Original Article
http://mjiri.iums.ac.ir
Medical Journal of the Islamic Republic of Iran (MJIRI)

Med J Islam Repub Iran. 2023 (16 May);37.53. https://doi.org/10.47176/mjiri.37.53

Thigh Length as the Most Consistent Anthropometric Parameter in Predicting the Size of Hamstring Tendon Autografts in Patients Undergoing Anterior Cruciate Ligament Reconstruction: A Cross-Sectional Study

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Received: 16 Jul 2022 Published: 16 May 2023

Abstract

Background: Individual variability in the length and thickness of hamstring tendon autografts is a serious drawback in using these tendons for anterior cruciate ligament reconstruction (ACLR). In this study, we aimed to determine the correlation between the anthropometric parameters and the size of hamstring tendon autografts.

Methods: In a cross-sectional study, 52 male ACLR candidates were included. The length of semitendinosus and gracilis tendons and the diameter of single, doubled, and quadrupled tendons were measured. A graft sizing block device with an incremental size change of 0.5 mm (range 4.5-12) was used to measure the tendon graft diameter. The evaluated anthropometric parameters included age, gender, height, weight, BMI, thigh length and diameter, calf length, thigh-to-calf ratio, wrist diameter, and ankle diameter. A Pearson's or Spearman's correlation coefficient test was used for evaluating the correlation of anthropometric factors with graft characteristics.

Results: The mean age of the patients was 27.1 ± 6.4 years. The semitendinosus length was significantly correlated with the patient's height (r = 0.373, P = 0.007), thigh length (r = 0.364, P = 0.009), and calf length (r = 0.340, P = 0.015). The gracilis length was significantly correlated with thigh length (r = 0.278, P = 0.049). The mean quadruple diameter was 8.56 ± 1.15 mm (range 6.5-11). The quadruple diameter was significantly correlated with the thigh length (r = 0.283, P = 0.044). No other significant correlation was found between the tendons' size and evaluated anthropometric parameters.

Conclusion: Thigh length was correlated with the semitendinosus length, gracilis length, and quadruple diameter. Therefore, it could be regarded as the most consistent and promising anthropometric factor in the prediction of hamstring autograft size.

Keywords: Hamstring Autograft, Semitendinosus, Gracilis, Anthropometric Parameters

Conflicts of Interest: *None declared*
Funding: *None*

Cite this article as: Bagherifard A, Jabalameli M, Mohammadpour M, Bahari M, Karimi A, Naderi N, Taqian MJ, Jokar R. Thigh Length as the Most Consistent Anthropometric Parameter in Predicting the Size of Hamstring Tendon Autografts in Patients Undergoing Anterior Cruciate Ligament Reconstruction: A Cross-Sectional Study. *Med J Islam Repub Iran.* 2023 (16 May);37:53. https://doi.org/10.47176/mjiri.37.53

Introduction

Anterior cruciate ligament (ACL) is the most frequently injured knee ligament and generally results in significant functional disability (1). Because of a growing trend toward participating in sports activities, the number of ACL injuries has shown a continuous increase over the past decades (2). ACL reconstruction (ACLR) is widely accepted as the

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↑What is "already known" in this topic:
Individual variability in the length and thickness of hamstring tendon autografts is a serious drawback in using these tendons for anterior cruciate ligament reconstruction (ACLR).

→What this article adds:
Semitendinosus length was significantly correlated with the patient's height, thigh length, and calf length. The gracilis length was significantly correlated with the thigh length. The quadruple diameter was also significantly correlated with the length of the thigh. These results reveal that thigh length could be regarded as a promising anthropometric factor in the prediction of hamstring autograft size.

[DOI: 10.47176/mjiri.37.53]

treatment of choice for addressing functional instability caused by ACL deficiency (3).

Hamstring tendon autografts, including gracilis and semitendinosus tendons, are commonly used in ACLR because of their good mechanical properties and small donor site morbidity (4, 5). However, individual variability in the length and thickness of these grafts is considered as one of the most serious drawbacks of using hamstring autografts (6). Technically, a minimum tendon length of 28 cm with a minimum thickness of 7 mm is required to obtain the optimal quadrupled graft construct for ACL reconstruction (6). Smaller graft lengths and diameters increase the rate of failure (6), making the surgeon harvest graft from other sites. This condition increases scar formation, postoperative pain, surgical time, and risk of infection (7, 8). Preoperative prediction of graft length and thickness helps the surgeon choose the ideal graft type and avoid these complications (7, 8).

