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Prediction of autologous hamstring graft size in ACL reconstruction using gender, activity level, anthropometric parameters & MRI- A prospective & retrospective study

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Abstract

Background: Arthroscopic reconstruction of torn ACL using the quadruple hamstring auto-graft has become the gold standard in treating ACL tears due to its robust stiffness & compatibility with contemporary surgical & fixation techniques. Recently, graft diameter has received increased focus as a source of ACLR failure. A higher failure rate for the reconstructed ACL with grafts smaller than 8 mm in diameter have been noted. Preoperative prediction of the sufficiency of the hamstring graft size for ACL reconstruction would be useful in order to plan alternative graft choices & alternative fixation methods to ensure the graft diameter is minimum 8mm. However, currently there is no well documented standard to accurately predict the diameter & length of quadruple hamstring auto-grafts for ACL reconstruction and existing studies present controversial findings.

Materials & Methods: The prospective study consists of 191 patients who had undergone Arthroscopic ACL reconstruction using quadrupled hamstring auto-graft at the Department of Orthopedic Surgery, Manipal Hospital, Bangalore, from January 2011 to May 2015. Several anthropometric preoperative measurements were obtained for each patient including height, weight, BMI, thigh length & thigh circumference. Activity was assessed using the Tegner activity score. A sub-group of patients (44 out of 191), whose MRI of the affected knee was performed in our institute has been included in the study. In these patients, MRI studies were performed using a standardized protocol.

Results: In our study, there is no correlation between weight, thigh circumference, activity level & BMI when correlated for males & females combined. There is a positive correlation with height in both males & females when considered separately. Taller patients tended to have thicker quadrupled hamstring grafts. However, weight, thigh circumference, BMI, activity level & CSA of combined ST+GT did not correlate with graft thickness. There is a positive correlation with MRI measurement of CSA of combined GT+ST graft thickness when measured combined for both sexes. There is a positive correlation with individual CSA of GT & ST with graft thickness when measured combined for both sexes. The regression equation that allows prediction of graft thickness based on individual MRI measurement of CSA of GT & ST is $\text{GRAFT THICKNESS} = (0.2105) \text{ CSA OF GT} + 6.8684$; $\text{GRAFT THICKNESS} = (0.0973) \text{ CSA OF ST} + 6.9645$

Conclusion: Our study overwhelmingly concludes that height is the most reliable single predictive parameter for graft diameter & length, both for males & females. MRI done by a standardized protocol is an excellent pre-operative predictor of graft size. Thigh length showed a positive correlation with graft diameter in the combined male & female group & in males & females considered separately. Other anthropometric parameters including body weight, BMI & thigh circumference have no predictive value with regard to graft diameter & length. Preoperative activity level failed to demonstrate a positive correlation with graft dimensions & has no predictive value.

Keywords: Knee, correlation, clinical, radiological, arthroscopy

Introduction

The Anterior Cruciate ligament (ACL) is the primary stabilizer of the knee and prevents abnormal anterior translation of the knee [1]. Reconstruction of ACL facilitates the patient's return to his/her pre-trauma activity level by stabilizing the knee [2] Arthroscopic reconstruction of torn ACL has become the gold standard in treating ACL tears [3]. The use of

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the quadruple hamstring auto-graft is gaining popularity due to its excellent stiffness and tensile load properties, reduced donor site morbidity, improvements in fixation techniques and implants, less postoperative anterior knee pain, better cosmesis and excellent clinical outcomes [4, 5]. The average diameter of the normal ACL is 11 mm and a graft with a minimum thickness of 7 mm has been recommended in the past [6, 7].

Potential sources of failure in hamstring auto-graft ACLRs have traditionally focused on technical errors with graft fixation or tunnel mal-positioning. Recently, graft diameter has received increased focus as a source of ACLR failure [11]. The diameter that exactly defines a diminutive graft has been a matter of debate but has been most commonly cited as 7mm. However, a more recent investigation has shown a higher failure rate for the reconstructed ACL with grafts smaller than 8 mm in diameter [8]. ACL reconstruction with a quadrupled-strand hamstring auto-graft with a diameter equal to or larger than 8 mm decreases failure rates. In addition, grafts larger than 8 mm decrease failure rates in patients aged younger than 20 years, a group identified to be at increased risk of failure [9-11].

