

Reliability of the measurements of cross-sectional area and diameter of semitendinosus and gracilis tendons using 1.5 T magnetic resonance imaging

MRI measurements of semitendinosus and gracilis tendons

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Abstract

Aim: Hamstring tendons are widely used for anterior cruciate ligament (ACL) reconstruction. Preoperative magnetic resonance (MR) images have been used to measure the dimensions of hamstring tendons and to predict the graft size prior to ACL reconstruction. The aim of this study was to determine the reliability of measurements of the diameter and area of semitendinosus and gracilis muscle tendons using 1.5 Tesla magnetic resonance imaging (MRI).

Materials and Methods: In this retrospective study, three evaluators independently reviewed 74 knee MRI to determine the diameter and cross-sectional area of semitendinosus and gracilis tendons at three levels (medial femoral condyle, joint line and below the tibial plateau). Mean values were calculated for each reviewer and intraclass correlation coefficient (ICC) values were used to assess inter-rater agreement.

Results: There was an excellent inter-rater agreement with respect to measurements of the width and cross-sectional area of semitendinosus and gracilis tendons at all levels. The inter-rater agreement with respect to the thickness of semitendinosus and gracilis tendons ranged from good to excellent at the three levels.

Discussion: Using 1.5 T MR imaging for preoperative hamstring graft size prediction, authors found excellent inter-rater agreement with respect to the measured cross-sectional area of semitendinosus and gracilis muscle tendons at three levels in this study. Even though the ICC values for tendon thickness of gracilis muscle were relatively low, the inter-rater agreement was rated as "good" in two axial planes, and "good to excellent" in one axial plane. More studies are needed to discover the exact inter-rater agreement levels for hamstring tendon measurements using 1.5 T MR images.

Keywords

Hamstring tendons; Autografts; Anterior cruciate ligament; Inter-observer variability; Magnetic resonance imaging

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Introduction

The anterior cruciate ligament (ACL) plays an important role in maintaining the stability of the knee joint by restricting tibial translation in relation to the femur [1]. ACL is also one of the most frequently reconstructed ligaments [2]. ACL reconstruction is currently the standard treatment for the prevention of meniscal tears and knee laxity in athletically active persons [3]. Hamstring tendons are widely used for ACL reconstruction [4]. The use of quadruple hamstring tendon grafts for ACL reconstruction has been shown to confer adequate ligament strength and achieve good clinical results [5,6].

Prior to harvesting the graft, meticulous preoperative planning is essential to achieve successful outcomes of ACL reconstruction. Various researchers have attempted to predict tendon autograft size using patient height, weight, and other anthropometric data [7-9]. Magnetic resonance (MR) imaging is a very useful diagnostic tool for the assessment of ACL injuries. Cross-sectional MR images in the axial, coronal, and sagittal planes are useful in measuring the dimensions of knee tendons. Prediction of allograft size using MR imaging has evoked considerable interest in contemporary literature [10,11].

In the present study, we aimed to assess the reliability of area measurements of semitendinosus (ST) and gracilis (GR) muscle tendons using routine 1.5 T knee MR images. Three reviewers measured the width, thickness, and cross-sectional area of these tendons which are widely used as autografts for ACL reconstruction. In addition to the widely used measurement techniques, three axial planes were used to measure tendon dimensions and tendon area calculations.

Material and Methods

Patients

After the approval of our institutional ethics committee, all patients (n=511) who were admitted to our hospital between January and December 2019, and underwent knee MR examination were reassessed to determine the knee pathology. The requirement for informed consent of subjects was waived off by the ethics committee owing to the retrospective study design. Patients in the age-group of 18–50 years were included in this research. This age-group was chosen considering the skeletal maturity and to avoid the effect of degenerative diseases on the measurement results. Patients with any knee deformity, knee osteoarthritis, history of patellar dislocation, septic arthritis, osteonecrosis, rheumatologic diseases, or previous knee surgery were excluded from the study. Patients with ligamentous injuries, tendinopathies of the knee, and meniscal tears were also excluded. Thus, skeletally mature patients with normal MR examinations were included in this research. All eligible patients were screened against the study-selection criteria based on the consensus of two observers (V.K. and O.Ö.) after the assessment of all knee MR images. Finally, 58 patients with unilateral and 8 patients with bilateral knee MR examinations were included in this retrospective cross-sectional study. Thus, 74 knee MR imaging of 66 patients (35 female and 31 male, mean age: 32 ± 8.3 years) were reassessed to determine the width, thickness, and the cross-sectional area of semitendinosus and gracilis tendons.