To date, several studies have attempted to find significant associations between the anthropometric characteristics and the size of hamstring grafts. Although some remarkable associations have been reported, the results of different studies have been inconclusive (7, 9-11). We hypothesized that a more comprehensive evaluation of the association between anthropometric characteristics and the size of hamstring grafts could result in finding more significant associations, thereby providing a more reliable anthropometric factor for the prediction of graft length and thickness.

In this study, we aimed to more comprehensively investigate the association of anthropometric parameters with the length and thickness of the hamstring tendons used as grafts in patients undergoing ACLR surgery.

Methods

This cross-sectional research was approved by the review board of the Iran University of Medical Sciences under the code IR.IUMS.REC.1400.143. Patients provided written consent before participation in the study. Between March and November 2021, patients who underwent ACLR surgery at our referral orthopedic hospital were evaluated for eligibility to include in the study. Inclusion criteria were indication for ACLR surgery and using four-strand hamstring autograft tendons. Patients with a history of previous surgery in the involved knee, patients with connective tissue disorders, and patients with congenital knee deformities were excluded from the study.

To harvest hamstring tendons, an oblique anteromedial incision was made in the proximal tibia at the level of the insertion of the hamstring muscles. To ensure maximum graft length, detachment of the tendon from its tibial attachment was performed as close as possible to the bone. After the removal of the muscle layer, the tendons' length was measured. Then, the tendons were folded in the middle to create double-strand grafts. The diameter of single, doubled, and quadruple grafts were measured using a graft sizing block device with an incremental size change of 0.5 mm, ranging from 4.5-12 mm (AR-1886, Arthrex, USA). The dimension of the smallest block that the graft could pass through was regarded as the graft diameter. The diameter of the tendon was measured without suturing at a distance of 10 mm, where the tendon was doubled.

The anthropometric parameters included age, gender, height, weight, BMI, thigh length and diameter, calf length, thigh-to-calf ratio, wrist diameter, and ankle diameter. Thigh length and diameter, calf length, wrist diameter, and ankle diameter were calculated as previously described (11, 12). Briefly,the distance between the anterior superior iliac spine and the base of the patella was considered as the thigh length. The diameter of the thigh was evaluated at 20 cm above the superior pole of the patella while the knee was fully extended. The distance from the junction of the medial edge of the tibial plateau and the medial edge of the patella to the center of the medial malleolus was considered the length of the calf. The diameter of the wrist was measured one centimeter proximal to the ulnar styloid. The diameter of the ankle was measured one centimeter proximal to the tip of the medial malleolus. All the measurements were done with two fellowship-trained knee surgeons. In case of significant disagreement between the two surgeons, a third surgeon measured the tendon size to achieve a consensus.

Statistical analysis

According to the study of Sakti et al., a significant correlation of 0.255 was found between the thigh Circumference and semitendinosus length (13). According to this correlation, an effect size of 0.5, type I error of 0.05, and power of 95%, a number of 34 patients was found to be enough for this correlation study (G*Power 3.1.9.2).

SPSS for Windows, version 16 (SPSS Inc., Chicago, Ill., USA) was used for the statistical analysis of data. The inter- and intra-observer reliability of measurements was checked and confirmed using Intraclass Correlation Coefficient analysis in a pilot study. Descriptive data were presented as mean ± standard deviation for quantitative variables and numbers with percentages for qualitative variables. The Kolmogorov-Smirnov test was used to test the normal distribution of variables. A Pearson's or Spearman's correlation coefficient test was used for evaluating the correlation of anthropometric factors with graft characteristics. A P-value < 0.05 was considered significant.

Results

Fifty-two patients who underwent ACLR were included in this study. All the patients were male. The mean age of the patients was 27.1 ± 6.4 years (range 17-44). The mean BMI of the patients was 25.6 ± 4 kg/m^2 (range 18-34.9). The mean and range of anthropometric factors are demonstrated in Table 1.

Association of anthropometric factors with semitendinosus tendon characteristics

The mean semitendinosus length was 29.3 ± 2.3 cm (range 26-35). The mean semitendinosus diameter was 2.2 ± 0.75 mm (range 0.75-4). The semitendinosus length was significantly correlated with the patient's height (r = 0.373, P = 0.007), thigh length (r = 0.364, P = 0.009), and calf-length (r = 0.340, P = 0.015). The semitendinosus length was not significantly correlated with other anthropometric

[DOI: 10.47176/mjiri.37.53]

Table 2. Descriptive analysis of anthropometric factors in patients undergoing ACLR

