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Morphometric Measurement of the Anterior Cruciate Ligament (ACL) In the Kenyan Population

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ABSTRACT

The anterior cruciate ligament (ACL) is one of the cruciate ligaments of the knee joint. It prevents anterior translation of the tibia on the femur and stabilizes the knee joint. In the event of a ligamentous knee injury, ACL reconstruction is prone to graft failure attributed to technical errors and lack of morphometric accuracy. There is a need for local ACL morphometric data from the Kenyan population to improve patient outcomes. To determine the length, mid-substance width, thickness, and cross-sectional area of the ACL among the Kenyan population. A descriptive cross-sectional anatomical study utilizing 60 cadaveric specimens was conducted at the Department of Human Anatomy in Moi University's School of Medicine. Adult skeletal cadaveric specimens of all sexes with intact knee joints were selected. Dissections were conducted as per the Cunningham Manual of Practical Anatomy. The ACL length, width, thickness and cross-sectional area were summarized as means and their corresponding standard deviations. Cross-sectional area was computed as π *(Width/2*thickness/2)* . A Student's t-test was used to determine statistically significant mean differences by sex and side. This study enrolled embalmed cadaveric specimens, 32 (53.3%) of which were male. The overall mean ACL length was 30.536 ± 2.074 mm, with males (31.132 ± 1.936 mm) having a significantly ($p=0.020$) longer ACL than females (29.900 ± 2.057 mm). The overall mean ACL width was 10.902 ± 1.219 mm, with a significant ($p<0.001$) mean difference (1.804; 95% CI: 1.380, 2.228) in male and female cadavers. The mean ACL thickness was 4.977 (±0.542) mm, with male (5.294 ± 0.328) cadavers having a significantly ($p<0.001$) thicker ACL than females (36.36 ± 4.93 mm). The average cross-sectional area was 42.95 ± 8.44 mm^2, with the mean for males significantly higher than that for females ($p<0.001$). The overall mean ACL length in the selected Western Kenya population was 30.54 (±2.07) mm, and the overall mean width of 10.902 (±1.219) mm. Male cadavers had a significantly longer, wider, and thicker ACL compared to females. Similarly, the mid-substance cross-sectional area was significantly higher in male compared to female cadaveric specimens. This study demonstrates a significant difference in morphometric measurements by sex.

Keywords: Anterior cruciate ligament, Morphometry, Knee joint, Cadaveric study

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INTRODUCTION

The anterior cruciate ligament (ACL) is one of the primary stabilizers of the knee joint, preventing anterior translation of the tibia relative to the femur and controlling rotational stability. It originates from the posteromedial aspect of the lateral femoral condyle and inserts into the anterior intercondylar area of the tibia, just medial to the tibial spine (1). Structurally, the ACL is composed of dense collagen fibers arranged into two functionally distinct bundles, the anteromedial and posterolateral bundles, which are differentially tensioned during flexion and extension, thereby maintaining knee stability throughout the range of motion (2). Histologically, it is a hypocellular structure with limited vascularity, which partly explains its poor intrinsic healing capacity once completely ruptured (3).

Functionally, the ACL provides up to 85% of resistance to anterior tibial translation at 90° flexion and is a secondary stabilizer against varus-valgus and rotational loads (4). Generally, it is critical in maintaining normal biomechanics of the knee joint, and its deficiency results in recurrent episodes of instability and impaired performance in pivoting sports. Chronic ACL deficiency is also associated with secondary injuries, most notably meniscal tears and articular cartilage damage, which accelerate the development of post-traumatic osteoarthritis (Friel & Chu, 2013). Since the ACL rarely heals spontaneously after rupture, conservative management often results in persistent instability in active patients, making surgical reconstruction the standard of care for restoring stability, function, and quality of life (5).

Accurate morphometric characterization of the anterior cruciate ligament (ACL) is central to the success of modern reconstructive surgery. Morphometry refers to quantitative measurements such as length, mid-substance cross-sectional area (CSA), fiber bundle orientation, and the dimensions of femoral and tibial footprints (6). These anatomical parameters vary widely among individuals, and the ability to reproduce native ACL geometry during reconstruction has been shown to correlate with improved biomechanical function and restoration of knee kinematics (7).

