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Angular dimensions and squatting facets in human dry tali of South Indian origin

Suresh Narayanan[1], Nachiket Shankar[2], Vijay Kishan[3], Vaidyanathan Balasubramanyam[2]

[1]Department of Anatomy, Sri Manakula Vinayagar Medical College and Hospital, Puducherry; [2]Department of Anatomy, St. John's Medical College and Hospital, Bangalore, Karnataka; [3]Department of Anatomy, Jawaharlal Institute of Postgraduate Medical Education and Research (JIPMER), Puducherry; India

Abstract

The angular dimensions of the talus are indicative of its biomechanical role in load transmission. Squatting facets on the neck of the talus are indicative of habitual squatting. The primary objective of this study was to estimate the strength of association between the talar angles and the presence of squatting facets. The secondary objectives were to estimate the side differences in the angular dimensions and to assess the reliability of the method. One hundred and sixty dry tali of unknown sex were studied. The neck angle, vertical angle, torsion angle, trochlear surface angle and depth angle were measured using a photographic method. The presence of squatting facets was noted. The mean and standard deviation of those angles were 108.3 ± 5.23, 89.87 ± 3.97, 37.57 ± 5.62, 9.7 ± 3.3 and 156 ± 5.1 degrees respectively. The neck, vertical and depth angles were significantly higher on the left side. There were significant positive correlations between the neck and vertical angles, the neck and depth angles and the torsion and depth angles. Squatting facets were noted in 90 of the 160 (56%) of the tali. The torsion angle was significantly higher in tali with squatting facets. Intraobserver and inter-observer reliability of the methods were found to be good to excellent. The findings of this study indicate the factors that can possibly influence the magnitude of the talar angles. This data can be useful for designing talar prostheses and analyzing the biomechanical interface of the hind foot bones.

Key words

Talus, angular dimensions, biomechanics, squatting facets.

Introduction

The talus is the key bone of the human tarsus as it transmits the body weight to the calcaneus and other tarsal bones. The parts of the bone include the head, neck and body. The neck is directed medially and connects the head with the body of the talus at an angle (Standring, 2008). The talus is a good example of the plasticity exhibited by bones in response to mechanical requirements of new functions which are imposed on it (Mahmoodian et al., 2009; Hellier and Jeffery, 2006). Since the talus endures significant differential forces during locomotion, the stress patterns across the talus influence its overall dimensions, articular surface areas and angles (Mahato and Murthy, 2012).

The talar angles include the neck angle (NA), vertical angle (VA) and torsion angle (TA) (Mahato and Murthy, 2012). The NA is defined as the outer angle sub-

* Corresponding author. E-mail: nsuresh3888@gmail.com

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tended between the axis of the head and neck of talus and an imaginary plane drawn across the superior articular surface through the mid-points of the tibial and fibular articular surfaces on either side of the body of talus. The VA is the angle formed between the axis of the head of the talus and the line connecting the summit of the medial talar articular surface to the tip of the posterior tubercle. The TA is measured as the angle between the transverse axis of the articular surface of the head of the talus and an imaginary transverse axis corresponding with the plane above the superior articular surface of the talus (Mahato and Murthy, 2012). Previous studies have measured the morphology of the trochlear surface and depth of the trochlear surface by linear parameters. The current study has attempted to define these parameters in terms of angles. The trochlear surface angle (TSA) is the angle subtended between the medial and lateral edges of the trochlear surface, which is directed posteriorly (Daud et al., 2013). The depth angle (DA) was measured as the angle formed between the medial and lateral slopes of the trochlear surfaces.

Squatting is a resting postural complex that involves hyperflexion at the hip and knee and hyperdorsiflexion at the ankle and subtalar joints. During locomotion, the foot is rarely dorsiflexed sufficiently to bring the anterior border of the inferior extremity of the tibia into contact with the dorsum of the neck of the talus. When habitual squatting occurs, modifications of the neck of the talus and the distal tibia occur, resulting in the appearance of squatting facets (Barnett et al., 1954; Boulle et al., 2001). Squatting facets are more frequent in adult Indians than Caucasians because of habitual squatting practices among them (Dixit et al., 2012).

