Knee Surg Sports Traumatol Arthrosc
DOI 10.1007/s00167-010-1387-7

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# Intra-operative four-stranded hamstring tendon graft diameter evaluation

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Received: 12 April 2010 / Accepted: 27 December 2010


**Abstract**
*Purpose* To evaluate whether clinical factors enable prediction of the diameter of hamstring tendons harvested for anterior cruciate ligament (ACL) reconstruction.
*Methods* Eighty patients were submitted for reconstruction of the ACL with hamstring tendons in a quadruple manner. During surgery the diameter of the graft was measured. The variables analyzed were: age, gender, weight, height, operated side, dominant side, leg length, thigh length, thigh diameter, body mass index (BMI), and sports activity. The data was collected pre-operatively and correlated with the diameter of the graft.
*Results* The diameter of the graft was strongly related to gender, height, leg length, thigh length, weight, and thigh diameter. Women presented significantly smaller graft diameter than men; as well as weight, height, leg length, and thigh length. Men with height equal to or greater than 1.80 m showed average graft diameter greater than the total group, and greater percentage of 9 mm grafts.
*Conclusion* The diameter of the hamstring graft is significantly associated to weight, height, leg length, thigh length, thigh diameter, and gender. The variable that had most influence was height, followed by gender and leg length. The variables BMI, age, sports activity, and dominant side did not present correlation. Tendon diameter was larger in men than in women. Men with a height equal to or greater than 1.80 m had a higher prevalence of 9 mm grafts and had a larger average tendon diameter.
*Level of evidence* Prospective cross sectional collection of data, Level IV.

**Keywords** Knee · Anterior cruciate ligament · Hamstring · Graft

## Introduction

A disadvantage of anterior cruciate ligament (ACl) reconstruction with hamstring tendons is the possibility of obtaining a graft of smaller diameter and theoretically of lesser mechanical resistance in some patients [3, 5–7, 10, 11, 13–15, 20]. Graft diameter in this technique does not depend upon the surgeon, but exclusively upon the anatomy of each patient, whereas with the patellar and quadriceps tendon, graft diameter is determined by the surgeon during harvesting. Thus, if the surgeon could define a method that helped him to avoid hamstring grafts of an insufficient diameter, he would be able to decide beforehand on another more suitable method.

The objective of this study is to evaluate if there are patient characteristics, like age, gender, weight, height, side operated on, dominant side, lower limb length, thigh length, thigh diameter, body mass index (BMI) and sports activity, that permit the prediction of the diameter of the hamstring graft for ACL reconstruction preoperatively.

The hypothesis is that graft diameter is larger in men with a high level of sports activity and thinner in women regardless the level of sports activity they do.

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Published online: 03 February 2011

## Materials and methods

This study was approved by the Committee of Ethics and Research of an Institution registered by CONEP (National Commission of Ethics and Research), under protocol N$^0$ 017/08.

From January to December 2008, 80 patients were submitted to arthroscopic reconstruction of the ACL using hamstring grafts (65 men and 15 women—81 and 19%, respectively), done by four different surgeons utilizing the same technique. The average age of the patients was 31.6 ± 9.4 years, ranging from 16 to 59 years. The average weight was 78.1 ± 15.3 kg, and the average height was 1.75 ± 0.08 m. The right lower limb was dominant in 68 patients (85%) and the left one in 12 (15%). The surgery was performed on the right side in 44 patients (55%) and on the left in 36 (45%). Regular sports activity was done by 72 patients (90%) (Table 1).

After harvesting the semitendinosus and gracilis tendons, grafts were prepared in a quadruple form, and measurements were done with 6.0–10.0 mm diameter tubes, after complete cleaning and removal of the muscle fibers adhering to the tendons. The smallest cylinder that permitted the passage of the graft was considered the final diameter. A difference of 1 mm between the tubes was considered adequate, because the drill bits used for making the tunnels had a 1 mm difference in diameter. No pretensioning was done on the surgical table.