One of the most important applications of ACL morphometry is in graft selection and sizing. Studies have demonstrated that smaller ACLs, more frequently observed in women and individuals with lower body height are associated with correspondingly smaller grafts when hamstring autografts are harvested (8). Graft-tunnel mismatch or undersized grafts have been linked to increased risk of failure and residual laxity post-reconstruction (9). Therefore, accurate preoperative prediction of native ACL size using morphometric parameters, or anthropometric correlations such as patient height, weight, or femoral epicondylar width, can aid surgeons in anticipating graft adequacy and deciding between hamstring, patellar tendon, or allograft sources (10).

Morphometric data also guides surgical techniques and tunnel placement. The ACL inserts onto relatively broad, variably shaped footprints on the femur and tibia, which cannot always be reproduced by a single circular tunnel (11). Precise knowledge of footprint size and shape allows surgeons to determine whether single-bundle or double-bundle reconstruction best restores the patient's anatomy. Another critical role of ACL morphometry is in biomechanical outcomes and joint stability**.** A close match between graft and native ACL dimensions improves anterior-posterior stability and rotational control, both of which are essential for return to high-level activities (12). When tunnel placement fails to align with the native fiber orientation, abnormal graft tensioning and altered kinematics can result, predisposing to failure or early degenerative changes (2). Hence, morphometric insights translate directly to surgical accuracy, graft longevity, and patient functional outcomes.

Published ACL morphometry work from Africa remains relatively limited but is increasing, with most data coming from South African cadaveric and imaging series and a scattering of small single-center reports across the continent. Van Zyl and colleagues conducted a cadaveric study of the ACL using knees from a South African population to provide normative morphometric data and explore preoperative predictors of ligament length. They measured intra-articular ACL length, finding a mean of 32.4 mm (range 22.9–45.1 mm), and demonstrated substantial variability between individuals. Importantly, they identified femoral epicondylar width (FECW) as a strong predictor of ACL length, suggesting it could be used clinically to anticipate graft requirements before reconstruction. This was one of the first comprehensive attempts to generate region-specific ACL morphometry data in sub-Saharan Africa, and it emphasized the importance of population-based anatomical research for surgical planning (Van Zyl et al., 2016).

Beyond South Africa there are few large, population-representative MRI or cadaveric series from East, West or Central Africa; instead the literature is dominated by small institutional series, case registries of ACL presentations and single-institution morphometric reports, which limits the ability to build robust sex-specific or anthropometric prediction models for the wider region (13). Because morphological risk factors and graft-to-native size matching are known to vary between populations and influence surgical decisions, the scarcity of regionally representative morphometric datasets creates a practical evidence gap for surgeons in much of sub-Saharan Africa and supports the need for larger, ideally multicenter MRI or combined cadaveric–imaging studies in the region (14).

The ACL is the most commonly injured knee ligament, accounting for >50% of knee injuries (Sengodan et al., 2022). In Kenya, the incidence of ACL tears has notably been rising, leading to a higher demand for surgical intervention among patients experiencing functional

knee instability (15). However, an increase in graft failure and revision surgeries remains a concern, often linked to grafts smaller than 8 mm in diameter (16,17). In Addition, the burden of disease resulting from revision ACL surgeries — including both direct and indirect costs — may adversely affect the patients' overall quality of life (Stewart et al., 2017). Lastly, there is a scarcity of local research detailing the average dimensions, cross-sectional area, and footprint dimensions of the ACL in the Kenyan population, knowledge that is critical for optimal graft sizing and minimizing revision surgery rates.

The findings of this study will guide evidence-based preoperative planning for ACL reconstruction, ensuring proper graft choice and tunnel preparation are tailored to the morphometry of the local population. By establishing the average ACL dimensions and cross-sectional areas, this study will support more accurate graft sizing, potentially reducing graft failure rates and the need for costly revision surgeries. This study will provide region-specific ACL morphometric data for the Kenyan population, addressing the current scarcity of local research and creating a reference for orthopaedic surgeons. The data will be valuable in sports medicine programs aimed at reducing ACL injury rates, particularly in high-risk athletic populations in Kenya, and may inform targeted prevention strategies.

This study aimed to determine the morphometric characteristics — including length, width, thickness, and cross-sectional area — of the anterior cruciate ligament in the Adult Kenyan population. Specifically, it measured the length, mid-substance width, and the mid-substance thickness of the ACL among the adult Kenyan population. Lastly, it calculated the mid-substance cross-sectional area of the ACL among the adult Kenyan population.