MR Imaging

MR imaging was performed using a 1.5 T machine (Magnetom Essenza; Siemens, Erlangen, Germany) equipped with an 8-channel knee coil. Standard MRI protocol consisted of T1 weighted (T1W) images in the sagittal plane and proton density-weighted (PDW) images in the axial, coronal, and sagittal planes. The technical parameters of MR imaging were as follows: sagittal T1W (TR: 515 ms, TE: 14 ms, Matrix: 192×256 , FOV: 160 mm, slice thickness: 3.5 mm, interslice gap: 0.7 mm, ETL: 55, NEX: 2); axial PDW (TR: 2500 ms, TE: 28 ms, matrix: 206×256 , FOV: 170 mm, slice thickness: 3.5 mm, interslice gap: 0.7 mm, ETL: 69, NEX: 1); sagittal PDW (TR: 2670 ms, TE: 24 ms, matrix: 205×256 , FOV: 190 mm, slice thickness: 3.5 mm, interslice gap: 0.7 mm, ETL: 70, NEX: 1); coronal PDW (TR: 2350 ms, TE: 26 ms, matrix: 205×256 , FOV: 180 mm, slice thickness: 3.5 mm, interslice gap: 0.7 mm, ETL: 69, NEX: 1).

MRI measurements

All measurements were performed using the picture and archiving communication system (PACS) workstation panel (Enlil PACS Viewer, Eskişehir, Turkey) provided by our university hospital. Fat saturated axial PDW images were used and three different levels were selected to perform measurements. Semitendinosus tendon width (STW) and gracilis tendon width (GTW) were measured as the widest diameter in the axial plane. The longest diameter perpendicular to the width was measured as the semitendinosus tendon thickness (STT) and gracilis tendon thickness (GTT). Freehand region of interest tool of the workstation panel was used to determine the cross-sectional area of semitendinosus tendon (STA) and gracilis tendon (GTA) in the axial plane by manually tracing the tendon borders. Axial planes at the widest point of the medial femoral condyle (MFC), at the joint line (JL), and at the first plane just below the tibial articular plateau (BTAP) were chosen to perform the measurements. To eliminate any conflict and to clarify the selection of the exact location for the measurements, the sagittal image passing through the middle of the medial condyle was chosen to determine the axial plane of the JL. Two axial images below the JL (as our slice thickness was 3.5 mm, totally 7 mm below the JL) were chosen as the BTAP level to measure the tendons. The measurements were independently performed by 3 observers (two radiologists with 15 and 21 years of experience, respectively, and one orthopedic surgeon with 25 years of experience) under $\times 15$ magnification. The 3 observers were blinded to each other's image interpretations and measurement results. All measurements were noted to the nearest hundredth of a millimeter (Figures 1-3).

Statistical analysis

After patient data and image acquisition, all statistical analyses were performed using IBM SPSS Statistics for Windows V.20 (IBM Corp). The mean values with standard deviation were calculated according to each observer's measurement results. The intraclass correlation coefficient (ICC) was used to assess inter-rater reliability. A standard scale developed by Koo and Li was used to verify inter-rater agreement [12]. According to this scale, the inter-rater agreement is graded as follows: ICC < 0.50, poor; 0.50–0.75, fair; 0.75–0.90, good; 0.90–1.00, excellent. All ICC values are presented with 95% confidence intervals (CI).

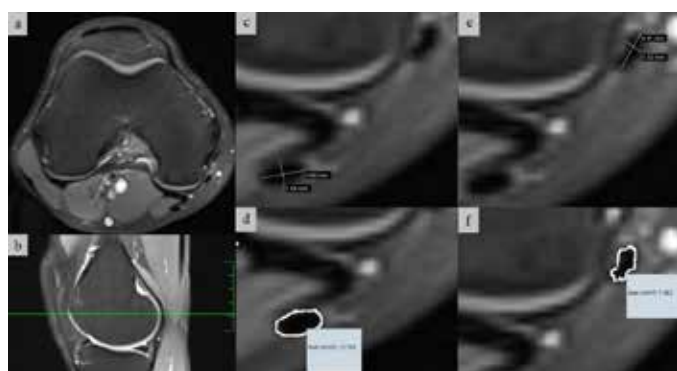


Figure 1. Axial proton density weighted images obtained at the level of the widest point of the medial femoral condyle (a) and the sagittal reference line (b). In this section, semitendinosus tendon width and thickness measurements (c) and semitendinosus tendon area measurement (d) are shown. In the same axial plane, gracilis tendon width and thickness measurements (e) and gracilis tendon area calculation are shown.

