Research Article

Morphometry of the Calcaneus and Its Application in Designing Orthopedic Heel Implants

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Introduction: This study aimed to analyze the morphometric characteristics of the calcaneum by determining the averages of the maximum length, height, and width in the South Indian population, and to interpret the findings in relation to heel implants, optimal sizing of the implant length, and design compatibility.

Methodology: The study was conducted at the Institute of Anatomy, Madras Medical College, Chennai, India, over a period of six months from November 2025 to April 2026. A total of 50 calcanei were examined in this study, excluding damaged bones with severe deformities and missing parts. Maximum length was recorded from the posterior calcaneal tuberosity to the anterior calcaneocuboid articular surface, maximum width from sustentaculum tali to fibular trochlea, and maximum height from the inferior calcaneal tuberosity to the superior posterior talar facet. Measurements were recorded using a high-precision digital vernier caliper with a least count of 0.01mm, and uploaded into the Jamovi software for statistical analysis. For each of the parameters, the mean, median, minimum, maximum, and range were noted.

Results: On measurement, the mean length of the calcaneum was 70.4 ± 6.01 mm, the mean width was 43.4 ± 4.4 mm, and the mean height was 51.6 ± 4.54 mm.

The length of the calcaneus ranged from 56.8 mm to 81.6 mm, giving a range of 24.8 mm. For width, the minimum value was found to be 34.9 mm, and the maximum 55.6 mm, giving a range of 20.7 mm. The height ranged from 40.5 mm to 59.5 mm, with a range of 19 mm.

Conclusion: This study provides useful insights into the morphometry of the calcaneus in the Indian population. In this study of 50 adult South Indian calcanei, the mean calcaneal length, width, and height were 70.4 ± 6.01 mm, 43.4 ± 4.4 mm, and 51.6 ± 4.54 mm, respectively. Substantial morphological variation was observed in each of the measured parameters, with ranges of 24.8 mm in length, 20.7 mm in width, and 19 mm in height, highlighting the need for customized implants for a better fit and reduced complications.

The findings corroborate with existing research while contributing valuable data specific to the Indian population. The present study may help by expanding our anatomical understanding of the calcaneus which can aid orthopedic surgeons in the effective management of calcaneal injuries. It may also contribute to the development of optimal implant designs and sizing, improving clinical outcomes, and reducing implant-related complications.

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Introduction

The calcaneus, also called the heel bone, forms the heel of the foot and transfers body weight to the ground. The Calcaneus is situated below the talus and extends behind it. It is directed forward and laterally with an upward inclination. It acts as a shock absorber and is important for stable walking and balance. Fracture of the calcaneus is considered one of the most complicated orthopedic injuries, often leading to significant disruption of normal foot biomechanics [1]. Treatment of calcaneal fractures remains a significant challenge owing to the bone's complex anatomy, morphology, its anatomical location, and the surrounding soft tissue. Various implants have been successfully used in the treatment of calcaneal fractures, including Kirschner wires (K-wires), absorbable

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screws (AS), cannulated screws (CS), and plate-screw system (PSS) [2]. One of the most common complaints after treatment of a calcaneus injury is pain due to mechanical issues related to the implant [3].

This study aims to morphometrically measure the average maximum length, width, and height of the calcaneum in a sample of dry human adult calcanei, of the South Indian population. The maximum length of the calcaneus, from the most posterior point of the calcaneal tuberosity to the most anterior point of the calcaneocuboid articular surface, determines the implant length. It plays a vital role in heel-striking biomechanics. It serves as a crucial lever arm for the plantarflexor muscles of the foot [4]. The maximum height of the calcaneus, measured from the inferior-most point of the calcaneal tuberosity to the superior-most point of the posterior talar facet, determines implant thickness, it restores the height of the hindfoot. The maximum calcaneal width is the maximum mediolateral dimension of the calcaneus, from sustentaculum tali to fibular trochlea, it determines the breadth of the implant. Proper dimensions are vital to prevent implant overhang and peroneal tendon irritation [5].

