



Posterior Single-Incision Semitendinosus Harvest for a Quadrupled Anterior Cruciate Ligament Graft Construct: Determination of Graft Length and Diameter Based on Patient Sex, Height, Weight, and Body Mass Index

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Purpose: This study aimed to determine final graft length and diameter for a quadrupled semitendinosus anterior cruciate ligament (ACL) construct harvested from a single-incision posterior approach with correlation to preoperative patient variables of sex, height, weight, and body mass index (BMI). **Methods:** This was a retrospective review of data collected prospectively on 60 patients undergoing all-inside quadrupled semitendinosus autograft ACL reconstruction. **Results:** The mean values of the final quadrupled constructs were a length of 70.3 mm and a diameter of 9.0 mm. Separated based on sex, female versus male final graft length was 68.1 mm versus 71.7 mm, and final mean graft diameter was 8.6 mm and 9.3 mm, respectively. In both sexes, patient height and weight were strongly correlated to final construct diameter ($r = 0.60$ and $r = 0.56$) and length ($r = 0.47$ and $r = 0.44$), respectively. **Conclusions:** A single-incision posterior harvest approach allowed for retrieval of semitendinosus tendon autografts of sufficient dimension to allow for construction of quadrupled ACL grafts of a diameter of 8 mm or more in 95% of cases. In addition, desired graft length was achieved in all cases. Graft dimensions had moderately strong direct correlations to patient height and weight, with significant size differences noted between the sexes. We believe this to be helpful data for surgeons who might consider performing a quadrupled semitendinosus autograft ACL reconstruction. **Level of Evidence:** Level IV, therapeutic case series.

Reconstruction of the anterior cruciate ligament (ACL) is performed in approximately 200,000 patients in the United States each year.¹ The use of hamstring tendon autografts has grown in the past decade based on a low rate of donor site morbidity and postoperative complications. Long-term randomized trials and outcome studies have reported hamstring tendon autografts to be a reliable option for ACL reconstruction across a broad spectrum of patients.²⁻⁵

The quadrupled semitendinosus graft may be preferred for ACL autografts based on its larger diameter and superior strength compared with patellar tendon or semitendinosus/gracilis grafts.⁶ However, the length and diameter of semitendinosus autografts can vary considerably depending on patient-related factors and harvest technique.⁷⁻⁹ This variability can influence the surgeon's options for reconstruction technique and fixation method and can affect outcome, because smaller diameter grafts (<8 mm) are associated with increased risk of failure.¹⁰⁻¹² Therefore, having a valid method for predicting final graft length and diameter preoperatively would be of great benefit to the surgical team.

Most studies correlating patient demographics to hamstring autograft measurements have evaluated combined semitendinosus and gracilis grafts.¹³⁻¹⁶ A recent study by Xie et al.¹⁷ correlated patient measurements to length and diameter of quadrupled semitendinosus and quadrupled gracilis tendon (GT) autografts for double-bundle ACL reconstruction. They concluded that length and diameter of the semitendinosus and GT grafts were strongly correlated to

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patient weight, height, and body mass index (BMI). Importantly, all of these previous studies used a traditional hamstring harvest from an anteromedial incision over the pes attachment site on the tibia.

The single-incision posterior semitendinosus autograft harvest technique is routinely used by the senior author (P.A.S.) to create a quadrupled construct for single-bundle, all-inside ACL reconstruction.¹⁸ This technique provides for a minimally invasive and highly cosmetic ACL reconstruction. For this technique, the senior author strives for a harvested graft length of 240 mm to obtain a final graft length of 60 mm and a final graft diameter of 8 mm as minimum measurements. In addition, based on published biomechanical data, the senior author also strives for a minimum of 15 mm of graft within the femoral and tibial sockets.¹⁹ To our knowledge, no study has assessed patient-related factors for correlation to semitendinosus autograft characteristics with graft harvest from a small single-incision posterior approach. Our clinical goal was to use these measurements—derived from a spectrum of patients undergoing ACL reconstruction—to help determine reference ranges for surgeons to use in predicting final ACL graft length and diameter preoperatively. Our hypothesis was that semitendinosus tendon autografts could be harvested using a single-incision posterior approach such that harvested tendon length is sufficient for constructing quadrupled ACL grafts of desired length (60 mm) and diameter (8 mm), with graft dimensions having strong ($r > 0.4$) direct correlations to patient sex, height, weight, and BMI.

