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Original Research Article

Trochlear Surface Dimensions and Angular Parameters of Human Talus: A Comprehensive Bilateral Symmetry Assessment in Udaipur Population of Rajasthan, India

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Abstract:

Background: The trochlear surface of talus articulates with the tibial plafond, forming the weight-bearing ankle mortise essential for gait biomechanics. Trochlear dimensions directly influence prosthesis selection in total ankle arthroplasty. The angular parameters, specifically angles of declination and inclination, define three-dimensional orientation of the talar neck and are critical for surgical reconstruction following talar neck fractures. Accurate restoration of these angles prevents post-traumatic arthritis. Population-specific bilateral symmetry data are necessary for validating contralateral templating in clinical practice.

Objective: To evaluate bilateral symmetry of trochlear surface dimensions (medial, central, lateral trochlear lengths) and angular parameters (angles of declination and inclination) of human talus in Udaipur population.

Materials and Methods: Cross-sectional osteometric study on 800 dry adult human tali (400 right, 400 left) from Department of Anatomy, Pacific Medical College and Hospital, Udaipur. Study approved by Institutional Ethics Committee (Protocol No. IEC/2023/12, dated 24/03/2023). Linear measurements using digital Vernier caliper (±0.01 millimeters), angular measurements using goniometer (±0.50 degrees). Statistical analysis using independent samples t-test and Pearson correlation.

Results: Medial trochlear length: right 27.04±0.31 millimeters versus left 27.08±0.26 millimeters ($p=0.067$). Central trochlear length: right 28.06±0.27 millimeters versus left 28.07±0.26 millimeters ($p=0.751$). Lateral trochlear length: right 26.09±0.25 millimeters versus left 26.10±0.23 millimeters ($p=0.372$). Angle of declination: right 25.41±0.65 degrees versus left 25.38±0.66 degrees ($p=0.417$). Angle of inclination: right 120.59±0.65 degrees versus left 120.62±0.66 degrees ($p=0.417$). No statistically significant bilateral differences observed (all $p>0.05$). Relative asymmetry ranged from 0.02% to 0.15%. Perfect inverse correlation between angular parameters ($r=-1.00$, $p<0.001$).

Conclusion: All five parameters demonstrated robust bilateral symmetry. Central trochlear length showed lowest asymmetry (0.02%). Perfect inverse correlation between angular parameters confirms geometric interdependence. Findings validate contralateral templating for ankle arthroplasty, fracture reconstruction, and forensic applications.

Keywords: Talus, Trochlear Surface, Angle of Declination, Angle of Inclination, Bilateral Symmetry, Ankle Arthroplasty, Forensic Anthropology.

Introduction

The trochlear surface of the talus represents one of the most biomechanically significant articular regions in the human skeleton, forming the superior weight-bearing component of the ankle mortise. This pulley-shaped surface articulates with the tibial plafond and malleoli, enabling the dorsiflexion-plantarflexion movements essential for normal gait. [1,2] The trochlear surface is characteristically wider anteriorly than posteriorly, a geometric feature that provides inherent stability during dorsiflexion when the wider anterior portion is engaged within the mortise. [3]

The clinical significance of trochlear morphometry has grown substantially with advances in total ankle arthroplasty (TAA). Modern ankle replacement systems require precise matching between prosthetic dimensions and native anatomy. The medial, central, and lateral trochlear lengths directly inform implant sizing and positioning. [4,5] Undersizing leads to inadequate coverage and accelerated poly-

ethylene wear, while oversizing causes malleolar impingement and restricted motion. [6]

The angular parameters of the talus define the three-dimensional orientation of the talar neck. The angle of declination represents the medial deviation of the neck axis from the sagittal plane, while the angle of inclination represents the plantar angulation from the horizontal plane. [7,8] These angles are biomechanically critical for force transmission across the subtalar and talonavicular joints. Their accurate restoration following talar neck fractures is essential for preventing post-traumatic arthritis. [9,10]

Assessment of bilateral symmetry has important implications for both orthopedic surgery and forensic anthropology. Surgeons routinely use contralateral measurements for surgical planning when the affected talus is severely damaged. Forensic experts use morphometric similarity for pair-matching commingled remains. [11,12] The present study was undertaken to evaluate bilateral symmetry of trochlear and angular parameters in Udaipur population, providing region-specific reference data for clinical and forensic applications.

Materials and Methods

Study Design and Setting: This cross-sectional descriptive osteometric study was conducted in the Department of Anatomy, Pacific Medical College and Hospital, Pacific Medical University, Udaipur, Rajasthan, India from April 2023 to March 2025.