Variable	Analysis
Age (year)	27.1±6.4 (17-44)
Weight (Kg)	79.9±13.2 (58-113)
Height (cm)	176.7±7 (153-190)
BMI (Kg/m^2)	25.6±4 (18-34.9)
Thigh diameter (cm)	52.7±7.4 (42-79)
Thigh length (cm)	51.2±3.5 (42-57)
Calf length (cm)	39.5±3.2 (32-46)
Thigh-to-calf ratio	1.3±.088 (1.04-1.46)
Wrist diameter (cm)	17.6±1.2 (15-20)
Ankle diameter (cm)	23.4±1.9 (20-29)

Data are presented as mean ± SD

factors of the patients (Table 2). The semitendinosus diameter was not associated with any of the evaluated anthropometric factors (Table 2). The doubled semitendinosus diameter was not associated with any of the evaluated anthropometric factors, as well (Table 2).

Association of anthropometric factors with gracilis tendon characteristics

The mean gracilis length was 25.8 ± 2.8 cm (range 15-30). The mean gracilis diameter was 1.44 ± 0.67 mm (range 0.5-4). The gracilis length was significantly correlated with thigh length (r = 0.278, P = 0.049) but not with any other evaluated anthropometric factors of the patients (Table 2). The gracilis diameter was not associated with any of the evaluated anthropometric factors (Table 2). The doubled gracilis diameter was not associated with any of the evaluated anthropometric factors, as well (Table 2).

Association of anthropometric factors with Quadruple diameter

The mean quadruple diameter was 8.56 ± 1.15 mm (range 6.5-11). The quadruple diameter was significantly correlated with thigh length (r = 0.283, P = 0.044). No other significant correlation was found between the quadruple diameter and other evaluated anthropometric factors (Table 2).

Discussion

In this study, we evaluated the correlation of anthropometric factors with the diameter and length of hamstring tendon grafts in patients undergoing ACLR. According to our results, semitendinosus length was significantly correlated with the patient's height, thigh length, and calf length. The gracilis length was significantly correlated with the thigh length. The quadruple diameter was also significantly correlated with the length of the thigh.

The association of anthropometric factors with the length and diameter of the hamstring tendon graft has been evaluated in several other studies. Mardani-Kivi et al. aimed to use anthropometry to predict the diameter of 4-strand (quadruple) hamstring tendons in 178 patients undergoing ACLR. The mean quadruple diameter was 7.8±0.7 mm and was significantly greater in males than in females (7.9 vs. 7.89 mm). The quadruple diameter was significantly correlated with BMI, height, and weight but not with age (14). The mean quadruple diameter was 8.56 mm in our study. This was probably because all our patients were male. The patients' height was correlated with semitendinosus length in the present study. However, the quadruple diameter was not associated with the patient's weight and BMI in the current series.

Pereira et al. investigated the correlation of anthropometric measurements with the thickness and length of semitendinosus and gracilis tendons in 64 patients undergoing ACLR. They found a positive correlation between the height and diameter of the quadruple graft, length of the semitendinosus, and length of gracilis, but not with age, weight, and BMI (11). We also found a significant correlation between the height and length of semitendinosus but not with the length of gracilis and diameter of quadruple.

Table 1. Correlation of anthropometric factors with hamstring tendons' characteristics

Anthropometric Factor		ST length	ST diameter	ST diameter (doubled)	G length	G diameter	G diameter (doubled)	Quadruple diameter
Age	Correlation	-.066	-0.043	0.031	0.056	-0.127	-0.130	-0.019
	P-value	.646	0.766	0.831	0.695	0.376	0.362	0.892
Weight	Correlation	.153	-0.003	0.18	0.125	-0.013	0.005	0.122
	P-value	.283	0.985	0.900	0.380	0.928	0.975	0.393
Height	Correlation	.373*	-0.002	0.056	0.196	-0.023	0.068	0.230
	P-value	.007	0.989	0.697	0.168	0.872	0.633	0.104
BMI	Correlation	-.012	-0.004	-0.010	0.034	-0.035	-0.035	0.016
	P-value	.933	0.980	0.947	0.813	0.809	0.806	0.909
Thigh diameter	Correlation	.142	-0.210	-0.186	0.268	-0.187	-0.148	-0.054
	P-value	.321	0.139	0.192	0.58	0.190	0.300	0.708
Thigh length	Correlation	.364*	0.000	0.076	0.278*	0.015	0.065	0.283*
	P-value	.009	0.998	0.597	0.049	0.916	0.650	0.044
Calf length	Correlation	.340*	-0.062	-0.024	0.176	-0.041	-0.043	0.090
	P-value	.015	0.668	0.870	0.216	0.775	0.765	0.530
Thigh-to-calf ratio	Correlation	-.022	0.078	0.115	0.073	0.058	0.109	0.190
	P-value	.879	0.586	0.422	0.613	0.684	0.447	0.183
Wrist diameter	Correlation	.159	-0.037	-0.053	0.071	-0.007	0.005	0.014
	P-value	.265	0.795	0.712	0.619	0.963	0.973	0.923
Ankle diameter	Correlation	.052	0.141	0.165	-0.125	0.101	0.141	0.141
	P-value	.717	0.323	0.247	0.382	0.483	0.322	0.323