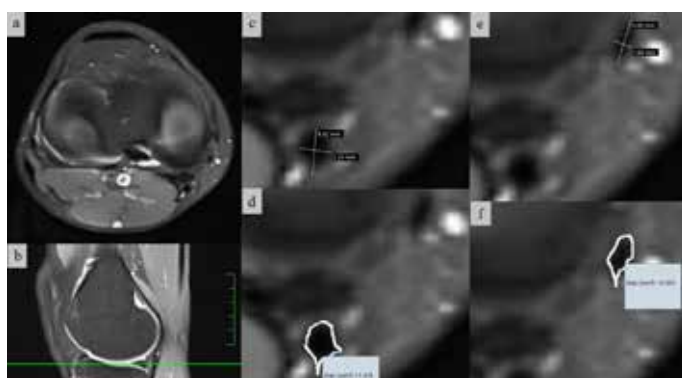


Figure 2. Axial proton density weighted images passing through the joint line (a) and the sagittal reference line (b). Semitendinosus tendon width and thickness measurements (c), semitendinosus tendon area measurement (d), gracilis tendon width and thickness measurements (e) and gracilis tendon area calculation (f) are shown.

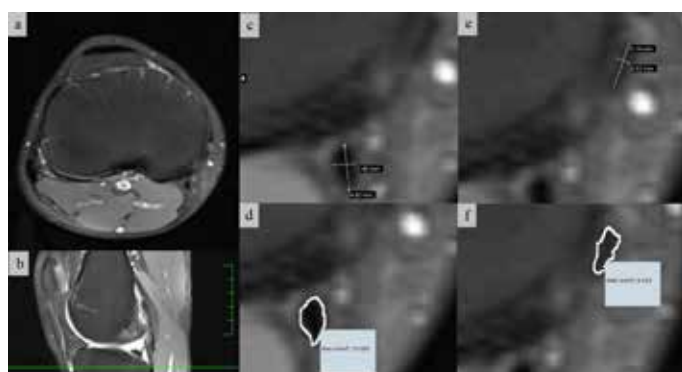


Figure 3. Axial proton density weighted images passing just below the tibial articular plateau (a) and the sagittal reference line (b). Semitendinosus tendon width and thickness measurements (c), semitendinosus tendon area measurement (d), gracilis tendon width and thickness measurements (e), and gracilis tendon area calculation (f) in this axial plane are shown.

Results

There was an excellent inter-rater agreement with respect to all measurements (STW, STT, STA, GTW, GTT and GTA) at the MFC level. All tendon measurements at the JL and BTAP levels showed excellent agreement with the exception of GTT. For GTT measurements, “good” agreement was observed at these levels. However, the lower bounds of the 95 % CIs for STT measurements at the JL and BTAP levels were less than 0.900. The mean values of all tendon measurements (STW, STT, STA, GTW, GTT and GTA) at the MFC, JL, and BTAP levels showed excellent agreement. For GTT measurements, the lower bound of 95 % CI was less than 0.900 at each level (Table 1).

Table 1. Measurements of semitendinosus and gracilis tendons performed by each observer in three axial planes and the corresponding ICC values

