

# Pre-operative ultrasonographic prediction of hamstring autograft size for anterior cruciate ligament reconstruction surgery

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## Abstract

**Objectives** To evaluate the feasibility of ultrasonographic examination in predicting 4-strand semitendinosus and gracilis tendon (4S-STG) autograft size preoperatively in anterior cruciate ligament reconstruction and to evaluate the use of anthropometric measurement to predict the 4-strand semitendinosus and gracilis tendons (4S-STG) autograft size pre-operatively in anterior cruciate ligament reconstruction.

**Method** Twenty-seven patients were included in this study conducted from 1st January to 31<sup>st</sup> December 2013. All patients were skeletally mature and scheduled to undergo primary anterior cruciate ligament reconstruction using 4S-STG autograft. Ultrasonographic examination of semitendinosus and gracilis tendons to measure the cross sectional area was conducted and anthropometric data (weight, height, leg length and thigh circumference) was measured one day prior to surgery. True autograft diameters were measured intraoperatively using closed-hole sizing block in 0.5 mm incremental size.

**Results** There is a statistically significant correlation between the measured combined cross sectional area (semitendinosus and gracilis tendons) and 4S-STG autograft diameter ( $p=0.023$ ). An adequate autograft size (at least 7 mm) can be obtained when the combined cross sectional area is at least 15 mm<sup>2</sup>. There was no correlation with the anthropometric data except for thigh circumference ( $p=0.037$ ). Autograft size of at least 7 mm can be obtained when the thigh circumference is at least 41 mm.

**Conclusions** Both combined cross sectional area (semitendinosus and gracilis tendons) and thigh circumference can be used to predict an adequate 4S-STG autograft size.

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## Introduction

Autogenous 4-strand semitendinosus and gracilis tendons (4S-STG) are increasingly becoming the preferred graft over the gold standard bone-patella-tendon-graft (BPTB) for anterior cruciate ligament reconstruction. This mainly due to the advantages associated with using 4S-STG as the donor for anterior cruciate ligament reconstruction as there is less donor site morbidity and the lack of extensor mechanism dysfunction and kneeling pain when compared to bone-patella-tendon-graft autograft, especially in the Asian population where daily activities involve kneeling such as during prayer [1-4].

Graft diameter used in anterior cruciate ligament reconstruction surgery correlates positively with the graft strength [5,6]. Traditionally, a graft size with minimum diameter of 7 mm is recommended to reduce risk of failure [7]. Hence, there is a need to establish a standard method of predicting the graft size pre-operatively and therefore allowing preparation for other graft options when there is graft inadequacy predicted pre-operatively.

Ultrasonographic examination can be used to measure the cross sectional area of the hamstring tendon with good correlation with hamstring tendon graft size [8].

Some anthropometric parameters have positive correlation with hamstring autograft size. Height has been shown persistently to have positive correlation with hamstring graft size in Caucasians [9-12]. Thigh circumference is reported to have a strong correlation with hamstring autograft size [10].

However, a study conducted in Singapore concluded that anthropometric measurement is not a reliable method of predicting hamstring autograft size [13].

## Methods

This single center prospective study was done in the University Kebangsaan Malaysia Medical Centre from