**Table 1** Demographics

| Variables | Mean ± standard deviation |
|---|---|
| Age (years) | 31.6 ± 9.4 |
| Weight (kg) | 78.1 ± 15.3 |
| Height (meter) | 1.7 ± 0.1 |
| Length of the lower limb (cm) | 89.5 ± 5.2 |
| Length of thigh (cm) | 51.6 ± 3.6 |
| Diameter of thigh (cm) | 53.4 ± 4.6 |
| BMI | 25.4 ± 4.3 |
| | *n* (%) |
| *Graft diameter* (mm) | |
| 6 | 2 (2.50) |
| 7 | 20 (25.00) |
| 8 | 43 (54) |
| 9 | 15 (19) |
| *Operated side* | |
| Right | 44 (55) |
| Left | 36 (45) |
| *Dominant side* | |
| Right | 68 (85) |
| Left | 12 (15) |
| *Gender* | |
| Male | 65 (81) |
| Female | 15 (19) |
| *Sports activity* | |
| Yes | 72 (90) |
| No | 8 (10) |

The variables analyzed were: age, gender, weight, height, side operated on, dominant side, lower limb length (anterior superior iliac spine to medial malleolus), thigh length (anterior superior iliac spine to medial joint space), thigh diameter (measured 20 cm above the superior pole of the patella), BMI, sports activity, and type and frequency of sport activity. All of the measurements were performed preoperatively, and correlated to the diameter of the graft observed during surgery.

### Statistical analysis

Student's *t* test was used for the independent samples, to compare the mean of the non-categorical variables. The Chi-square ($\chi^2$) test was done to verify the association of the categorical variables with the diameter of the graft. The Pearson correlation coefficient was calculated to identify the degree of the association of the categorical co-variables with the response. After the univariate analysis, a multivariate analysis was done by multiple linear regression, which was adjusted to quantify the effect of each of the co-variables in the explanation of the diameter of the graft. Values of $P < 0.05$ were considered significant. The results were evaluated with the help of free *software* R® version 2.7.2.

## Results

The averages of the length of the operated lower limb, thigh length, thigh diameter, and BMI, as well as graft diameter are shown in Table 1.

The average graft diameter in women was significantly smaller than in men ($P < 0.001$), as were weight ($P < 0.001$), height ($P < 0.001$), leg length ($P < 0.001$), and the length of the thigh ($P = 0.009$) (Table 2). The average graft diameter in men was 0.85 mm larger than in women. The average age, thigh diameter, and the BMI showed no significant gender related difference.

Sports activity and the surgery on the dominant side showed no significant influence on the diameter of the graft.

The $\chi^2$ test showed that among the categorical co-variables, only gender was significantly associated to the diameter of the graft (Table 3). The analysis of the Pearson correlation coefficients showed that height, weight, leg length, thigh length, and thigh diameter were significantly related to graft diameter.

**Table 2** Descriptions by gender and test of difference between the means

| Variables | Male | Female | *P* value |
|---|---|---|---|
| Diameter of the tendon (mm) | 8.1 ± 0.6 | 7.2 ± 0.7 | 0.001 |
| Age (years) | 31.5 ± 8.6 | 32.1 ± 13.0 | n.s. |
| Weight (kg) | 81.8 ± 13.5 | 61.9 ± 12.2 | 0.001 |
| Height (meter) | 1.8 ± 0.1 | 1.6 ± 0.1 | 0.001 |
| Length of the leg (cm) | 90.6 ± 4.9 | 84.6 ± 3.8 | 0.001 |
| Length of the thigh (cm) | 55.1 ± 3.6 | 49.4 ± 3.3 | 0.009 |
| Diameter of the thigh (cm) | 53.9 ± 4.5 | 51.8 ± 4.9 | n.s. |
| BMI | 26.0 ± 3.8 | 23.0 ± 5.7 | n.s. |

The *P* value refers to the *t* test for the differences between the means of the genders