A thin layer of soft tissue with delicate skin envelopes the lateral aspect of calcaneus that is more prone to wound healing problems. The sole of the foot also has a unique plantar skin that is important for weight-bearing, and this skin cannot be properly replaced once it is badly damaged or torn off [6]. Three-dimensional personalized implants could potentially help resolve these mechanical issues [7].

Methods and Materials

This was a descriptive cross-sectional study conducted at the Institute of Anatomy, Madras Medical College, Chennai, India, over a period of six months from November 2025 to April 2026 (Table 1). Ethical approval was obtained from the Institutional Ethics Committee, Madras Medical College, Chennai, India prior to the commencement of the study (IEC Approval Number: 84032026). A total of 50 well-preserved human adult calcanei were selected for analysis. The bones were carefully examined to ensure structural integrity and damaged bones with severe deformities and missing parts were excluded from the study. The bones were thoroughly cleaned and dried to remove any soft tissue remnants or debris that could compromise measurement accuracy.

The morphometric variables analyzed in this study included maximum length, maximum height, and maximum width of the calcaneus. All variables were treated as continuous quantitative measurements and recorded in millimeters using an Adoric digital vernier caliper with high precision and accuracy of 0.01 mm. Measurements were taken twice and averaged to minimize observer bias. The parameters were measured and defined as follows: maximum length was recorded from the most posterior point of the calcaneal tuberosity to the most anterior point of the calcaneocuboid articular surface, maximum width was measured from the sustentaculum tali to the fibular trochlea, and maximum height was assessed from the inferior-most point of the calcaneal tuberosity to the superior-most point of the posterior talar facet (Figures 1 and 2; Tables 2-4).

The measurements were initially recorded manually to ensure simplicity and accuracy and then reviewed and entered into Jamovi software. Descriptive statistics including mean, median, minimum, maximum, range, and 95% confidence intervals were calculated for each of the morphometric parameters. The data obtained was compared with findings from previously published studies to identify similarities and variations (Table 5).

Results

On calculation, the average length of the calcaneus was found to be 70.4 ± 6.01 mm (95% Confidence Interval: 68.7–72.1 mm), the average value of width was measured as 43.4 ± 4.4 mm (95% CI: 42.2–44.6 mm), and the average height was calculated as 51.6 ± 4.54 mm (95% CI: 50.3–52.9 mm). In the sample of 50 calcanei, the maximum, minimum, and range were also determined for each parameter. The length of calcaneum varied from 56.8 mm to 81.6 mm, yielding a range of 24.8 mm. Width varied from a minimum of 34.9 mm to a maximum of 55.6 mm, with a range of 20.7 mm. On measuring the height, the range was found to be 19 mm with a minimum value of 40.5 mm and a maximum of 59.5 mm.

Discussion

The calcaneus, the largest of the tarsal bones, forms the structural foundation of the heel and plays a crucial role in weight transmission during standing and locomotion [1]. Although relatively uncommon, calcaneal fractures are among the most complex orthopedic injuries. Calcaneal fractures may also lead to increased economic burden as they commonly result from axial impact and are frequently seen in young male industrial workers [8,9]. Delicate, thin skin on the lateral wall of calcaneus is especially prone to wound healing issues [6].

