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Original Research Article

Morphometric Analysis of the Human Calcaneum: A Comparative Study of Dry Bone Specimens and Computed Tomography Images

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Abstract:

Background: The calcaneum is the largest and one of the earliest ossifying tarsal bones, forming the posterior pillar of the medial and lateral longitudinal arches of the foot. Its superior surface bears talar articular facets whose number and configuration, together with the anteroposterior length, transverse width and interfacet distances of the bone, influence subtalar joint stability and determine the feasibility of osteotomy and reconstructive procedures. Population-specific morphometric data are therefore essential for orthopaedic and forensic practice.

Objectives: To assess the morphometry of the calcaneum, including its anteroposterior length, transverse width, interfacet distances and the pattern of talar articular facets, in dry bone specimens and three-dimensional computed tomography (CT) reconstructions.

Materials and Methods: This descriptive cross-sectional study was conducted in the Department of Anatomy in association with the Department of Radiology of a tertiary care teaching institute over three years. Eighty adult dry calcaneum specimens (40 left, 40 right) and fifty CT images (25 male, 25 female) were examined. Calcaneal type was classified according to Bunning and Barnett as Type A (three separate facets), Type B (two facets, subtypes B1-B4) and Type C (single fused facet). Anteroposterior length, transverse width and interfacet distances were measured using a sliding Vernier calliper for dry bones and volume-rendering CT software for radiological images. Data were analysed using SPSS version 21; quantitative variables were expressed as mean ± standard deviation and compared using the independent t-test.

Results: Type B calcaneum was the most common pattern, seen in 76.25% of dry bones and 68% of CT images, followed by Type A (22.5% and 26% respectively) and Type C (1.25% and 6%). The mean anteroposterior length and transverse width of dry bones were 7.313 ± 0.541 cm and 3.994 ± 0.394 cm, while CT images showed slightly higher values of 7.720 ± 0.700 cm and 4.379 ± 0.824 cm ($p < 0.001$ for both). Male calcanei on CT had significantly greater anteroposterior length and transverse width than female calcanei ($p = 0.002$ and $p = 0.003$). No significant right-left difference was found for any morphometric parameter in dry bones.

Conclusion: Type B calcaneum with two talar articular facets is the predominant morphological pattern in this South Indian population, corroborating most Indian series and contrasting with several Western reports where the three-facet Type A predominates. The demonstrable sexual dimorphism in CT-derived dimensions supports the use of calcaneal morphometry as an adjunct in sex estimation, while knowledge of facet configuration and interfacet distances is of direct relevance to calcaneal osteotomy, subtalar arthrodesis and fracture fixation.

Keywords: Calcaneum; Morphometry; Talar articular facet; Subtalar joint; Computed tomography; Bunning and Barnett classification.

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Introduction

The tarsus comprises a proximal row formed by the talus and calcaneum and a distal row consisting of the navicular, the three cuneiforms and the cuboid [1]. The calcaneum, situated below and behind the talus, is the largest tarsal bone and is unique among foot bones in being the first to ossify and the only tarsal bone with two ossification centres [2]. It is a six-surfaced irregular cuboidal bone whose superior surface articulates with the talus through anterior, middle and posterior talar facets, while its anterior surface articulates with the cuboid. Together with the talus it forms the subtalar (talocalcaneal) joint, a modified multiaxial joint principally responsible for inversion and eversion of the foot. The morphological pattern of the talar articular facets is a major determinant of subtalar joint stability. The posterior facet shows comparatively little variation, whereas the anterior

and middle facets vary considerably in shape, fusion and degree of separation, giving rise to well-recognised racial and individual differences [3]. Bunning and Barnett classified the calcaneum into Type A, with three separate facets; Type B, with the anterior and middle facets fused into a single facet (subdivided into B1-B4 depending on the presence of a notch or an absent anterior or middle facet); and Type C, with all three facets fused into one irregular area. This classification, along with measurement of the anteroposterior length, transverse width and interfacet distances, has practical significance for orthopaedic surgeons undertaking calcaneal osteotomy, subtalar arthrodesis, triple arthrodesis and internal or external fixation of intra-articular fractures, since the size, shape and facet configuration of the bone dictate the feasibility and safety of these procedures [5].

Despite an extensive body of literature describing calcanei from European, African and various Indian populations, considerable inter-population variability has been reported, attributable to genetic, racial, occupational and biomechanical factors such as squatting posture and footwear use.