MATERIALS AND METHOD

This was a descriptive cross-sectional anatomical study utilizing 60 cadaveric specimens, conducted at the Department of Human Anatomy in Moi University's School of Medicine. Adult skeletal cadaveric specimens of all sexes with intact knee joints were selected. The research team accessed the lab alongside a technologist in the department who helped identify eligible cadavers. A census sampling technique was used to sample the cadavers. Selected cadavers meeting the inclusion criteria were placed supine on the dissection table. Knee dissection was carried out as per Cunningham's Manual of Practical Anatomy, sixteenth Edition Page 259 - 263 (Koshi, 2017). The skin, soft tissues and articular capsules were dissected. The soft tissues were stripped except for the ligaments and menisci. The attachment of the ACL in the tibia and femur was identified by careful dissection (Figure 1).



Figure 1: Attachment of the ACL in the tibia and femur

The length of the ACL was measured using a digital vernier caliper (able to measure to 0.01) along the ligament's long axis from the centre of the tibial footprint to the center of the femoral footprint with the knee at 90 degrees of flexion (Figure 2).



Figure 2: ACL length measurement

The width of the ACL was measured as the maximum mediolateral dimension at the ligament's midpoint (Figure 3).



Figure 3: ACL width Measurement

Thickness was measured as the maximum anteroposterior dimension at the ligament's midpoint (Figure 3.4). To ensure measurement validity, all study procedures were done in line with methodologies of previously published studies (18).



Figure 4: Measurement of the ACL Mid-substance thickness

Cross-sectional area was calculated using the following geometrical calculation:

$$\pi\left\{\left(\frac{\text{ACL Width}}{2}\right)\left(\frac{\text{ACL Thickness}}{2}\right)\right\}^2$$

Where $\pi = 3.142$

A Student's t-test was used to determine statistically significant mean differences by sex and side. Ethical approval to conduct the study was obtained from the Institutional Research and Ethics Committee (IREC). Approval was obtained from the Chair, Department of Human Anatomy, and a research permit was obtained from the National Commission of Science, Technology and Innovation (NACOSTI). The study was conducted as per the Anatomy Act Chapter 249-3 of the laws of Kenya. Additionally, the procedures for accessing and utilizing cadaveric knees (including the knee dissection methods) adhered to established ethical

standards and no invasive procedures were performed without appropriate ethical and administrative approval.

RESULTS AND DISCUSSION

This study enrolled 60 cadavers, of which 31 (51.7%) were male and 29 (48.3%) were female. When the cadaveric limbs were stratified by side, 32 (53.3%) were on the left and 28 (46.7%) on the right. This study assessed the length of the ACL, its width, cross-sectional area and mid-substance volume in the selected adult Western Kenya population.

Length of the ACL among the adult Kenyan population

The overall mean and median length of the ACL was 30.536 (±2.074) mm and 30.370 (IQR: 29.125, 32.190) mm, respectively. When the average length was stratified by sex, male cadavers had a higher mean (31.132 ± 1.936) mm than female cadavers (29.900 ± 2.057) mm. On the other hand, there was no statistically significant (p=0.395) variation in the mean difference in length on the left (30.321 ± 2.166 mm) and right side (30.782 ± 1.973) mm (Table 1).

Table 1: Length of the ACL among the adult Kenyan population

Length of the ACL (mm)		Value	Mean difference	p-value
Overall **Mean** (SD)		30.536 (2.074)		
Overall **Median** (IQR)		30.370 (29.125, 32.190)		
Sex	Male (n=31)	31. 132 (1.936)	**1.232 (0.199, 2.264)**	**0.020**
	Female (n=29)	29.900 (2.057)		
Side	Left (Mean (SD)	30.321 (2.166)	0.461 (-1.537, 0.616)	0.395
	Right (Mean (SD))	30.782 (1.973)		

Mid-substance width of the ACL among the adult Kenyan population

The overall mean width of the ACL was 10.902 (± 1.219) mm, while the median was 10.735 (IQR: 9.830, 12.100) mm. On sex stratification, the mean width sex differences were statistically significant (p<0.001) with male cadavers having 11.774 (± 0.963) mm while females 9.969 (± 0.630) mm. There were no statistically significant differences in the mean width for the right (11.081 ± 1.243 mm) and left (10.745 ± 1.195mm) sides (Table 2).

