International Journal of Medical and Pharmaceutical Research

Online ISSN-2958-3683 | Print ISSN-2958-3675
Frequency: Bi-Monthly
Available online on: https://ijmpr.in/

Original Article

Morphometric Analysis of the Medial Malleolus and Tibial Plafond in Dry Adult Human Tibiae of the Eastern Uttar Pradesh Population

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Received: 08-04-2026
Accepted: 01-05-2026
Available online: 13-05-2026

ABSTRACT

Background: The distal end of the tibia plays an important role in ankle stability, weight transmission, and maintenance of talocrural joint congruity. Morphometric knowledge of the medial malleolus and tibial plafond is clinically significant in fracture fixation, implant design, ankle reconstruction, and prosthesis development. Population-specific anatomical data remain limited in Indian populations, particularly from Eastern Uttar Pradesh.
Aim: To analyse the morphometric characteristics of the medial malleolus and tibial plafond in dry adult human tibiae.
Materials and Methods: This cross-sectional osteological study was conducted on 50 dry adult human tibiae obtained from the bone bank of the Department of Anatomy, Institute of Medical Sciences, Varanasi. Medial malleolus vertical length (MMVL), medial malleolus anteroposterior length (MMAPL), tibial plafond anteroposterior length (TPAPL), tibial plafond transverse length (TPTL), and tibial length (TL) were measured using a digital vernier calliper and osteometric table. Data were analysed using SPSS version 20. Pearson's correlation coefficient was used for statistical analysis.
Results: The mean MMVL was 15.05±1.14 mm, MMAPL was 22.29±2.07 mm, TPAPL was 26.71±2.30 mm, and TPTL was 22.30±1.58 mm. Mean tibial length was 35.06±1.74 cm. MMVL showed weak and statistically nonsignificant correlations with other parameters. MMAPL demonstrated significant positive correlation with TPAPL ($p<0.01$), TPTL ($p<0.01$), and TL ($p<0.05$). TPAPL showed a strong positive correlation with TPTL ($p<0.01$) and a moderate correlation with TL ($p<0.01$). The transverse diameter of the tibial plafond observed in the present study was comparatively lower than values reported in most previous studies.
Conclusion: The present study demonstrates significant morphometric variation in the distal tibia among the Eastern Uttar Pradesh population. The findings provide useful baseline anatomical data for orthopaedic surgeons during fracture fixation, implant selection, ankle reconstruction, and prosthesis design. Population-specific morphometric databases may improve implant compatibility and surgical outcomes.

Keywords: Distal tibia, Medial malleolus, Tibial plafond, Morphometry, Osteometry, Ankle joint.

INTRODUCTION

The lower end of the tibia, together with its medial malleolus and the lateral malleolus of the fibula, forms the ankle mortise, and together with the trochlea of the talus forms the talocrural joint.[1] It is a hinge variety of synovial joint.[2] The talocrural joint is a uniaxial joint, responsible for dorsiflexion and plantarflexion.[3] It has a direct role in body weight bearing and keeping the ankle joint stable. Due to the size variation in different people, measurement of these structures is important for proper surgery and implant design, and slight variation in shape can disrupt the joint alignment, affect load distribution and increase the risk of degenerative changes like osteoarthritis.[3,4] The medial malleolus provides attachment for the deltoid ligament, and helps to keep the ankle stable, but its size and shape influence ligament function and safe screw placement; variations in this area can affect the surgical outcomes and fixation stability.[5] Fractures involving the distal end of the tibia, mainly tibial plafond fracture (Pilon fracture) and malleolar fractures, disrupt the normal ankle joint structure and affect the stability and smooth movement of the ankle joint.[6] Pilon fractures are intra-articular fractures, usually caused by high-energy trauma such as road traffic accidents or falls from height, and are characterized by comminution with disruption of the articular surface.[7] In case of the distal end of tibial fracture, the surgical goal is restoration of anatomical alignment and joint congruity, which reduces the risk of post-traumatic osteoarthritis and improves long-term function.[7] Direct measurement methods like bone studies provide more accurate results in comparison to radiological imaging.[8] Orthopaedic implants are generally designed by using data from the Western population, but the bone dimensions differ among different populations, which results in implant mismatch; therefore, it is crucial to consider the differences during implant design.[4] Despite the improvement of modern orthopaedic techniques, the reconstruction of the lower end of the tibia still remains a challenge.[5] Most research has focused on isolated components of the distal tibia rather than studying the medial malleolus and tibial plafond together, and there is a lack of comprehensive data for different populations, especially Non-Western groups, so there is a lack of detailed information for its clinical use.[9]

The present study aims to analyse the morphometric characteristics of the lower end of the tibia and to document its anatomical variations. Understanding these parameters is important as the distal tibia plays a key role in the formation and stability of the ankle joint. The findings of this study provide baseline data that can assist orthopaedic surgeons in fracture management, implant design, and ankle reconstruction, while also contributing to anatomical knowledge and forensic applications.