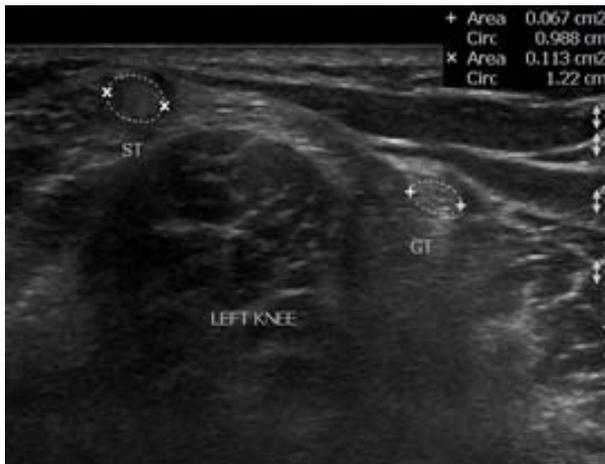


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1st January to 31st December 2013. All patients who were more than 18 years old, who underwent primary anterior cruciate ligament reconstruction using 4-strand semitendinosus and gracilis tendons (4S-STG) of the ipsilateral leg as donor were included in the study. Patients with a history of fracture of long bones and previous knee surgery (except diagnostic arthroscopy) were excluded from the study. Patients who were morbidly obese (BMI > 40 kg/m<sup>2</sup>) or severely under-weight (BMI < 18 kg/m<sup>2</sup>) were also excluded from the study.

Ultrasonographic device (Philips HD11 XE) and its 50 mm linear array probe (12-5 MHz) were used by a single radiologist to examine all patients one day prior to surgery.

On the examination table, patients were in prone position with the knee in slight flexion (30°). The semitendinosus and gracilis tendons were identified and cross sectional area measurement were taken proximal to the medial joint line, at the widest point of the distal femur as this is the site where the tendon is most rounded and oval in shape (Figure 1). The cross sectional area of each tendon was automatically calculated using the ellipse tool included in the ultrasonographic software (Figure 1). The average from two reading was taken as the final cross sectional area for each examined tendon.



**Figure 1. Ultrasound linear probe positioned on the posterior aspect of the left knee to measure the semitendinosus and gracilis tendons (ST=semitendinosus tendon, GT= gracilis tendon, SM=Semimembranosus muscle)**

Anthropometric data was collected on the same day as the ultrasonographic examination. Data included height, weight, body mass index (BMI), leg length, and thigh circumference. Leg length and thigh circumference were measured for both lower limbs. The leg length was defined as length from anterior superior iliac spine (ASIS) to the inferior border of the medial malleolus. The thigh circumference was measured at 15cm above the joint line as this represents the hamstring muscle bulk.

A 3 cm longitudinal incision was performed about 2 cm medial to the medial border of the tibial tubercle. Fat and subcutaneous tissues were cleared to expose the sartorius fascia. Both semitendinosus and gracilis tendons could be palpated and rolled under the palpating finger and were covered under the sartorius fascia. The sartorius fascia was identified and opened transversely just above the semitendinosus and gracilis tendons. Both tendons were then transected longitudinally at its insertion on the tibia. Semitendinosus and gracilis tendons were then separated from the surrounding fascia and whip-stitch were applied on individual tendons. The tendons were harvested using closed-end tendon harvester.

Muscles and soft tissues around the tendons were cleaned. Both tendons was coupled and doubled over around a suture and passed through a closed-hole sizing block. The sizing of the final autograft tendon was done in 0.5 mm incremental diameter and was recorded before pre-tensioning or trimming of the graft.

### Statistical analysis

Relationship between the final intraoperative 4S-STG graft diameter and the combined cross sectional area of both semitendinosus and gracilis tendons were determined using the Pearson correlation coefficient. A simple linear regression analysis was performed to produce a formula to predict the size of the final autograft based on combined cross sectional area of both semitendinosus and gracilis tendons. The best cut-off point of combined cross sectional area was calculated to discriminate autograft diameter of 7 mm or more. Age, height, weight, BMI, and combined cross sectional area, thigh circumference and leg length of the operated side was analysed with using skewness, kurtosis and Shapiro-Wilk test. All data were approximately normally distributed except for weight. Similar tests were used to study the relationship between the final 4S-STG autograft and anthropometric predictor variables (age, gender, height, weight, BMI, leg length and thigh circumference). P values below 0.05 were considered significant. All statistical analyses were performed using SPSS version 22.

Local ethics committee approval was obtained and written informed consent was taken from patients prior to the study.

