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**Original Research Article**

# Anthropometric predictors of hamstring graft size in anterior cruciate ligament reconstruction

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## ABSTRACT

**Background:** The anterior cruciate ligament (ACL) is commonly injured in the knee joint, necessitating surgical reconstruction where quadrupled hamstring tendon autografts are frequently utilized for their favourable outcomes. Predicting the appropriate dimensions of these grafts is essential for surgical success. This study aims to investigate whether simple anthropometric measurements-height, weight, body mass index (BMI), thigh length, and circumference-can predict the length and diameter of quadrupled hamstring tendons used in ACL reconstruction.
**Methods:** This cross-sectional study included 45 patients undergoing ACL reconstruction with quadrupled hamstring autografts at department of orthopaedics, Renai Medicity Kerala, India. Preoperative anthropometric measurements were correlated with intraop graft dimensions using Pearson correlation and SPSS statistical software (version 22).
**Results:** Taller patients exhibited a positive correlation with graft diameter ($p=0.028$). Height and thigh length correlated positively with both gracilis and semitendinosus tendon lengths ($p<0.001$). Thigh circumference correlated positively with semitendinosus length ($p=0.005$), while weight, BMI, and other measures did not significantly correlate with graft dimensions.
**Conclusions:** Anthropometric measurements, particularly height and thigh length, serve as valuable predictors for hamstring graft dimensions in ACL reconstruction. These findings may assist surgeons in selecting appropriate grafts and optimizing surgical outcomes.

**Keywords:** ACL, Hamstring graft, Ligament reconstruction

## INTRODUCTION

Anterior cruciate ligament (ACL) injuries are prevalent and significantly impair the knee joint, occurring at rates of 29 to 38 per 100,000 individuals annually worldwide.[1] The ACL serves as a critical stabilizer in knee joint mechanics, providing primary restraint against anterior translation and secondary support for rotational movements. Structurally, it consists of two primary components: the anteromedial (AM) band, crucial for resisting internal rotation and anterior tibial translation, and the posterolateral (PL) bundle, which aids in controlling extension and external rotation.[2]

The knee is a complex weight-bearing joint composed of the femur, tibia, and patella, supported by ligaments such as the medial collateral ligament (MCL), lateral collateral ligament (LCL), ACL, and posterior cruciate ligament (PCL), along with essential musculature including the quadriceps femoris and patellar tendon.[3] Functionally, it operates as a modified hinge joint with two primary articulations: the patellofemoral and tibiofemoral joints, facilitating flexion, extension, and a limited degree of axial rotation in the flexed position.[4]

During fetal development, the AM and PL bundles of the ACL can be distinguished, each with distinct origins and insertions influencing their biomechanical properties. Intra-articularly, the ACL typically measures between 22 to 41 mm in length, with average dimensions of approximately 20.5±2.4 mm in length and 4.4±0.8 mm in width for the PL bundle, and 36.9±2.8 mm in length and 5.1±0.7 mm in width for the AM bundle.[5] These bundles originate within the intercondylar region of the femur: the PL bundle originates distally near the cartilage border of the femoral condyle, while the AM bundle originates posteriorly within the tibial footprint, influencing their tension patterns during knee movement.[6]

ACL injuries predominantly affect young individuals and are commonly precipitated by dynamic activities such as cutting, deceleration, jumping, twisting, and direct impact to the knee joint. Mechanistically, injury occurs with the knee in positions of external rotation and flexion between 20° to 40°, or shallow knee flexion, exacerbated by medial ground reaction forces during pivoting maneuvers.[7,8]

Clinical evaluation of ACL injuries involves grading based on severity, ranging from grade I (minimal stretching) to grade III (complete tear with rotational instability), which significantly impacts joint stability and function.[9] Additionally, Sherman et al classified ACL injuries into four types based on the amount of ligament tissue remaining on the femur: type 1 (minimal tissue), type 2 (up to 20% remaining), type 3 (up to 33% remaining), and type 4 (mid-substance tear with up to 50% remaining).[10]

Diagnostic assessment typically includes clinical tests such as the Lachman, anterior drawer, and pivot shift tests, complemented by imaging modalities such as MRI to evaluate ACL integrity and associated soft tissue injuries.[11]

