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Original Article

Morphometric Measurements of Cadaveric Anterior Cruciate Ligament and Hamstring Tendons Graft among Indian Population

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Abstract

Introduction: Anatomical graft placement is important for the best clinical outcome of anterior cruciate ligament (ACL) reconstruction. The objectives were to study the dimensions of the ACL, the quadrupled hamstring tendon graft and reveal the correlation between the size of the ACL native and transplant quadrupled hamstring tendon of the Indian population.

Materials and Methods: In this study, 44 cadaveric knees from 22 cadavers (13 males and 9 females) were included for measuring the dimensions of the ACL and hamstring tendon graft. The measurement of ACL was taken using Vernier calipers. The length was taken from the main axis of the insertion zone and the width was taken perpendicular to the longitudinal axis of the widest point.

Results: Average diameter and cross-sectional area of the ACL were found to be 6.6 mm and 34.35 mm^2, respectively. The average diameter and cross-sectional area of the hamstring tendon graft are 7.2 mm and 41.28 mm^2, respectively. The average tibial cross-sectional area of ACL was 129.63 mm^2, femoral insertional area was 97.23 mm^2. The quadruple transplant hamstring tendon is 20.17% larger than the ACL midsubstance. The difference was statistically significant ($P = 0.0207$).

Conclusions: There is a good correlation between the cross-section of midsubstance of the ACL and quadrupled hamstring tendon graft in Indian population. With the use of graft quadrupled hamstring tendon for reconstruction of the ACL, the graft is oversized to the average of 20.17%. With the use of the current reconstruction using hamstring quadrupled tendon graft technique, it is unlikely to reproduce the footprints of the ACL.

Key words: Anterior cruciate ligament, Cadaveric study, Quadrupled hamstring graft

INTRODUCTION

Injury of the anterior cruciate ligament (ACL) is rising due to the increased participation in sporting activities in the recent years. As knee is majorly stabilized by ACL in extreme balancing, climbing, and gymnastic exercises, there is increased demand from patients for repair or reconstruction of ACL injuries. ACL is primary restraint to anterior translation of the tibia and secondary restraint to internal rotation of the knee.[1] Arthroscopic reconstruction of the ACL is one of the most frequently performed procedures in knee surgery in recent years. ACL reconstruction has been performed using bone-patellar tendon-bone graft (BPTB) or using Hamstring tendon graft.[2] Anatomical graft placement is important for the best clinical outcome of ACL reconstruction[3] and non-anatomical graft placement in bone tunnel is the main cause of graft failure in the ACL reconstruction.[4] Reconstruction surgery of ACL presents as challenge even for experienced surgeons. Therefore, the surgeon must have complete knowledge of the anatomy of the knee ligaments, graft used for reconstruction and normal biomechanics to reduce operative time, and improve postoperative functional

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outcome.[1] Length and diameter of the native ACL play an important role in the selection and preparation of the graft for reconstruction.

With the new techniques of reconstruction of the ACL, the main objective was to reproduce the impression of the native ACL to restore the kinematics and improve functional outcome. However, it is also important to consider that there is a design of the graft relative to the native ACL midsubstance to avoid the risk of encroachment of the graft. The impact on the graft causes tearing, which leads to joint laxity and failure of the graft transplant.[5]

In recent years, studies have been conducted to reveal the biomechanics of the knee joint and the establishment of the tunnel in graft reconstruction.[6,7] However, there are little data available on the dimensions of the ACL graft and hamstring tendons used for reconstruction of the ACL in the Indian population. There were questions about the discrepancy between the size of the ACL and tendon graft hamstring used for reconstruction. This study reveals the details of the dimensions of the ACL and its footprints, hamstring quadruple graft used for reconstruction surgery.

The objectives were to study the dimensions of the ACL, the quadrupled hamstring tendon graft and reveal the correlation between the size of the ACL native and transplant quadrupled hamstring tendon of the Indian population.

