to graft failure.[12] There are some studies that evaluated the graft thickness with the correlations of anthropometric characteristics of the patients.[3,13-15] As an alternative method to anthropometric characteristics in preoperative evaluations, there are some studies based on quantitative analysis in the prediction of intraoperative graft size. And these studies focused on the correlation between CSA and diameter of hamstring tendon on preoperative MRI and intraoperative hamstring graft size.[1,6-8] For this reason, standard sections were evaluated for the comparisons. Wernecke *et al.*,[6] Bickel *et al.*,[7] and Erquicia *et al.*[8] measured the ST diameter at the level of the largest region of the medial femoral condyle, and Beyzadeoglu *et al.*[1] measured at two different levels – distal to the musculotendinous junction and at the level of the JL. In this study, MRI measurements of diameters and CSA of STs were performed at the level of the JL and femoral PL.

Inadequate graft size is one of the major causes of the surgical failure. Based on recent studies, large graft diameter that is equal to or larger than 8 mm decreases the risk of graft failure.[5] Therefore, in this study, it was accepted that the threshold value of the graft diameter for ROC analysis was 8 mm. However, 7 mm was considered as the baseline threshold value in some MRI studies.[1,6,7]

Measurements were performed under × 10 magnification by an observer blinded to the intraoperative measurements of the autograft diameter. A significant statistical correlation was found between the diameter of the 4-stranded ST autograft and ML diameter at both levels, AP diameter at the level of the PL, CSA at both levels. But the correlation between MRI measurements of CSA and 4-stranded ST diameters was more significant than that between MRI measurements of the graft diameter and 4-stranded ST diameter. In previous studies, it has been indicated that CSA of hamstring tendons could be used in the prediction of hamstring graft thickness but no correlation between MRI measurements of tendon diameters and intraoperative graft diameters was found.[1,6] It was thought that even there is a correlation between MRI measurements of ST diameters and intraoperatively measured graft diameters at the level of PL, because of oblique course of the tendon and inability to obtain completely circular images in axial MRI sections in all cases, measurements of CSA will provide more reliable information.

Threshold values for hamstring tendon CSA have been described to predict the diameter of autograft. Bickel *et al.* asserted that combined CSA of ST and GT ≥18 mm^2 on MRI corresponds to the intraoperatively measured tendon diameter of 7 mm with 88% probability.[7] Wernecke *et al.* indicated that preoperatively combined CSA of at least 22 mm^2 on MRI predicts harvesting 4-stranded tendon graft diameter of 7 mm in 93% of cases.[6] Beyzadeoglu *et al.* indicated threshold values for combined CSA under ×2 magnification as 6.4 mm^2, 12 mm^2 and 18.4 mm^2 for 5 mm-thick for GT tendon, 6 mm-thick for ST, and 7 mm-thick for combined ST-GT tendon, respectively.[1] Erquicia *et al.* predicted threshold values for combined ST

and GT CSA for 4-stranded ST-GT graft with a minimum diameter of 8 mm as 25 mm^2 and 17 mm^2 under ×2 and ×4 magnifications, respectively. In their study, 17 mm^2 CSA measured under ×4 magnification had 96.2% sensitivity and 100% specificity.[8] The authors indicated that measurements with MRI under ×4 magnification were more accurate than those performed under ×2 magnification.[8] In this current study, measurements on MRI were performed under ×10 magnification. Other magnifications were not evaluated.

In daily practice, only ST autograft is used for ACL reconstruction in the institute in which this study was designed. For that reason, GT was not evaluated in this study. In other studies, combined CSA was used for 4-stranded grafts and corresponding threshold values were provided. In this study, to be able to harvest a graft with a diameter of 8 mm, a threshold value of 5.9 mm^2 for CSA of ST was found with the 75% sensitivity and 77.8% specificity at the level of the JL. The area at the level of the JL was more reliable than the level of the PL. According to this result, it is believed that CSA at the JL will provide more accurate prediction.

In a study that evaluated the length of ST and its CSA with 3D CT, it was expressed that preoperatively measured ST length was closely related to the intraoperatively measured length of ST, however, contrary to data obtained from MRI studies, an apparent correlation was not found between preoperatively determined CSA and that measured during operation.[9] Erquicia *et al*. compared preoperative USG and MRI measurements of tendon CSA and diameters, and measured during surgery and demonstrated reliability of USG in the preoperative evaluation of CSA which also comparable to MRI results obtained under ×2 magnification.[8] However, in clinical practice, for the diagnostic confirmation of ACL lesions, CT and USG are not routinely used.

It was believed that the advantages of this current study are: All surgical interventions were performed with a single tendon by the same operative team, and MRI evaluations were made from two levels under ×10 magnification.

The limitations of the current study are that all measurements were performed by a single observer, and cylindrical caliber gauges which were used to measure graft diameter intraoperatively could not determine the exact diameter of 4-stranded graft.

Conclusion

Preoperative evaluation of CSA at the JL of the ST on MRI for ACL reconstruction with 4-stranded ST graft is the most reliable parameter to predict graft size. CSA of ST <5.9 mm^2 at the level of the JL warns the surgeon before the operation about the requirement of other graft alternatives. This is precious for the surgeons to improve preoperative preparation with respect to graft choice.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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