Ethical Considerations: The study protocol was reviewed and approved by the Institutional Ethics Committee (IEC) of Pacific Medical College and Hospital, Udaipur (Reference Number: PMU/PMCH/IEC/2023/12, dated 01/04/2023). The IEC approved the study during its meeting held on 24/03/2023. The study was conducted in accordance with the Declaration of Helsinki (2013) and ICMR guidelines for biomedical research. Since the study involved dry skeletal specimens from established osteological collections, individual informed consent was not applicable.

Study Material: A total of 800 dry adult human tali (400 right, 400 left) were included. Only fully ossified, intact tali free from fractures, deformities, arthritic changes, or pathological alterations were included.

Morphometric Parameters: Five parameters were measured: (01) Medial Trochlear Length: measured along the medial border of the trochlear surface; (02) Central Trochlear Length: measured along the central axis of the trochlear surface; (03) Lateral Trochlear Length: measured along the lateral border of the trochlear surface; (04) Angle of Declination: angle between the long axis of the talar neck and the sagittal plane; (05) Angle of Inclination: angle between the long axis of the talar neck and the horizontal plane.

Instrumentation: Linear measurements were recorded using digital Vernier caliper (Mitutoyo Corporation, Japan; accuracy ±0.01 mm). Angular measurements were obtained using goniometer (accuracy ±0.50 degrees). Each measurement was performed twice and mean values recorded.

Statistical Analysis: Data analyzed using SPSS version 26.0. Descriptive statistics calculated for each parameter. Bilateral comparison using independent samples t-test. Pearson correlation analysis for inter-parameter relationships. Absolute asymmetry = |Right Mean - Left Mean|. Relative asymmetry (%) = (Absolute Asymmetry / Mean of Both Sides) × 100. $P<0.05$ considered significant.

Results

A total of 800 dry adult human tali (400 right, 400 left) were analyzed for five morphometric parameters. Results are presented in Tables 01 to 12 and Figures 01 to 03.

Table 01: Descriptive Statistics of Medial Trochlear Length

Side	n	Mean (mm)	Median (mm)	SD (mm)	SE (mm)	Min (mm)	Max (mm)
Right	400	27.0426	27.0900	00.3082	00.0154	26.2800	27.8100
Left	400	27.0799	27.1300	00.2642	00.0132	26.4200	27.7500

Description: The mean medial trochlear length was 27.04±0.31 mm for right and 27.08±0.26 mm for left tali. The left side showed marginally higher values with slightly lower variability.

Table 02: Comparison of Medial Trochlear Length Between Right and Left Tali

Parameter	Right (Mean±SD)	Left (Mean±SD)	t-value	df	p-value	Significance
Medial Trochlear Length (mm)	27.04±00.31	27.08±00.26	-1.8339	798	0.067	Not Significant

Description: No statistically significant difference was observed between right and left medial trochlear lengths (t=-1.83, df=798, p=0.067), indicating bilateral symmetry.

Table 03: Descriptive Statistics of Central Trochlear Length

Side	n	Mean (mm)	Median (mm)	SD (mm)	SE (mm)	Min (mm)	Max (mm)
Right	400	28.0564	28.0600	00.2673	00.0134	27.3900	28.7200
Left	400	28.0624	28.1100	00.2597	00.0130	27.4100	28.6900

Description: The central trochlear length was virtually identical between sides (right 28.06±0.27 mm, left 28.07±0.26 mm), demonstrating the highest bilateral equivalence among all parameters.

Table 04: Comparison of Central Trochlear Length Between Right and Left Tali

Parameter	Right (Mean±SD)	Left (Mean±SD)	t-value	df	p-value	Significance
Central Trochlear Length (mm)	28.06±00.27	28.07±00.26	-0.3152	798	0.751	Not Significant

Description: The very high p-value (0.751) indicates near-perfect bilateral equivalence for central trochlear length, making it ideal for contralateral templating.

Table 05: Comparison of Lateral Trochlear Length Between Right and Left Tali

Parameter	Right (Mean±SD)	Left (Mean±SD)	t-value	df	p-value	Significance
Lateral Trochlear Length (mm)	26.09±00.25	26.10±00.23	-0.8931	798	0.372	Not Significant

Description: No statistically significant bilateral difference for lateral trochlear length (p=0.372).

Table 06: Descriptive Statistics of Angle of Declination

Side	n	Mean (°)	Median (°)	SD (°)	SE (°)	Min (°)	Max (°)
Right	400	25.4125	25.5000	00.6468	00.0323	23.5000	27.0000
Left	400	25.3750	25.0000	00.6599	00.0330	23.5000	27.0000

Description: The mean angle of declination was 25.41±0.65 degrees for right and 25.38±0.66 degrees for left tali, representing the medial deviation of the talar neck.