Comparative morphometric data using both dry bone specimens and three-dimensional CT reconstructions from the same population remain relatively limited. This study was therefore undertaken with the following objective: to assess the morphometry of the calcaneum bone and the variations of the talar articulating facets of the calcaneum in dry bone specimens and CT images of a South Indian population.

Materials and Methods

Study design and setting: This was a descriptive cross-sectional study conducted in the Department of Anatomy, in association with the Department of Radiology, of a tertiary care teaching institute, using dry calcaneum specimens from the bone bank of the Department of Anatomy and CT images from the Department of Radiology.

Ethical Approval: The study was approved by the Institutional Research Committee (IRC number IRC202020, dated 27 October 2020) and the Institutional Ethics Committee (IEC number 270/IEC-30/PP/2020, dated 12 December 2020) prior to commencement.

Study period and sample size: The study was carried out over three years. Eighty dry calcaneum specimens (40 left-sided and 40 right-sided) of unknown age and sex were examined, along with 50 CT images comprising 25 male and 25 female subjects.

Inclusion and exclusion criteria: All adult dry calcaneum bones, irrespective of side, were included. Bones with obscuring pathology or physical damage that precluded accurate measurement were excluded.

Measurement tools and technique: Dry bone measurements were made with a sliding Vernier calliper, and CT measurements were made using volume-rendering three-dimensional reconstruction software. The calcaneum was classified into Type A, Type B (subtypes B1-B4) and Type C according to the classification of Bunning and Barnett, based on the pattern of the talar articular facets on the superior surface. The anteroposterior length was measured as the distance from the most posterior point of the calcaneal tuberosity to the most anterior point of the cuboidal articular surface.

The transverse width was measured as the distance between the most medial and most lateral points of the bone. The interfacet distance was measured between the anterior and middle facets, the middle and posterior facets, and the anterior and posterior facets, according to the facets present in each type.

Statistical analysis: Data were entered in Microsoft Excel and analysed using SPSS software version 21. Normality of the data was assessed with the Kolmogorov-Smirnov test; all variables followed a normal distribution and were expressed as mean ± standard deviation. Categorical variables were expressed as frequencies and percentages. The independent samples t-test was used to compare quantitative variables between sides (dry bones) and between sexes (CT images), and to compare dry bone and CT-derived values; a p-value < 0.05 was considered statistically significant.

Results

Of the 80 dry calcaneum specimens, Type B was the most frequent pattern, seen in 61 bones (76.25%), followed by Type A in 18 bones (22.5%) and Type C in a single bone (1.25%). Among the Type B specimens, subtype B2 (anterior and middle facets fused with an intervening notch) was the commonest (47.54%), followed by B1 (completely fused anterior and middle facets, 40.98%) and B3 (absent anterior facet, 11.47%); no B4 pattern was observed in dry bones. In the CT sample, Type B was again predominant (68%), followed by Type A (26%) and Type C (6%), with subtype B1 predominating (47.05%) over B2 (38.23%).

Table 1: Incidence of type of calcaneum in dry bone (by side) and CT (by gender) samples

Type of calcaneum	Dry bone - Left (n=40)	Dry bone - Right (n=40)	CT - Male (n=25)	CT - Female (n=25)
Type A	11 (27.5%)	7 (17.5%)	9 (36%)	4 (16%)
Type B	28 (70%)	33 (82.5%)	15 (60%)	19 (76%)
Type C	1 (2.5%)	0 (0%)	1 (4%)	2 (8%)

The mean anteroposterior length and transverse width of the dry calcaneum were 7.313 ± 0.541 cm and 3.994 ± 0.394 cm respectively, with no statistically significant difference between the right and left sides (p = 0.533 and p = 0.398). On CT imaging, the mean anteroposterior length was 8.008 ± 0.816 cm in males and 7.432 ± 0.402 cm in females, and the mean transverse width was 4.710 ± 0.898 cm in males and 4.048 ± 0.592 cm in females.

Both differences were statistically significant (p = 0.002 and p = 0.003 respectively), indicating clear sexual dimorphism in calcaneal dimensions.