In some surgical situations, the harvested quadrupled hamstring auto-graft may be less than optimally required. In this situation, the surgeon may need to consider an alternative graft source and fixation technique intra-operatively. Therefore, preoperative prediction of the sufficiency of the hamstring graft thickness for ACL reconstruction would be useful in order to plan alternative graft choices & arrange alternative fixation methods ready to use in the operation theatre. A few studies have investigated several anthropometric and clinical characteristics of patients to predict the quadrupled hamstring auto-graft thickness [12-16]. The purpose of this study is to identify the parameters which may be used to accurately predict the size of hamstring tendons for ACL reconstruction surgery. The variables we have considered included simple anthropometric measurements (Height, weight, body mass index, thigh circumference) age, sex and activity level.

Methodology

The prospective study consists of 191 patients who had undergone Arthroscopic ACL reconstruction using quadrupled hamstring auto-graft at the Department of Orthopedic Surgery, Manipal Hospital, Bangalore during January 2011 to May 2015. All patients undergoing ligamentous reconstruction using ipsilateral hamstring auto-graft were included. One hundred ninety one consecutive patients undergoing ACL reconstruction using hamstring auto-graft tendons were included in the study.

Several anthropometric preoperative measurements were obtained for each patient including height, weight, BMI, thigh length & thigh circumference. Thigh girth measurements were made on each lower extremity with a measuring tape at distances of 15cm from the superior poles of the patellae with the knees in extension. Thigh length measurements of the involved leg were taken by measuring the distances from the anterior superior iliac spines to the lower pole of patella. Measurements of height, weight, BMI, thigh length, thigh circumference & Tegner activity score were obtained in the out-patient department prospectively.

MRI technique: A sub-group of patients (44 out of 191), whose MRI of the affected knee was performed in our institute has been included in the study. In these patients, MRI

studies were performed with a 1.5-T superconducting magnet (Signa, GE Healthcare) using a knee specific circular coil. A positioning device for the ankle was used to ensure uniformity. A 16-cm field of view with a 256 * 256 matrix size was used. Slices were 3 mm thick with no inter-slice gap for all studies. The tendons were measured in the axial fast spin echo T2-weighted sequence with fat saturation. The chosen level of CSA measurement was at the widest point of the medial femoral epicondyle, similar to that described in the Bickel *et al.* [20] and Wernecke *et al.* [21] studies. The images were analyzed under a 43-magnified view according to the method described by Hamada *et al.* [22]. Measurements were performed by a Musculoskeletal Radiology Consultant. The CSA was calculated with a Instarispace workstation (Mediff technologies pvt limited: V4.0.0). This software has a region of interest tool that is a method for manually tracing an area, after which the software automatically calculates the CSA (in mm²).

Surgical technique: All grafts were harvested by two different orthopaedic surgeons trained in sports medicine using closed-end tendon harvester (Arthrex, Naples, Florida). After blunt removal of all muscle and fatty tissue around the tendons both the tendons were doubled over a suture (Fig. 1-2) and passed through a closed-hole sizing block (Arthrex, Naples, Florida). The sizing block measured 0.5-mm-diameter increments from 3 to 12 mm. Measurements were obtained before any further post-harvest alteration such as graft pre-tensioning for trimming of the graft. The smallest sizing hole through which the proximal end of the 4ST-GT graft could be pulled with maximal manual force was the final diameter considered for the study's purpose.



Fig 1: Graft diameter measuring



Fig 2: Graft length measurement

Results

This study consisted of 163 male and 28 female subjects with an average age of 30.8 +/- 7.69 years. Average measurements included height (173.3 +/- 4.73 cm), weight (77.7 +/- 11.46

kg), and BMI (25.9 +/- 3.70). Average values for thigh length of 52.8 +/- 4.39 cm, thigh circumference 47.9 +/-4.92 cm, and Tegner score 4.9 +/- 1.06 were obtained. Preoperative MRI measurement of CSA of 44 patients (38 male; 6 female) yielded an average CSA of gracilis (5.6 +/- 1.04), CSA of semitendinosus (11.1+/- 2.20 mm²), combined CSA of gracilis & semitendinosus (16.7+/- 2.85). Lastly, Intra-operative measurements of graft tissue yielded an average quadrupled hamstring graft length of (107.4 +/- 13.03 mm), and quadrupled hamstring graft diameter of (8.1 +/- 0.75

mm). Statistical analysis was performed using SPSS (Version 11.0, SPSS Inc, Chicago, IL). The relationship between the hamstring graft diameter, graft length and the variables: age, gender, height, weight, body mass index, thigh length, thigh circumference, Tegner activity score & relation between hamstring graft diameter & CSA of STT & GT were analyzed utilizing the Pearson r correlation coefficient.