MATERIAL AND METHODS

This study is a cross-sectional osteological study conducted on dry adult human tibiae obtained from the bone bank of the Department of Anatomy, Institute of Medical Sciences, Varanasi. The bones were preserved, labelled, and routinely used for teaching and research purposes. The study was started after obtaining suitable approval from the ethical committee of the institute.

Sampling was done using convenience sampling from available specimens in the bone bank. Bones that were fully ossified (adult tibiae), intact distal ends, and had clearly identifiable anatomical landmarks were included in the study. Bones with broken or damaged distal ends, deformed bones, and bones with evidence of pathological changes were excluded from the study. A total of 50 out of 87 tibiae fulfilled all the inclusion criteria.

Parameters Measured:

1. Medial malleolus:

1a. Medial Malleolus Vertical Length (MMVL): MMVL was measured as the vertical distance from the tibial plafond to the tip of the medial malleolus. It was chosen as this point was clinically relevant for ligament attachment and determining screw length[10] (Figure 1a).

1b. Medial Malleolus Antero-posterior Length (MMAPL): It was measured between the anterior and posterior margins of the medial malleolus (Figure 1d).

2. Tibial Plafond:

2a. Tibial plafond anteroposterior length (TPAPL): Measured as the maximum distance between the anterior and lower lip of the articular surface (Figure 1b).

2b. Tibial Plafond Transverse Length (TPTL): It was measured mediolaterally across the articular surface (Figure 1c). These points are important for load-bearing, sagittal alignment, and mediolateral stability of the ankle joint. Morphometric variations in these parameters directly affect ankle biomechanics and implant design.[11]

Measurement Technique:

All measurements except tibial length were recorded using a digital vernier calliper with a precision of up to 0.01 mm. Tibial length was measured using an osteometric table. These instruments are standard for osteometric studies due to their high accuracy and reliability. Data were recorded in Microsoft Excel sheets and analyzed using SPSS software, version 20. Results were expressed as mean and standard deviation (SD). Correlation analysis was performed using Pearson's correlation coefficient. A p-value less than 0.05 was considered statistically significant.

RESULTS

The mean medial malleolus vertical length (MMVL) was 15.05 mm, with a standard deviation of 1.14 mm. The mean medial malleolus anteroposterior length (MMAPL) was 22.29 mm with a standard deviation of 2.07 mm. The mean tibial plafond anteroposterior length (TPAPL) was 26.71 mm, with a standard deviation of 2.3 mm. The average tibial plafond transverse length (TPTL) was 22.3 mm, with a standard deviation of 1.58 mm. The total tibial length (TL) showed a mean value of 35.06 cm and a standard deviation of 1.74 cm (Table 1).

Correlation analysis was performed using Pearson's correlation test. MMVL showed weak and statistically non-significant correlations with all other parameters. MMAPL showed moderate positive correlations with several parameters. It was significantly correlated with TPAPL ($p<0.01$) and TPTL ($p<0.01$). It showed a weak but significant correlation with TL ($p<0.05$). TPAPL showed strong positive correlations with TPTL ($p < 0.01$). It also showed moderately significant correlations with TL ($p < 0.01$) and MMAPL ($p< 0.01$). TPTL demonstrated significant positive correlations with all parameters except MMVL. The strongest correlation was with TPAPL ($p<0.01$). It also correlated with TL ($p < 0.01$) and MMAPL ($p< 0.01$). TL showed moderate positive correlations with TPAPL ($p < 0.01$), TPTL ($p<0.01$), and MMAPL ($p< 0.05$). However, its correlation with MMVL was weak and not significant (Table 1).

Table 1: Pearson correlation analysis showing the relationship among morphometric parameters of the distal tibia. Values are expressed as mean ± standard deviation (SD). MMVL = Medial Malleolus Vertical Length; MMAPL = Medial Malleolus Anteroposterior Length; TPAPL = Tibial Plafond Anteroposterior Length; TPTL = Tibial Plafond Transverse Length; TL = Tibial Length. (*Correlation is significant at p<0.05 and **correlation is significant at p < 0.01. n = sample size).

	n	Mean (mm)	SD	MMVL (Pearson Correlation)	MMAPL (Pearson Correlation)	TPAPL (Pearson Correlation)	TPTL (Pearson Correlation)	TL (Pearson Correlation)
MMVL	50	15.052	1.14504	1	0.225	0.189	0.064	-0.117
MMAPL	50	22.294	2.07811	0.225	1	0.453**	0.489**	0.300*
TPAPL	50	26.716	2.30964	0.189	0.453**	1	0.650**	0.376**
TPTL	50	22.306	1.58557	0.064	0.489**	0.650**	1	0.391**
TL	50	35.06	1.74274	-0.117	0.300*	0.376**	0.391**	1

Figure 1: Morphometric measurements performed on the distal end of dry adult human tibiae using a digital Vernier calliper. (a) Measurement of the vertical length of the medial malleolus from the tibial plafond to the tip of the medial malleolus (MMVL). (b) Measurement of the anteroposterior length of the tibial plafond (TPAPL). (c) Measurement of the transverse width of the tibial plafond (TPTL). (d) Measurement of the anteroposterior diameter of the medial malleolus (MMAPL).