Table 2: Mean and standard deviation of anteroposterior length and transverse width

Group	Anteroposterior length (cm)	Transverse width (cm)	p value
Dry bone - Left (n=40)	7.275 ± 0.434	3.957 ± 0.324	0.533 / 0.398
Dry bone - Right (n=40)	7.351 ± 0.633	4.032 ± 0.455	(vs Left)
CT - Male (n=25)	8.008 ± 0.816	4.710 ± 0.898	0.002 / 0.003
CT - Female (n=25)	7.432 ± 0.402	4.048 ± 0.592	(vs Male)

Interfacet distances were measured according to the facets present in each type.

In dry bones, the mean anterior-posterior interfacet distance was 12.912 ± 2.109 mm on the left and 13.129 ± 2.881 mm on the right (p = 0.717); the mean middle-posterior interfacet distance was 5.807 ± 1.513 mm on the left and 5.928 ± 1.613 mm on the right (p = 0.732); and the mean anterior-middle interfacet distance, measurable only in Type A calcanei, was 3.686 ± 1.763 mm on the left and 5.061 ± 2.061 mm on the right (p = 0.150).

Based on the anterior-middle interfacet distance, Type A calcanei were further sub-classified as narrow (<2 mm, 5.55%), moderate (2-5 mm, 66.66%) and wide (>5 mm, 27.77%) intervals, with the moderate interval predominating.

Table 3: Mean and standard deviation of interfacet distances (dry bone samples, by side)

Interfacet distance	Left side (mm)	Right side (mm)	p value
Anterior - Posterior	12.912 ± 2.109	13.129 ± 2.881	0.717
Middle - Posterior	5.807 ± 1.513	5.928 ± 1.613	0.732
Anterior - Middle	3.686 ± 1.763	5.061 ± 2.061	0.150

On CT imaging, the mean anterior-posterior interfacet distance was 10.588 ± 4.069 mm in males and 10.442 ± 3.219 mm in females (p = 0.896); the mean middle-posterior interfacet distance was 5.940 ± 2.082 mm in males and 5.824 ± 1.719 mm in females (p = 0.838); and the mean anterior-middle interfacet distance was 5.607 ± 2.040 mm in males and 5.515 ± 0.578 mm in females (p = 0.932), with none of these differences reaching statistical significance.

Table 4: Mean and standard deviation of interfacet distances (CT images, by gender)

Interfacet distance	Male (mm)	Female (mm)	p value
Anterior - Posterior	10.588 ± 4.069	10.442 ± 3.219	0.896
Middle - Posterior	5.940 ± 2.082	5.824 ± 1.719	0.838
Anterior - Middle	5.607 ± 2.040	5.515 ± 0.578	0.932

When the dry bone and CT-derived measurements were compared directly, CT images showed significantly greater mean anteroposterior length (7.720 ± 0.700 cm vs 7.313 ± 0.541 cm, p = 0.0002) and transverse width (4.379 ± 0.824 cm vs 3.994 ± 0.394 cm, p = 0.0004) than dry bones. The mean anterior-posterior interfacet distance was significantly greater in dry bones than on CT (13.024 ± 2.520 mm vs 10.513 ± 3.615 mm, p = 0.000007), while the anterior-middle interfacet distance was significantly greater on CT (5.579 ± 1.691 mm vs 4.221 ± 1.950 mm, p = 0.00008); the middle-posterior interfacet distance did not differ significantly between the two modalities (p = 0.917).

Table 5: Comparison of mean morphometric values between dry bone and CT samples

Parameter	Dry bone	CT images	p value
Anteroposterior length (cm)	7.313 ± 0.541	7.720 ± 0.700	0.0002
Transverse width (cm)	3.994 ± 0.394	4.379 ± 0.824	0.0004
Anterior-posterior interfacet (mm)	13.024 ± 2.520	10.513 ± 3.615	0.000007
Middle-posterior interfacet (mm)	5.869 ± 1.556	5.901 ± 1.911	0.917
Anterior-middle interfacet (mm)	4.221 ± 1.950	5.579 ± 1.691	0.00008