Summary of all data

Table 1: Data

	N	Minimum	Maximum	Mean	S D	Median
Age	191	15	55	30.8	7.69	30.0
Tegner Score	191	3	7	4.9	1.06	5.0
Weight(KG)	191	50	125	77.7	11.46	76.0
Height(CMS)	191	159	186	173.3	4.73	174.0
Thigh Length (CMS)	191	41	62	52.8	4.39	53.0
thigh circumference (CMS)	191	34	67	47.9	4.92	47.5
Graft Thickness (mm)	191	7.0	10.0	8.1	0.75	8.0
GRAFT LENGTH(mm)	191	80	150	107.4	13.03	110.0
BMI(KG/M2)	191	16.90	42.52	25.9	3.70	25.4
Gracilis CSA (MM2)	44	3	8	5.6	1.04	6.0
Semitendinosus CSA (MM2)	44	7	16	11.1	2.20	11.0
GT+ST CSA (MM2)	44	11.00	23.00	16.7	2.85	16.0

The results of this study support our hypothesis that clinically measurable anthropometric data can reliably predict the length and diameter of hamstring grafts used for ACL reconstruction. When separated by gender, it appears that height is the strongest predictor for quadrupled hamstring

graft diameter in both men & women (Table 2). For graft length, height and weight may be important predictors with pooled genders but when separated, only height is the only predictor for graft length in both males & females (Table 3 & 4).

Table 2: Graft thickness correlation

Correlations combined for males & females	Graft Thickness (mm)		
	Pearson Correlation	p value	N
Tegner Score	0.068	0.352	191
Weight (KG)	0.195	0.007	191
Height (CMS)	0.630	0.000	191
BMI	-0.042	0.560	191
Thigh Length (CMS)	0.617	0.000	191
Thigh Circumference(CMS)	0.055	0.452	191
Semitendinosus CSA(MM2)	0.300	0.048	44
Gracilis CSA(MM2)	0.307	0.043	44
GT+ST CSA	0.344	0.022	44

Table 3: Graft thickness correlation (males)

Correlations (Males)			
	Graft Thickness(mm)		
	Pearson Correlation	p value	N
Tegner Score	-.013	.867	163
Weight(KG)	.214	.006	163
Height(CMS)	.633	.000	163
Thigh Length	0.608	0.000	163
Thigh Circumference(CMS)	.120	.127	163
Graft Length(mm)	.291	.000	163
BMI(KG/M2)	.011	.893	163

Table 4: Graft thickness correlation (females)

Correlations (Females)			
	GRAFT THICKNESS(mm)		
	Pearson Correlation	p value	N
Tegner Score	-0.02	0.920	28
Weight(KG)	-0.26	0.185	28
Height(CMS)	0.45	0.017	28
Thigh Length	0.47	0.012	28
Thigh Circumference(CMS)	-0.23	0.243	28
Graft Length(mm)	-0.37	0.056	28
BMI(KG/M2)	-0.02	0.920	28

Discussion

Thickness of the Quadrupled hamstring tendon graft has been shown to be directly correlated with graft stiffness, stability, ability to withstand against tensile loads, graft failure and risk of re-rupture. Potential sources of failure in hamstring auto-graft ACLRs have traditionally focused on technical errors with graft fixation or tunnel mal-positioning. Recently, graft diameter has received increased focus as a source of ACLR failure. The diameter that exactly defines a diminutive graft has been a matter of debate but has been most commonly cited as 7mm.

However, a more recent investigation has shown a higher failure rate for the reconstructed ACL with grafts smaller than 8 mm in diameter. ACL reconstruction with a quadrupled-strand hamstring auto-graft with a diameter equal to or larger than 8 mm decreases failure rates. In addition, grafts larger than 8 mm decrease failure rates in patients aged younger than 20 years, a group identified to be at increased risk of failure.

The preoperative prediction of graft measurements (length & diameter) of a quadrupled hamstring tendon graft (GT & ST) is a useful tool in the hands of a surgeon planning to perform arthroscopic ACL reconstruction. It could help him decide whether a minimum graft thickness of 8 mm would be obtained so as to increase the chances of a durable result especially in patients under 25 years of age. Alternative techniques or graft sources may be considered in cases where the predicted graft diameter or length using a quadrupled hamstring auto-graft was inadequate.

Preoperative prediction of the thickness of the tendon graft could allow for the arrangement of alternative graft options and patient notification of other graft options in patients with a potential graft size insufficiency. This preoperative information would help in patient counseling as well as appropriate ORT preparation to ensure an optimal graft selection & to prevent intra-operative surprises.