Methods

The study was approved by our institution's medical ethics committee and institutional review board. All patients signed informed consent before surgical intervention. Consecutive patients who had an ACL rupture diagnosed by clinical examination, magnetic resonance imaging, and arthroscopy and who underwent all-inside ACL reconstruction between June 2011 and August 2013 using a quadrupled autograft semitendinosus ACL reconstruction obtained by posterior single-incision harvest were included.¹⁸ Excluded patients were those with multiple-ligament knee injuries, because it is the preference of the senior surgeon (P.A.S.) to generally avoid using hamstring autografts in this scenario. Preoperative evaluation was performed to document patient age, sex, height, weight, BMI, and the activity being performed at the time of injury.

All graft harvest procedures were performed by the senior author (P.A.S.) using the single-incision posterior harvest technique as described by Franz and Ulbrich.²⁰ Graft harvest was performed with the patient supine, allowing the hip to abduct with the knee flexed. A 2.5-cm transverse incision was made directly posterior in the popliteal crease and carried down through

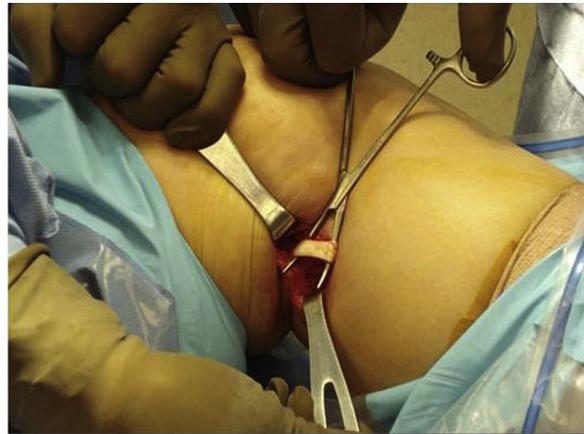


Fig 1. Semitendinosus hamstring tendon harvest for ACL reconstruction through a single posterior incision harvest technique from a left knee, with the foot to the right and the hip to the left.

the subcutaneous layer to the popliteal fascia. The semitendinosus tendon was easily palpable in its superficial location just deep to the fascia. The fascia was sharply incised, allowing placement of a right-angle clamp to deliver the semitendinosus out of the wound (Fig 1). The semitendinosus was differentiated from the gracilis based on its more lateral location, its larger size, its greater mobility, and the more proximal location of its musculotendinous junction.

The semitendinosus was mobilized proximally, and a standard open pigtail tendon stripper was then used to release the tendon proximally from the musculotendinous junction to harvest maximal length. Next, the tendon was mobilized distally, in particular to release the commonly encountered accessory semitendinosus tendon. A short closed-ended stripper was then used to release the tendon distally from its tibial attachment. The posterior incision was closed with No. 2-0 MONOCRYL suture (Ethicon, Somerville, NJ) for the subcutaneous layer to reapproximate the skin, and the skin was closed with a running subcuticular No. 3-0 Prolene suture (Ethicon, Somerville, NJ).

The harvested tendon was debrided of adherent muscle and any thin tendon tissue was removed from the ends of the tendon. The final harvested length of the semitendinosus was then measured with a sterile ruler and recorded in millimeters. The ACL graft was prepared by quadrupling the semitendinosus through a TightRope RT (Arthrex, Naples, FL) on one end, and a no-button TightRope on the other end. The 2 free ends were then sutured together, the graft construct was placed under tension, and 4 No. 0 FiberWire sutures (Arthrex, Naples, FL) were used to suture all 4 limbs of the graft together on each end near the loops to create the final construct (Fig 2). It is important to note that preparation of the quadrupled hamstring graft involves tensioning the graft before final suturing of the construct. Therefore, the



Fig 2. A quadrupled semitendinosus anterior cruciate ligament (ACL) reconstruction GraftLink (Arthrex, Naples, FL) construct.

result is not an exact 4:1 ratio, because the measurements of the initial length harvested are that of an untensioned graft, and the measurements of the final quadrupled graft are that of a tensioned graft. Final graft length and diameter were then measured with a sterile ruler and graft sizer, respectively, and recorded in millimeters.