Talar prostheses are increasingly being used for the treatment of fractures of the talus. The angular dimensions of the prosthesis need to be accurate to provide good joint motion (Islam et al., 2014). In pathological conditions like club foot, the NA is increased and the severity of club foot is also classified based on the NA. Hence during surgery the focus is to reduce the malalignment of the hind foot bones and thereby correcting the NA by osteotomy procedures (Kamegaya et al., 2001; Farsetti et al., 2009).

This study focuses on the angular dimensions of the talus and their association with squatting facets. Previous studies have independently investigated the talar angles and squatting facets. Squatting facets are evidence of specific forces that the talus is exposed to. We hypothesized that there would be an influence of these forces on the angular dimensions of the talus. The primary objective of this study was to estimate the strength of association between the talar angles and the presence of squatting facets. The secondary objectives of the study were to estimate the side differences in the angular dimensions and to assess the reliability of the methods used to estimate the angular dimensions.

Materials and methods

This was a cross-sectional analytical study. A total of 160 dry tali (Eighty right and eighty left) of unknown sex, available in the Department of Anatomy, St. John's Medical College, Bangalore were studied. Damaged tali were excluded. The bones were numbered and placed on a flat osteometric board to which a camera was fixed. A graph paper pasted on the board helped to align the bone and the camera to avoid errors of parallax. Digital photographs of the superior, medial and end-on views of the talus were then taken and used for further analysis.

The digital images were transferred to Microsoft PowerPoint software 2010 and the required lines were drawn. The NA was measured between the axis of head and neck (two points were marked along the midpoint of medial and lateral edges of the head neck region, the midpoint of this line was extended posteriorly to meet the midpoint of axis of the body), and a transverse line representing the body of the talus (four points were marked along the four corners of the body of talus, the midpoints of anterior and posterior points were marked and connected) (Figure 1) (Mahato and Murthy, 2012). The VA was measured on the comma shaped medial surface. Two lines were drawn from the summit, one to the posterior tubercle and the other to the midpoint of head span (two points were marked along the superior and inferior edges of the head neck junction). The angle subtended was measured as the VA (Figure 2) (Mahato and Murthy, 2012). The TA was measured as the angle between the oblique axis of the head of the talus (a line was drawn parallel to the head orientation) and an imaginary line corresponding to the superior articulating surface of the talus (a line connecting the medial and lateral edges of the body of talus) (Figure 3) (Mahato and Murthy, 2012). The TSA was measured as the angle subtended between the medial and lateral edges of the trochlear surface (points were marked along the medial and lateral edges of the body of talus on the anterior, middle and posterior part of body of talus. The lines were connected and extended posteriorly to meet at an angle: Figure 4) (Daud et al., 2013). The DA was measured as the angle formed between the medial and lateral slopes of the trochlear surfaces (Figure 5). The angles were then measured using ImageJ software.

Squatting facets were identified as smooth areas present on the dorsum of the

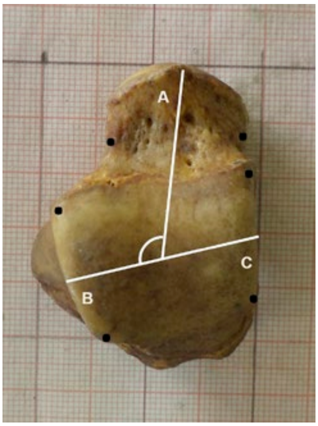

Figure 1. Method of determining the neck angle (NA). NA was measured between lines A and BC at the midpoint of the latter. A – axis of head and neck; BC – transverse line across the body of talus.

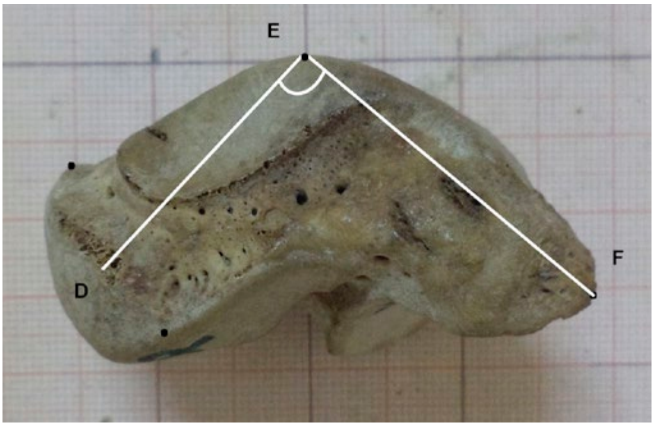

Figure 2. Method of determining the vertical angle (VA). The VA was measured between lines DE and EF. E – highest point of medial articular surface; DE – axis of head and neck; EF – line connecting the summit to posterior tubercle of talus.