### Results

Thirty patients were included in the study. One patient with BMI of 51.2 (height 170 cm, weight 146 kg) was excluded and another two patients did not proceed with surgery. Therefore, a total of 27 patients were included in the final analysis. There were 23 (92.6%) males and 4 females (7.4%), the mean age was 28.48 years.

The mean combined cross sectional area (semitendinosus + gracilis tendons) was 18.99 mm<sup>2</sup> (range, 13.5 to 28.8 mm<sup>2</sup>). There was no significant difference in

the cross sectional areas of the semitendinosus, gracilis or combined tendons between males and females (Table 2). Mean combined cross sectional area (semitendinosus + gracilis tendons) of the non-operated limb was 16.98. There was no significant difference between combined cross sectional area of the operated limb and the non-operated lower limb ( $p=0.243$ ).

Final intraoperative 4S-STG autograft size ranged from 6mm to 8mm. The graft was 6mm in one patient; 6.5 mm in four, 7 mm in seven patients, 7.5 mm in 6 patients, and 8 mm in 9 patients. In total, 81.5% of patients had final 4S-STG autograft size of at least 7 mm

The Pearson correlation coefficient for combined cross sectional area and final 4S-STG autograft sizes was 0.436 ( $p = 0.023$ ). A linear regression analysis was then performed between combined cross sectional area and final 4S-STG autograft size, and we found that the 4S-STG graft diameter can be predicted using the following formula;

4S-STG graft diameter =  $5.933 + (0.074 \times \text{combined cross sectional area in mm}^2)$

Sufficient 4S-STG graft diameter =  $5.933 + (0.074 \times 15) = 7.043 \approx 7 \text{ mm}$

Using the above formula, when the combined cross sectional area was at least  $15 \text{ mm}^2$ , 20 out of 24 patients had true final 4S-STG autograft size of at least 7 mm, giving

a sensitivity of 83.3%. When the combined cross sectional area was less than  $15 \text{ mm}^2$ , only one out of three patients had a true final 4S-STG autograft size less than 7 mm, hence specificity was 33.3%.

There was no correlation between final 4S-STG autograft size and age, height, weight, BMI, and leg length. However, thigh circumference was found to correlate positively with the final 4S-STG autograft size ( $p = 0.037$ ). A linear regression analysis between final 4S-STG autograft size and thigh circumference was performed. Based on this a formula was developed to predict the final 4S-STG autograft size using thigh circumference;

4S-STG graft diameter =  $4.912 + (0.051 \times \text{thigh circumference in cm})$

Sufficient 4S-STG graft diameter =  $4.912 + (0.051 \times 41) = 7.003 \approx 7 \text{ mm}$

The best cut off point to discriminate a sufficient 4S-STG autograft (at least 7 mm) was at least 41 cm (thigh circumference). Twenty one out of 26 patients who had a thigh circumference 41 cm and above had true 4S-STG graft diameter of 7 mm and above (sensitivity = 80.8%). One patient had a thigh circumference of less than 41 cm, which was predicted to give a graft size of 6.8 mm, however intraoperatively the true final 4S-STG size was 7 mm, which gives it zero specificity. However, the low specificity could be due to the small sample size.

**Table 1. Characteristics of the patients**

Variables	Mean	Std. Dev.	Range
Age	28.48	6.00	(17-40)
Combined cross sectional area (mm <sup>2</sup> )	18.99	3.57	(13.5-28.8)
Semitendinosus tendon cross sectional area (mm <sup>2</sup> )	10.14	2.25	(6.4-14.3)
Gracilis tendon cross sectional area (mm <sup>2</sup> )	8.84	3.34	(3.4-16.8)
Thigh circumference (cm)	47.52	4.78	(37.5-58.0)
Leg length (cm)	87.98	3.61	(81.0-97.0)
Height (cm)	168.56	5.26	(157.0-176.0)
Weight (kg)	72.60	14.07	(50.0-118.0)
BMI	25.56	4.72	(19.13-38.74)