Table 2: Mid-substance width of the ACL among the adult Kenyan population

Width of the ACL (mm)		Value	Mean difference	p-value
Overall **Mean** (SD)		10.902 (1.219)		
Overall **Median** (IQR)		10.735 (9.830, 12.100)		
Sex	Male (n=31)	11.774 (0.963)	**1.804 (1.380, 2.228)**	**<0.001**
	Female (n=29)	9.969 (0.630)		
Side	Left (Mean (SD))	10.745 (1.195)	0.336 (-0.967, 0.295)	0.291
	Right (Mean (SD))	11.081 (1.243)		

Mid-substance Thickness of the ACL among the adult Kenyan population

The overall mean thickness of the ACL was 4.977 (± 0.542) mm, with the median of 4.990 (IQR: 4.703, 5.388) mm. There were statistically significant (p< 0.001) differences in male cadavers (5.294 ± 0.328) and female cadavers (4.638 ± 0.523) mm. However, there were no statistically significant (p<0.974) differences in the mean thickness on the right (4.979 ±0.703 mm) and left (4.975 ± 0.360mm) sides (Table 3).

Table 3: Mid-substance Thickness of the ACL among the adult Kenyan population

Thickness (mm)		Value	Mean difference	p-value
Overall **Mean** (SD)		4.977 (0.542)		
Overall **Median** (IQR)		4.990 (4.703, 5.388)		
Sex	Male (n=31)	5.294 (0.328)	0.657 (0.43253, 0.881)	**<0.001**
	Female (n=29)	4.638 (0.523)		
Side	Left (Mean (SD))	4.975 (0.360)	0.005 (-0.288, 0.279)	0.974
	Right (Mean (SD))	4.979 (0.703)		

Cross-sectional area of the ACL among the adult Kenyan population

The overall mean of the mid-substance cross-sectional area was 42.95 (± 8.44) mm^2. The median was 40.86 (IQR: 36.57, 50.86) mm^2. Sex differences noted were statistically significant (p<0,001), with a mean of 49.11 (± 6.03) mm^2 for male cadavers and 36.36 (± 4.93) mm^2. There were no statistically significant (p=0.489) differences in the right (43.76 ± 9.60) mm^2 and the left (42.23 ± 7.37) mm^2 sides (Table 4).

Table 4: Cross-sectional area of the ACL among the adult Kenyan population

Cross-sectional Area of the ACL (mm^2)		Value	Mean difference	p-value
Overall **Mean** (SD)		42.95 (8.44)		
Overall **Median** (IQR)		40.86 (36.57, 50.86)		
Sex	Male (n=31)	49.11 (6.03)	**12.75 (9.89, 15.61)**	**<0.001**
	Female (n=28)	36.36 (4.93)		
Side	Left (Mean (SD))	42.23 (7.37)	1.53 (-5.92, 2.86)	0.489
	Right (Mean (SD))	43.76 (9.60)		

DISCUSSION

Length of the ACL among the adult Kenyan population

The current study established that the mean ACL length in the adult Kenyan population was 30.54 ± 2.07 mm**,** with male cadavers averaging 31.13 mm and female cadavers 29.90 mm**.** These findings are consistent with global reports, which generally place ACL length within a 27–38 mm range (19,20)**.** Additionally, these findings align closely with cadaveric data from South Africa, where Van Zyl et al. (2016) reported a mean ACL length of 32.4 mm**.** This similarity suggests that East and Southern African populations may share broadly comparable ACL dimensions, reinforcing the value of continental datasets for surgical planning.

Similarly, a study by Saxena et al. (2016) documented mean ACL lengths of 32.2 mm in South Indian cadavers, a figure within the range of the current study (21) .

Conversely, Shaw et al. (2021) in Bengal reported significantly shorter ACLs, 21.07 mm in males and 18.78 mm in females**,** values that are markedly smaller than those observed in the current and most Western populations. At the other extreme, Kumar et al. (2017) described unusually long ACLs in an Indian cohort (males: 43.5 mm**,** females: 39.4 mm), likely attributable to methodological inclusion of insertional fibers. These discrepancies emphasize how differences in dissection protocol, definition of attachment sites, and anthropometric variation can influence ACL length measurements.