MATERIALS AND METHODS

In this study, 44 cadaveric knees from fresh frozen 22 cadavers were included for measuring the dimensions of the ACL and hamstring tendon graft. Adults from the age group 18–70 years were included for the study. The ethical committee approval was taken. The uninjured, unoperated knee and unwounded joint with intact ACL were included in this prospective study. Decomposed cadavers, cadavers with previous knee surgeries, torn ACL, and osteophytes in the notch (tibia and/or femur) were excluded from the study. There were 13 males and 9 females. The average storage time of death to dissection was 40 days. Full extension was possible in all knees, while flexion ranges from 120 to 135.

The body was placed in supine position, knee was opened by paramedian incision. The subcutaneous tissue and retinaculum were incised, the capsule has been cut and the patella was everted so as to expose the ACL [Figure 1]. Anterior and posterior bundles and foot prints were visible all the time. The measurement of ACL was taken using Vernier calipers before cutting the ligament so as to maintain the native ligament tension. Soft tissue including synovial membrane around the ACL has been removed. The diameter was taken with a digital Vernier caliper in two different axes and the average of both was taken [Figure 2].

The ACL was released from its tibial and femoral insertion. Sites of femoral and tibial insertion were stained, the length and width were taken. The length was taken from the main axis of the insertion zone and the width was taken perpendicular to the longitudinal axis of the widest point.

The incision was extended until the insertion of the semitendinosus and gracilis on the center upper part of the tibia shaft and the semitendinosus and gracilis tendon was removed with tendon stripper. The graft was cleaned and prepared as four tendon grafts and the diameter of cross-section was taken with a digital caliper by tensioning with 25 g weight.

Cross-sectional area and the diameter were calculated using the geometric calculation used to calculate the surface of the cylinder and ellipse as

$$\text{Area of the circle pie} \times = (\text{diameter}/2)\ 2$$

Field of the ellipse pie × = length of the major axis (length) × length of the minor axis (width)/4. All continuous data are expressed as mean (SD). Z test was used to calculate *P* value. $P < 0.05$ was considered statistically significant. Coefficient of correlation (R) of Karl Pearson coefficient was used to evaluate the correlation between different parameters.

RESULTS

The study was conducted on 44 knees of 22 human cadavers including 13 males and 9 females. The results are summarized in Tables 1 and 2.

ACL

Average diameter of the ACL was found to be 6.6 mm (range from 5.7 to 7.4 mm) and the average cross-sectional area of the ACL was 34.35 mm^2 (range from 25.53 mm^2 to 43.03 mm^2). Average ACL diameter in male was 6.77 (range from 6.2 mm to 7.4 mm) and in female 6.36 mm (5.7 mm to 6.8 mm). Average ACL diameter in right was 6.64 mm (range from 5.8 mm to 7.4 mm) and on left was 6.56 mm (range from 5.7 mm to 7.3 mm). Cross-sectional area in male was 36.10 mm^2 (range from 30.3 mm^2 to 43.03 mm^2) and in female 31.81 mm^2 (range from 25.53 mm^2 to 36.33 mm^2). Cross-sectional area of the ACL on right side was 34.72 mm^2 (range from 26.43 mm^2 to 43.03 mm^2) and on left was 33.97 mm^2 (range from 25.53 mm^2 to 41.87 mm^2) [Figure 3].