Intraoperative measurements and calculations were performed to determine intra-articular ACL femoral-tibial distance, length of graft within the femoral socket, and length of graft within the tibial socket. The intra-articular distance was measured using an arthroscopic depth gauge. The length of graft within each socket was calculated by subtracting the intra-articular distance from the final construct length to ensure at least 15 mm of graft in each socket.

Statistical Analyses

Data were separated by patient sex, and mean \pm standard deviation (SD) was determined for each variable assessed. Each measurement variable was compared for statistically significant differences between the sexes using *t* tests. Effect of sex on the probability for grafts to be less than the minimum desired final graft length (60 mm) and diameter (8 mm) was analyzed using Fisher's exact test and odds ratios. $P < .05$ was deemed significant. Strength of correlation was determined between each patient-related variable (age, height, weight, and BMI) and each measurement variable using Pearson's product moment analyses. Correlations were considered moderately strong when *r* was greater than 0.4 and were strong when *r* was greater than 0.7. Reference ranges (95% confidence intervals) for final graft length and diameter were determined and plotted for each sex by height and weight, separately, over the ranges of patients included in this study.

Results

Demographic Data

Sixty patients were included in this study. There were 36 male patients (60%) and 24 female patients (40%).

Table 1. Patient Demographic Data

Variable	Group (n = 60)	Male Patients (n = 36)	Female Patients (n = 24)
Age, yr	25.3 \pm 8.9	25.9 \pm 8.4	24.3 \pm 9.7
Height, cm	176.4 \pm 10.6	183 \pm 6.5	166.7 \pm 7.4
Weight, kg	79.4 \pm 16.7	88.7 \pm 13.3	65.4 \pm 10.4
BMI	25.3 \pm 3.9	26.4 \pm 3.7	23.5 \pm 3.6

NOTE. Data presented as mean \pm standard deviation.
BMI, body mass index.

The mean age at surgery was 25 years (range, 12 to 46 years). The mean height (cm) and weight (kg) were 176.4 (152.4 to 195.6) and 79.4 (50.5 to 125.9), respectively. The mean BMI was 25.3. When divided by sex, the mean age for male patients versus female patients in the study group was 25.9 years versus 24.3 years. The mean height was 182.9 cm versus 166.7 cm, respectively. The mean weight was 88.7 kg versus 65.4 kg, and average BMI was 26.4 versus 23.5, respectively. Demographic data are summarized in [Tables 1](#) and [2](#).

Intraoperative Data

The mean harvested semitendinosus tendon length for the treatment group was 268 mm (240 to 310 mm). The mean diameter of the final quadrupled tendon was 9.0 mm (7.5 to 11.0 mm), and the mean final construct length was 70.3 mm (60.0 to 76.0 mm). The mean intra-articular distance measured was 24.3 mm (20.0 to 29.0 mm).

When separated by sex, mean intraoperative measurements were as follows: initial harvested tendon length was 274.0 mm (260.0 to 310.0 mm) for male patients versus 259.0 mm (240.0 to 280.0 mm) for female patients, quadrupled tendon diameter was 9.3 mm (7.5 to 11 mm) for male patients versus 8.6 mm (7.5 to 10 mm) for female patients, final length was 71.7 mm (65.0 to 76.0 mm) for male patients versus 68.1 mm (60 to 73 mm) for female patients, and intra-articular to articular distance was 24.9 mm (22.0 to 29.0 mm) for male patients versus 23.4 mm (20.0 to 26.0 mm) for female patients. Each of these differences between male patients and female patients was statistically significant ($P < .05$). All reconstructions exceeded the desired minimum of 15 mm of graft in each socket, with final mean lengths of graft within the femoral and tibial sockets being 22.4 mm (17 to 25 mm) and 23.7 mm (18 to 32 mm), respectively. Intraoperative measurements are summarized in [Table 3](#), are separated by sex in [Table 4](#), and are described by sex in [Figure 3](#).