Data from countries in the West similarly demonstrate some divergence but generally cluster higher than the Kenyan mean. Chandrashekar et al. (2005) reported ACL lengths of 29.82 mm in males and 26.85 mm in females in a North American cohort, which are shorter than our Kenyan values, particularly for males. On the other hand, Cone et al. (2019), in a systematic review of 92 studies, synthesized ACL lengths within the 30–38 mm range, a bracket that encompasses our findings. Collectively, these comparisons confirm that the Kenyan population falls within the global range but tends toward the lower end compared to some European and North American cohorts.

Furthermore, the present study demonstrated statistically significant sex-based differences, with male ACLs approximately 1.2 mm longer than female ACLs. This observation aligns with multiple international reports confirming sexual dimorphism in ACL morphology (Chandrashekar et al., 2005; Barnett et al., 2021). Similarly, Shaw et al., (2021), in a cadaveric study conducted in Bengal, India, reported significantly shorter ACL lengths in females compared to males. Male ACLs measured 21.07 ± 0.48 mm, while female ACLs were 18.78 ± 0.27 mm, with a highly significant sex difference ($p < 0.001$). Kumar et al. (2017) reported remarkably longer ACL lengths in males than females among Indian population from Mangalarai (male, 43.5 ± 4.1 mm and female, 39.4 ± 3.8 mm) ($p<0.001$).

From a biomechanical standpoint, shorter ACLs in females may correspond to reduced ligament volume and cross-sectional area, potentially lowering resistance to tensile and shear forces (Chandrashekar et al., 2006). This anatomical disadvantage, coupled with neuromuscular and hormonal factors, has been proposed to contribute to the higher incidence of ACL injuries in females (Hewett et al., 2006). In the Kenyan context, where increased female participation in competitive athletics and field sports is evident, this anatomical susceptibility underscores the need for preventive training programs tailored to female athletes, as well as for sex-specific considerations in surgical reconstruction.

Accurate knowledge of native ACL length is critical for graft sizing and tunnel preparation during reconstruction. In the Kenyan cohort, mean ACL length of about 30.5 mm indicates that surgeons should anticipate graft lengths capable of reproducing this intra-articular distance while also accommodating fixation length within tunnels. Autografts such as hamstring tendons are often harvested to lengths exceeding 20mm, allowing flexibility in quadrupling or tripling the graft. However, precise tunnel positioning remains dependent on reliable reference values for native ACL length. An underestimation could lead to graft-tunnel mismatch, resulting in either excessive graft laxity or over tensioning, both of which compromise stability and increase revision risk (Magnussen et al., 2012). Mid-substance width of the ACL among the adult Kenyan population

The present study found the mean mid-substance width of the ACL in the Kenyan cadaveric cohort to be 10.90 ± 1.22 mm**,** with a statistically significant sex difference: males averaged 11.77 mm**,** while females measured 9.97 mm ($p < 0.001$). There was no significant laterality difference between the right and left sides. These values fall within the 9–12 mm range typically reported in global literature, but their distribution and sex-specific variation carry important implications for ACL reconstruction in Kenya.

These measurements from Kenya align closely with those reported internationally, though they occupy a somewhat narrower band than those in Western cadaveric series. Śmigielski et al. (2015), in their description of the ACL's ribbon-like morphology, reported widths ranging from 11.43–16.18 mm in American cadavers. This suggests that Kenyan ACLs, at about 10.9 mm, are on the smaller side of the global spectrum**,** and considerably narrower than the "ribbon" dimensions described in North American cohorts. Similarly, the findings closely align with Stijak et al. (2009) in Serbia where the anterior cruciate ligament (ACL) had a mean width of 12.20 ± 1.50 mm. By contrast, Saxena et al. (2016) documented an average mid-substance width of 9.38 mm in a South Indian population, values slightly lower than in the current study. Similarly, Van Zyl et al. (2016) reported a mean ACL width of 8.23 mm in South African cadavers, indicating that ACLs in Sub-Saharan African populations may generally be smaller than those observed in Western cohorts. Our findings, therefore, reinforce the notion of regional variation, with Kenyan ACL width sitting between Indian and South African averages, but below North American figures.