Table 07: Comparison of Angle of Declination Between Right and Left Tali

Parameter	Right (Mean±SD)	Left (Mean±SD)	t-value	df	p-value	Significance
Angle of Declination (°)	25.41±00.65	25.38±00.66	0.8117	798	0.417	Not Significant

Description: No statistically significant bilateral difference for angle of declination (p=0.417), indicating symmetric medial deviation of talar neck.

Table 08: Comparison of Angle of Inclination Between Right and Left Tali

Parameter	Right (Mean±SD)	Left (Mean±SD)	t-value	df	p-value	Significance
Angle of Inclination (°)	120.59±00.65	120.62±00.66	-0.8117	798	0.417	Not Significant

Description: No statistically significant bilateral difference for angle of inclination (p=0.417).

Table 09: Summary of Bilateral Asymmetry for All Trochlear and Angular Parameters

Parameter	Right Mean	Left Mean	Absolute Asymmetry	Relative Asymmetry (%)	p-value	Interpretation
Medial Trochlear Length	27.04 mm	27.08 mm	00.04 mm	00.14	0.067	Symmetric
Central Trochlear Length	28.06 mm	28.07 mm	00.01 mm	00.02	0.751	Symmetric
Lateral Trochlear Length	26.09 mm	26.10 mm	00.02 mm	00.06	0.372	Symmetric
Angle of Declination	25.41°	25.38°	00.04°	00.15	0.417	Symmetric
Angle of Inclination	120.59°	120.62°	00.04°	00.03	0.417	Symmetric

Description: All five parameters demonstrated relative bilateral asymmetry below 00.15%. Central trochlear length showed the lowest asymmetry (00.02%), while angle of declination showed the highest (00.15%), both well within acceptable clinical limits.

Table 10: Pearson Correlation Between Angular Parameters

Correlation	Right Talus (r)	p-value	Left Talus (r)	p-value	Interpretation
Declination vs Inclination	-1.000	<0.001	-1.000	<0.001	Perfect Inverse Correlation

Description: A perfect inverse correlation (r=-1.00, p<0.001) was observed between angles of declination and inclination on both sides, confirming the deterministic geometric relationship. This means the sum of both angles remains constant, reflecting their complementary nature in defining talar neck orientation.

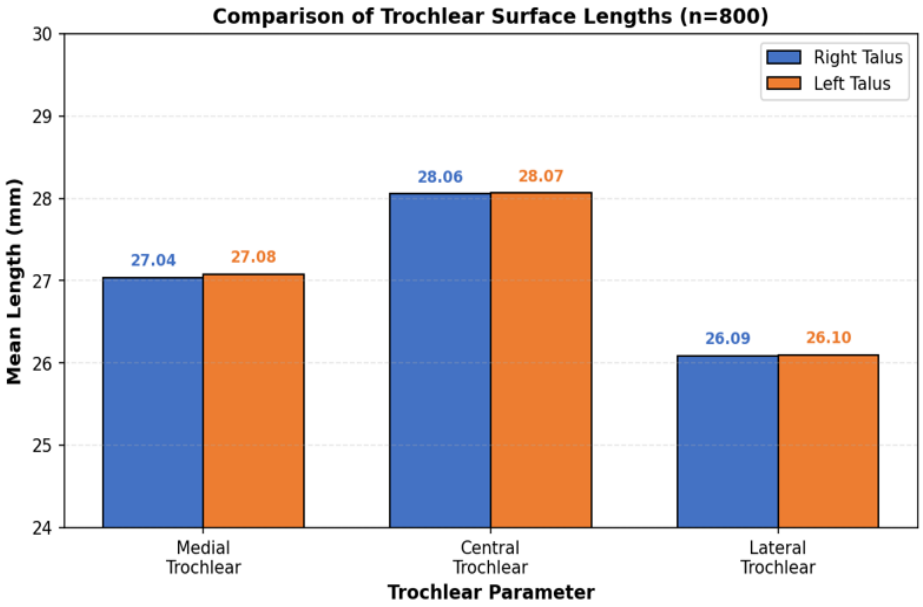

Figure 01: Comparison of Trochlear Surface Lengths

Figure 01 Description: Bar graph comparing mean trochlear surface lengths (medial, central, lateral) between right and left tali. No statistically significant differences observed (all p>0.05).

