Predictors for Hamstring Graft Diameter in Anterior Cruciate Ligament Reconstruction

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Background: The ability to accurately predict the diameter of autograft hamstring tendons has implications for graft choice and fixation devices used in anterior cruciate ligament (ACL) reconstruction.

Purpose: To determine whether simple anthropometric measurements such as height, mass, body mass index (BMI), age, and gender can be used to accurately predict the diameter of hamstring tendons for ACL reconstruction surgery.

Study Design: Cohort study (prevalence); Level of evidence, 2.

Methods: The authors conducted medical record reviews and telephone interviews of 106 consecutive patients with ACL reconstruction using quadrupled semitendinosus-gracilis autograft from 2004 to 2006. Data included anthropometric measurements (height, mass, gender, and age at the time of surgery). Hamstring diameter was obtained using cylindrical sizers in 0.5-mm increments and recorded in the patient's surgical record. Correlation coefficients (Pearson *r*) and stepwise, multiple linear regression were used to determine the relationship between the outcome variable (hamstring graft diameter) and the predictor variables (age, gender, height, mass, and BMI). Independent sample *t* tests were used to compare hamstring graft diameter between genders.

Results: Hamstring graft diameter was related to height ($r = .36$, $P < .001$), mass ($r = .25$, $P = .005$), age ($r = –.16$, $P = .05$), and gender ($r = –.24$, $P = .006$) but was not related to BMI ($P > .05$). Height was a statistically significant prediction variable ($R^2 = .13$, $P < .001$). From the current data, a regression equation was calculated that suggested that a patient <147 cm (58 in) tall is likely to have a quadrupled hamstring graft diameter <7 mm in diameter (graft size = 2.4 + 0.03 × height in cm). Women had significantly smaller hamstring graft diameters (7.5 ± 0.7 mm) than did men (7.9 ± 0.9 mm, $P = .01$).

Conclusions: Of the parameters studied, height was the best predictor of hamstring tendon diameter, particularly in women.

Keywords: knee; anterior cruciate ligament; graft diameter; hamstring

Graft selection in anterior cruciate ligament (ACL) reconstruction depends on many factors, including surgeon preference, patient age and activity level, and patellofemoral pain, with the final decision typically discussed on an individual basis.[2] Hamstring autografts provide postsurgical outcomes similar to patellar tendon autografts[4,5,7] but are less likely to be associated with anterior knee pain due to graft harvest morbidity. However, difficulty in obtaining consistent hamstring graft diameter and length may affect the usability of these autografts.[1] To our knowledge, there exists no well-documented standard to accurately predict the diameter of 4-strand hamstring autografts for ACL reconstruction. This information would be useful in guiding clinical decision making in ACL reconstruction cases. Some fixation methods and implants require a minimum graft diameter or length. In addition, graft strength is related to cross-sectional diameter, and surgeons may not be comfortable with the strength of smaller graft sizes. If the surgeon could reasonably predict that a patient's hamstring graft would fall below a certain threshold, alternative fixation methods or graft choices could be arranged before harvest.

A simple yet accurate predictor of hamstring diameter before surgery could also prevent the associated morbidity of harvesting a tendon of unacceptable size. Studies show that hamstring harvest may decrease hamstring muscle strength for up to 9 months after surgery[11] and may prove limiting to the athletic patient. Scar formation, pain, operating time, and infection risk may also potentially be lowered by an accurate predictor of hamstring diameter.

The purpose of this study was to determine whether simple anthropometric measurements such as height, mass, body mass index (BMI), age, and gender can be used to accurately predict the diameter of hamstring tendons for ACL reconstruction surgery.

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TABLE 1
Means ± Standard Deviations of Demographic Data Used for Current Analyses of Hamstring Tendon Diameter[a]

	n	Age (y)	Height (cm)	Mass (kg)	BMI	Graft Size (mm)
Men	51	34.1 ± 14.1	178.3 ± 7.9	82.5 ± 13.8	26.1 ± 4.9	7.9 ± 0.9
Women	55	31.7 ± 11.9	167.0 ± 7.3	68.8 ± 12.7	24.7 ± 4.6	7.5 ± 0.7
Total	106	32.9 ± 13.0	172.4 ± 9.4	75.4 ± 14.9	25.4 ± 4.8	7.7 ± 0.8

[a]BMI, body mass index.