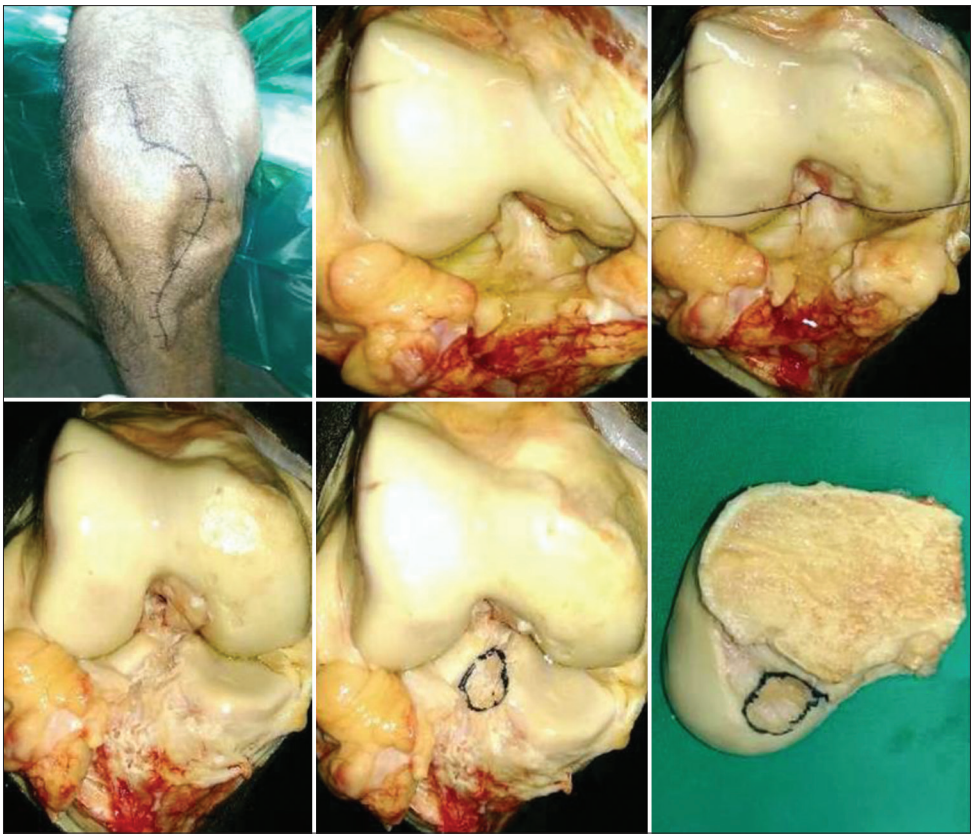

Figure 1: Stepwise measurement of anterior cruciate ligament cruciate ligament dimensions and its footprint

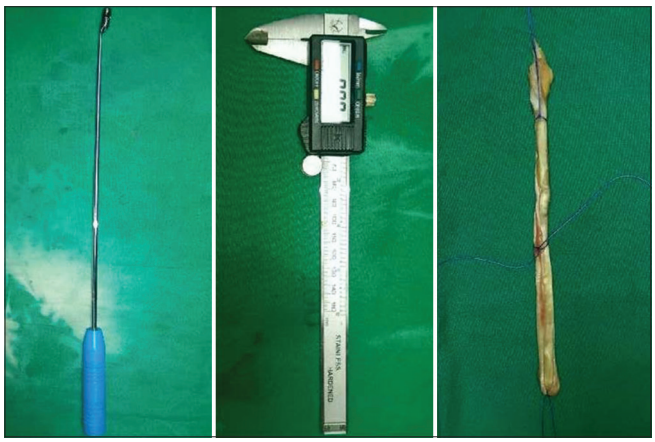

Figure 2: Tendon stripper, Vernier caliper, and harvested tendon graft

Quadrupled Hamstring Tendon Graft

The average diameter of the hamstring tendon graft was 7.2 mm (range from 6.3 mm to 8.5 mm). The average cross-sectional area of the hamstring tendon graft was 41.28 mm^2 (range from 31.19 mm^2 to 56.77 mm2). The diameter of the hamstring tendon graft in male was 7.46 mm (range from 6.7 mm to 8.5 mm) and in female was 6.8 mm (6.3 mm to 7.5 mm). The diameter of the hamstring tendon graft on the right side was 7.26 mm (range from 6.4 mm to 8.5 mm) and on the left side 7.19 mm (6.3 mm to 8.4 mm). The cross-sectional area of the hamstring tendon graft is male was 43.94 mm^2 (range from 35.27 mm^2 to 56.77 mm^2) and in female was 37.43 mm^2 (range from 31.19 mm^2 to 44.23 mm^2). The cross-sectional area of the hamstring tendon graft on the right side was 41.70 mm^2 (range from 32.18 mm^2 to 56.77 mm^2) and on the left side is 40.86 mm^2 (range from 31 mm^2 to 55 mm^2).

