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*ORIGINAL STUDY*

# Role of anthropometric data in the prediction of 4-stranded hamstring graft size in anterior cruciate ligament reconstruction

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**To evaluate whether pre-operative anthropometric data can predict the optimal diameter and length of hamstring tendon autograft for anterior cruciate ligament (ACL) reconstruction.**

**This was a cohort study that involved 169 patients who underwent single-bundle ACL reconstruction (single surgeon) with 4-stranded MM Gracilis and MM Semi-Tendinosus autografts. Height, weight, body mass index (BMI), gender, race, age and smoking status were recorded pre-operatively. Intra-operatively, the diameter and functional length of the 4-stranded autograft was recorded. Multiple regression analysis was used to determine the relationship between the anthropometric measurements and the length and diameter of the implanted autografts.**

**The strongest correlation between 4-stranded hamstring autograft diameter was height and weight. This correlation was stronger in females than males. BMI had a moderate correlation with the diameter of the graft in females. Females had a significantly smaller graft both in diameter and length when compared with males. Linear regression models did not show any significant correlation between hamstring autograft length with height and weight ($p > 0.05$). Simple regression analysis demonstrated that height and weight can be used to predict hamstring graft diameter. The following regression equation was obtained for females : Graft diameter = 0.012 + 0.034*Height + 0.026*Weight ($R^2 = 0.358$, $p = 0.004$) The following regression equation was obtained for males : Graft diameter = 5.130 + 0.012*Height + 0.007*Weight ($R^2 = 0.086$, $p = 0.002$).**

**Pre-operative anthropometric data has a positive correlation with the diameter of 4 stranded hamstring autografts but no significant correlation with the length. This data can be utilised to predict the autograft diameter and may be useful for pre-operative planning and patient counseling for graft selection.**

**Keywords** : anterior cruciate ligament reconstruction ; hamstring graft ; anthropometric.

## INTRODUCTION

Anterior cruciate ligament injury is increasingly common in the active individual. Graft options for repair include autografts such as bone-patellar-tendon-bone (BPTB) autograft, quadriceps tendon autograft, hamstring autograft and various allograft sources. Graft selection is often multi-factorial with

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age, activity level, donor site morbidity and surgeon preference all involved in reaching a final choice with the patient. Whilst the bone-patellar-bone graft has yielded good results, there is increasing evidence to show that hamstring tendon autografts can expect similar outcomes (*5,6,12*). The hamstring graft is able to provide adequate biomechanical strength whilst potentially reducing the incidence of anterior knee pain and extensor mechanism dysfunction, commonly associated with BPTB grafts (*22*). Improved fixation techniques have also increased the popularity of hamstring grafts (*7,15*). However, hamstring graft diameter cannot be altered in vivo, unlike a BPTB graft diameter that is subject to adjustments during harvest by the surgeon. Graft diameter has been shown to have an important role in anterior cruciate ligament (ACL) autograft failure rates. The minimum graft diameter recommended is 7.0 mm in order to reduce the rate of graft failure (*8,9*). As such, the role of pre-operative imaging such as ultrasound and magnetic resonance imaging (MRI) have been explored, to determine if an accurate assessment of graft diameter can be obtained pre-operatively. Pre-operative knowledge of hamstring graft diameter enables surgeons to perform better surgical planning and the opportunity to obtain alternate graft options such as allografts if required.

The purpose of this study was to determine if pre-operative anthropometric data such as height, weight, body mass index (BMI), age, gender as well as smoking status can be used to accurately determine the hamstring graft diameter and length pre-operatively.

## MATERIALS AND METHODS

This was a cohort study involving 169 subjects (141 males and 28 females) who underwent a single bundle ACL reconstruction utilising a 4-stranded hamstring graft by a single surgeon (Senior surgeon) from 2008 to 2012. Pre-operatively, the height, weight, body mass index (BMI), age, gender and smoking status was recorded.

All hamstring grafts were harvested in a similar fashion, utilising a medial vertical incision with a hamstring graft harvester. Both the MM Gracilis and MM Semi-Tendinosus grafts were cleaned and trimmed appropriately. The tendons were then prepared using a 4-stranded, single bundle technique, with the ends of each tendon graft whip-stitched with Ethibond 2 sutures. The grafts were saucerised with vicryl 2-0. The functional length of the 4-stranded graft was defined as the measured end to end length of the prepared graft. The diameter of the graft was measured using slotted cylinders with 0.5 mm step increments. The smallest possible diameter that allowed smooth passage of the graft was taken to be the final diameter. Femoral fixation was achieved with Enbobutton CL loop (Smith & Nephew) while tibial fixation was achieved with Biosure screw.