Treatment strategies for ACL injuries vary based on injury severity, patient age, and activity level. Initial management often involves conservative approaches with rest, physical therapy, and bracing to reduce inflammation, restore range of motion (ROM), and strengthen surrounding musculature.[12] Surgical reconstruction using autografts, such as hamstring tendons, is frequently recommended for active individuals or those with significant instability. Surgical techniques include precise femoral and tibial tunnel drilling, graft fixation using cortical buttons and interference screws, and comprehensive postoperative rehabilitation to optimize knee function and stability.[13]

Understanding the intricate anatomy, biomechanics, injury mechanisms, classification systems, and treatment options of ACL injuries is essential for healthcare providers to deliver tailored care and achieve optimal patient.

It has become increasingly important to identify patients with inadequate graft size to make informed pre-operative decisions and explore alternative graft sources. Anthropometric measurements, alongside demographic and radiological parameters, have been proposed as predictors of hamstring tendon graft size. Previous studies have examined how these measurements correlate with graft size, but findings have been inconsistent. Thus, the primary objective of this study is to investigate the relationship between various anthropometric measures and graft size in ACL reconstruction surgery. Additionally, the study aims to identify the most reliable predictors of tendon graft size to improve pre-operative planning and enhance patient outcomes.

## METHODS

This study aims to investigate whether anthropometric parameters such as height, weight, BMI, thigh length, and thigh circumference can predict the length and diameter of quadrupled hamstring tendons used in ACL reconstruction surgery. Conducted at department of orthopaedics Renai Medicity Kochi, Kerala, India the study included 45 eligible patients scheduled for arthroscopic ACL reconstruction, who provided informed consent. It was a cross sectional study of one year duration from October 2022 to October 2023.

In a similar study conducted on anthropometric correlation with hamstring graft size in male by Moghamis et al shows patient height and thigh length have moderate positive correlation with graft length and thickness.[12] Using this data, the minimum sample sizewas calculated as under

N=[(Zα+Zβ)/C]2+3

Where N-sample size

α=0.05-type 1 error rate (threshold probability for rejecting the null hypothesis)

β=0.10-type 2 error rate (probability of failing to reject the null hypothesis under thealternative hypothesis)

r=0.464-The expected correlation coefficient

The standard normal deviate for α=Zα=1.9600 The standard normal deviate for β=Zβ=1.2816 C=0.5×ln[(1+r/1-r)]=0.502

N=[(Zα+Zβ)/C]2+3

=[(1.9600+1.2816)/0.502]2+3

=[3.2416/0.502]2+3

=(6.4574)2+3

=41.69+3=44.69

So, we kept our sample size as 45.

### ***Inclusion criteria***

Both males and females above 18 years who are posted for ACL reconstruction surgery were included.

### ***Exclusion criteria***

Revision surgery and fractures of lower limb and hip were excluded from study.

### ***Surgical treatment***

All patients underwent preoperative physiotherapy and achieved full ROM before surgery. Standard anatomic ACL reconstruction was carried out using an autograft of hamstring tendon. This involved independent drilling of the femoral tunnel, proximal graft fixation with a cortical button, and tibial graft fixation with an interference screw.

### ***Patient selection***

The ideal candidates for ACL surgery include individuals with an active lifestyle who either have an acute ACL deficiency or a chronic ACL deficiency resulting in functional instability that threatens the menisci. Arthroscopic techniques have largely replaced open procedures for ACL reconstruction, significantly reducing morbidity. Additionally, the widespread availability of MRI has enhanced preoperative diagnosis and patient counseling.

Patient positioning for arthroscopic surgery.

### ***Standard portals***

*Anterolateral portal:* Created adjacent to the patellar tendon at the level of the inferior pole of the patella for visualization.

*AM portal:* Positioned adjacent to the patellar tendon on the medial side. This portal is used for accessing intra articular lesions, with a spinal needle placed intra-articularly to confirm correct placement.

### ***Accessory portals***

*Superolateral and superomedial portals:* Positioned 2 to 2.5 cm above the lateral or medial border of the patella, these portals provide additional channels for joint distention.

*Posteromedial portal:* Located about 1 cm above the posteromedial joint line and 1 cm posterior to the medial femoral condyle's posteromedial margin.