Tibial Insertional Area

The average tibial insertional length is 14.31 mm (range from 11.8 mm to 16.6 mm) and width was 11.47 mm (range from 9.7 mm to 13 mm). The average tibial cross-sectional area was 129.63 mm^2 (range from 99 mm^2 to 169.56 mm^2). The average tibial cross-sectional area in male was 140.83 mm^2 (range from120.03 mm^2 to 169.56 mm^2) and in female was 113.46 mm^2 (99 mm^2 to 146.49 mm^2). The average tibial insertional area on the right side was 131.10 mm^2 (100.1 mm^2 to 169.56 mm^2) and on the left side was 128.16 mm^2 (99 mm^2 to 164.94 mm^2).

Femoral Insertional Area

The average femoral insertional area of the ACL was 97.23 mm^2 (range from 56.57 mm^2 to 144.63 mm^2). The femoral insertional area of the ACL in male was 110.78 mm^2 (range from 80.21 mm^2 to 144.63 mm^2) and female was 77.66 mm^2 (range from 56.57 mm^2 to

Table 1: Mean diameter of ACL, quadrupled hamstring tendon, and mean cross-sectional area of ACL midsubstance, hamstring tendon

Parameters	Mean diameter of the ACL midportion in mm	Mean diameter of the quadrupled hamstring tendon graft in mm	Mean cross-sectional area of the ACL midportion in mm^2	Mean cross-sectional area of the quadrupled hamstring tendon graft in mm^2
Mean	6.6 (±0.39)	7 (±0.55)	34.35 (± 4.09)	41.28 (±6.53)
Male	6.77 (±0.35)	7.46 (±0.56)	36.10 (±3.80)	43.94 (±6.78)
Female	6.36 (±0.31)	6.89 (±0.33)	31.81 (± 3.09)	37.43 (±3.65)
Right	6.64 (±0.39)	7.26 (±0.56)	34.72 (± 4.13)	41.70 (±6.67)
Left	6.56 (±0.39)	7.19 (±0.55)	33.97 (± 4.12)	40.86 (±6.49)

ACL: Anterior cruciate ligament

Table 2: Tibial and femoral insertional area dimensions

Parameters	Tibial insertional length/width (mm)	Tibial insertional area (mm^2)	Femoral insertion length/width (mm)	Femoral insertional area (mm^2)
Mean	14.31 (±1.31)/11.47 (±0.9)	129.63 (±20.71)	12.76 (±1.62)/9.55 (±1.24)	97.23(± 24.37)
Male	14.83 (±1.09)/12.06 (±0.56)	140.83 (±15.58)	13.7 (±1.17)/10.22 (±0.94)	110.78(± 19.23)
Female	13.55 (±1.26)/10.62 (± 0.56)	113.46 (±15.78)	11.41 (±1.18)/8.57 (±0.95)	77.66 (±16.51)
Right	14.37 (±1.34)/11.55 (±0.92)	131.10 (±21.32)	12.79 (±1.63)/9.57 (±1.26)	97.68 (±24.67)
Left	14.25(±1.31)/11.39 (±0.9)	128.16 (±20.47)	12.73 (±1.65)/9.52 (±1.25)	96.78 (±24.63)

ACL: Anterior cruciate ligament

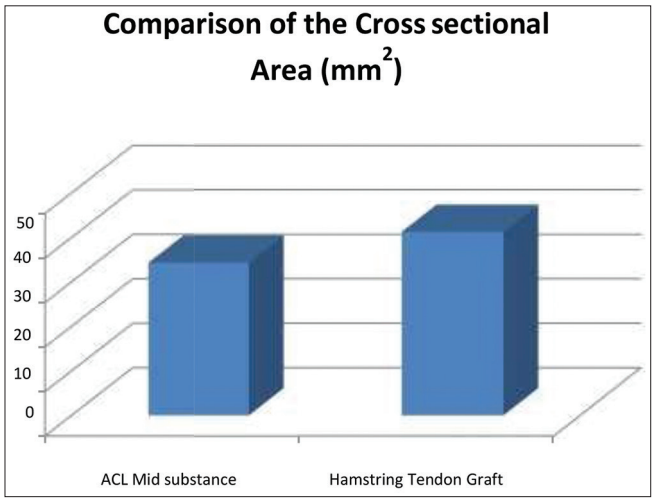

Figure 3: Comparison between the cross-sectional area of the anterior cruciate ligament midsubstance and hamstring tendon graft