In our study, the most consistent predictor of graft size (both length & diameter) was the patient's height for males & females when considered individually & combined. Our findings were consistent with the conclusions drawn by - Tuman *et al.* [12] (N= 106; 51male, 55female), Treme *et al.* [13] (N=50; 29male, 21 female), Ma *et al.* [10] (N=536; 234 male, 302 female), Pinhero *et al.* [16] (N=80; 65male, 15 female) & Celiktas *et al.* [18] (N=164; all male). In studies by Ma *et al.* [10] & Pinhero *et al.* [16] height was considered the most significant predictor where as Tuman *et al.* & Treme *et al.* found weak to moderate correlation with height. The study by Celiktas *et al.* considered only male patients & is not directly comparable to any other study mentioned. However, our group of 191 patients consisted of 163 males which is almost identical to Celiktas's [18] study & also found height to be a strong predictor of graft thickness which reinforces the observation that patient height has the most significant predictive value. It must be noted that Treme's study & Tuman's study had a small subset of male patients & it is possible that their findings might have been different if their numbers were larger.

In our study, weight, BMI & thigh circumference had no statistically significant correlation with graft thickness. However, the graft length seem to correlate weakly with weight (p=0.023). In comparison with literature, Treme's study showed strong predictive value for weight in men & Schwartzberg's [17] showed moderate correlation with weight in both genders. We believe that weight may not be a primary predictive factor & may need further study.

Leg length correlates with height & one might expect leg

length to be a positive predictive factor since height is a strong predictor. In our study we measured thigh length rather than lower limb length & found a positive correlation of thigh length with graft thickness (p=0.00 in male female combined; p=0.00 in males & p=0.012 in females). In an out-patient clinic environment, measurement of thigh length is easy to perform & might be considered as a useful parameter.

BMI was found to be of no predictive value with regard to graft diameter or length in our study. This is at variance with Treme's study [13] who found BMI to be a strong predictor but similar to Tuman's study [12] which found BMI to be a weak predictor. Most studies have not emphasized BMI & it may be of little value in predicting the size of four stranded hamstring auto-graft.

Thigh circumference showed no correlation to graft length or thickness in both males & females in the current study. This is similar to the findings of Schwartzberg *et al.* [14] which found only weak correlation with thigh girth in their study of 119 patients. Thigh girth would be influenced by muscle wasting & body fat composition & distribution. Since the patients in our study group were a mix of acute, sub-acute & chronic presentations, our study is under powered to draw conclusions regarding the importance of thigh circumference as a predictor of graft length & thickness.

Activity level is an interesting predictive parameter & simple logic may lead one to expect that a higher activity level, especially weight bearing activity involving the lower limbs would lead to better muscle development & hence increased thigh diameter. Park *et al.* [11] in their study of 296 patients, found a significant correlation between athletic individuals & graft diameter. Treme's study failed to demonstrate a similar correlation. In our study we used the self-reported Tegner activity score as a measure of activity level & failed to demonstrate the value of higher activity as a predictor of graft thickness or length in both males & females, considered separately & combined.

MRI offers an interesting possibility for preoperative assessment of graft diameter but not length. All patients in our study underwent preoperative MRI to confirm their ACL tears & look for associated injuries. However, since our hospital is a tertiary referral centre, a number of patients came with MRI scans done elsewhere. In order to do a meaningful study, it is important to standardize the MRI protocol & to sensitize the radiologist to the measurement protocol. We were able to achieve this in 44 patients out of the study group of 191 patients in whom the MRI was carried out as per the protocol detailed in the materials & methods. This led to an inherent drawback of a small sub group size added to the fact that males & females were not considered separately in this sub group. Notwithstanding these limitations, we thought it useful to consider this sub group of patients as a pilot cohort which could form the nucleus for further studies. As per our findings, the CSA of Gracilis alone, CSA of Semitendinosus alone & CSA of the two tendons combined showed a positive predictive value for the diameter of the four stranded hamstring auto-graft. Our findings are similar to the findings of a study by Leiter *et al.* [19], done in Canada, which showed MRI to be a very reliable predictor of graft size. The threshold values in our study with 4× MRI are as follows.

Conclusion

Our study overwhelmingly concludes that height is the most reliable single predictive parameter for graft diameter & length, both for males & females, considered separately & combined. MRI done by a standardized protocol is an

excellent pre-operative predictor of graft size. Thigh length showed a positive correlation with graft diameter in the combined male & female group & in males & females considered separately. Other anthropometric parameters including body weight, BMI & thigh circumference have no predictive value with regard to graft diameter & length. Preoperative activity level failed to demonstrate a positive correlation with graft dimensions & has no predictive value.

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