The correlation coefficient (Pearson r) and multiple linear regression models were used to determine the relationship between the outcome variable of graft diameter/length and predictor variables such as height, weight, BMI, age, gender and smoking status. Higher correlation coefficients indicate stronger relationships between the variables. Independent samples t-test was used to compare hamstring graft diameters between the genders. Differences were considered significant when P values were below .05. All statistical analysis was done using SPSS program version 17.0 (SPSS Inc, Chicago, Illinois).

## RESULTS

A total of 169 patients were recruited, with 141 males and 28 females. The mean age was 25.7 years (16 to 54 years) for males and 24.3 years (17 to 44 years) for females. (Table I) The most common graft diameter was 8.0 mm (43.3%) and 7.0 (39.3%) for males and females respectively. (Table II) The graft diameter and functional length was significantly smaller in females than in males.

Hamstring graft diameter was related to height ($r = .42$, $p < .001$), weight ($r = .40$, $p < .001$) and body mass index ($r = .19$, $p < .05$) but not related to age ($r = .14$, $p > .05$) or smoking status ($r = .14$, $p > .05$). Linear regression analyses separated by gender showed a statistically significant correlation between graft diameter and measured variables such as height and weight in both males (Figs. 1 and 2) and females (Figs. 3 and 4).

Hamstring graft length correlated poorly to all the pre-operative measured variables. Using a multiple regression model, there were no significant findings in our series.

Utilizing a simple regression model, the cut-off anthropometric data for a 7.0 mm diameter graft in females was 60 kg ($r = .51$, $p < .05$) and 161 cm

Table I

| | n | Age (y) | Height (cm) | Weight (kg) | BMI | Smoking Status |
|---|---|---|---|---|---|---|
| Males | 141 | 25.7 ± 6.8 | 173.3 ± 7.1 | 76.0 ± 15.8 | 25.5 ± 6.0 | Y (57)<br>N (84) |
| Females | 28 | 24.3 ± 8.8 | 161.0 ± 6.4 | 61.2 ± 11.6 | 24.0 ± 5.8 | Y (2)<br>N (26) |

Table II

| Diameter (mm)[a] | | |
|---|---|---|
| Graft Size | Female | Male |
| 6.0 | 4 (14.3) | 0 |
| 6.5 | 4 (14.3) | 2 (1.4) |
| 7.0 | 11 (39.3) | 23 (16.3) |
| 7.5 | 4 (14.3) | 36 (25.5) |
| 8.0 | 4 (14.3) | 61 (43.3) |
| 8.5 | 1 (3.6) | 4 (2.8) |
| 9.0 | 0 | 15 (10.6) |

[a]Data presented as n (%).

($r = .39$, $p < .05$). These associations suggest that shorter and lighter females tend to have smaller graft sizes. There were no meaningful cutoff points for males using the simple linear regression model.

Multiple regression models yielded the following equation for females :

$$\text{Graft diameter} = 0.012 + 0.034*\text{Height} + 0.026*\text{Weight}\ (R^2 = 0.358, p = 0.004).$$

The following regression equation was obtained for males :

$$\text{Graft diameter} = 5.130 + 0.012*\text{Height} + 0.007*\text{Weight}\ (R^2 = 0.086, p = 0.002)$$

## DISCUSSION

The quadrupled hamstring graft is a common graft choice for Orthopaedic surgeons, owing to its comparable biomechanical strength and minimal donor site morbidity (*2,4*). The cross-sectional area of the graft has been known to be directly correlated to graft stiffness, stability, higher peak to graft failure as well as other favorable biomechanical attributes (*10*). Smaller hamstring autograft size has also been shown to be a predictor of poorer KOOS sport/recreation function 2 years after primary ACL reconstruction (*11*). In view of the potential relationship between graft size and graft failure, some authors have recommended a minimal graft diameter of 7 mm (*8,9*). Pre-operative determination of hamstring graft size is challenging. Magnetic resonance imaging (MRI) and ultrasound scanning have been used to predict hamstring graft sizes to moderate success (*3*). However, the variability between MRI machines and resolutions, measurement technique, radiologists and the high cost of these investigations limit the practical usage of imaging. Conversely, anthropometric data collection is seen to be an easier and less costly way of predicting the hamstring graft size. There have been several studies that have utilised anthropometric data to predict hamstring graft size, but these have mainly been in the western population (*1,18,19*). The accuracy of anthropometric data in the prediction of hamstring graft sizes coincides with recent findings that anthropometric data is an important predictor in the sizing of meniscal allografts for transplantation. Appropriate size-matching of meniscal allografts is believed to be important in force transmission and optimizing meniscal function (*14*). Anthropometric data, especially patient height, has been shown to be equal to or more accurate than radiological measurement techniques in predicting meniscal allograft size (*17, 21*).