	Observer 1 (mean ± SD)	Observer 2 (mean ± SD)	Observer 3 (mean ± SD)	ICC value	95 % Confidence Interval	
					Lower Bound	Upper Bound
MFC						
STW (mm)	4.47 ± 0.71	4.32 ± 0.60	4.42 ± 0.72	0.939	0.909	0.960
STT (mm)	3.08 ± 0.52	3.02 ± 0.49	3.06 ± 0.53	0.948	0.924	0.966
STA (mm ²)	11.42 ± 2.84	11.29 ± 2.68	11.26 ± 2.87	0.974	0.962	0.983
GTW (mm)	3.51 ± 0.62	3.37 ± 0.56	3.40 ± 0.63	0.939	0.908	0.960
GTT (mm)	2.10 ± 0.39	2.06 ± 0.37	2.04 ± 0.38	0.904	0.858	0.936
GTA (mm ²)	6.02 ± 1.74	6.14 ± 1.71	5.91 ± 1.76	0.963	0.945	0.976
JL						
STW (mm)	4.33 ± 0.70	4.21 ± 0.71	4.27 ± 0.69	0.952	0.929	0.969
STT (mm)	2.88 ± 0.61	2.81 ± 0.52	2.80 ± 0.59	0.928	0.895	0.953
STA (mm ²)	10.18 ± 2.60	10.6 ± 2.80	10.07 ± 2.58	0.976	0.959	0.986
GTW (mm)	3.79 ± 0.75	3.76 ± 0.80	3.69 ± 0.75	0.948	0.923	0.965
GTT (mm)	2.00 ± 0.32	1.96 ± 0.29	1.95 ± 0.35	0.894	0.844	0.930
GTA (mm ²)	6.02 ± 1.68	6.33 ± 1.71	5.94 ± 1.68	0.966	0.945	0.979
BTAP						
STW (mm)	4.49 ± 0.79	4.47 ± 0.95	4.40 ± 0.80	0.939	0.911	0.960
STT (mm)	2.66 ± 0.52	2.59 ± 0.45	2.63 ± 0.53	0.921	0.883	0.947
STA (mm ²)	9.96 ± 2.61	10.29 ± 2.55	9.86 ± 2.59	0.970	0.955	0.980
GTW (mm)	4.08 ± 0.84	3.88 ± 0.93	4.03 ± 0.81	0.944	0.915	0.963
GTT (mm)	1.77 ± 0.40	1.74 ± 0.33	1.72 ± 0.39	0.892	0.798	0.909
GTA (mm ²)	5.69 ± 1.64	5.97 ± 1.71	5.60 ± 1.65	0.944	0.916	0.964
Mean						
STW (mm)	4.43 ± 0.64	4.33 ± 0.65	4.31 ± 0.62	0.958	0.937	0.973
STT (mm)	2.87 ± 0.48	2.81 ± 0.42	2.79 ± 0.49	0.958	0.937	0.972
STA (mm ²)	10.52 ± 2.54	10.74 ± 2.53	10.31 ± 0.48	0.982	0.972	0.989
GTW (mm)	3.79 ± 0.65	3.67 ± 0.67	3.65 ± 0.65	0.957	0.934	0.973
GTT (mm)	1.96 ± 0.31	1.92 ± 0.27	1.84 ± 0.30	0.905	0.848	0.940
GTA (mm ²)	5.91 ± 1.58	6.14 ± 1.58	5.73 ± 1.57	0.969	0.947	0.982

ICC: intraclass correlation coefficient, SD: Standard deviation, MFC: The axial plane in which the widest point of the medial femoral condyle was observed, JL: The axial plane passing through the joint line, BTAP: The axial plane just below the tibial articular plateau, STW: Semitendinosus tendon width, STT: Semitendinosus tendon thickness, STA: Semitendinosus tendon area, GTW: Gracilis tendon width, GTT: Gracilis tendon thickness, GTA: Gracilis tendon area

Discussion

In this study, we observed an excellent agreement between reviewers in terms of cross-sectional area measurements of semitendinosus and gracilis muscle tendons at all axial levels. The width and thickness measurements also showed excellent agreement at the MFC level, and for all other diameter

measurements except GTT at the JL and BTAP levels. GTT measurements showed good agreement at the JL and BTAP levels.

The hamstring tendons have been widely used as ACL autograft in recent years. Unlike quadriceps and patellar tendon autografts, the diameter of hamstring tendons shows considerable inter-individual variability and cannot be precisely predicted prior to its harvest during surgery [13]. Previous studies have shown that anthropometric parameters such as age, sex, weight, height, and body mass index are associated with the hamstring graft size [7-9]. Graft prediction studies using MR imaging have evoked considerable interest in recent years. Researchers have sought to characterize the relationship of the diameter and cross-sectional area measurements of hamstring tendons with the actual autograft size.