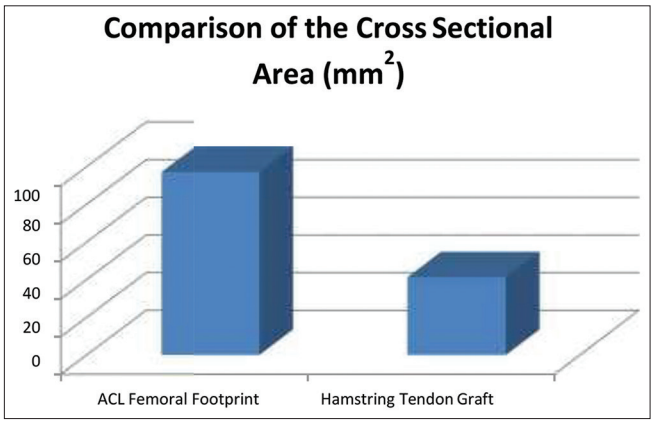

Figure 4: Comparison between the cross-sectional area of the anterior cruciate ligament femoral footprint and hamstring tendon graft

104.19 m^2). The femoral insertional area on the right side was 97.68 mm^2 (range from 56.57 mm^2 to 144.63 mm^2) and on the left side was 96.78 mm^2 (56.37 mm^2 to 142.49 mm^2) [Figure 4].

The quadruple transplant hamstring tendon is 20.17% larger than the ACL mid substance. The difference was statistically significant (P = 0.0207). Although there is a significant difference in size (20.17%) between the hamstring tendon graft and ACL midsubstance, it always showed the highest correlation (coefficient correlation Karl Pearson (R) 0.92), which is considered a good correlation [Table 3, Figure 5]. ACL femoral and tibial footprint also has a correlation with hamstring tendon graft but midsubstance has the highest correlation amplitude (coefficient of Karl Pearson correlation R was 0.92).

DISCUSSION

ACL is most commonly injured in internal derangement of knee. ACL reconstruction is important because it restores back the stability of the knee and prevents the development of osteoarthritic changes in the knee joint. Various grafts are used for ACL reconstruction, BPTB graft and quadrupled hamstrings tendon graft are commonly used for the graft ACL reconstruction. However, graft quadrupled hamstring tendon is more popular and commonly used in Indian subcontinent. The reconstruction of the ACL is passed by the evolution of open ACL reconstruction to reconstruction under

Table 3: The correlation between ACL tibial, femoral footprint, and midsubstance

Parameters	Karl Pearson's coefficient of correlation (R) Wrt hamstring tendon graft
ACL tibial footprint area	0.85
ACL femoral footprint area	0.89
ACL midsubstance cross-sectional area	0.92

ACL: Anterior cruciate ligament

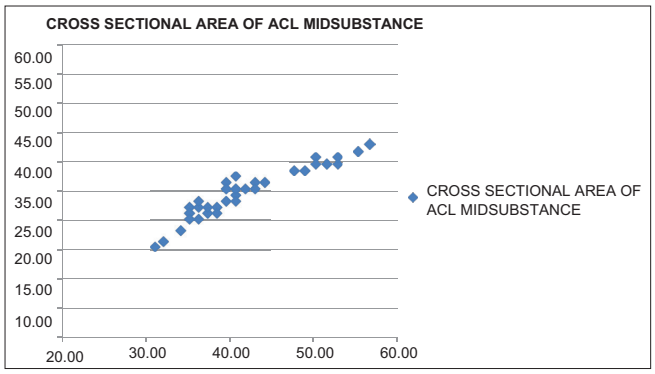

Figure 5: Scattered diagram showing the correlation between cross-sectional area of hamstring tendon graft and anterior cruciate ligament midsubstance

assisted arthroscopy. The reconstruction of assisted arthroscopic ACL has become more popular after 1980. In the first technical time, transtibial tunnel was used for ACL reconstruction. However, it has the disadvantage of a more vertical position and non-anatomical graft that undermines the rotation stability.[8] Nowadays, it is replaced by the establishment of the anterior graft tunnel, anterolateral tunnel technique is useful for anatomical placement graft.[9] ACL is the primary restraint against anterior translation of the tibia. Therefore, the anatomical placement of the graft is important to prevent the development of osteoarthritic changes in the knee joint and prevent the encroachment of the graft in the intercondylar notch.[10]

The purpose of this study is to investigate the dimensions of the ACL and quadruple hamstring tendon graft used for ACL reconstruction.

