

Correlation of Anthropometric Measurements with Hamstring Graft Size in Anterior Cruciate Ligament Reconstruction in Nepalese Population: A Prospective Observational Study

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ABSTRACT

Background: The use of autologous hamstring tendon for arthroscopic Anterior Cruciate Ligament (ACL) reconstruction is very common. The size of hamstring tendons varies significantly between individuals, and graft diameter is unpredictable. Anthropometric measurements may be a simple way to estimate hamstring tendon length and diameter. This study aims to determine the correlation between anthropometric measurements of patients with length and diameter of harvested hamstring autograft during ACL reconstruction.

Methods: A prospective observational study was carried out after ethical approval. All patients who underwent arthroscopic ACL reconstruction from 1 March 2022 to 30 April 2023 in Birat Medical College Teaching Hospital were included. Forty seven patients' age, sex, height, weight and thigh length were recorded preoperatively. Hamstring tendons were harvested and length of the semitendinosus tendon and diameter of the quadrupled graft (doubled semitendinosus and doubled gracilis) was measured intraoperatively. We used Pearson's correlation coefficient to observe the relationship between anthropometric measurements and graft variables.

Results: Mean length of harvested semitendinosus tendon was 27.4 ± 1.8 cm and mean quadrupled hamstring autograft diameter was 7.4 ± 0.8 mm. A significant positive correlation between graft variables (semitendinosus tendon length and quadrupled hamstring autograft diameter) and patients' height and thigh length was found. Regression equations for predicting Semitendinosus tendon length and quadrupled hamstring autograft diameter from thigh length in males and females are also derived.

Conclusion: Height and thigh length of patients are useful parameters for predicting semitendinosus tendon length and quadrupled hamstring graft diameter before ACL reconstruction.

Keywords: Anterior cruciate ligament, autografts, hamstring tendons

INTRODUCTION

Anterior cruciate ligament (ACL) tear is a common knee injury encountered in our daily practice.¹ ACL deficiency alters the knee's biomechanics, which causes pain and instability.² The goal of reconstruction of ACL is restoring the biomechanics and function of the native ACL and thus the knee.³

There are several grafts available for the reconstruction of ACL like bone-patellar tendon-bone (BPTB) graft, hamstring graft, quadriceps tendon graft, allograft.⁴ Hamstring is one of the most often used autograft because of its high strength, ease of harvesting and low donor site morbidity.^{5,6} According to Scott and Insall,

the average adult ACL length is 38 mm (25-41 mm) and breadth is 10 mm (7-12 mm).⁷ Many experts recommend a graft diameter higher than 7 mm for reconstruction to offer enough strength and lower the likelihood of graft failure.^{7,8} According to biomechanical research, the stress at which a hamstring graft fails is proportional to its diameter.⁸ In case of bone-patellar tendon-bone graft, quadriceps tendon and allografts, the size of the graft can be predetermined in contrast to hamstring tendon which depends upon the size of tendons harvested during surgery which is not consistent and also cannot be controlled during harvest.⁹ The size of hamstring tendon significantly varies between individuals, and thus the

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autograft diameter is unpredictable.

Preoperative parameters like weight, height, body mass index, thigh length, etc is said to have predictive value in various studies.⁹⁻¹³ Thus, pre-operative assumption of the length and diameter of hamstring graft has clinical importance because it may help surgeons in identifying patients at risk of having hamstring tendons of inadequate length or diameter, making appropriate decisions about the graft choices, proper preoperative equipment planning and patient counseling regarding the graft choice.^{9,11,13}

This study aims to determine the correlation between anthropometric measurements of patients with length and diameter of harvested hamstring autograft during arthroscopic ACL reconstruction in Nepalese population.

MATERIALS AND METHODS

A prospective observational study was carried out after ethical approval was received from the Institutional Review Committee (IRC) of Birat Medical College Teaching Hospital, Morang (Ref: IRC-PA-198/2078-79). A total of 47 consecutive patients aged more than 18 years who underwent arthroscopic ACL reconstruction using hamstring tendon autograft at Birat medical college teaching hospital between March 1, 2022 and April 30, 2023 and gave informed consent were included in the study. Patients under 18 years of age, those undergoing revision ACL reconstruction, patients with multi-ligamentous injuries, previous fractures around the knee and neuromuscular diseases and cases where graft other than hamstring was used were excluded from the study.