Hamada et al. used axial images at the level of the JL to measure the cross-sectional area of semitendinosus muscle tendon; they found a close correlation of these measurements with the intraoperative measurements [14]. Bickel et al. measured the hamstring dimensions just below the physis or physeal scar where hamstring tendons were more tubular in shape [2]. In many other studies, similar axial planes were used to measure the diameter of hamstring muscles at the level of MFC, knee JL, or both of these axial planes [11,15]. In the study by Vardiabasis et al., gracilis tendon and semitendinosus tendon diameter at 3 cm above the medial knee JL showed the strongest correlation with the actual hamstring autograft diameter [13].

We observed that the obliqueness of hamstring tendon alignment was nearly the same for MFC level, JL, and in the first axial plane just under the tibial articular plateau. In addition, the axial planes which are close to the site of tendon insertion would not be appropriate to measure, since the distal-most edges of the tendon autograft are cut away and not used for ACL reconstruction. Moreover, after cutting the edges of the autograft, the remaining edges will be placed in the tunnel to fix the ACL reconstruction. We performed the tendon measurements on routine MR images of the knee placing emphasis on the axial planes owing to the convenience and better reproducibility of the measurements. Thus, we used three axial planes (MFC, JL, BTAP), which we perceived as being very close to the actual cross-sectional area measurements of semitendinosus and gracilis muscle tendons.

It is desirable to preoperatively predict the dimensions or cross-sectional area of muscle tendons which are planned to be used as autograft; this would ensure that these are large enough for ACL reconstruction surgery. The exact autograft diameter required to avoid ACL reconstruction failure is not absolutely clear; however, recent studies suggest that even an increase of 0.5 mm up to an autograft size of 10 mm is beneficial for the patient [16]. In several previous studies, the mean graft diameter of quadruple hamstring grafts was in the range of 7.7 mm to 8.5 mm [7,17,18]. In a meta-analysis by Conte et al. (2014), grafts \leq 8 mm in diameter were associated with 6.8 times greater relative risk of graft failure [19]. Schlumberger et al. studied 2448 cases of four-strand doubled semitendinosus-gracilis ACL reconstruction; however, they found that no significant difference between re-ruptured and non-ruptured groups when comparing outcomes of grafts $<$ 8 mm and $>$ 8

mm [20]. Based on comprehensive pre- and post-operative morphological studies and follow-up of patients with ACL reconstruction, in addition to the graft size, other factors (especially the patient's age) should be considered before reconstruction surgery [21-23].

In the 3T MRI study by Beyzadeoğlu et al. (n=51), the mean values of STW, GRW, STA, and GTA were 4.2 ± 0.4 mm, 3.1 ± 0.3 mm, 12.9 ± 2.5 mm² and 7.3 ± 1.6 mm², respectively [11]. In the 1.5T MRI study by Bickel et al. conducted on adolescent patients (n=26), the mean STA and GRA were 13.3 ± 2.86 mm² and 6.97 ± 2.16 mm², respectively [2]. Camarda et al.'s results (n=100) for STW and GTW were 4.2 ± 0.4 mm and 3.3 ± 0.4 mm, respectively, on MR images obtained with a 1.5 T scanner [10]. In another 1.5 T MRI study by Hamada et al. (n=79), the mean STA value was 10.1 ± 2.1 mm² [14]. Hanna et al. (n=30) assessed the correlation (r) between preoperative MR measurements and intraoperative measurements of the size of tendons. Preoperative measurements of STW and GRW showed the best correlation at the level of MFC. In addition, the sum of STA and GTA (STA+GTA) measurements showed a stronger correlation at the level of MFC compared to that at the level of JL and the average measurement value of MFC and JL (r = 0.492) [24]. Hollnagel et al. (n=68) studied the relationship between preoperative autograft size measured on MR images and intraoperative autograft size using 1.5T and 3T MR machines. The measurements of STW and STA+GTA, at the MFC level showed a stronger correlation with intraoperative results than those at the level of JL and the average measurement value of MFC and JL for both 1.5T and 3T MR imaging [25]. In our study, we observed very high ICC values of STA and GTA at all levels, and there was an excellent inter-rater agreement for MFC, JL, and BTAP levels on 1.5T MR images.