*Posterolateral portal:* Created approximately 2 cm superior to the posterolateral joint line at the posterior edge of the iliotibial band and the anterior edge of the biceps femoris tendon.

*Central or trans-patellar tendon portal:* Made with a no. 11 knife blade held parallel to the tendon fibers at the proximal part of the tendon.

### ***Graft selection***

The use of hamstring tendon grafts has become more prevalent due to their relatively low donor site morbidity. Surgeons commonly employ a quadruple-stranded semitendinosus-Gracilis tendon graft, which provides adequate tensile strength. However, disadvantages of this soft-tissue graft include its healing within the osseous tunnels and the lack of rigid bony fixation.

### ***Surgical technique***

#### *Patient positioning*

The patient is placed in the supine position. The injured knee is examined under anesthesia to confirm the ACL injury diagnosis before final positioning. Diagnostic arthroscopy may be performed before harvesting the hamstring tendons. A padded nonsterile tourniquet is placed high on the operative thigh. The operative leg is positioned so that it hangs off the end of the operating table in a leg holder, with the contralateral leg in a well-leg holder. Alternatively, the leg can be kept on the operating table and placed into a Figure 4 position. The operative leg is prepped and draped in a standard fashion.

#### *Graft harvest*

An incision is made along the pes anserinus, midway between the tibial tubercle and the posteromedial border of the tibia, approximately 2 to 3 cm in length. The incision is made with a No. 10 scalpel, followed by blunt dissection of the subcutaneous tissue down to the sartorial fascia. Alternatively, the graft can be harvested via a posteromedial incision over the hamstrings. Using tissue forceps and Metzenbaum scissors, the Gracilis and semitendinosus tendons are dissected from the sartorial fascia.

Once the tendons are identified, each is individually dissected from the sartorial fascia and whip-stitched with a no. 2 high-strength nonabsorbable suture. A tendon stripper (closed or open-ended) is used to release each tendon from its proximal musculotendinous attachment. Steady traction on the sutures combined with a steady push of the tendon stripper toward the hamstring origin allows for smooth release.

#### *Graft preparation*

The quadrupled semitendinosus-Gracilis graft is prepared by folding it symmetrically over the loops of the implant and performing suturing.

*Graft sizing*

Measure the graft length and diameter. Pass both the femoral and tibial ends of the graft into the sizing block to determine the diameter needed for socket creation.

*Femoral tunneling*

The femoral tunnel should be 5-10 mm longer than the graft to ensure proper tensioning. The tunnel is placed 5-8 mm above the articular cartilage and 5 mm in front of the resident's ridge to replicate the isometric position of the ACL. Resident's ridge, crescent-shaped bony landmark, marks the anterior border of the ACL femoral attachment, and the posterior articular margin of the lateral femoral condyle marks the posterior border of the ACL footprint. Direct a guide pin near the normal femoral attachment of the ACL. Once the guide pin is satisfactorily placed, create a tunnel in the lateral femoral condyle using a cannulated reamer. Ream the femoral tunnel according to graft size.

*Tibial tunneling*

The tibial tunnel is placed 10 mm anterior to the PCL, at the level of the anterior horn of the lateral meniscus. Insert a guide pin and direct it proximally and medially to enter the joint area of the normal tibial attachment of the ACL. Use a cannulated reamer to create a tunnel in the tibial condyle over the guide pin. Ream the femoral and tibial sockets according to the graft size.

*Graft insertion*

Pass the graft through the loop until it is centered in the femoral tunnel. Use a surgical marker to mark the graft for the femoral tunnel drill depth. Pull the leading and trailing sutures through the tibial and femoral tunnels. Use the leading suture to pull the graft through the femoral tunnel until the mark on the graft is visible at the aperture. Gently remove any slack from the trailing suture.

*Deploy implant*

Deploy the button onto the lateral femoral cortex by pulling on the trailing sutures. Toggle the leading and trailing sutures and pull on the distal ends of the graft to confirm button deployment. Cycle the knee to ensure proper graft tensioning. Perform tibial fixation with an appropriately sized interference screw and remove the leading and trailing sutures.