There were 3 patients (2 female patients, one male patient) who had final graft diameters less than 8 mm, with each measured at 7.5 mm diameter. No patients had final quadrupled graft lengths less than 60 mm. Based on these data, female patients were 3.2 times more likely to have a final graft diameter less than 8 mm ($P = .044$) compared with male patients in this

Table 2. Percentage of Patients Involved in Various Activities at the Time of Injury

Injury-Related Activity	Total, % (n = 60)	Male Patients, % (n = 36)	Female Patients, % (n = 24)
Soccer	6.7	2.8	12.5
Football	10.0	16.7	NA
Volleyball	8.3	5.6	12.5
Basketball	36.7	36.1	37.5
Jumping off objects	10.0	13.9	4.2
Martial arts	1.7	NA	4.2
Weight lifting	1.7	2.8	NA
Softball	5.0	2.8	8.3
Slipping on ice	3.3	5.6	n/a
Car accident	1.7	2.8	n/a
Skiing	5.0	NA	12.5
Static twisting injury	6.7	8.3	4.2
Lacrosse	1.7	NA	4.2
Snowboarding	1.7	2.8	NA

NA, not available.

population. Six patients had grafts exactly 8 mm in diameter, meaning that 51 of 60 (85%) patients had grafts larger than 8 mm.

Patient height showed moderately strong direct correlations to harvested tendon length ($r = 0.47$), intra-articular distance ($r = 0.52$), and final quadrupled tendon diameter ($r = 0.60$). Patient weight also showed moderately strong direct correlations to harvested tendon length ($r = 0.44$), intra-articular distance ($r = 0.39$), and final quadrupled diameter ($r = 0.56$). BMI ($r = 0.26$), however, showed weak correlations to these variables. Based on correlation analyses, reference ranges (95% confidence intervals) for final graft length and diameter were determined and plotted for each sex by height and weight, separately, over the ranges for patients included in this study (Figs 4-7).

Discussion

The results of this study support our hypothesis that a single semitendinosus hamstring autograft may be harvested using a single posterior incision approach to consistently result in the desired final quadrupled ACL construct length (>60 mm) and diameter (≥ 8 mm). In addition, the desired minimum of 15 mm of graft in both the femoral and tibial sockets was exceeded in all patients. Patient height and weight showed moderately strong direct correlations to harvested tendon length and final quadrupled graft diameter. In addition, this study provides reference ranges for dimensions of a quadrupled semitendinosus tendon graft used for ACL reconstruction

Table 3. Intraoperative Values for Treatment Group

Quadrupled diameter, mm	9.0 \pm 0.8
Final Length, mm	70.3 \pm 3.9
Intra-articular distance, mm	24.3 \pm 1.7

NOTE. Data presented as mean \pm standard deviation.

Table 4. Intraoperative Values for Male and Female Patients

Graft Characteristics	Male (n = 36)	Female (n = 24)
Harvested tendon length, mm	274.0 \pm 14.6	259.0 \pm 12.7
Final quadrupled diameter, mm	9.3 \pm 0.8	8.6 \pm 0.7
Final quadrupled length, mm	71.7 \pm 3.3	68.1 \pm 3.9
Intra-articular distance, mm	24.9 \pm 1.5	23.4 \pm 1.6

NOTE. Data presented as mean \pm standard deviation.

harvested with a single posterior incision. The mean harvested semitendinosus tendon length, final quadrupled graft length, and quadrupled graft diameter all exceeded the desired minimums. Each of these dimensions was significantly smaller for female patients, who were 3 times more likely to have a final graft diameter less than 8 mm compared with male patients.