Table 1: Descriptive statics for length, width, and height

Parameters	*Length (in mm)*	*Width (in mm)*	*Height (in mm)*
Mean	70.4	43.4	51.6
Median	71.3	43.6	52.8
Standard deviation	6.01	4.4	4.54
Minimum	56.8	34.9	40.5
Maximum	81.6	55.6	59.5
Range	24.8	20.7	19
95% Confidence Interval	68.7–72.1	42.2–44.6	50.3–52.9

Table 2: Descriptive statics for length of calcanei

Length (in mm)	
Mean	70.4
Median	71.3
Standard deviation	6.01
Minimum	56.8
Maximum	81.6
Range	24.8
95% Confidence Interval	68.7–72.1

Table 3: Descriptive statics for width of calcanei

Width (in mm)	
Mean	43.4
Median	43.6
Standard deviation	4.4
Minimum	34.9
Maximum	55.6
Range	20.7
95% Confidence Interval	42.2–44.6

Table 4: Descriptive statics for height of calcanei

Height (in mm)	
Mean	51.6
Median	52.8
Standard deviation	4.54
Minimum	40.5
Maximum	59.5
Range	19
95% Confidence Interval	50.3–52.9

Considerable variations have been noted in the morphometry of calcanei, hence standardization of plate dimensions is not the best approach. Standard sizes may not fit every patient, leading to pain, wound healing problems, and soft tissue irritation [10].

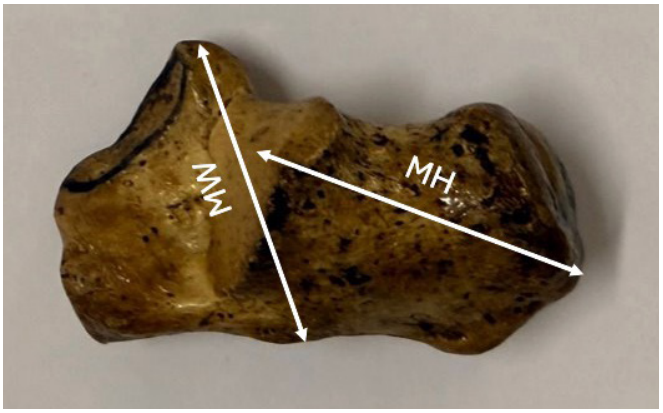

Figure 1: Posterior point of the calcaneal tuberosity

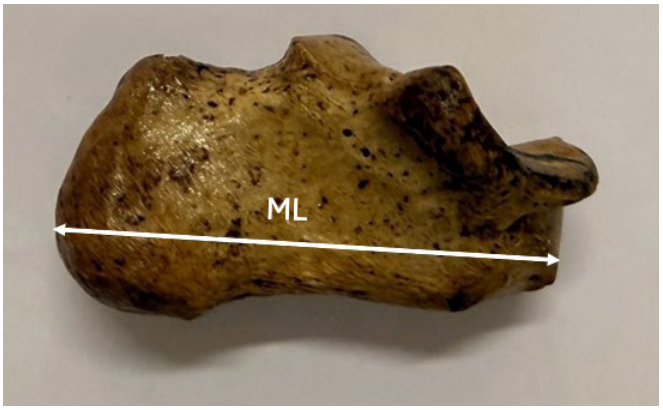

Figure 2: Anterior point of the calcaneocuboid articular surface

In this study, we measured certain parameters of 50 human adult calcanei of the South Indian population and calculated the mean values. The average dimensions of the calcaneus were 70.4 ± 6.01 mm for length, 43.4 ± 4.4 mm for width, and 51.6 ± 4.54 mm for height. These findings are in concordance with other studies [11-15]. For each parameter, we also noted the minimum, maximum, and range of values. The ranges varied from 24.8 mm for length, 20.7 mm for width, and 19 mm for height. We note considerable variability in the measurements, indicating a wide range.