*Rehabilitation*

Postoperative rehabilitation is crucial for ACL-deficient patients and is typically divided into four phases:

*Phase I: Preoperative period*

The goal is to achieve full ROM comparable to that of the uninjured knee.

*Phase II: 0 to 2 weeks post-surgery*

Objectives include achieving full extension, allowing wound healing, maintaining quadriceps control, minimizing swelling, and reaching 90° of flexion.

*Phase III: 3 to 5 weeks post-surgery*

The focus is on maintaining full extension and increasing flexion to achieve full ROM.

*Phase IV: 6 Weeks post-surgery*

The goal is to maintain motion and gradually improve strength and agility, depending on the patient's progress and desire to return to sports activities.

Based on findings by Moghamis et al which reported a moderate positive correlation between patient height, thigh length, and graft dimensions in males, the minimum sample size was determined.[12] This calculation used standard parameters for α, β, and expected correlation coefficients, confirming the significance of these factors in graft size prediction.

Anthropometric data including height, weight, thigh length, and circumference were recorded preoperatively. BMI was calculated using the formula BMI=Weight (kg)/height (m)$^2$. Same surgeon harvested all grafts (Figure 1), measuring the intraoperative diameter of the quadrupled graft and the lengths of semitendinosus and Gracilis tendons. Graft diameter was precisely measured to 0.5 mm using sizing tubes after removing adjacent muscle and fat, but before any additional trimming.

Quantitative variables were summarized using mean and standard deviation, while categorical variables were presented as frequencies and percentages. Statistical significance was assessed using independent sample t-tests, ANOVA test, Pearson chi-square tests for categorical data, and Pearson correlation tests for continuous variables. A $p<0.05$ was considered statistically significant. This rigorous analysis aimed to elucidate how these anthropometric factors influence graft dimensions, thereby potentially impacting surgical outcomes in ACL reconstruction.

***Statistical analysis***

Fisher's exact test was used to compare age group, weight status and gender with optimal thickness. Pearson's correlation was used to find the correlation of anthropometric variables with Gracilis length and semitendinosus length. Spearman's correlation was used to find the correlation of anthropometric variables with Diameter. Independent sample t test was used to compare the continuous variables by gender. One way ANOVA was used to compare the (length measurements) by age group and weight status. One way ANOVA with a post hoc Bonferroni test was used to compare the diameter by age group. Statistical analyses were conducted using SPSS version 20.0 for Windows.

### *Ethical considerations*

No extra burden for the patient, no extra invasive techniques required. The clearance of the research protocol by the ethics committee is obtained for progress of treatment (reference number RM/RIMS/393).

## RESULTS

This study included 45 participants, with 89% being male (n=40) and 11% female (n=5). The average height was 169.0±7.1 cm, weight was 71.2±10.4 kg, and BMI was 24.9±3.3.

Analysis of graft diameters based on age, gender, and BMI showed no significant differences (Table 1). However, a notable correlation was found between patient height and graft diameter (p=0.028) (Table 2).

Gracilis tendon length did not correlate significantly with age, gender, or BMI (Table 3). Nevertheless, it positively correlated with patient height (p<0.001) and thigh length (p=0.034) (Table 4).

Similarly, semitendinosus tendon length did not correlate significantly with age, gender, or BMI (Table 5). However, both height (p<0.001) and thigh length (p=0.007) were positively correlated with semitendinosus length (Table 6).

These findings highlight the impact of anthropometric factors, particularly height and thigh length, on graft dimensions in ACL reconstruction surgery. The statistically significant correlations identified in this study provide valuable insights for predicting graft sizes and optimizing surgical outcomes.