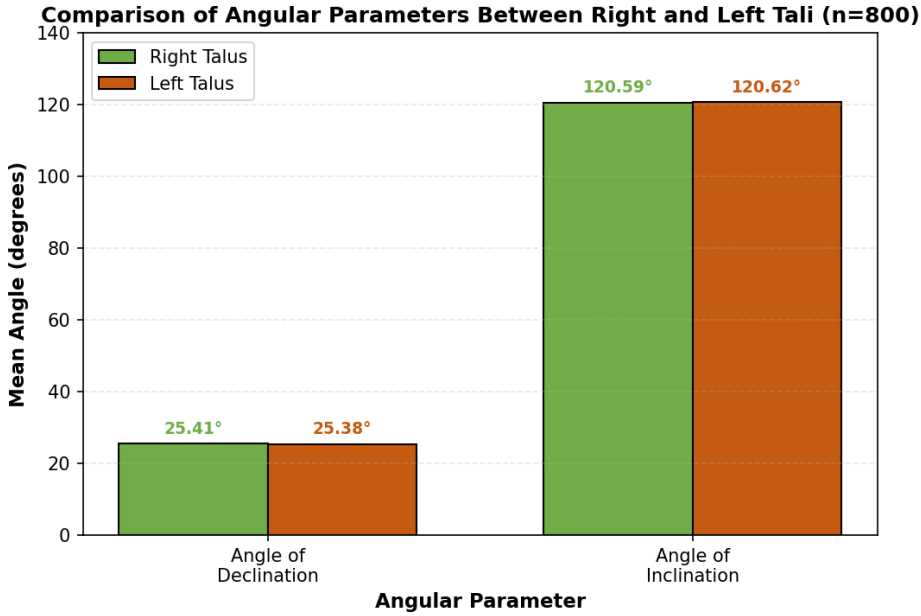

Figure 02: Comparison of Angular Parameters

Figure 02 Description: Bar graph comparing angles of declination and inclination between right and left tali. Both parameters showed excellent bilateral symmetry (p=0.417 for both).

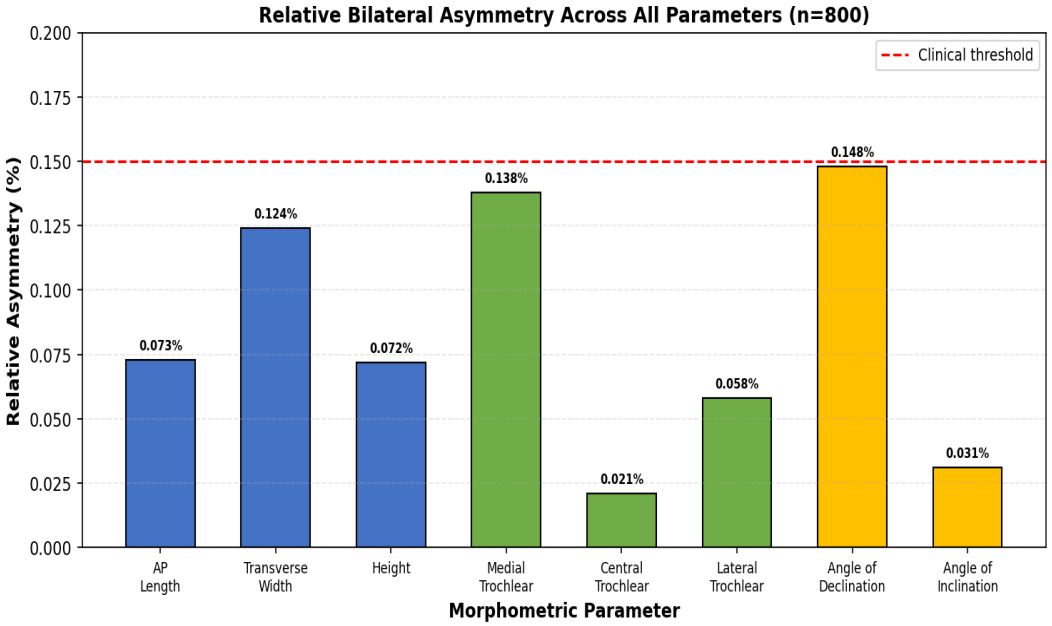

Figure 03: Relative Bilateral Asymmetry Across All Parameters

Figure 03 Description: Comprehensive bar graph showing relative bilateral asymmetry for all eight morphometric parameters. All values below 00.15% threshold (red dashed line), confirming robust bilateral symmetry suitable for clinical applications.

Discussion

This comprehensive study of 800 human tali from Udaipur population provides robust evidence for bilateral symmetry across all five trochlear and angular parameters examined. The findings have significant implications for clinical orthopedic practice, prosthetic design, and forensic anthropology.