The quadrupled semitendinosus graft has become a popular choice for ACL reconstruction based on its availability for harvest, its documented material properties, and the associated preservation of the gracilis. Hamstring strength in knee flexion and internal rotational torque are better preserved when only the semitendinosus is harvested versus both the semitendinosus and gracilis.^{21,22} However, consistently obtaining a semitendinosus tendon graft with adequate dimensions for construction of a functional quadrupled ACL graft is critical to the clinical application of these advantages.

An important question is whether there is a minimal accepted graft diameter to ensure an optimal outcome with a quadrupled hamstring graft. A systematic review by Conte et al.¹² of hamstring autograft size as a potential risk factor for ACL reconstruction failure concluded that a graft size equal to or larger than 8 mm in diameter decreased ACL failure rates. An independent study by Magnussen et al.¹⁰ of quadrupled semitendinosus and gracilis grafts had 8 failures in 165 grafts (4.8%) 8 mm or larger and 10 failures in 81 grafts (12.3%) less than 8 mm. One hundred seven of 256 (42%) patients in their study had grafts that were exactly 8 mm and only 58 of 256 (23%) patients had grafts larger than 8 mm. Our study had only 6 of 60 grafts (10%) that were exactly 8 mm, and 51 of 60 (85%) grafts were larger than 8 mm in diameter. In addition, the mean graft diameter in their study was 7.9 mm (8.1 mm for male patients and 7.7 mm for female patients), whereas the mean graft diameter for our study was 9.0 mm (9.3 mm for male patients and 8.6 mm for female patients). A study by Mariscalco et al.¹¹ of the Multicenter Orthopaedic Outcomes Network cohort data evaluated a subset of patients with quadrupled semitendinosus-only grafts and found only 30 of 61 (49%) grafts with diameters greater than 8 mm. Our data compare very favorably to these studies, because only 3 grafts (5%) in the present study were less than 8 mm, with all 3 having diameters of 7.5 mm, and 51 of 60 (85%) grafts were larger than 8 mm.

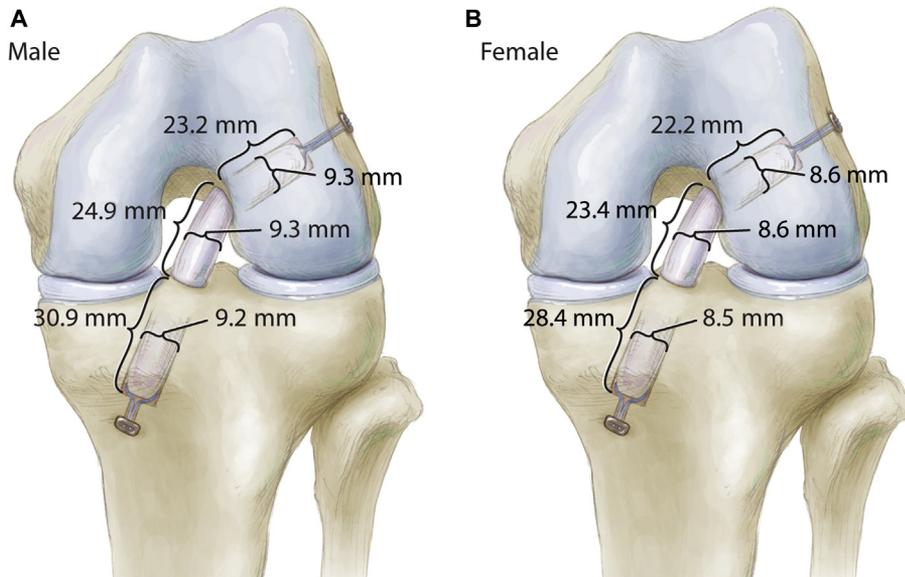


Fig 3. Intraoperative measurements for a final quadrupled semitendinosus autograft anterior cruciate ligament (ACL) reconstruction construct for (A) male patients and (B) female patients.