Preoperatively, the demographic and anthropometric data including sex, age, weight, height, body mass index and thigh length of patients undergoing ACL reconstruction was recorded. Length of the semitendinosus (ST) tendon and diameter of the quadrupled graft (doubled Semitendinosus and doubled Gracilis) was measured intraoperatively using 1 mm calibrated scale and recorded in proforma.

Bivariate analysis using Pearson's correlation coefficients (Pearson's *r*) was performed to determine the relationship between the outcome variables, semitendinosus length and quadrupled hamstring autograft diameter and the predictor variables (age, gender, height, thigh length, body mass index). A *p* value of less than 0.05 was considered statistically significant. The continuous variables were assessed for assumption of normality using Shapiro-Wilk test and all continuous outcomes were found to be normally distributed. The assumptions for linear regression were assessed before employing the statistical analysis. Linear regression was performed to predict the equation for determining the outcome variables based on the different predictor variables. The dependent variables or outcome variables included semitendinosus tendon length and quadrupled hamstring autograft diameter. Similarly, independent variables or predictor variables included age, gender, height, thigh length, body mass index. The prediction models for linear regression were undertaken in two strata; male and female.

RESULTS

Our study enrolled a total of 47 patients, out of which 40 (85.1%) were male and 7 (14.9%) were female. The mean age of the patients was 30.9 ± 8.9 . The average

height of male patients was 168.9 ± 6.9 cm and that of female patients was 161.6 ± 4.5 cm. The mean thigh length in males was 54.5 ± 3.4 cm and in females was 51.1 ± 2.3 cm. Mean length of harvested semitendinosus tendon was 27.4 ± 1.8 cm. Mean diameter of quadrupled autograft (doubled semitendinosus and doubled gracilis) was 7.4 ± 0.8 mm. Gender specific distribution of mean semitendinosus tendon length and quadrupled graft diameter is shown in table 1.

The correlation between autograft size and age, height, weight and thigh length of patients is shown in table 2.

Since there is variation in anthropometric variables in males and females and also there is significant difference in length of semitendinosus tendon and quadrupled hamstring graft diameter between males and females ($p = 0.001$) as shown in table 1, the analysis was done separately for males and females and prediction model were also developed separately.

Male prediction model:

A linear regression analysis was conducted to predict ST length from thigh length among male participants. A statistically significant prediction of ST length variable was obtained from thigh length variable [F (1,38) = 383.430, $p < 0.001$, $R^2 = 0.910$]. Other variable of height which was statistically significant in bivariate analysis was excluded from regression model due to multicollinearity (VIF=103.889).

The final regression equation that accounts for 91% of the variability of the dependent variable for predicting ST length from thigh length is shown below.

ST length (in cm) = $1.773 + 0.477 \times$ Thigh length (in cm)

A linear regression analysis was conducted to predict Quadrupled graft diameter from thigh length among male participants. A statistically significant prediction of quadrupled graft diameter variable was obtained from thigh length variable [F (1,38) = 61.231, $p < 0.001$, $R^2 = 0.617$]. Other variable of height which was statistically significant in bivariate analysis was excluded from regression model due to multicollinearity (VIF=103.889).

The final regression equation for estimating quadrupled graft diameter from thigh length is represented by the equation given below, which accounts for 61.7% of the variability of the dependent variable.

Quadrupled graft diameter (in mm) = $-1.560 + 0.167 \times$ Thigh length (in cm)

Female prediction model:

A linear regression analysis was conducted to predict ST length from Thigh length among female participants. A statistically significant prediction of ST length variable was obtained from thigh length variable, F (1,5) = 16.623, $p < 0.010$, $R^2 = 0.769$. Other variable of Height which was statistically significant in bivariate analysis was excluded from regression model due to multicollinearity (VIF=87.065).

The final regression equation that accounts for 76.9% of the variability of the dependent variable for predicting ST length from thigh length is shown below.

ST length (in cm) = $2.556 + 0.444 \times$ Thigh length (in cm)

A linear regression analysis was conducted to predict Quadrupled graft diameter from Thigh length among male participants. A statistically significant prediction of

Table 1: Gender specific distribution of hamstring tendon length and graft diameter

Parameters	Male	Female	Mean Difference	95% CI	p-value+
ST length (in cm)	27.8 ± 1.7	25.3 ± 1.1	2.4	0.8 – 4.0	0.001
Quadrupled graft (doubled ST & Gr) diameter (in mm)	7.5 ± 0.7	6.4 ± 0.5	0.9	0.3 – 1.6	0.001