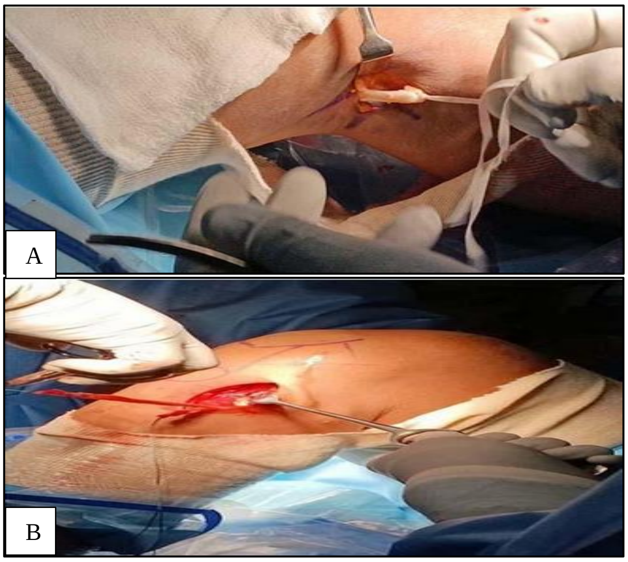

**Figure 1 (A and B): Graft harvesting through posterior approach and anterior approach.**

**Table 1: Factors associated with graft diameter.**

| Variables | Graft diameter | | P value |
|---|---|---|---|
| | N | Mean±SD | |
| **Age (in years)** | | | |
| <20 | 5 | 7.60±0.65 | 0.004 |
| 21-30 | 23 | 8.20±0.58 | |
| 31-40 | 11 | 8.73±0.75 | |
| >41 | 6 | 7.83±0.26 | |
| **Gender** | | | |
| Males | 40 | 8.29±0.63 | 0.033 |
| Females | 5 | 7.60±0.89 | |
| **BMI** | | | |
| Normal | 28 | 8.18±0.70 | 0.215 |
| Overweight | 13 | 8.42±0.70 | |
| Obese | 4 | 7.75±0.29 | |

**Table 2: Correlation of graft diameter with other factors.**

| Variables | Correlation coefficient | P value |
|---|---|---|
| **Height** | 0.328 | 0.028* |
| **Weight** | 0.279 | 0.063 |
| **BMI** | 0.093 | 0.544 |
| **Thigh length** | 0.255 | 0.091 |
| **Thigh circumference** | 0.184 | 0.225 |

*Statistically significant.

**Table 3: Factors associated with Gracilis length.**

| Variables | Gracilis length | | P value |
|---|---|---|---|
| | N | Mean±SD | |
| **Age (in years)** | | | |
| <20 | 5 | 25.20±1.64 | 0.071 |
| 21-30 | 23 | 26.65±1.53 | |
| 31-40 | 11 | 27.55±1.97 | |
| >41 | 6 | 26.67±0.82 | |
| **Gender** | | | |
| Males | 40 | 26.88±1.62 | 0.062 |
| Females | 5 | 25.40±1.67 | |
| **BMI** | | | |
| Normal | 28 | 26.96±1.69 | 0.242 |
| Overweight | 13 | 26.54±1.51 | |
| Obese | 4 | 25.50±1.92 | |

**Table 4: Correlation of Gracilis length with other factors.**

| Variables | Correlation coefficient | P value |
|---|---|---|
| **Height** | 0.517 | <0.001* |
| **Weight** | 0.105 | 0.492 |
| **BMI** | -0.232 | 0.125 |
| **Thigh length** | 0.317 | 0.034* |
| **Thigh circumference** | 0.284 | 0.059 |

*Statistically significant

### Table 5: Factors associated with semitendinosus length.

| Variables | Semitendinosus length | | P value |
|---|---|---|---|
| | N | Mean±SD | |
| **Age (in years)** | | | |
| <20 | 5 | 28.40±1.67 | 0.0 |
| 21-30 | 23 | 30.17±1.75 | |
| 31-40 | 11 | 31.00±1.84 | |
| >41 | 6 | 30.17±1.17 | |
| **Gender** | | | |
| Males | 40 | 30.38±1.75 | 0.036 |
| Females | 5 | 28.60±1.52 | |
| **BMI** | | | |
| Normal | 28 | 30.61±1.81 | 0.100 |
| Overweight | 13 | 29.62±1.61 | |
| Obese | 4 | 29.00±1.63 | |

### Table 6: Correlation of semitendinosus length with other factors.

| Variables | Correlation coefficient | P value |
|---|---|---|
| **Height** | 0.661 | <0.001* |
| **Weight** | 0.101 | 0.508 |
| **BMI** | -0.315 | 0.035 |
| **Thigh length** | 0.400 | 0.007* |
| **Thigh circumference** | 0.410 | 0.005* |

*Statistically significant.