Notably, other than the study by Mariscalco et al.,¹¹ the majority of data reviewed by the aforementioned studies were for semitendinosus/gracilis ACL constructs, not quadrupled semitendinosus-only constructs. Given this information, it is valuable to evaluate techniques for optimizing tendon harvest that are able to consistently produce adequate quadrupled semitendinosus graft constructs. Furthermore, although it is important to evaluate established minimums for graft construct size, it is also important to take into account individual patient variables and to understand that not every patient will always be able to meet such minimums with an autograft construct. For instance, in the study by Xie et al.,¹⁷ final graft diameters as small as 5.5 mm were reported in their patient population, the Chinese Han population, with their reasoning for such small diameters being the typically small stature of that population.

Prodromos et al.²³ first described the use of a popliteal incision in combination with an anterior tibial incision for hamstring graft harvest. The harvest technique described in the present study is based on the approach of Franz and Ulbrich,²⁰ which used only a short transverse popliteal incision for semitendinosus mobilization and harvest. Using this technique, minimum standards set by the senior author (P.A.S.) for quadrupled semitendinosus graft constructs were consistently met. Potential advantages of this single posterior incision technique include low risk of premature tendon release during harvest,^{20,23} maximizing distal tendon harvest length,²⁰ low risk of injury to the popliteal neurovascular bundle and saphenous nerve,²³ and the cosmetic size and location of the incision. The ability to fully visualize the accessory bands to the semitendinosus (preventing premature tendon release) and the improved cosmesis of the scar in the posterior

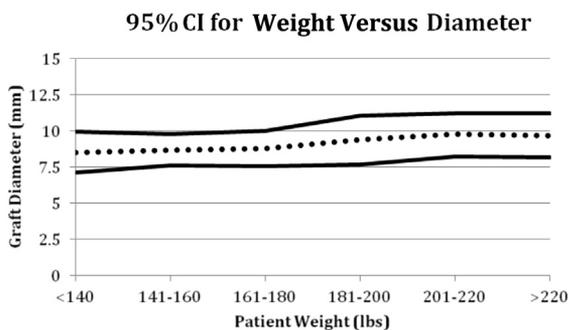


Fig 4. Ninety-five percent confidence interval (CI) for final quadrupled semitendinosus autograft anterior cruciate ligament (ACL) graft construct diameter correlated to patient preoperative weight.

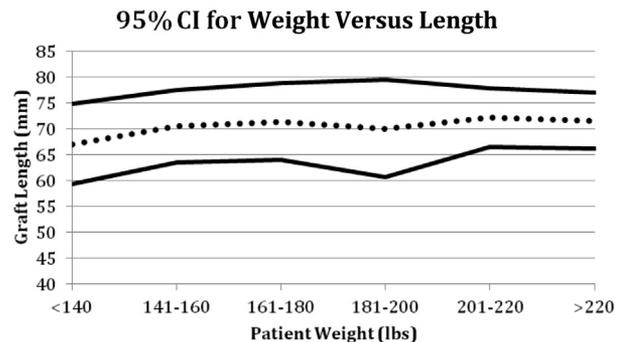


Fig 5. Ninety-five percent confidence interval (CI) for final quadrupled semitendinosus autograft anterior cruciate ligament (ACL) graft construct length correlated to patient preoperative weight.

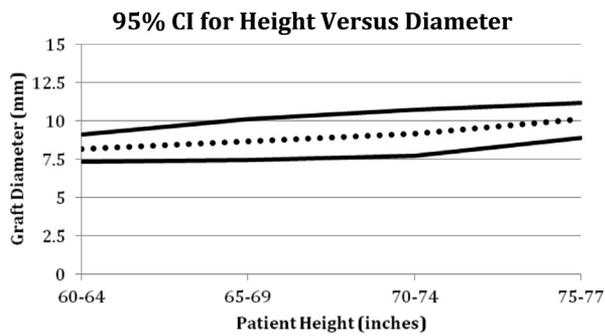


Fig 6. Ninety-five percent confidence interval (CI) for final quadrupled semitendinosus autograft anterior cruciate ligament (ACL) graft construct diameter correlated to patient preoperative height.

crease of the knee are potential advantages compared with an anterior harvest approach.