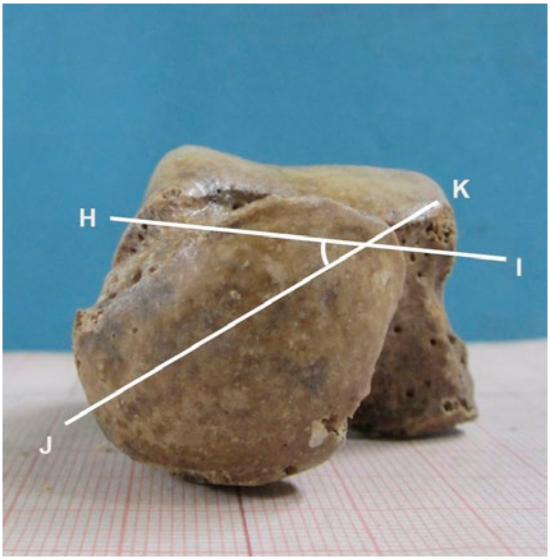

Figure 3. Method of determining the torsion angle (TA). TA was measured between lines HI and JK. HI – superior articular surface of talus; JK – oblique axis of head and neck of talus.

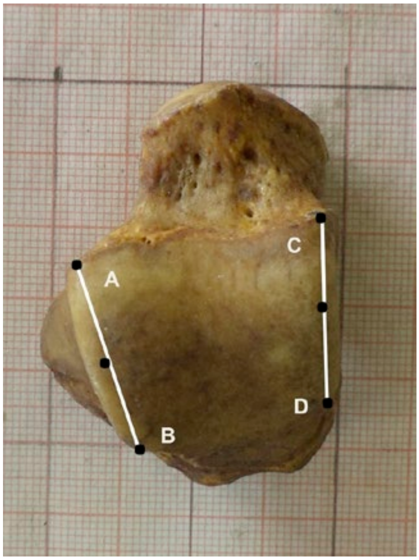

Figure 4. Method of determining trochlear surface angle (TSA). TSA was measured between lines AB and BC, by extending them posteriorly. AB – lateral edge of trochlear surface; BC – medial edge of trochlear surface.

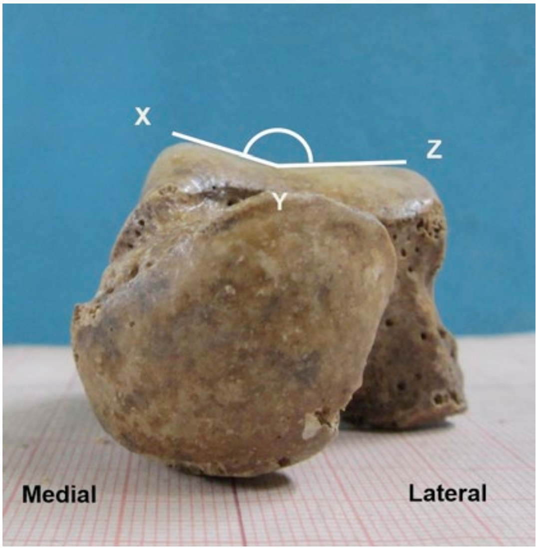

Figure 5. Method of determining depth angle (DA). DA was measured between lines XY and YZ. XY – medial trochlear facet; YZ – lateral trochlear facet.