The smallest diameter measured in this research was GTT at all levels. Even the inter-rater agreement for GTT was "good" at the JL and BTAP levels; the "relatively low" agreement level may be attributable to the small sample size. On the other hand, for STT, the lower bounds of 95 % CIs were less than 0.900 and the upper bounds were more than 0.900 at the JL and BTAP levels. From a statistical perspective, the obtained ICC value with a 95 % CI implies that there is a 95 % chance of the true ICC value to lie between the lower and upper bounds of the CI. Although the ICC values obtained in this research were 0.928 at the JL level and 0.921 at the BTAP level, it would be more appropriate to deem the agreement level as "good" to "excellent". This interpretation has previously been reported by Koo and Li [12]. Despite the high agreement levels observed in this study, some limitations of our study should be considered while interpreting the results. This study was not focused on the prediction of autograft size; nonetheless, a comparison of the preoperative diameter measurements on MR imaging with the intraoperative measurements of the graft helps verify the utility of MR imaging for predicting the actual graft dimensions. The purpose of this research was to assess the inter-rater agreement with respect to the measurement of the dimensions of semitendinosus and gracilis tendons using MR images; however, we did not assess the potential relation of these dimensions with other parameters such as weight, height, and body mass index. Furthermore, we only used MR images of normal individuals to

assess the reliability of tendon measurements; comparison of the measurement results of patients with and without rupture of ACL may provide a more robust assessment of the inter-rater agreement in each patient group. This study used three experienced reviewers to assess the inter-rater agreement; the inclusion of more observers would provide a more accurate assessment of the inter-rater agreement.

Conclusion

At the MFC, JL, and BTAP levels, we observed excellent inter-rater agreement with respect to the measurements of the diameter and cross-sectional area of the semitendinosus and gracilis muscle tendons using 1.5 Tesla MR images. Among all parameters measured in this research (STW, STT, STA, GTW, GTT and GTA), the lowest ICC values were recorded for GTT.

Scientific Responsibility Statement

The authors declare that they are responsible for the article's scientific content including study design, data collection, analysis and interpretation, writing, some of the main line, or all of the preparation and scientific review of the contents and approval of the final version of the article.

Animal and human rights statement

All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. No animal or human studies were carried out by the authors for this article.

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Conflict of interest

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References

- Kaya A, Karadağ D, Güçlü B, Uçar F, Benli T. Evaluation of the two bundles of the anterior cruciate ligament with 1,5 tesla magnetic resonance imaging. *Acta Orthop Traumatol Turc.* 2010; 44(1): 54-62.
- Bickel BA, Fowler TT, Mowbray JG, Adler B, Klingele K, Phillips G. Preoperative magnetic resonance imaging cross-sectional area for the measurement of hamstring autograft diameter for reconstruction of the adolescent anterior cruciate ligament. *Arthroscopy.* 2008; 24(12): 1336-41.
- Wright RW, Kuhn JE, Amendola A, Jones MH, Spindler KP. Symposium integrating evidence-based medicine into clinical practice. *J Bone Joint Surg Am.* 2007; 89(1): 199-205.
- Charalambous CP, Kwaees TA. Anatomical considerations in hamstring tendon harvesting for anterior cruciate ligament reconstruction. *Muscles Ligaments Tendons J.* 2012; 2(4): 253-7.
- Sun K, Zhang J, Wang Y, Xia C, Zhang C, Yu T, et al. Arthroscopic anterior cruciate ligament reconstruction with at least 2.5 years' follow-up comparing hamstring tendon autograft and irradiated allograft. *Arthroscopy.* 2011; 27(9): 1195-202.
- Ferretti A, Monaco E, Giannetti S, Caperna L, Luzon D, Conteduca F. A medium to long-term follow-up of ACL reconstruction using double gracilis and semitendinosus grafts. *Knee Surg Sports Traumatol Arthrosc.* 2011; 19(3): 473-8.
- Tuman JM, Diduch DR, Rubino LJ, Baumfeld JA, Nguyen HS, Hart JM. Predictors for hamstring graft diameter in anterior cruciate ligament reconstruction. *Am J Sports Med.* 2007; 35(11): 1945-9.
- Ma CB, Keifa E, Dunn W, Fu FH, Harner CD. Can preoperative measures predict quadruple hamstring graft diameter? *Knee.* 2010; 17(1): 81-3.
- Thomas S, Bhattacharya R, Saltikov JB, Kramer DJ. Influence of anthropometric features on graft diameter in ACL reconstruction. *Arch Orthop Trauma Surg.* 2013; 133(2): 215-8.
- Camarda L, Grassettoni E, Albano D, Galia M, Midiri M, D'Arienzo M. MRI evaluation to predict tendon size for knee ligament reconstruction. *Muscles Ligaments Tendons J.* 2017; 7(3): 478-84.
- Beyzadeoğlu T, Akgün U, Taşdelen N, Karahan M. Prediction of semitendinosus and gracilis autograft sizes for ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2012; 20(7): 1293-7.
- Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med.* 2016; 15(2): 155-63.
- Vardiabasis N, Mosier B, Walters J, Burgess A, Altman G, Akhavan S. Can we accurately predict the quadruple hamstring graft diameter from preoperative magnetic resonance imaging? *Orthop J Sports Med.* 2019; 7(3): 1-60.
- Hamada M, Shino K, Mitsuoka T, Abe N, Horibe S. Cross-sectional area measurement of the semitendinosus tendon for anterior cruciate ligament