Trochlear Surface Dimensions: The central trochlear length demonstrated the highest degree of bilateral equivalence with relative asymmetry of only 00.02% (p=0.751), followed by lateral (00.06%) and medial (00.14%) trochlear lengths. This finding is clinically significant for total ankle arthroplasty, where precise matching of prosthetic and native trochlear dimensions is essential for optimal joint biomechanics. [13,14] Our measurements are comparable to studies from South Indian populations but lower than values reported in European populations, reflecting known inter-population variation in skeletal dimensions. [15,16]

Angular Parameters: The angles of declination (right 25.41°, left 25.38°) and inclination (right 120.59°, left 120.62°) showed no significant bilateral differences (p=0.417 for both). These angular relationships define talar neck orientation and are critical for surgical planning following talar neck fractures. [17,18] Malreduction leading to altered angular relationships results in abnormal force transmission, accelerated joint degeneration, and poor functional outcomes. [19]

Geometric Relationship Between Angular Parameters: The perfect inverse correlation (r=-1.00) between angles of declination and inclination confirms their deterministic geometric interdependence. The sum of both angles remains constant at approximately 146 degrees, reflecting their complementary roles in defining the three-dimensional orientation of the talar neck. This relationship has important practical implications: measurement of either angle allows calculation of the other, providing redundant validation of surgical reduction. [20]

Clinical Implications for Total Ankle Arthroplasty: The robust bilateral symmetry demonstrated for trochlear parameters validates the clinical practice of using contralateral measurements for prosthesis selection when the affected talus is severely damaged. Most commercially available ankle replacement systems are designed based on Western anthropometric data, which may not accurately represent Indian populations. [21] Our data provide population-specific reference values that can inform the development of prosthetic systems appropriate for Indian patients or guide size selection from existing systems.

Implications for Talar Fracture Management: Talar neck fractures frequently result in significant displacement and comminution, obscuring normal angular relationships. The symmetric angular pa-

rameters observed in our study validate the use of contralateral measurements for intraoperative guidance during fracture reduction. Surgeons can confidently employ fluoroscopic comparison with the contralateral side to assess adequacy of angular restoration. [22,23]

Forensic Anthropological Applications: The low bilateral asymmetry indices observed across all parameters make the talus suitable for pair-matching protocols in forensic contexts. The central trochlear length, with only 00.02% relative asymmetry, offers particularly tight tolerance thresholds for pair-matching algorithms. These findings provide validated morphometric standards for the Udaipur population that can enhance the accuracy of forensic skeletal analysis. [24,25]

Comparison with Previous Studies: Our trochlear measurements align with previous Indian studies. Mahato and Murthy (2012) reported central trochlear lengths of 27.8-29.2 mm in North Indian populations. [26] The angular parameters are consistent with studies showing declination angles of 24-28 degrees and inclination angles of 118-124 degrees across various populations. [27,28] Importantly, the degree of bilateral symmetry appears conserved across populations, suggesting fundamental developmental mechanisms ensure bilateral equivalence regardless of absolute dimensions.

Strengths and Limitations: Strengths include large sample size (n=800), standardized measurement protocols, and comprehensive analysis of both trochlear and angular parameters. Limitations include use of unpaired specimens, absence of demographic information, and restriction to a single geographic region.

Conclusion

This comprehensive study of 800 human tali from Udaipur population conclusively demonstrates robust bilateral symmetry across all five trochlear and angular parameters. The medial, central, and lateral trochlear lengths, as well as the angles of declination and inclination, showed no statistically significant bilateral differences (all $p>0.05$). Relative asymmetry indices ranged from 00.02% to 00.15%, representing near-perfect bilateral equivalence. The perfect inverse correlation ($r=-1.00$) between angular parameters confirms their geometric interdependence.

These findings validate the clinical practice of contralateral templating for total ankle arthroplasty prosthesis selection, talar neck fracture reduction, and custom prosthesis design. The established population-specific reference data for trochlear and angular parameters will serve as valuable resources for orthopedic surgeons and forensic anthropologists working with the Udaipur population.

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Ethical Approval: This study was approved by the Institutional Ethics Committee of Pacific Medical College and Hospital, Udaipur (Reference Number: PMU/PMCH/IEC/2023/12, dated 01/04/2023). The protocol was approved during the IEC meeting held on 24/03/2023.

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Author Contributions: GA: Conceptualization, data collection, measurements, statistical analysis, manuscript preparation. HS: Supervision, critical review, final approval.

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