**Table 3** Descriptions by diameter of the tendon and test of association

| | 6 mm | 7 mm | 8 mm | 9 mm | Total |
|---|---|---|---|---|---|
| Gender versus diameter of tendon *n* (%) | | | | | *P* value = 0.002 |
| Female | 2 (100) | 8 (40) | 5 (12) | 0 (0) | 15 |
| Male | 0 (0) | 12 (60) | 38 (88) | 15 (100) | 65 |
| Sports activity versus diameter of tendon *n* (%) | | | | | *P* value (n.s.) |
| No | 0 (0) | 3 (15) | 4 (9) | 1 (7) | 8 |
| Yes | 2 (100) | 17 (85) | 39 (91) | 14 (93) | 72 |
| Operated side versus diameter of tendon *n* (%) | | | | | *P* value (n.s.) |
| Right | 0 (0) | 11 (55) | 23 (53) | 10 (67) | 44 |
| Left | 2 (100) | 9 (45) | 20 (47) | 5 (33) | 36 |
| Dominant side versus diameter of tendon *n* (%) | | | | | *P* value (n.s.) |
| Right | 2 (100) | 15 (75) | 39 (91) | 12 (80) | 68 |
| Left | (0) | 5 (25) | 4 (9) | 3 (20) | 12 |

The *P* value refers to the $\chi^2$ test for association between the co-variables and the response

The simple linear regression demonstrated that the variables: height, weight lower limb length, thigh length, and thigh diameter explained, respectively, 99, 97, 99, 99, and 98% of the variability of the graft diameter. Through these models, it is possible to predict that individuals with a height less than 1.55 m ($r = 0.47$, $R^2 = 0.99$, $P = 0.001$), lower limb length less than 79.5 cm ($r = 0.39$, $R^2 = 0.99$, $P = 0.001$), length of the thigh less than 47 cm ($r = 0.39$, $R^2 = 0.99$, $P = 0.001$), diameter of the thigh less than 50 cm ($r = 0.27$, $R^2 = 0.98$, $P = 0.014$), weight less than 71.4 kg ($r = 0.36$, $R^2 = 0.97$, $P = 0.001$), and the female gender ($R^2 = 0.99$, $P = 0.001$) show greater probability of having a graft with a diameter equal to or less than 7 mm.

The average graft diameter in men with a height equal to or greater than 1.80 m was significantly larger (*P* value = 0.032).

There were 24 individuals in the study presenting an average graft diameter of 8.3 mm, with a height equal to or greater than 1.80 m, median age of 30 years, and weight, lower limb length, thigh length, and BMI averaging 88.9 kg, 94.4 cm, 55.4 cm, and 26.5, respectively.

This study showed a higher prevalence of 9 mm grafts among men with a height equal to or greater than 1.80 m when compared to men and women with a height less than 1.80 m ($n = 54$) $P = 0.001$ and to men whose height was less than 1.80 m ($P = 0.007$).

## Discussion

The most important finding of this study was to define which preoperative data or measurements, obtained by a simple history or physical examination, can help in the prediction of graft diameter. This should be a part of the preoperative evaluation of the ACL lesions, mainly in those cases in which the hamstring tendons are the option of choice. The main results of this study are in accordance with literature [17–19].

The average diameter of the normal ACL is 11 mm, therefore a graft with a minimum thickness of 7 mm is recommended [4, 8, 9.] Differently from patellar and quadriceps tendons, the hamstring tendons can not be measured by the surgeon before their harvesting, and few studies in the literature suggest preoperative parameters for the estimation of the hamstring graft [1, 17–19, 21].

There are few articles that suggest image parameters. Yasumoto et al. [21] analyzed preoperative measurements of the semitendinosus tendon by a 3-D computer tomography scan, but did not find any significant correlation between the measured sectional area at the CT scan and the diameter of the tendon measured intraoperatively. The only correlation was related to the length of the tendon. Bickel et al. [1] measured the sectional area of the semitendinosus and gracilis tendons by magnetic resonance imaging preoperatively in adolescents with rupture of the ACL and found strong correlation between the MRI and the area of the harvested graft.