We reviewed a consecutive series of ACL reconstructions by a single surgeon from 2008 to 2012 and identified 169 patients who had a primary single-bundle ACL reconstruction using a 4-stranded hamstring graft. Our results show that the hamstring graft diameter correlated strongly with height and weight. There was no significant correlation between the graft length with height and weight. There was no correlation between graft diameter and age,

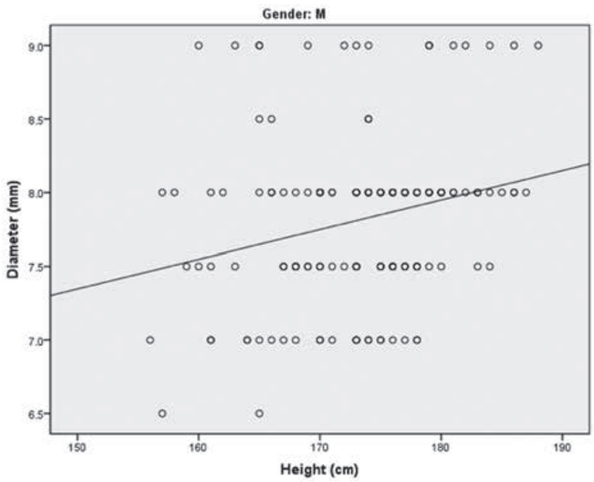


*Fig. 1.* — Scatter plots showing relationship between height and hamstring graft diameter in males. r = 0.26, p < 0.01.

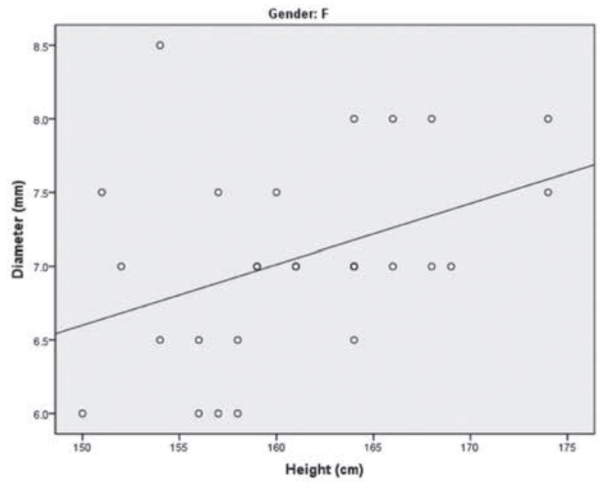


*Fig. 3.* — Scatter plots showing relationship between height and hamstring graft diameter in females. r = 0.39, p < 0.05.

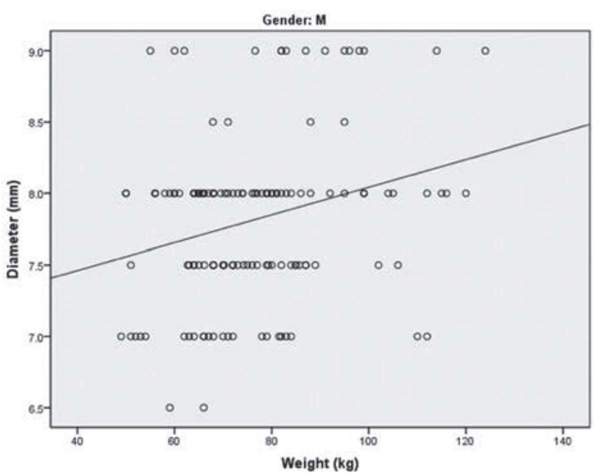


*Fig. 2.* — Scatter plots showing relationship between weight and hamstring graft diameter in males. r = 0.24, p < 0.01.