Further, the current study revealed a robust and statistically significant sex difference in ACL width, males averaged nearly 1.8 mm wider ACLs than females. This dimorphism is consistent with global reports. Chandrashekar et al. (2005) and Barnett et al. (2021) confirmed that female ACLs are consistently narrower, even after adjusting for body size and notch width. Narrower ACLs in females are not merely an anatomical curiosity; they carry

significant clinical implications. First, width correlates with ligament volume and cross-sectional area, both of which predict tensile strength (Chandrashekar et al., 2006). Narrower ACLs therefore likely translate into structurally weaker ligaments, increasing susceptibility to rupture during high-demand tasks such as pivoting or landing. Second, graft selection must consider this sex difference, as narrower female ACL footprints may be more easily compromised by oversized tunnels or implants. The Kenyan findings are particularly relevant given the growing participation of Kenyan women in athletics, football, and other pivoting sports. Female athletes already demonstrate higher ACL injury risk globally (Hewett et al., 2006). Narrower ACLs in Kenyan women may further exacerbate this vulnerability, underscoring the need for preventive neuromuscular training and sex-specific rehabilitation strategies locally.

Additionally, sex stratification findings in the current study are also consistent with Rizzo et al. cadaveric analysis of 26 knees (15 male and 11 female) in North Carolina-USA which demonstrated a statistically significant clear difference in mid-substance ACL width between sexes. The mean ACL width in males was 10.59 ± 1.30 mm**,** whereas in females it was significantly smaller at 8.09 ± 1.12 mm ($p < 0.001$). Further consistency is noted with Wang et al. (2019) morphometric study in China which reported mean ACL width was significantly greater in men **(**8.5 ± 2.3 mm**)** than in women **(**7.0 ± 1.2 mm**)** ($p = 0.02$).

ACL width is a crucial parameter for tunnel sizing and graft-tunnel matching. In reconstruction, surgeons aim to reproduce the native ligament footprint as closely as possible. A width of about11 mm in Kenyan males and 10 mm in females suggests that tunnels drilled to 9–10 mm may provide the most anatomical reconstruction in this population. By contrast, reliance on Western norms (often assuming widths of 12–14 mm) risks excessive tunnel enlargement, which can destabilize fixation, compromise bone stock, and predispose to graft laxity. Conversely, undersized tunnels relative to graft diameter increase the risk of impingement, abnormal graft bending, or early failure.

These findings also inform graft selection. Quadrupled hamstring grafts typically measure 8–10 mm in diameter, which approximates the mean ACL width in Kenyans. This congruence suggests hamstring autografts may be particularly suitable for Kenyan patients, provided preoperative anthropometric predictors confirm adequate graft size. For patients with narrower ACLs (particularly females averaging <10 mm), smaller grafts or alternative sources (e.g., patellar tendon or quadriceps tendon) may be preferable to avoid graft-tunnel mismatch.

Mid-substance Thickness of the ACL among the adult Kenyan population

The present study found the mean mid-substance thickness of the ACL in the Kenyan

cadaveric population to be 4.98 ± 0.54 mm**,** with males averaging 5.29 mm and females 4.64 mm ($p < 0.001$). No significant laterality difference was observed between the right (4.98 mm) and left (4.98 mm) sides. These findings situate the Kenyan ACL thickness near the upper limit of the 3.4–4.5 mm range reported in many global cadaveric studies, with notable sex differences that parallel international observations.

Global literature describes ACL thickness as relatively modest compared to its width, reflecting its ribbon-like morphology. Triantafyllidi et al. (2013), in a Californian cadaveric study, reported mid-substance thickness of 3.9–4.5 mm**,** with an average close to 4 mm. On the other hand, Śmigielski et al. (2015), in a Portland-Oregon series, described even lower mean values (about 3.4 mm**).** Similarly, Siebold et al. (2014) confirmed a flat, ribbon-shaped ACL with thickness averaging 3.9 mm in a Heidelberg-Germany study**.** By contrast, our Kenyan cohort demonstrated thicker ACLs**,** suggesting possible population-specific variation.