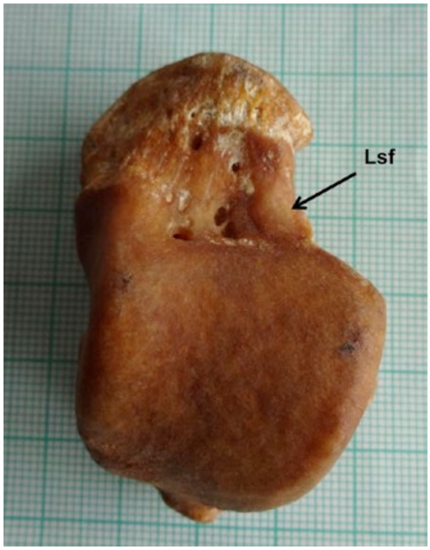

Figure 6. A lateral squatting facet (LSF).

neck of the talus which did not follow the line of curvature of the trochlear surface (Barnett et al., 1954; Boulle et al., 2001). The dry bones were analyzed for the presence of medial and lateral squatting facets (Figure 6). The angular dimensions were independently measured by another observer on 20 randomly selected tali to test the inter-observer reliability of the method. The measurements were also repeated by the principal investigator on 20 randomly selected tali to assess intra-observer reliability.

The mean and standard deviation of the angles were calculated. Side differences between the angles were estimated using the independent sample T test and the strength of association between the angles by Pearson's correlation coefficient. The differences between the angular dimensions with and without squatting facets were estimated using the independent sample T test. Intra-class correlation coefficient (ICC) was used to estimate the intra and inter-observer reliability. A two-way mixed model and consistency type was used to calculate the ICC and the single measures coefficient reported in the results. The statistical analysis was done using SPSS version16.0 software. P values less than 0.05 were registered and assumed as significant.

Results

The mean and standard deviation of NA, VA, TA, TSA and DA were 108.3 ± 5.23, 89.87 ± 3.97, 37.57 ± 5.62, 9.7 ± 3.3 and 156 ± 5.1 degrees respectively when all 160 bones were considered. There were significant side differences in the NA, VA and DA, but not in the TA and TSA (Table 1). Significant positive correlations between the NA and VA, NA and DA, and TA and DA were observed (Table 2). Among the 160 dry talus bones, 90 bones (56.3%) had squatting facets while in the other 70 (43.7%) bones squatting facets were absent. Among the 90 bones with squatting facets, 8 had medial facets (8.9 %), 60 had lateral facets (66.7 %) and 22 had both medial and lateral facets (24.4 %). A significant difference was observed in TA between bones with and without squatting facets. The ICC values indicated that there was good intra-

Table 1. Side differences in the talar angles (SD: Standard deviation).

Angle	Side (n=80, right and left)	Values in degrees (mean ± SD)	P
Neck angle	Left	110 ± 5.21	< 0.001
	Right	105.8 ± 3.90	
Vertical angle	Left	90.58 ± 4.27	< 0.05
	Right	89.18 ± 3.56	
Torsion angle	Left	38.19 ± 6.32	not significant
	Right	36.96 ± 4.81	
Trochlear surface angle	Left	9.3 ± 3.2	not significant
	Right	10 ± 3.3	
Depth angle	Left	157 ± 5.2	< 0.001
	Right	154 ± 4.6	

Table 2. Correlation between the talar angles.

Angles (n = 160)	NA (r and P value)	VA	TA	TSA	DA
NA	1				
VA	0.251 < 0.01	1			
TA	- 0.01 not significant	- 0.05 not significant	1		
TSA	- 0.05 not significant	- 0.08 not significant	0.02 not significant	1	
DA	0.17 < 0.05	0.08 not significant	0.29 < 0.001	<0.01 not significant	1

observer reliability (0.852 to 0.993 depending on angles) and inter-observer reliability (0.665 to 0.916) with p value $p < 0.001$ in all angles.

Discussion

The average values of NA, VA and TA obtained in the present study were comparable with previous Indian and French studies where a similar photographic method was used (Bonnel et al., 2011; Mahato and Murthy, 2012). However, studies in Western populations using CT and MRI scans showed variability in the values (Kamegaya et al., 2001; Windisch et al., 2007; Farsetti et al., 2009). This could be due to the lack of a standardized definition or protocol to measure the angles. In the current study, there were significant positive correlations between the NA and VA, NA and DA and TA and DA. These results indicate that there may be common factors that influence the magnitude of these angles. Previous studies have stated that the NA is a reflector of the magnitude of stress across the trochlear surface (Mahato and Murthy, 2012). Increased load transmission across the trochlear surface of the talus results in flattening of the bone and medial deviation of head and neck region thereby increasing the VA and NA (Mahato and Murthy, 2012). The DA also increases as the bone is flattened, thus possibly explaining the significant positive correlation between NA and DA. Mahato and Murthy (2012) have also stated that an increase in the VA is associated with a corresponding increase in the NA and a decrease in TA. However, this inverse correlation between the VA and NA with the TA was not observed in the present study. It was noted with interest that the NA, VA and DA were significantly greater on the left side. These significant side differences noted in the present study could possibly be explained by altered load transmission across the hind foot bones on each side.