MATERIALS AND METHODS

We obtained data from records of 106 patients (2 surgeons) with primary or revision ACL reconstruction surgery using a hamstring autograft from 2004 to 2006. Anthropometric measurements including height, mass, age, and gender recorded at the time of surgery were obtained (Table 1). We supplemented medical record data with a telephone interview to provide missing chart information (eg, height was not available in all medical records). This study was approved by our university's institutional review board for health sciences research.

Because graft length is somewhat subjective and heavily influenced by harvest technique, we focused on quadrupled hamstring diameter as our primary outcome variable. All patients had semitendinosus and gracilis tendon autografts harvested in a similar manner. An oblique incision was made in the skin along the distal insertions of the semitendinosus and gracilis tendons on the proximal tibia. The tendons were removed using a hamstring graft harvester. The tendons were prepared using a double-bundle, 4-strand technique with each end of the tendon grafts whipstitched with a No. 2 nonabsorbable polyester suture. The graft was passed through sizing cylinders to determine the diameter of the graft. For the purposes of this study, the smallest cylinder that permitted the passage of the portion of the graft that was to be placed within the femoral tunnel was considered the graft diameter. Any difference in diameter for the trailing, whipstitched end was handled by adjusting the diameter of the drilled tibial tunnel. All grafts were of sufficient length, with a minimum of 100 mm of total "graft length" after quadrupled preparation. Using each patient's height and mass, we calculated BMI according to standard formulas.[3]

We used correlation coefficients (Pearson r) and stepwise, multiple linear regression to determine the relationship between the outcome variable, hamstring graft diameter, and the predictor variables, age, gender, height, mass, and BMI. We used independent samples t tests to compare hamstring graft diameter between genders. A test result was considered statistically significant if the P value was less than 5% ($P \leq .05$).

RESULTS

Hamstring graft diameter was related to height ($r = .36$, $P < .001$), mass ($r = .25$, $P = .005$), age ($r = -.16$, $P = .05$), and gender ($r = -.24$, $P = .006$) but was not related to BMI ($P > .05$). These associations suggest that shorter, lighter, older, and female patients tend to have smaller hamstring graft diameters.

Stepwise, multiple regression indicated that height was statistically important as a predictor for hamstring graft diameter ($R^2 = .13$, $F_{1,104} = 15.2$, $P < .001$) and yielded the following regression equation for predicting hamstring graft diameter: graft size = 2.4 + 0.03 × height in centimeters.

The shorter the patient, regardless of mass, gender, age, or BMI, the smaller the hamstring graft diameter. The regression equation suggests that hamstring graft diameter will be 0.5 mm different (larger or smaller, respectively) for every 17-cm increment in height and also reveals that a patient less than 147 cm (approximately 58 in) tall is likely to have a quadrupled hamstring graft diameter less than 7 mm. For example, according to this equation, a 170-cm (67-in) patient will have a quadrupled hamstring graft diameter of 7.5 mm. The predictive ability of our regression equation was not significantly affected by including all other variables ($P > .05$). Gender comparisons indicate that women had significantly smaller hamstring graft diameters on average (7.5 ± 0.7 mm) than men (7.9 ± 0.9 mm, $t_{104} = 2.6$, $P = .01$). Although gender did not add to the predictive ability of this model, we performed separate correlation and linear regression analyses separated by gender. Hamstring graft size is correlated to height and age in women only, suggesting that taller and younger women are likely to have larger hamstring grafts. Further, height remained a statistically significant predictor of hamstring graft sizes for women but not for men. Scatterplots are presented in Figure 1.

Graft size frequencies among the current data are as follows: 6 mm (2%), 7 mm (38.7%), 7.5 mm (7.5%), 8 mm (34%), 8.5 mm (3.8%), 9 mm (12%), 10 mm (1%), and 11 mm (1%).

DISCUSSION

We reviewed a series of consecutive ACL reconstructions from 2004 to 2006 and identified 106 patients who had a primary or revision ACL reconstruction surgery using a hamstring autograft and who agreed to participate in our study. Anthropometric measurements including height, mass, age, and gender recorded at the time of surgery were obtained from the patient's charts and telephone interviews. We hypothesized that BMI would be an accurate predictor of hamstring tendon diameter before ACL reconstruction. Our results show that a short-stature female patient who is lightweight has the greatest risk for small graft diameter. Height was moderately correlated with