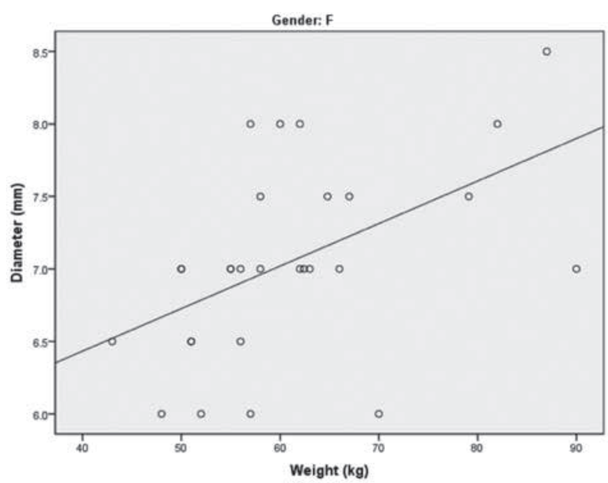


*Fig. 4.* — Scatter plots showing relationship between weight and hamstring graft diameter in females. r = 0.51, p < 0.01.

race or smoking status. Ma *et al* (*13*) found in his series of 536 patients that height was a strong predictor of quadrupled hamstring graft diameter. These findings echo those of Xie *et al* (*23*) and Thomas *et al* (*18*) that show that body height is a useful parameter for prediction of hamstring graft diameter.

In our series, the correlation between hamstring graft diameter with height and weight was particularly strong in females. Females were also noted to have a significantly smaller hamstring graft than males. Our study is similar to Tuman *et al* (*20*) that showed height was the best predictor of hamstring tendon diameter, particularly in women. Based on our results, we conclude that a short (< 160 cm) and low weight (< 60 kg) female would be at the greatest risk for small graft diameter.

Body mass index (BMI) had a moderate correlation with graft diameter in females, but this correlation was not present in males. This is consistent with Tuman *et al* (20) and Pinheiro *et al* (16) that have shown no correlation between BMI and hamstring graft size.

An accurate pre-operative assessment of hamstring graft diameter would play a pivotal role in graft selection. If the surgeon is concerned regarding the small graft size pre-operatively, additional measures should be taken to counsel the patient for alternative options such as contralateral hamstring graft supplementation, allograft supplementation or conversion to allograft altogether. Intra-operatively, the contra-lateral knee can be prepped for surgery simultaneously so as to avoid unnecessary delay should the ipsilateral hamstring graft be insufficient.

Hamstring graft length is an important component in the ACL reconstructive surgery. An inadequate length may compromise fixation of the graft, in particular the tibial fixation component. In our study, the minimum graft length encountered was 9 cm. There was poor correlation between graft length and the pre-operative measured variables. One explanation for the poor correlation may be the graft measurement technique. The combined 4-stranded graft was measured after trimming and cleaning, whilst the individual MM Gracilis and MM Semi-Tendinosus tendons were not measured. This process may be subjective, depending on the preparation of the graft. The ability to anticipate poor graft lengths would allow surgeons to plan for other alternatives to the 4-stranded graft. Surgeons may choose to use a triple stranded hamstring graft instead (at the expense of reduced graft diameter) or utilize other graft options such as a BPTB autograft or allografts. Poor graft lengths would preclude the surgeon's ability to offer double bundle ACL reconstruction without the use of allografts. Tibial fixation devices would also vary, depending on the graft length available after femoral fixation.

There are some limitations in our study. Firstly, there is a small sample size (n = 28) of female patients and this may not be sufficient for our results to be generalised. Secondly, measurement of the individual tendons (MM Gracilis and MM Semi-Tendinosus) was not performed. Measurement of the functional length of the 4-stranded graft was performed after trimming and may be prone to inconsistency. In our study, we used patients from a single surgeon and as such, errors arising from surgical technique are kept to a minimum. The intra-articular length of the graft was not measured after fixation and this may have been a more accurate reflection of functional length. Finally, we accept that there are likely other factors that may influence the hamstring graft size that we have not measured in this study, such as pre-injury activity levels, lean body mass index, limb length and limb girth. Nonetheless, the results from this study can still be used for pre-operative planning of graft options.

## CONCLUSION

Patient height and weight are anthropometric variables that can be used to predict the hamstring graft diameter in ACL reconstruction. This allows surgeons to advise patients accordingly and plan for alternative graft options if required. Women of short height and low body weight are at highest risk of small graft sizes.

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