reconstruction. *Arthroscopy.* 1998; 14(7): 696-701.

- Wernecke G, Harris IA, Houang MTW, Seeto BG, Chen DB, MacDessi SJ. Using magnetic resonance imaging to predict adequate graft diameters for autologous hamstring double-bundle anterior cruciate ligament reconstruction. *Arthroscopy.* 2011; 27(8): 1055-9.
- Figueroa F, Figueroa D, Espregueira-Mendes J. Hamstring autograft size importance in anterior cruciate ligament repair surgery. *Effort Open Reviews.* 2018; 3(3): 93-7.
- Wilson TW, Zafuta MP, Zobitz M. A biomechanical analysis of matched bone-patellar tendon-bone and double-looped semitendinosus and gracilis tendon grafts. *Am J Sports Med.* 1999; 27(2): 202-7.
- Hamner DL, Brown CH Jr, Steiner ME, Hecker AT, Hayes WC. Hamstring tendon grafts for reconstruction of the anterior cruciate ligament: biomechanical evaluation of the use of multiple strands and tensioning techniques. *J Bone Joint Surg Am.* 1999; 81(4): 549-57.
- Conte EJ, Hyatt AE, Gatt CJ Jr, Dhawan A. Hamstring autograft size can be predicted and is a potential risk factor for anterior cruciate ligament reconstruction failure. *Arthroscopy.* 2014; 30(7): 882-90.
- Schlumberger M, Schuster P, Schulz M, Immendörfer M, Mayer P, Bartholoma J, et al. Traumatic graft rupture after primary and revision anterior cruciate ligament reconstruction: retrospective analysis of incidence and risk factors in 2915 cases. *Knee Surg Sports Traumatol Arthrosc.* 2017; 25(5): 1535-41.
- Kamien PM, Hydrick JM, Replogle WH, Go LT, Barrett GR. Age, graft size, and Tegner activity level as predictors of failure in anterior cruciate ligament reconstruction with hamstring autograft. *Am J Sports Med.* 2013; 41(8): 1808-12.
- Magnussen RA, Lawrence JT, West RL, Toth AP, Taylor DC, Garrett WE. Graft size and patient age are predictors of early revision after anterior cruciate ligament reconstruction with hamstring autograft. *Arthroscopy.* 2012; 28(4): 526-31.
- Marchand JB, Ruiz N, Coupry A, Bowen M, Robert H. Do graft diameter or patient age influence the results of ACL reconstruction? *Knee Surg Sports Traumatol Arthrosc.* 2016; 24(9): 2998-3004.
- Hanna A, Hollnagel K, Whitmer K, John C, Johnson B, Godin J, et al. Reliability of magnetic resonance imaging prediction of anterior cruciate ligament autograft size and comparison of radiologist and orthopaedic surgeon predictions. *Orthop J Sports Med.* 2019; 7(12): 1-7.
- Hollnagel K, Johnson BM, Whitmer KK, Hanna A, Miller TK. Prediction of autograft hamstring size for anterior cruciate ligament reconstruction using MRI. *Clin Orthop Relat Res.* 2019; 477(12): 2677-84.

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