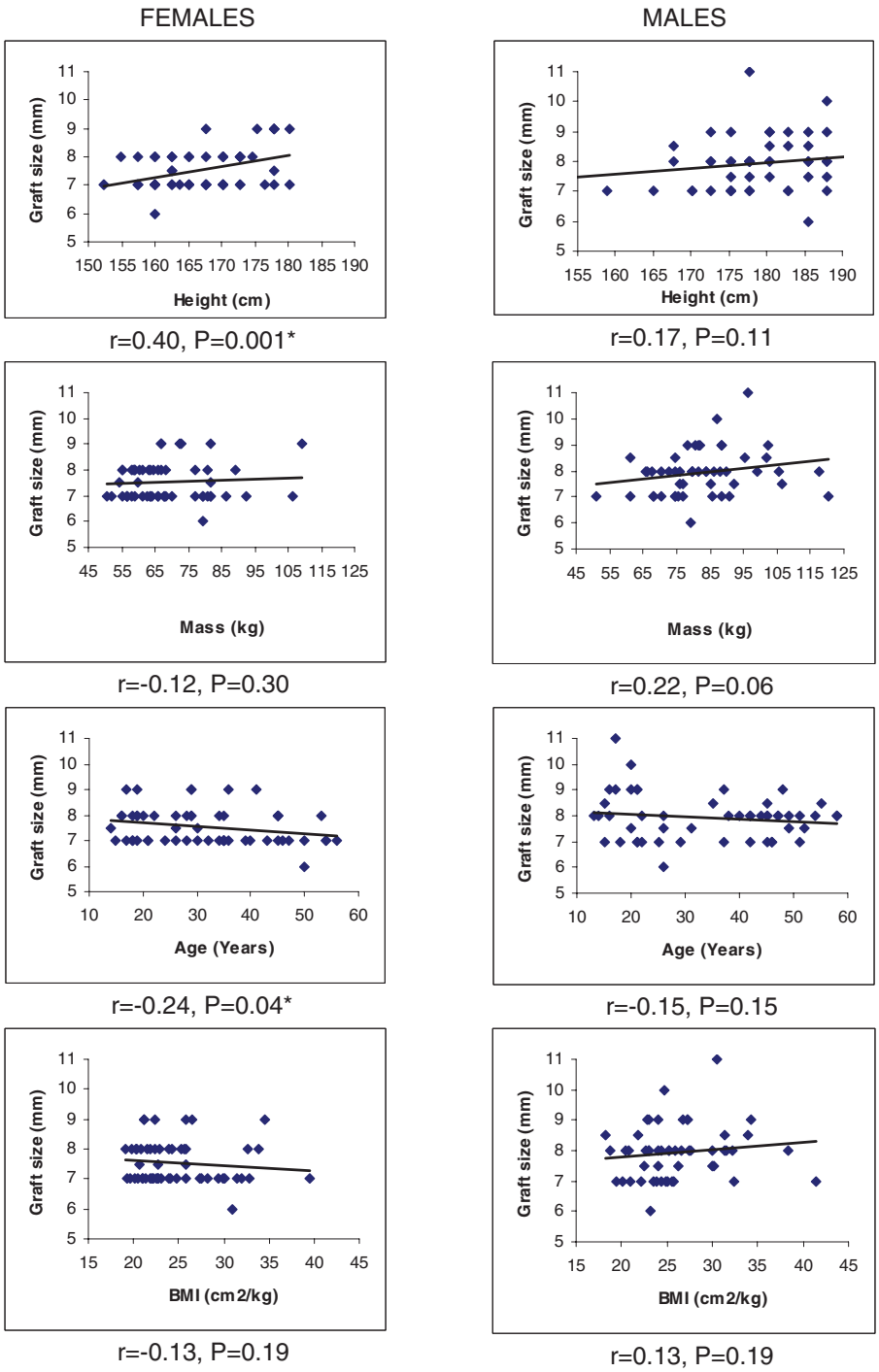

Figure 1. Scatterplots showing relationships with hamstring graft size, separated by gender. Associated correlation coefficients and *P* values are included. BMI, body mass index.

graft diameter and is the most significant predictor of graft diameter, as it is likely that the graft will fall below 7 mm in diameter for patients shorter than 147 cm (roughly 58 in). This relationship does not appear to be by chance (more than 95% certain), and we believe it should be kept in mind when determining graft site in shorter individuals. Also, BMI does not appear to accurately predict hamstring diameter and should not be relied upon before harvest. In the context of the current study and for future data collection, lean body mass may be a better predictor of hamstring tendon graft diameter. That is, heavier persons with greater lean body mass and greater muscle strength would

likely have larger diameter tendons than a heavier person with less lean body mass and weaker muscles. Body mass index calculations are intended as a measure of obesity and to identify persons at risk for obesity-related problems and may not be an appropriate clinical predictor of hamstring tendon diameter.