[DOI: 10.47176/mjiri.37.53]

Similarly, the diameter and length of tendons were not correlated with age, weight, and BMI in the present series.

Stergios aimed to determine the correlation of the hamstring tendon graft length and diameter with anthropometric parameters in 61 patients undergoing ACLR. According to their results, the length of harvested semitendinosus tendon was inadequate in 21% of patients to be used alone as a four-strand graft, especially in females. Semitendinosus and gracilis graft diameter was moderately correlated to the patient's height and weight and fairly correlated to the patient's BMI (7). We found a moderate correlation between the height and semitendinosus length but not with semitendinosus diameter.

The correlation of anthropometric factors such as age, height, weight, and BMI with the length and diameter of hamstring tendon grafts has also been investigated in some other studies (8, 15). However, the results are not conclusive. Therefore, other authors aimed to use more specific anthropometric parameters for the prediction of hamstring tendon graft length and diameter.

Moghamis et al. evaluated the correlation of anthropometric measurements, including thigh length and circumference with the size of the hamstring tendon graft in 50 patients undergoing ACLR. Patient's height and thigh length showed a positive correlation with gracilis and semitendinosus graft length. The age of the patients demonstrated a positive correlation with the quadrupled graft diameter. Abdominal girth revealed a significant negative correlation with gracilis and semitendinosus graft thickness (16). Similarly, thigh length was positively correlated with gracilis and semitendinosus graft length in this study.

Sakti et al. aimed to predict the length of semitendinosus and gracilis tendon and quadrupled graft diameter using anthropometric parameters, including true leg length, thigh circumference, and thigh length in 60 patients undergoing primary ACLR. According to their report, height and true leg length were significantly correlated gracilis length and quadruple autograft diameter, while thigh circumference significantly correlated to semitendinosus length (13). Thigh length was also significantly correlated with the quadruple autograft diameter in the present study.

Goyal et al. also studied the used anthropometric parameters, including thigh circumference, thigh length, and Tegner activity level, to predict the length and diameter of hamstring tendons. According to their report, height and weight had a strong correlation with graft length and quadruple diameter. Thigh length showed a positive correlation with graft length, double diameter, and quadruple diameter of the graft. BMI and thigh circumference did not show a correlation with graft size. Male patients had longer semitendinosus grafts and larger double and quadruple diameters. Tegner activity scale was not correlated with graft size (12). Similarly, in the present series, thigh length was the most correlated anthropometric factor with hamstring autograft size.

The results of the current study, conjunct with the results of earlier investigations, reveal that femoral length could be regarded as a promising factor in the prediction of hamstring tendon size. The present study was not without limitations, though. One main limitation of this study was the small number of patients. In addition, all the included patients were male. Therefore, the results cannot be generalized to the female population. And it is better to compare and report anthropometric measurements and graft size with short-term and long-term clinical and radiological outcomes in future studies.

Conclusion

Semitendinosus length was significantly correlated with the patient's height, thigh length, and calf length. The gracilis length was significantly correlated with the thigh length. The quadruple diameter was also significantly correlated with the length of the thigh. These results reveal that thigh length could be regarded as a promising anthropometric factor in the prediction of hamstring autograft size. However, future studies with larger patients numbers are required to further formulate this association.

Acknowledgments

None.

Ethical approval

This cross-sectional research was approved by the review board of the Iran University of Medical Sciences under the code IR.IUMS.REC.1400.143.

Authors contributions

Abolfazl Bagherifard: Study design and conception
Mahmoud Jabalameli: Study design and conception
Mehdi Mohammadpour: Writing the original manuscript
Milad Bahari: Data collection
Amirali Karimi: Data collection
Nima Naderi: Data collection
Mohamad Javad Taqian: Reviewing the manuscript critically
Rahmatollah Jokar: Data collection and writing the original manuscript

Conflict of Interests

The authors declare that they have no competing interests.

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[DOI: 10.47176/mjiri.37.53]

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[DOI: 10.47176/mjiri.37.53]