DISCUSSION

The distal end of the tibia plays a significant role in the stability and biomechanics of the ankle joint. The medial malleolus and tibial plafond are directly involved in load transmission, ankle congruity, and ligamentous stability. Because of this functional importance, the morphometric evaluation of these structures has significant clinical relevance. The present study evaluated the morphometric dimensions of the medial malleolus and tibial plafond in dry adult human tibiae.[1,12] In the present study, the mean medial malleolus vertical length (MMVL) was 15.05 ± 1.14 mm. This value is close to the findings as reported by Naidoo et al. in the South African population (male: 15.05 mm; female: 14 mm), Juned et al. in the South Indian population (left: 15.87 ± 1.42 mm; right: 15.81 ± 1.55mm), and Shishirkumar et al. in the Indian population (14.93 mm)[12–14] (Tables 1 and 2). This data is slightly higher than the value reported in Pamela et al. in the Kenyan population (14.19 ± 1.89 mm), Sarala et al. (left: 13.98 ± 1.59 mm; right: 13.75±1.73mm) and Solanki et al. (left: 14.09mm; right: 13.31mm) in Indian studies.[15–17] Kaloo et al. reported a relatively higher mean value of 16.13 mm in the Kashmiri population.[18] The variations suggest that medial malleolar height demonstrates significant regional and ethnic variability. (Table 1 & 2)

The mean anteroposterior length of the medial malleolus in the present study was 22.29 ± 2.07 mm. This value is close to the value reported by Pamela M (21.88 ± 2.22 mm), Solanki et al. (left: 21.25 mm; right: 20.82 mm), Smriti et al. (left:22.21 mm; right: 20.9 mm), and Shishirkumar et al. (22.03 mm.[12,15,17,19] However, larger dimensions were reported by Sarala et al. (left:24.11 ± 2.6 mm; right:24.32 ± 2.18 mm), Juned et al. (left: 23.95 ± 2 mm; right: 23.01 ± 1.88 mm), and Ulkir et al. in the Turkish population (25.08 mm)[4,14,16] (Tables 1 and 2). The reason behind this variation from region to region is opined that population with greater habitual weight-bearing activity and different skeletal loading patterns may develop relatively larger medial malleolar dimensions. Genetic constituent, nutrition, and overall skeletal build may also influence medial malleolar morphology.[15,18] Ribeiro et al. also demonstrated that distal tibial morphology varies according to morphologic patterns of the posterior malleolus and showed that larger distal epiphyses were associated with broader medial malleoli.[9] This shows that distal tibial dimensions are structurally interrelated and may adapt to functional loading requirements. The tibial plafond is the main articular surface of the ankle joint. Variations in its dimensions may influence force distribution and articular congruity. Gupta et al. emphasized that the morphometry of the tibial plafond plays an important role in reconstruction surgeries and implant manufacturing.[1] The present study observed a mean anteroposterior length of the tibial plafond of 26.71 ± 2.3 mm. This value is close to the findings reported by ülkir et al. (26.96 mm) and Shishirkumar et al. (26.3 mm).[4,12] Pamela M et al. reported a higher mean value of 28.61 ± 2.39 mm, while Juned et al. and Kaloo et al. observed even larger values ranging from 29 to 31 mm.[14,15,18] In contrast, Sarala et al. reported smaller measurements (left: 25.55 ± 2.35 mm; right: 25.61 ± 2.5 mm)[16] (Tables 1 and 2).

The mean transverse diameter of the tibial plafond in the present study was 22.3 ± 1.58 mm, which was lower than all previous studies. Pamela M et al. reported 26.55 ± 2.18 mm, Sarala et al. approximately 27 mm, Ulkir et al. 27.71 mm, Shishirkumar et al. 28.56 mm, and Kaloo et al. approximately 29.02 mm. Juned et al. reported the highest values, with means greater than 29 mm bilaterally.[4,12,14–16,18] One possible explanation for the comparatively smaller transverse tibial plafond diameter observed in the present study may be regional skeletal variation within Indian populations (Tables 1 and 2).