Greater clinical laxity in women after ACL reconstruction using hamstring autograft has been speculated to be due to smaller graft size.[9] Specifically, graft laxity as measured by anterior-posterior translation appears to be correlated with the cross-sectional area of the graft.[6] There is a lack of information in the literature addressing the possibility that persons with smaller hamstring tendons may have poorer outcomes because of insufficient graft diameter and potential to retear. However, previous research has found that grafts for ACL reconstruction with smaller cross-sectional area may be weaker.[8] The ability to accurately predict graft size before harvesting could affect clinical decision making regarding graft choice in ACL reconstruction. Typically, graft choice depends on information gathered during clinical examination, patient activity goals, and physician preference. Adequately sized autografts are crucial to acceptable surgical outcomes. The associations observed among the current data suggest that shorter, lighter, and older female patients tend to have smaller diameter hamstring grafts. Currently, there are no published data that describe clinical predictors for quadrupled hamstring graft size for ACL reconstruction surgery. In the current data set, height and age were related to hamstring diameter in women but not in men. Linear regression analysis suggested that the ability to predict hamstring graft diameter from clinical data may be best applied to female patients. Gender comparisons among prospectively collected data will help elucidate this relationship.

Accurate clinical predictors of hamstring graft size could affect graft choice decision making during ACL reconstruction. Autografts that surgeons believe are too small, especially in larger, more active patients, either must be supplemented with a soft tissue allograft or contralateral autograft or must be abandoned for a more suitable graft. Larger diameter grafts may also be necessary for revision ACL reconstructions.[8] In addition, some fixation methods and devices, such as absorbable cross pins, may not work with smaller grafts. Careful consideration of these anthropometric and demographic factors may help guide graft choice decision making to avoid harvesting small, unusable hamstring autografts.

We recommend prospective studies of hamstring graft size prediction including clinical measures such as leg length, thigh length, thigh girth, hamstring muscle strength, athletic history, and other mechanical stressors that influence the hamstring muscle-tendon unit in that particular individual. To our knowledge, there is a lack in the current literature concerning these variables and their possible predictive power for hamstring tendon diameter. Ultimately, a prospective study analyzing these additional variables along with those discussed in this study may demonstrate the existence of other important clinical predictors of hamstring graft size in ACL reconstruction surgery.

Limitations

There are some limitations with this study. First, the mean age of the groups is relatively old for the population undergoing ACL reconstruction. However, we believe our range of ages for patients in the study was sufficiently broad, and age was considered as a variable. Within the context of this study and the ages of the subjects involved, age was significantly related to graft size. Another possible limitation is inaccuracy of the sizing of the grafts using the cylindrical sizers. This step requires the surgeon to pull the graft through the sizer, and it is possible to pull harder and get the graft to pass through a tunnel that may be slightly smaller. The tightest possible cylinder that permitted the graft to pass was considered the graft size. Because the folded end that was to go into the femoral tunnel determined the graft size for this study, any remaining muscle on the free, trailing ends after graft preparation did not influence the size. In our preparation of the hamstring grafts, attempts are made to remove all visible fat and muscle from the tendons. Finally, self-reporting height introduces a potential source of bias that could have underestimated the effect of height on graft diameter. Self-reports for demographic measures such as height have been found to be an accurate assessment in larger study groups.[10]

CONCLUSION

In conclusion, the ability to accurately predict the size of autograft hamstring tendons used in ACL reconstruction remains an important factor in graft choice decision making. This study has found a statistical correlation between height, mass, gender, and hamstring tendon diameter. Height alone remains the most statistically significant predictor of hamstring graft size. In the context of the current data, the relationship between clinical data and hamstring graft size appears to be limited to female patients only, where shorter and older female patients would be most likely to have smaller hamstring grafts. Body mass index fails to provide such predictive power. According to the current data, patients shorter than 147 cm (approximately 58 in) tall are likely to have a quadrupled hamstring graft diameter less than 7 mm in diameter. Furthermore, our data suggest that the calculation of $2.4 + 0.03 \times$ height in centimeters may predict hamstring graft diameter.

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