**Table 2. Comparing the cross sectional area of semitendinosus tendon, gracilis tendon and both tendons in the operated and non-operated limbs**

	Operated limb Mean (SD)	Non-operated limb Mean (SD)	Significance (p value)
Both tendons-combined cross sectional area	18.99 (3.57)	16.98 (9.4)	0.24
Semitendinosus tendon combined cross sectional area	10.14 (2.25)	9.13 (4.64)	0.23
Gracilis tendon combined cross sectional area	8.84 (3.34)	7.84 (5.81)	0.43

Independent sample t test used to compare means

## Discussion

The use of the cross section area of the hamstring tendon from magnetic resonance imaging (MRI) to predict the final hamstring autograft size for anterior cruciate ligament reconstruction has been described previously, and has proven to be a reliable method [14-17]. However, MRI is an expensive procedure and takes time to carry out.

Ultrasonographic examination is a reliable method to assess the basic architectural parameters of the hamstring tendon [18]. It is a cheap bedside procedure and at the hand of experienced users takes as little as five minutes to complete. A recent study found that the cross sectional area of the hamstring tendon calculated using ultrasonography correlated positively with the final hamstring autograft size intraoperatively [8].

Bickel *et al.* reported a mean combined cross sectional area of 19.9 mm<sup>2</sup> in a series of 26 patients examined using MRI [19]. They described a sensitivity of 81.8% in detecting 4S-STG autograft size of 7mm or more when combined cross sectional area is at least 18 mm<sup>2</sup> using MRI examination to predict 4S-STG autograft size preoperatively. In our study, we noted a sensitivity of 83.3% in predicting 4S-STG autograft of 7 mm or more when the combined cross sectional area was 15 mm<sup>2</sup> using ultrasonographic examination. The mean cross sectional area in our series of patients was 18.99 mm<sup>2</sup>. These findings are comparable even though the former study used MRI examination to measure cross sectional area. However, the specificity of MRI examination was 100% compared to our study where specificity was only 33.3%. A larger sample size would give a better estimate of sensitivity and specificity.

A more recent study which used a similar method of ultrasonographic examination to measure the combined cross sectional area of the hamstring tendon by Erquicia *et al.* found a positive correlation between combined cross sectional area and final 4S-STG autograft [8]. This study included 33 patients (25 males, 8 females), and found that ultrasonographic prediction of hamstring graft is comparable with 2X MRI magnification. The mean combined cross sectional area using ultrasound in this study was 15.7 mm<sup>2</sup>. However, the mean combined cross sectional area with 2X MRI magnification was 27.2 mm<sup>2</sup>. Using ultrasonographic cross sectional area measurement, they reported a sensitivity of 80.8% in detecting true 4S-STG autograft sizes of at least 8 mm when the combined cross sectional area is at least 14 mm<sup>2</sup>. All patients predicted to have final 4S-STG autograft of less than 8 mm had a true final 4S-STG autograft of less than 8 mm intraoperatively when the combined cross sectional area was less than 14 mm<sup>2</sup>, giving a specificity of 100%. Using MRI measurement of combined cross sectional area, this study noted that a combined cross sectional area of 25 mm<sup>2</sup> is required to get a hamstring graft of at least 8 mm<sup>2</sup>. However, the definition of sufficient graft size by Erquicia *et al.* was

a graft size of at least 8 mm [8]. Recent findings have noted a higher failure rate in graft sizes smaller than 8 mm, especially in patients aged less than 20 years. In comparison in our study, we took 7 mm as the acceptable hamstring graft size. Using ultrasonographic prediction, mean combined cross sectional area of 15 mm<sup>2</sup> is required to yield a hamstring graft of at least 7 mm. Twenty out of 24 patients were predicted correctly to have a hamstring graft of at least 7 mm, when the combined cross sectional area was at least 15 mm<sup>2</sup>. Thus the sensitivity was 83.3%. However, only one patient was predicted correctly to have a hamstring graft size of less than 7 mm when the combined cross sectional area was less than 15 mm<sup>2</sup>. This gives a specificity of 33.3%. This poor specificity could be due to the small sample size.