+ Independent t-test; p < 0.05 signifies statistical significance

Table 2: Correlation between anthropometric data and measured graft variables

	ST length		Quadrupled graft diameter					
	Male	Female	Male	Female	Male	Female		
	r	p-value	r	p-value	r	p-value	r	p-value
Age	-0.008	0.960	0.584	0.169	-0.177	0.275	0.343	0.452
Height	0.960	<0.001	0.839	0.018	0.790	<0.001	0.858	0.014
Weight	0.291	0.068	-0.108	0.818	0.156	0.337	0.154	0.741
Thigh length	0.954	<0.001	0.877	0.010	0.786	<0.001	0.904	0.005

r: Pearson correlation coefficient; p < 0.05 signifies statistical significance

Table 3: Linear regression model for prediction of graft dimensions from anthropometric measurements.

	ST Length (in cm)			Quadrupled graft diameter (in mm)		
	Unstan- dardised coefficient (B)	95% CI for B	p-value	Unstan- dardised coefficient (B)	95% CI for B	p-value
Male prediction model						
constant	1.773	-0.920 – 4.66	0.191	-1.560	-3.915 – 0.795	0.188
Thigh length (cm)	0.477	0.428 – 0.526	<0.001	0.167	0.124 – 0.210	<0.001
Female prediction model						
constant	2.556	-11.787 – 16.899	0.666	-4.463	0.111	-10.407 – 1.481
Thigh length (in cm)	0.444	0.164 – 0.725	0.010	0.213	0.005	0.097 – 0.329

Quadrupled graft diameter variable was obtained from thigh length variable [F (1,5) = 22.227, p=0.005, R² = 0.816]. Other variable of Height which was statistically significant in bivariate analysis was excluded from regression model due to multicollinearity (VIF=87.065).

The final regression equation for estimating quadrupled graft diameter from thigh length is represented by the equation below, which accounts for 81.6% of the variability of the dependent variable.

Quadrupled graft diameter (in mm) = -4.463 + 0.213 x Thigh length (in cm)

DISCUSSION

Hamstring tendon grafts are one of the most commonly used autografts in ACL reconstruction. However, their length and diameter are variable and unpredictable.

The mean length of semitendinosus tendon autograft in patients undergoing arthroscopic ACL reconstruction found in this study was 27.4 ± 1.8 cm (27.8 ± 1.7 cm in males and 25.3 ± 1.1cm in females). Our finding was similar to the findings shown by various international studies, which was 27.7 – 30.7 cm.^{2,3,10,14-16} A study conducted in India by Goyal et al. (2020) including 95 patients with Arthroscopic ACL reconstruction found the mean

semitendinosus tendon graft length to be 27.7 ± 2.6cm.¹⁵ Similar findings were made by Xie et al. (2012) in China, who discovered that the average semitendinosus tendon autograft length was 27.9 ± 2.1 cm in their study of 235 Han Chinese patients having arthroscopic double bundle ACL restoration.¹⁶ This implies that the length of the semitendinosus tendon is comparable among Nepalese, Indian, and Han Chinese populations. In contrast, a study conducted by Treme G et al (2008) in USA including 50 patients undergoing arthroscopic ACL reconstruction found the mean semitendinosus tendon graft length to be 30.1 ± 3.1 cm.¹⁰ Similarly, in a study carried out in Qatar involving 50 male patients undergoing arthroscopic ACL reconstruction, Moghamis et al. (2020) observed that the average semitendinosus tendon length was 30.8 ± 3.2 cm.³ The mean semitendinosus tendon length was found to be 29.4 ± 2.4 cm in a study by Stergios et al. (2012) that involved 61 patients having an ACL reconstruction in Greece.² This implies that semitendinosus tendon lengths are greater in Americans, Arabs, and Europeans than in Nepalese.

A significant positive correlation between the length of the semitendinosus tendon autograft and the patients' height (r= 0.960, p<0.001 in males and r= 0.839, p= 0.018 in females) and thigh length (r=0.954, p<0.001 in males

and $r = 0.877$, $p = 0.01$ in females) was also found in this study. This indicates that tendon length increases as the height and thigh length increase. Our findings were also similar to those shown various international studies. In a study carried out in India, Goyal et al. discovered a significant positive correlation between the length of the semitendinosus tendon autograft and the patients' height ($r = 0.41$, $p = 0.001$) and thigh length ($r = 0.43$, $p = 0.001$).¹⁵ Similar results were obtained by Moghamis et al., who found that among Qatari patients, the semitendinosus tendon autograft length substantially correlated with both their height ($r = 0.541$, $p < 0.001$) and thigh length ($r = 0.578$, $p < 0.001$).³ Additionally, Stergios et al. noted a significant correlation between American patients' height and the length of the semitendinosus tendon.² This implies that the length of semitendinosus tendon autograft has positive correlation with patients' height and thigh length irrespective of geographical variation.