The mean TSA obtained in the present study was 9.7 ± 3.3 degrees. Other studies have reported values ranging from 9.9 to 11.87 degrees (Daud et al., 2013; Siegler et al., 2014). The shape and orientation of the trochlear surface is vital in allowing for smooth joint motion and in providing ankle stability (Frigg et al., 2007; Kleipool and Blankevoort 2010; Parra et al., 2012). In the present study, the DA was used as a novel method to analyze the trochlear groove. It was found that the medial slope was steeper than the lateral slope. An increase in the depth of the trochlear surface could give better congruence and stability to the tibio-talar articulation. Previous studies have attempted to analyze the trochlear groove by using linear parameters and the talar dome ratio (Wiewiorski et al., 2012; Pablos et al., 2013). The trochlear groove is a three-dimensional groove which might vary in depth from anterior to posterior (Wiewiorski et al., 2012), but the DA measured in the present study only gives an approximate value of the depth which we intend to measure. Evolutionarily, a flatter trochlear surface favors terrestrial locomotion as opposed to arboreal locomotion (Harcourt-Smith and Aiello, 2004).

To determine the association between presence of squatting facets and the angular dimensions, talar angles with and without squatting facets were compared. The TA of tali with squatting facets (36.6 ± 5.1) and without squatting facets (38.7 ± 6) showed significant difference ($p < 0.05$), other angles did not show such differences. In the present study, the prevalence of lateral squatting facets was more than medial squatting facets. This was in concurrence with a similar study from India (Dixit et al., 2012). These results point to the fact that squatting more often increases load transmission in the lateral region of the neck of the talus than the medial region. This could be a possible explanation for the significant differences observed in the TA.

Many of the previous studies have employed CT and MRI scans to measure the angular parameters of the talus (Kamegaya et al., 2001; Windisch et al., 2007; Farsetti et al., 2009). However, the photographic method is likely to provide more accurate data since the soft tissues are removed. The intra-observer reliability was found to be excellent for all the angles, the inter-observer reliability was found to be good for the NA, VA, TA, and TSA and excellent for the DA.

The clinical correlates of the talar angles are important. In club foot, the NA and TA are increased and the severity of club foot is also classified based on it (Kamegaya et al., 2001; Windisch et al., 2007). Therefore, during surgery, the focus is to reduce the malalignment of the hind foot bones and thereby correct the NA by osteotomy procedures (Kamegaya et al., 2001). A decrease in TA can alter the talo-navicular articulation and cause it to shift to a more horizontal orientation. This may lead to partial obliteration of the transverse arching of the fore-foot (Mahato and Murthy, 2012). There is a high risk of malunion in talar fractures which can lead to chronic ankle pain and disabilities (Rammelt and Zwipp, 2009). Orthopedic surgeons need to have a detailed knowledge of the angular dimensions of the talus to perform osteotomy and screw fixation (Suter et al., 2013). In the present study, significant side differences were noted in the NA, VA and DA. This should be borne in mind while designing talar prostheses (Islam et al., 2014).

This study has focused on the angular dimensions of talus and the importance of squatting in determining it. Since the study was done on dry bones of unknown origin, the associations with gender and soft tissue measurements were not studied. Our study provided normative data about the NA, VA, TA, TSA and DA. Significant correlations were found between the NA and VA, NA and DA and TA and DA. The side differences in the magnitude of the NA, VA and DA were also significant. Squatting facets were associated with a significantly reduced TA. The methods used to in the measurement of the angles were reliable. The findings of this study indicate the factors that can possibly influence the magnitude of the talar angles. This data can be useful for designing talar prostheses and analyzing the biomechanical interface of the hind foot bones.