In our series of patients, the average cross sectional area of the semitendinosus, gracilis, or both combined were more in the operated limb than in the non-operated limb. However, the difference was not significant.

A study by Loo *et al.* done on Singaporean Chinese patients noted that anthropometric data such as height, weight and BMI were unreliable in predicting the hamstring autograft size for use in anterior cruciate ligament reconstruction surgery [13]. In the past, anthropometric data especially height have been proven many times to be a reliable predictor of hamstring autograft size in Caucasian population [9-12]. Our study is in agreement with the study done in Singapore, which stated that height, weight, and BMI is not a reliable variable to predict hamstring autograft size. The differences in these findings may be due to the differences in ancestral lineage [13,21].

Boisvert *et al.* noted that BMI more than 25 kg/m<sup>2</sup> may predict a larger hamstring autograft (more than 7mm). However the study found that BMI of less than 18 kg/m<sup>2</sup> did not predict a smaller graft (less than 7mm) [12]. The range of BMI in these 132 patients was between 18.2 to 31 kg/m<sup>2</sup>, with an average BMI of 23.25 kg/m<sup>2</sup>. Morbid obesity is defined as having BMI of more than 40. In our study, morbidly obesity and extremely underweight patients were not included in the study as a single outlier may affect the normal distribution of data. Patients included in our study had BMI ranging from 19 to 39 kg/m<sup>2</sup> with mean BMI of 25.56 kg/m<sup>2</sup>.

Treme *et al.* found several factors associated with a hamstring autograft size of less than 7 mm; thigh circumference of less than 37 cm, weight less than 50kg, height less than 140 cm, and BMI less than 18 kg/m<sup>2</sup> [10]. The higher the number of risk factors, the more chance of a hamstring autograft of less than 7 mm.

Our study found that thigh circumference of less than 41 cm was associated with having a hamstring autograft of less than 7 mm. The sensitivity of detecting adequate graft size (7mm or more) was 80.8% if the thigh circumference is more than 41 cm. Out of 27 patients, there was only one patient with thigh circumference of less than

41cm (37.5 cm). This patient was predicted to have final 4S-STG autograft size of 6.8 mm. However, intraoperatively, the graft size was 7 mm. This is an isolated unexplainable case, and might be an outlier. This makes the specificity of thigh circumference in predicting hamstring size zero. A larger sample size is needed to confirm this.

To date, this is the first investigation performed on Asian patients specifically in Malaysian patients, where ultrasonographic examination was used to measure the cross sectional area of hamstring tendon to predict final 4S-STG autograft sizes. The results of this study provide new information on the reliability of ultrasonographic examination as a method to predict 4S-STG autograft sizes. In addition, it provided evidence about the reliability of anthropometric data to predict hamstring autograft in Malaysian community.

In our data series, 26 out of 27 patients were of Malay ethnicity and only one patient was of Indian ethnicity. Therefore, the data above may only be generalised to the Malay community in Malaysia. Further studies are needed to extrapolate these findings to other ethnicities.

## Conclusion

The current study emphasizes the feasibility of using ultrasonographic examination for predicting the final intraoperative 4S-STG autograft for anterior cruciate ligament reconstruction surgery. This clinical bedside examination is reliable and available at a minimal cost and could be performed without the “time consuming” factor involved when using MRI. Thigh circumference was found to be reliable to estimate the adequacy 4S-STG autograft. This study proposed preparation for alternative graft for anterior cruciate ligament reconstruction surgery if the combined cross sectional area for both semitendinosus and gracilis tendons are less than 15 mm<sup>2</sup> or if the thigh circumference is less than 41 cm in patient with BMI within 18 to 40 kg/m<sup>2</sup>

## Conflicts of interest

There are no conflicts of interest.

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