In our study, mean diameter of quadrupled autograft (doubled semitendinosus and doubled gracilis) was 7.4 ± 0.8 mm (7.5 ± 0.7 mm in males and 6.4 ± 0.5 mm in females). The finding in our study was similar to the findings shown by various international studies, which ranged from 7.3 to 8.1 mm.^{2,9,10,13,14} In a study conducted by Stergios et al. in USA including 61 patients undergoing arthroscopic ACL reconstruction, the mean quadrupled graft diameter using semitendinosus and gracilis tendon was 7.3 ± 0.48 mm (7.41 ± 0.47 mm in males and 7.0 ± 0.37 mm in females).² In a study by Boisvert et al., the mean quadrupled graft diameter among 132 individuals was 7.64 ± 0.62 mm in males and 7.07 ± 0.49 mm in females.¹² In a study conducted by Saumitra et al including 160 patients undergoing ACL reconstruction, the mean quadrupled autograft diameter was found to be 7.7 ± 0.6 mm.¹⁴ A study done by Celiktas et al. in Turkey found the mean quadrupled hamstring graft diameter to be 8.17 ± 0.68 mm among 164 males undergoing arthroscopic ACL reconstruction.¹³

This study also found that there was significant positive correlation between quadrupled hamstring autograft diameter and patients' height ($r = 0.790$, $p < 0.001$ in males and $r = 0.858$, $p = 0.014$ in females) and thigh length ($r = 0.786$, $p < 0.001$ in males and $r = 0.904$, $p = 0.005$). The studies by Tuman et al.,⁹ Ma et al.,¹¹ Saumitra et al.¹⁴ also identified significant positive correlation between quadrupled hamstring autograft diameter and patients' height and thigh length as in our study. This implies that hamstring autograft diameter increases with body height and thigh length. However, in our study, correlation was not significant between patients' age and weight with length and diameter of hamstring autograft.

Many authors have recommended a graft diameter greater than 7 mm for ACL reconstruction in order to provide adequate strength and lower the risk of graft failure, and biomechanical studies have shown that increasing the diameter of a hamstring graft increases its strength and stiffness.^{7,8} Thus, it is advisable to have a graft diameter of minimum 7mm, and if possible, longer for successful ACL reconstruction. We have derived a regression equation for predicting semitendinosus (ST) tendon length and quadrupled hamstring autograft diameter from thigh length in males and females separately based upon our data. However, the equation

cannot be generalized to all the population and needs to be validated in large study population in multiple centers. Predicting the diameter and length of the hamstring graft prior to surgery might be helpful in identifying patients that may have comparatively small hamstring tendons and avoiding the intraoperative problem of a short and thin hamstring tendon. Thus, patients can be counseled about the necessity for any alternative tendon as a graft option well before surgery and surgeon can do proper preoperative equipment planning as well. In our study, females had a mean quadrupled hamstring autograft diameter of 6.4 ± 0.5 mm and 6 patients (2 males and 4 females) had graft diameter of 6mm, which is insufficient. Thus, we can say different graft options, such as peroneus tendon autograft, may need to be considered for females and males with short height.

This study has some limitations as well. This is an observational study with small sample size from a single center with the potential for selection and reporting bias, as well as a lack of external validity. The graft size used was only in the increment of 1mm. Other important indicators like pre-injury exercise levels and ethnicity were not taken into consideration.

CONCLUSION

We conclude that, height and thigh length of patients are good parameters for predicting semitendinosus tendon length and quadrupled hamstring autograft diameter in Nepalese population. However, a multi-centric study with a larger sample size, using randomized sampling and blinded assessment is required to validate the observations of our study.

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Data availability statement: Available data of our study will be provided to readers and other researchers as per reasonable request.

Author's Contributions: Dr Santosh Nepal: Concept and design of research, literature search, data collection, analysis and interpretation, drafting the manuscript, correspondence to the journal; Dr Mithilesh Kumar Gupta: Data collection, reviewing the manuscript; Dr Rajan Panthee: literature search, data collection, drafting the manuscript; Dr Gokul Kafle & Dr. Raj kumar Sah: Data collection, drafting the manuscript.

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