## DISCUSSION

The size of quadrupled hamstring tendon grafts in ACL reconstruction is closely linked to graft stiffness, failure rates, and tensile strength, as evidenced by several studies.[13,14] Accurately predicting graft dimensions preoperatively is crucial to mitigate risks associated with graft insufficiency. This study investigated 45 patients undergoing ACL reconstruction using quadrupled hamstring autografts, analyzing how anthropometric measurements correlate with graft lengths and diameter. The results revealed that the diameter of quadrupled grafts correlated significantly with patient height, while the lengths of the semitendinosus and Gracilis grafts were associated with both height and thigh length. Predicting hamstring graft dimensions not only impacts ACL reconstruction but also extends to periarticular reconstructive procedures, posterolateral corner reconstructions, collateral ligament repairs, and techniques involving the elbow and ankle.

Gender distribution did not significantly influence these correlations within our study cohort. Previous research underscores the biomechanical and clinical benefits of larger hamstring graft diameters.[15,16] Mariscalco et al reported improved KOOS sports scores and reduced pain levels with larger graft diameters, highlighting their therapeutic advantage.[16] Conversely, Magnussen et al identified smaller graft diameters as a significant risk factor for early revision surgery, particularly in younger patients.[15] Tuman et al noted that individuals shorter than 147 cm often had hamstring graft diameters less than 7 mm when quadrupled, further emphasizing the impact of anthropometric factors on graft sizing.[17] Height emerged as a consistent predictor of graft diameter across various studies by Ma et al, Pinheiro et al and others, without a clear height cut off for insufficient graft sizing.[18,19]

Thigh length also played a notable role in predicting hamstring graft dimensions in our study. While previous findings suggested a weaker influence of thigh length on graft diameter, our results demonstrated significant positive correlations, albeit slightly less pronounced compared to height (p=0.091 for thigh length versus p=0.028 for height).[19] Both height and thigh length showed strong positive correlations with gracilis and semitendinosus graft lengths in our analysis (Tables 5 and 7). These correlations underscore the utility of anthropometric measurements in personalized surgical planning for ACL reconstruction, potentially optimizing graft selection and improving surgical outcomes.

Recent studies by Spragg et al and Krishna et al further support the clinical significance of graft diameter in ACL reconstruction. Spragg et al highlighted that even a modest increase in graft diameter from 7.0 to 9.0 mm significantly reduces the likelihood of revision surgery.[22] Similarly, Krishna et al demonstrated that techniques such as using a 5-strand hamstring autograft can achieve adequate graft diameter and comparable clinical outcomes to traditional 4-strand grafts, underscoring the importance of graft dimension optimization.[23] Additionally, Xu et al found that thick hybrid grafts provided superior clinical outcomes compared to thin autografts, reinforcing the preference for thicker grafts in ACL reconstruction.[24]

This discussion emphasizes the critical role of anthropometric measurements in predicting hamstring graft size for ACL reconstruction. Height and thigh length serve as robust predictors of graft dimensions, influencing surgical decision-making and potentially enhancing postoperative outcomes. Further research and standardization of measurement techniques could refine preoperative planning, optimize graft selection, and ultimately improve the overall success of ACL reconstruction procedures.

Limitation of the study include unavailability of a regression analysis due to a lesser sample size, dearth of female representation (only 5 females).

## CONCLUSION

This study highlights the crucial role of anthropometric parameters, particularly height and thigh length, in preoperative planning for hamstring tendon autograft ACL reconstruction. These parameters serve as reliable predictors of graft dimensions, guiding surgeons in selecting appropriate surgical approaches and counselling patients effectively. Ensuring a hamstring graft diameter of 8mm or more is pivotal for achieving optimal postoperative outcomes and reducing the likelihood of graft failure. This emphasizes the significance of accurate preoperative assessment to mitigate the risks associated with graft insufficiency and subsequent revision surgeries.

The ability to predict and optimize hamstring graft size based on anthropometric measurements enhances the precision and effectiveness of ACL reconstruction procedures. By integrating height and thigh length into preoperative evaluations, surgeons can better tailor graft selection and surgical techniques, thereby improving overall patient outcomes. Moving forward, continued research into refining predictive models and exploring innovative strategies will further advance the field, aiming to enhance graft sizing precision and optimize outcomes in ACL reconstruction.

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