Recent studies examining relationships between patient demographics and dimensions of hamstring grafts have focused on double-stranded or combined semitendinosus and GT grafts.¹³⁻¹⁶ Xie et al.¹⁷ evaluated 4-stranded semitendinosus and GT double-bundle ACL reconstructions and reported strong correlations to patient height, weight, and BMI. Tuman et al.²⁴ reported strong correlations between graft diameter and patient height, weight, sex, and BMI. Patient height was considered to be the best predictor of hamstring tendon diameter and was recommended for predicting graft size preoperatively, particularly in women. The systematic review by Conte et al.¹² evaluated studies that attempted to predict hamstring graft size based on patient-specific measurements and found height to be the most commonly reported significant parameter, with an overall correlation of 0.45 ($P < .00001$). These results were similar to our study; we found height showed moderately strong direct correlations to harvested tendon length ($r = 0.47$) and final quadrupled tendon diameter ($r = 0.60$). In addition, our data showed moderately strong direct correlations of initial harvested tendon length and quadrupled graft length and diameter to patient weight but only weak correlations to patient BMI and age, with significant differences noted between male patients and female patients. Taken together, the data suggest that patient height and weight can be used to reliably predict harvested hamstring tendon dimensions within reference ranges and that reference ranges should be separated by sex.^{9,13-17,23,24} This is clinically relevant because the surgeon may predict final construct dimensions preoperatively using reference range for patient height and weight for male patients and female patients. We believe this to be useful data for surgeons making decisions about graft choice and harvest approach during the preoperative planning process and could be applicable to any

potential semitendinosus ACL construct for which minimum dimensions are required.

Limitations

The limitations of this study include its single-center, single-surgeon, single-technique design and lack of assessment of patient outcomes associated with the technique being studied. In addition, we did not include controls or cohorts with respect to harvest technique or graft construct type. Although these limitations certainly need to be considered when applying the data from this study, our primary objective with this initial study was to clinically evaluate harvested semitendinosus tendon length and quadrupled ACL graft dimensions using a single-incision posterior approach and determine strength of correlations to patient sex, height, weight, and BMI to determine reference ranges for surgeons to use in predicting graft length and diameter preoperatively. The study design and resultant data addressed these initial goals and provide the foundation for subsequent multicenter and cohort studies aimed at comparing harvest techniques and ACL graft constructs with respect to graft size, technical factors, cosmesis, and patient outcomes.

Conclusions

A single-incision posterior harvest approach allowed for retrieval of semitendinosus tendon autografts of sufficient dimension to allow for construction of quadrupled ACL grafts of a diameter of 8 mm or larger in 95% of cases. In addition, desired graft length was achieved in all cases. Graft dimensions had moderately strong direct correlations to patient height and weight, with significant size differences noted between the sexes. We believe this to be helpful data for surgeons who might consider performing a quadrupled semitendinosus autograft ACL reconstruction.

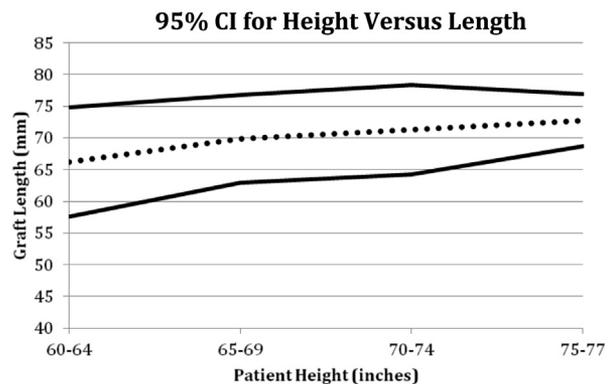


Fig 7. Ninety-five percent confidence interval (CI) for final quadrupled semitendinosus autograft anterior cruciate ligament (ACL) graft construct length correlated to patient preoperative height.

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