Our study found highly significant sex-based differences: Kenyan males averaged 5.29 mm**,** while females measured 4.64 mm**.** This 0.65 mm difference is proportionally large given the small absolute size of the ligament. Comparable dimorphism has been described elsewhere. For example, Chandrashekar et al. (2005) reported smaller ACL volumes and thicknesses in females, contributing to structural vulnerability. Barnett et al. (2021) confirmed that these sex differences persist even after adjusting for knee size and body dimensions, suggesting intrinsic biological determinants. The findings further concurs with Hashemi et al. (2008) study in Texas-USA which reported that male ACLs were significantly thicker than female ACLs. Specifically, the mean mid-substance thickness was 4.7 ± 0.5 mm in males compared to 3.8 ± 0.4 mm in females, representing nearly a 20% difference ($p<0.001$)**.** This also in agreement with Wang et al. (2019) in China, where mean thickness values were 4.5 ± 0.6 mm in men and 3.9 ± 0.5 mm in women ($p < 0.05$).

Thicker ACLs in men may confer biomechanical advantages. Tensile strength correlates with cross-sectional geometry, and ligaments with greater thickness can distribute stress more effectively under loading (Chandrashekar et al., 2006). Conversely, thinner ACLs in women are more prone to strain, micro-failure, and eventual rupture during high-demand tasks such as landing or cutting maneuvers. In Kenya, where female participation in soccer, athletics, and volleyball is high, these anatomical disadvantages may partly explain the higher injury burden observed in women.

Mid-substance thickness directly influences graft-tunnel matching**.** Quadrupled hamstring autografts typically measure 7–10 mm in diameter, far thicker than the native ACL thickness of about 5 mm in Kenyan knees. This discrepancy highlights one of the persistent challenges of ACL reconstruction: balancing graft diameter with native anatomy. Oversized grafts

relative to the native thickness can alter intra-articular kinematics, producing abnormal tensioning and potentially accelerating degenerative changes (Siebold, 2011). Conversely, grafts thinner than 8 mm are associated with higher revision risk (Snaebjörnsson et al., 2019). In Kenya, where access to allografts is limited, autografts remain the standard. Surgeons must therefore reconcile the difference between native ACL thickness (about 5 mm) and common graft diameters (8–10 mm). Our population-specific data provide crucial reference points: Kenyan surgeons can anticipate that their reconstructions will nearly always involve grafts thicker than the native ligament, but careful tunnel positioning and tensioning can minimize adverse kinematic effects.

Cross-sectional area of the ACL among the adult Kenyan population

The current study found the mean mid-substance CSA of the ACL in Kenyan cadavers to be 42.95 ± 8.44 mm², with males averaging 49.11 mm² and females 36.36 mm² ($p < 0.001$). There was no significant laterality difference between right and left knees. These values fall within the 30–53 mm² range reported in global literature (Cone et al., 2022), but the sex disparity in our cohort is striking and carries major clinical implications for both injury risk and reconstruction outcomes.

Our Kenyan CSA values are broadly consistent with reports from international cadaveric studies, but the distribution highlights meaningful population differences. Siebold et al. (2014) reported a mean CSA of 38.7 mm² in Germany, slightly lower than our Kenyan mean. Triantafyllidi et al. (2013) described a relatively flat ACL with CSA averaging 32–36 mm², again smaller than our population's values. By contrast, Yahagi et al. (2023) in Japan reported higher mean CSA of 49.0 mm², aligning more closely with Kenyan male values. Similarly, in another study in Japan by Iriuchishima et al. (2014) described CSA averaging 46.9 mm², which is also within the upper end of the current study range.

European and American studies also show lower values. Pujol et al. (2013) reported mean CSA of 29.2 mm² in France, significantly smaller than the Kenyan mean. Fujimaki et al. (2016), using laser scanning, found CSA varied dynamically with flexion but averaged 39.9 mm² at extension. Collectively, these comparisons indicate that Kenyan ACLs are larger in cross-sectional area than those in European populations, comparable to or slightly smaller than Japanese cohorts, but larger than many American cadaveric reports.

The current findings also showed a pronounced sex disparity: male ACLs averaged 49.1 mm², while female ACLs measured only 36.4 mm². This difference (about 13 mm²) represents nearly a 30% reduction in CSA in females. Such dimorphism is widely reported globally. Chandrashekar et al. (2005) demonstrated that female ACLs are significantly smaller in CSA and volume, even after adjusting for body size (of 47.1 ± 4.5 mm² in males

and 36.1 ± 3.2 mm² in females**,** p<0.001). Barnett et al. (2021) confirmed that these differences persist across populations, with smaller CSA directly translating into lower tensile capacity. There is also in concurrence with a cadaveric study by Harner et al. (1999) in Penyslyvania-USA which reported a mean mid substance CSA of 44.0 ± 6.0 mm² in men and 35.0 ± 5.0 mm² in women, representing a 20% sex difference ($p < 0.05$).