The present study supports the concept that distal tibial morphology is population-specific. Ulkir et al. concluded that distal tibial morphometry is essential for the design of anatomically compatible total ankle prostheses.[4] Similarly, Gupta et al. and Kaloo and Khurshid emphasized that regional osteometric databases are necessary for construction procedures and implant customization.[1,18] Thus, the present morphometric findings of this study have direct implications in selecting implant dimensions and screw trajectories during ankle fracture fixation. Recent studies have concluded that apart from dimensions, trabecular architecture and bone density of the distal tibia are of similar significance. Ribeiro et al. stated that rounded, triangular, and trapezoid morphologic types of posterior malleolus differ in cortical thickness and trabecular bone density.[9] Similarly, Kleinertz et al. reported that bone density is greatest near the tibial articular surface and decreases proximally.[5] These studies collectively suggest that not only gross dimensions but also internal bone architecture influence fixation stability and implant performance.

Limitations of the study:

The sex and age of the bones taken in the study were not known. The sample size was moderate, and radiological or biochemical correlations were not performed. Despite these limitations, the study provides useful baseline morphometric data for the distal tibia in an Indian population and contributes to the existing literature on ankle morphometry.

Table 2: Comparative analysis of morphometric parameters of the distal tibia reported in previous studies from different populations, including mean values of medial malleolar vertical length (MMVL), medial malleolar anteroposterior length (MMAPL), tibial plafond anteroposterior length (TPAPL), and transverse diameter of the tibial plafond (TPTL).

Study	Year	Region	MMVL Mean (mm)	MMAPL Mean (mm)	TPAPL Mean (mm)	TPTL Mean (mm)

Pamela M et al.[15]	2013	Kenya	14.19 ± 1.89	21.88 ± 2.22	28.61 ± 2.39	26.55 ± 2.18
Sarala D et al.[16]	2014	India	Left: 13.98 ± 1.59 Right: 13.75 ± 1.73	Left: 24.11 ± 2.60 Right: 24.32 ± 2.18	Left: 25.55 ± 2.35 Right: 25.61 ± 2.50	Left: 27.07 ± 2.59 Right: 26.90 ± 2.89
Naidoo N et al.[13]	2015	South Africa	Male: 15.05 Female: 14.00			
Juned et al.[14]	2024	South Indian	Left: 15.87 ± 1.42 Right: 15.81 ± 1.55	Left: 23.95±2.00 Right: 23.01±1.88	Left: 29.28 ± 2.36 Right: 28.88 ± 2.63	Left: 29.31 ± 1.89 Right: 29.37 ± 2.06
Solanki et al.[17]	2025	India	Left:14.09, Right:13.31	Left: 21.25, Right: 20.82		
Shishirkumar et al.[12]	2014	India	14.93	22.03	26.30	28.56
Simriti et al.[19]	2019	India	Left:15.43, Right:13.72	Left:22.21 Right:20.90		
Kaloo et al.[18]	2019	India	16.13		30.88	29.02
Ulkir et al.[4]	2024	Turkey	14.73	25.08	26.96	27.71

CONCLUSION

The present study demonstrated variations in the morphometric parameters of the medial malleolus and tibial plafond. The mean medial malleolar height and anteroposterior dimensions were comparable to several Indian and international studies, whereas the transverse diameter of the tibial plafond was relatively smaller than most previously reported populations. The findings of this study suggest that parameters of the distal tibia are greatly influenced by ethnic, regional, biochemical, and functional factors. Population-specific morphometric databases are important for improving implant compatibility. The data obtained in this study may be useful for orthopaedic surgeons during fracture fixation, ankle reconstruction, syndesmotic stabilization, and prosthesis design.

Conflict of Interest: None

Funding: No external funding was received

Acknowledgement: The authors acknowledge the support of the Neuro-Anatomy Lab, Department of Anatomy, Institute of Medical Sciences, Banaras Hindu University, for facilitating this work.

List of Abbreviations: MMVL – Medial Malleolus Vertical Length; MMAPL – Medial Malleolus Anteroposterior Length; TPAPL – Tibial Plafond Anteroposterior Length; TPTL – Tibial Plafond Transverse Length; TL – Tibial Length; SD – Standard Deviation; SPSS – Statistical Package for the Social Sciences.

Competing Interests: The authors declare that they have no competing interests, financial or non-financial, related to this study.

Authors' Contributions:

AS contributed to data collection, morphometric measurements, literature review, statistical analysis, and preparation of the initial manuscript draft; AKN conceptualized and supervised the study, contributed to study design, interpretation of results, critical revision of the manuscript, and final approval of the submitted version; DD contributed to methodological planning, manuscript review, and interpretation of anatomical findings; AKS assisted in statistical interpretation, clinical correlation, and critical revision of the manuscript; RS contributed to literature search, data organization, formatting, and manuscript preparation. All authors read and approved the final manuscript; MJA contributed to critical review and final manuscript preparation.

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