Three recent articles correlated the diameter of the graft with clinical parameters and the anthropometric measurements of patients. Tuman et al. [19] evaluated 106 patients and found correlation between the diameter of the graft and height, weight, gender, and age. Women presented a graft diameter significantly smaller than men. Height was the measurement that mostly correlated with the graft estimation especially in women.

Treme et al. [18] analyzed the length and diameter of the semitendinosus and gracilis tendons of 50 patients in whom an ACL reconstruction was done. They found strong correlation among graft length, patient height, and lower limb length. The graft diameter was correlated to the patient weight and to thigh circumference. Graft diameter was not

influenced by the level of activity and age. Women, especially those of small stature and lower weight presented grafts with smaller diameter and length on average.

Schwatzberg et al. [17] analyzed length and diameter of the semitendinous and gracilis of 119 patients in whom ACL reconstruction was also done. They found a strong correlation between lower limb length and hamstring length. The graft diameter had moderate correlation to weight and lower limb length. Correlations to age, height, and thigh girth were weak.

This study confirmed Tuman et al. [19] and Treme et al. [18] results, in relation to gender. The mean values of graft diameter in women were smaller than in men, as well as the weight, height, lower limb length, and thigh length. Is this the reason for these tendons having a smaller thickness in women or is it related to the smaller average anthropometric measurements in this gender? [2, 4, 6, 12, 16]. The answer could be given with similar anthropometric groups of different gender, which did not happen in this study.

There was no correlation between graft diameter and sports activity, what was similar to Treme et al. [18] data. This study did not find any correlation between graft diameter and dominant or non-dominant leg, what was not studied in the other articles about this subject.

Patient's BMI did not influence graft diameter, what was coincident with Tuman et al. [19] findings. On the other hand, Treme et al. [18] observed a positive effect of the BMI on graft diameter.

In this study, age did not have any correlation with graft diameter, what was in accordance with Treme et al. [18] findings. Schwatzberg et al. [17] also found weak correlation with age. Tuman et al. [19] found that graft diameter was influenced by age in women, but not in men. According to them, older and smaller women presented thinner grafts.

In this study the multivariable analysis showed that height, gender, and lower limb length were the variables that most influenced the graft diameter, nevertheless height was the most important one. The variables weight, thigh length, and thigh diameter had less influence in graft diameter. Tuman et al. [19] showed that height was also the most important variable mainly in women, while Treme et al. [18] found the strongest correlation with weight and thigh circumference. Schwatzberg et al. [17] found moderate correlation between weight and lower limb length with graft diameter and weak correlation to height and thigh diameter.

It was observed in this study that men with height equal to or greater than 1.80 m had a higher percentage of 9 mm grafts and a larger average of graft diameter when compared to the other patients with a height less than 1.80 m, men or women or both. There was no article in the literature to compare these results.

There are some limitations in this study. First of them is that most of the patients were recreational athletes with different levels of sports activity. Thus, the frequency of sports activity, in the statistical analysis, could not be quantified. Second, 1 mm difference between the cylindrical tube diameters reduced the accuracy of graft measurements. However, the clinical relevance of this study is that it showed that preoperative anthropometric measurements, obtained by a simple physical examination, can help in the prediction of graft diameter, when the hamstring tendons are the option of choice.

## Conclusion

The diameter of the hamstring graft was significantly correlated with weight, height, leg length, thigh length, thigh diameter, and gender. The variable that most influenced the graft diameter was height, followed by gender and leg length. The variables BMI, age, sports activity, and the dominant side did not present correlation to the graft diameter. The graft diameter in men is larger than in women.

Men with a height equal to or greater than 1.80 m had a higher prevalence of 9 mm grafts and had a larger average graft diameter.

**Conflict of interest** The authors report no conflict of interest.

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