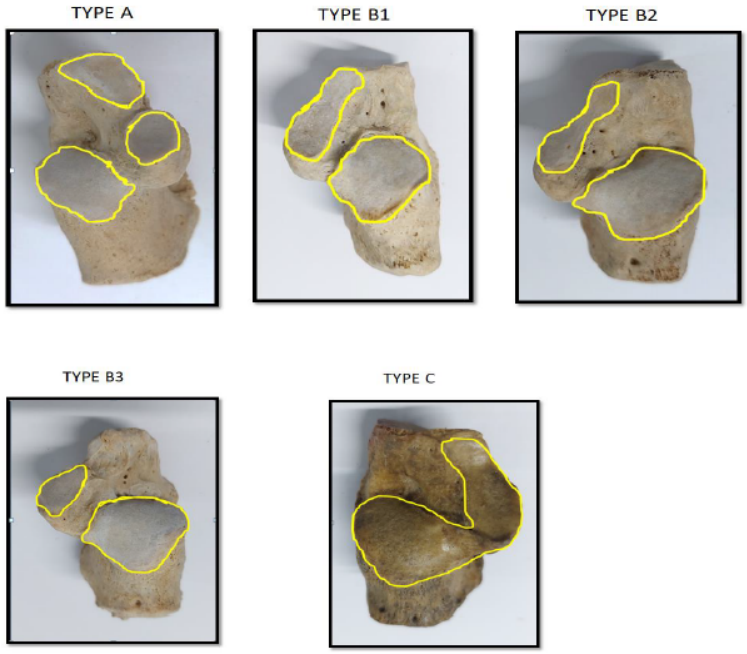

Figure 1: Types of calcaneum

Discussion

The predominance of Type B calcaneum (two talar facets) in the present study (76.25% in dry bones, 68% on CT) is consistent with most Indian studies. Muthukumaravel et al. reported a similar preponderance of the fused anterior-middle facet pattern in Tamil Nadu and Puducherry [21], and comparable findings have been reported by Anjaneyulu et al. in North-East India [5], by Bhanusudha et al. in the Andhra region, by Anbumani et al. in Tamil Nadu, and by Taqdees et al. in North Karnataka. In contrast, Bunning and Barnett's original European series and the later Belgian series of Barbaix et al. found Type A (three separate facets) to be more common, with an approximate ratio of Type A to Type B of 2:1 - almost the reverse of the pattern typically seen in Indian populations. This divergence has been attributed to genetic, racial and biomechanical factors, including habitual squatting posture and footwear use, and underscores the need for population-specific data before Western surgical templates for calcaneal osteotomy are applied to Indian patients.

The mean anteroposterior length and transverse width obtained in this study (7.313 ± 0.541 cm and 3.994 ± 0.394 cm in dry bones) closely approximate the values reported by Sarvaiya et al. in Gujarat, while Chavan et al. reported somewhat larger dimensions. No significant side-to-side difference was found in dry bone dimensions, in agreement with Vijaya Laxmi et al., whereas the CT-derived data showed statistically significant sexual dimorphism, with males having greater anteroposterior length and transverse width than females - a finding that parallels the results of Bidmos and Asala in a South African population and supports the potential utility of calcaneal morphometry in sex estimation from skeletal or radiological remains.

Interfacet distances are of direct surgical relevance because the osteotomy line used in the correction of pes planus and in bone-graft interposition typically passes through the interval between the anterior and middle facets; accurate knowledge of this distance is required to position retractors correctly and to avoid iatrogenic articular damage.

The anterior-middle interfacet distance observed here (predominantly in the 2-5 mm range) is broadly comparable to the findings of Muthukumaravel et al. and differs from series such as that of Minimol et al., where narrower intervals predominated, again reflecting population variation. The modest but statistically significant

differences between dry bone and CT measurements likely reflect a combination of soft-tissue and cartilage thickness accounted for on CT, measurement-plane differences inherent to volume-rendered reconstruction, and possible differences between the reference population contributing dry bone specimens and the living cohort undergoing CT imaging.

Conclusion

This study of eighty dry human calcanei and fifty three-dimensional CT reconstructions demonstrates that Type B calcaneum, with two talar articular facets, is the predominant morphological pattern in this South Indian population, in keeping with most other Indian series but in contrast to several Western reports. Statistically significant sexual dimorphism was evident in CT-derived anteroposterior length and transverse width, supporting a role for calcaneal morphometry in sex determination. The morphometric and interfacet data generated by this study add to the population-specific anatomical knowledge base required for the safe planning of calcaneal osteotomy, subtalar arthrodesis and internal fixation of intra-articular calcaneal fractures, and reinforce the need to modify Western surgical templates to the anatomical realities of the Indian foot.

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