Moreover, the current study agrees with MRI-based studies by Hashemi et al. (2008), in Texas-USA, which reported statistically significant average CSA values of 44.2 ± 4.9 mm² in males and 35.8 ± 3.7 mm² in females, nearly identical to cadaveric datasets. Wang et al. (2019) study also showed significantly larger CSA in males than females **(**42.7 ± 5.2 mm² vs 34.6 ± 4.8 mm²; $p < 0.01$**).**

Biomechanically, CSA is a key predictor of ligament strength. Smaller CSA increases strain for a given load, predisposing the ligament to failure under physiologic stresses (22)Thus, Kenyan females with CSA averaging about 36 mm² are structurally more vulnerable to rupture compared to Kenyan males. This observation parallels global epidemiology showing women face higher ACL injury risk (23). However, our data confirm that anatomical size differences contribute to this risk in the Kenyan context.

Cross-sectional area is critical for graft selection and tunnel sizing. Ideally, the graft CSA should approximate the native ligament to reproduce normal biomechanics. In Kenya, with mean CSA about 43 mm², quadrupled hamstring autografts (which typically measure 40–50 mm²) are generally well matched. However, sex differences complicate this picture. In females with CSA about 36 mm², hamstring grafts may actually oversize the native ACL, potentially altering joint kinematics and producing abnormal tensioning. In males, grafts may be appropriately sized or even slightly undersized if hamstring tendons are small. These findings highlight the importance of preoperative graft prediction models**.** Studies have consistently shown that graft diameters <8 mm carry higher failure risk (5). Kenyan surgeons must therefore anticipate when hamstring autografts may be inadequate particularly in small-statured females and consider alternatives such as quadriceps or patellar tendon grafts. CSA data provide a reliable benchmark for anticipating these challenges.

CONCLUSION AND RECOMMENDATIONS

The morphometric values of this research are consistent with the world ranges reported in literature (27-38 mm length; 30-53 mm2 CSA; 854-1858 mm3 volume). Notably, Kenyan ACLs are more likely to lie on the low end of the Western range and are more like South African cohorts but differ significantly some populations in Asia that report extremes in size. This sets Kenyan ACL morphometry as distinct but internationally comparable and offers a long-desired regional reference. The clinical implication of the frequent finding that male

ACLs are longer, wider, thicker, and larger in CSA and volume as compared to those of females is direct. Since female ACLs are smaller, they are weaker in structure, and therefore, more likely to tear when loaded. The observed mean ACL width of approximately 11 mm in males and 10 mm in females should inform the selection of the graft and the size of the tunnels first. This means that the 9-10 mm diameter tunnels would yield the best anatomic reconstruction. Conversely, when the Western reference values of 12-14 mm are used, there is a risk of over-sizing; in this case, surgery might entail an over-resection of the bone, fixation, and graft impaction. Second is the issue of graft-native mismatch. Hamstring autografts are 8-10 mm thick, much larger than the native ACL, which is about 5 mm on average.

Several recommendations can be drawn out of the results of this research. First, the morphometric data that is utilized in planning of ACL reconstructions, particularly during grafts selection and tunnel preparation, has to be Kenyan-specific. This will ensure that surgical choices are made on local anatomical standards instead of being extrapolated from the Western population. Second, anthropometric predictors, including patient height, thigh circumference, and femoral epicondylar width, should be included in preoperative measurements and may offer valuable estimates of graft adequacy. Third, both preventive and surgical strategies should be sex specific, as women are at a higher risk of ACL injuries because they have smaller ligament size. Lastly, surgeons are instructed to expect graft-native mismatch and understand how to differentiate between the mean native thickness of ACL of 5mm and hamstring autograft diameter of 8-10mm to achieve the best patient outcomes through tweezing of the tunnels and graft tensioning. Future studies should reference this study's findings as they improve on ACL data availability in Kenya.

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