Author's contributions

Dr. Suresh Narayanan, Dr. Nachiket Shankar - Contributed to standardizing the methodology, data collection and statistical analysis.

Dr. Vijay Kishan, Dr. Vaidyanathan Balasubramanyam - Contributed to formulating the research objectives, taking photograph and testing the reliability of the methodology.

Conflicts of interest

There are no conflicts of interest.

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References

Barnett C.H. (1954) Squatting facets on the European talus. J. Anat. 88: 509–513.

Bonnel F. (2011) Biometry of bone components in the talonavicular joint: A cadaver study. Orthop. Traumatol. Surg. Res. 97 (6 suppl.): 66–73.

Boulle E.L. (2001) Evolution of two human skeletal markers of the squatting position: A diachronic study from antiquity to the modern age. Am. J. Phys. Anthropol. 115: 50–56.

Daud R. (2013) Three-dimensional morphometric study of the trapezium shape of the trochlea tali. J. Foot Ankle Surg. 52: 426–431.

Dixit S.G., Kaur J., Kakar S. (2012) Racial variation on articular surface of talus (astragalus) in North Indian population. J. Forensic Leg. Med. 19: 152–157.

Farsetti P. (2009) CT study on the effect of different treatment protocols for clubfoot pathology. Clin. Orthop. Relat. Res. 467: 1243–1249.

Frigg A. (2007) The biomechanical influence of tibio-talar containment on stability of the ankle joint. Knee Surg. Sports Traumatol. Arthrosc. 15: 1355–1362.

Harcourt-smith W.E.H., Aiello L.C. (2004) Fossils, feet and the evolution of human bipedal locomotion. J. Anat. 204: 403–416.

Hellier C.A., Jeffery N. (2006) Morphological plasticity in the juvenile talus. Foot Ankle Surg. 12:1 39–147.
Islam K., Dobbe A., Duke K., El-Rich M., Dhillon S., Adeeb S., Jomha N.M. (2014) Three-dimensional geometric analysis of the talus for designing talar prosthetics. Proc. Inst. Mech. Eng. H 228: 371–378.
Kamegaya M. (2001) MRI study of talonavicular alignment in club foot. J. Bone Surg. Br. 83: 726-730.
Kleipool R.P., Blankevoort L. (2010) The relation between geometry and function of the ankle joint complex: A biomechanical review. Knee Surg. Sports Traumatol. Arthrosc. 18: 618–627.
Mahato N., Murthy S. (2012) Articular and angular dimensions of the talus: Inter-relationship and biomechanical significance. Foot 22: 85–89.
Mahmoodian R. (2009) Mechanical properties of human fetal talus. Clin. Orthop. Relat. Res. 467: 1186–1194.
Pablos A. (2013) Human talus bones from the Middle Pleistocene site of Sima de los Huesos (Sierra de Atapuerca, Burgos, Spain). J. Hum. Evol. 65: 79–92.
Parra W.C.H., Chatterjee H.J., Soligo C. (2012) Calculating the axes of rotation for the subtalar and talocrural joints using 3D bone reconstructions. J. Biomech. 45: 1103–1107.
Rammelt S., Zwipp H. (2009) Talar neck and body fractures. Injury 40: 120–135.
Siegler S. (2014) The Clinical Biomechanics Award 2013 - Presented by the International Society of Biomechanics: New observations on the morphology of the talar dome and its relationship to ankle kinematics. Clin. Biomech. 29: 1–6.
Standring S. (2008) Gray's Anatomy: The Anatomical Basis of Clinical Practice. 40th edn. New York, Elsevier Churchill Livingstone.
Suter T. (2013) Surgical technique: Talar neck osteotomy to lengthen the medial column after a malunited talar neck fracture foot and ankle. Clin. Orthop. Relat. Res. 471: 1356–1364.
Wiewiorski M. (2012) Computer tomographic evaluation of talar edge configuration for osteochondral graft transplantation. Clin. Anat. 25: 773–780.
Windisch G. (2007) Anatomical study for an update comprehension of clubfoot. Part I: Bones and joints. J. Child. Orthop. 1: 69–77.