The subtalar joint is a functional unit that is formed by the articulations of the calcaneus and talar bones. Variations in the morphology of articular facets of calcaneus may alter subtalar joint mechanics, which can compromise joint stability and contribute to ligamentous laxity as well as degenerative arthritic changes over time. Studies have shown that Pattern 1 calcanei, that have fused anterior and middle facets, are most common in

Table 5: Comparison of calcanei measurements with previous studies

S. No.	*Author*	*Year*	*Population*	*N (number of samples)*	*Maximum Length (in mm)*	*Maximum Width (in mm)*	*Maximum Height (in mm)*	*Citation*
1.	Ilknur Ari, Ilker Mustafa Kafa	2009	Turkish	160 (88R, 72L)	R- 75 ± 0.71 L- 74.3 ± 0.84	R- 44±0.53 L- 43.5±0.43	-	[11]
2.	Neslıhan Boyan, Esın Ozsahın, Emıne Kızılkanat, Roger Soames, Ozkan Oguz	2016	Antolian	57 (27R, 30L)	R- 75.69 ± 6.76 L- 76.07 ± 5.44	R- 45.84 ± 4.21 L- 43.92 ± 3.97	-	[12]
3.	İlhan Otağ, Hasan Tetiker, Yaşar Taştemur, Vedat Sabancıoğulları, Mehmet İlkay Koşar, Mehmet Çimen	2017	Turkish	65 (35R, 30L)	R- 76.21 ± 5.68; L- 76.14 ± 5.53	R- 42.97 ± 3.75 L- 43.51 ± 3.34	-	[13]
4.	G Jyotsna, Anuradha Mamidi	2021	Indian	98	76.01 ± 5.74	45.94 ± 4.35	-	[14]
5.	Don Koh, Beatrice Tan, Kinjal Mehta, James Loh, Le Roy Chong, Charles Kon Kam King	2024	Singapore	100	72.1 ± 6.0	40.9 ± 5.1	50.8 ± 4.8	[15]
6.	Present Study	2026	Indian	50	70.4 ± 6.01	43.4 ± 4.4	51.6 ± 4.54	

the Indian population and are at a higher risk of subtalar joint instability. Hence, it is of importance to study the morphometry of the calcaneum in the Indian population and alter Western techniques to better suit Indian anatomical variations and clinical requirements [16, 17]. Calcaneus plays a major role in the medial longitudinal arch for weight bearing. Pes planus is a foot deformity characterized by the partial or complete flattening of the medial longitudinal arch, particularly during weight-bearing [18]. Some angular measurements of the calcaneus are found to be associated with arch height in the human foot [19]. Lateral column lengthening (LCL) of the calcaneus is a surgical intervention commonly done in patients with pes planus and corrects peritalar subluxation [20].

Limitations of this study include a relatively small sample size and the use of samples from a single institution. Due to the absence of demographic data, sex-based and side-based variations could not be assessed. Further research can be done by including additional parameters such as Böhler's angle, measurements of articular facets and sulcus calcanei, and correlating these findings with measurements of calcaneal implants currently available in the market. This may provide valuable insight into implant fit and potential problems and complications. In recent years, advances in imaging and better surgical techniques have improved the feasibility of foot salvage procedures, leading to better outcomes. Personalized three-dimensional implants that are custom-made have been used in patients who underwent total calcaneus resection and reconstruction [7]. Additionally, minimally invasive surgery techniques are seen to reduce complications and improve patient outcomes [21]. The substantial variation observed in calcaneal dimensions highlights the need for multiple implant size options and supports the growing role of modular and patient-specific implant systems in calcaneal surgery.

Conclusion

The present study provides valuable insights into the morphometry of the calcaneus in the Indian population. The predominance of pattern 1 calcanei, which has been associated with a higher risk of subtalar joint instability, highlights the clinical importance of studying the morphometry of the calcaneus in the Indian population. The wide range observed across the measured parameters indicates considerable morphological variability, highlighting the advantage of customized implants. The morphometric data generated in this study may contribute to the optimization of implant design, reduce complications due to incorrect implant sizing, and improve surgical outcomes.

These findings are consistent with existing research and add to the limited data on calcaneal morphometry available for the Indian population. The study contributes by expanding our anatomical knowledge of the calcaneus that can aid orthopedic surgeons in the management and

treatment of calcaneus injuries, and in achieving better outcomes in calcaneal reconstruction.

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