In our study, the statistical analysis shows that: (a) There is a good correlation between the middle part of the ACL and quadrupled hamstrings tendon graft of the Indian population. (b) There is a correlation between the hamstring tendon graft, tibial and femoral ACL footprint. However, the magnitude of the correlation is less compared to the midsubstance ACL. With the tendon graft quadrupled hamstrings, the femoral and tibial footprints of the ACL could not be reproduced.

In our study, we measured the dimensions of the middle portion of the ACL intact unlike other studies in the past and Dargel *et al.*,[11] where measurements were carried out after removal of ACL knee. In this study, the dimensions of the ACL were taken after the removal of the synovial membrane to obtain the most accurate dimensions. The results obtained by this method are comparable to those obtained after removal of the synovial membrane.[12-14]

According to the previous studies, the area of the ACL femoral ranges from 83 mm^2 footprint to 198 mm^2 and of the tibial footprint from 114 mm^2 to 229 mm^2.[12,15-19] The area of quadrupled hamstring tendon graft ranges from 20 mm^2 to 50 mm^2 and the surface of the middle portion of the ACL ranges from 20 mm^2 to 38.9 mm^2.[20] The findings of the present study are similar to the previous studies. The tibial footprint is substantially greater than the footprint of the femur, middle part, and quadrupled graft tendon hamstrings.

As described by Mochizuki *et al.*[21] and Hara *et al.*,[22] the ACL is attached to the femoral origin as a fan-shaped structure on the side wall of the intercondylar notch of the femur. Therefore, insertional area at the femoral footprint is larger than the midsubstance of the ACL. These results are similar to the present study.

The technique of double-bundle and bone-patellar tendon-bone graft can reproduce footprints of ACL, but the reconstructed graft must be as large as and as close as the native ACL. The major problem with the use of larger graft and so as to mimic the footprint is the transplant impingement. The tibial and femoral footprints are significantly larger compared to the average cross-sectional area of the ACL. Therefore, it is important to evaluate the graft, which must imitate reconstructed cross midsubstance ACL to avoid impingement. In this study, we found a good correlation between the graft and ACL midsubstance.

The arthritic knees are not included as osteoarthritic changes can alter the dimensions of the ACL and transplant hamstring tendon. The main limitation of the study is that the assessment is done by macroscopic examination only. There could be human error and prejudice. The measurement of the size of the ACL was manually taken with digital calipers. However, as the ACL is three-dimensional structure,[16] better dimensions have been obtained with the three-dimensional camera or computer graphics. Some took with dimensions X-ray and magnetic resonance imaging.[23]

For the clinical relevance, there is a good correlation between the ACL and the medial part of the ACL, but the correlation between the footprints of the ACL and

hamstring tendon graft is four-fold less in amplitude. Therefore, it is unlikely to reproduce with the graft tendon hamstring quadrupled the femoral and tibial footprint of the ACL. Furthermore, Bedi *et al.*[24] said, in its study, that the restoration of the footprint of the ACL in reconstruction is paramount.

CONCLUSIONS

There is a good correlation between the cross-section of midsubstance of the ACL and quadrupled hamstring tendon graft in Indian population (coefficient of Karl Pearson correlation (R) 0.92). With the use of graft quadrupled hamstring tendon for reconstruction of the ACL, the graft is oversized to the average of 20.17%. The ACL dimensions are more in men than women ($P < 0.05$). With the use of the current reconstruction using hamstring quadrupled tendon graft technique, it is unlikely to reproduce the footprints of the ACL.

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