



Morphometric analysis of talus and calcaneus

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Abstract

Purpose The variations in the subtalar joint regarding its morphology and articulation of bones are common worldwide. This study aimed to analyze the morphometric variations in articulating facets of talus and calcaneum in South Indian population.

Methods For this study, the morphometric parameters of 92 dry tali and 49 dry calcanei of unknown gender were analyzed. The pattern of articulating facets was classified based on Boyan et al. as Type A (A1–A4), Type B (B1 and B2), and Type C.

Results Type B was found to be the most common pattern in the study population (talus—97.8%; calcaneus—80.2%). The morphometric parameters were expressed as mean \pm 2 SD. The anteroposterior length of the left talus was more than right talus, while the transverse width of right and left talus is almost equal. The length of right sulcus tali appears to be more than left sulcus tali, whereas the width and depth of right and left sulcus tali was almost equal. The transverse width of the right calcaneus was greater than left calcaneus. Width and depth of right and left sulcus calcanei were almost equal, but the length of right sulcus calcanei was more than the left sulcus calcanei (p value = 0.036).

Conclusion Analysis of the pattern of articulating facets of talus and calcaneum and establishing the common types and their morphometric parameters will be helpful as an important tool for reconstruction surgeries of hind-foot deformities and foot rehabilitation procedures.

Keywords Calcaneus · Morphometry · Subtalar joint · Talus

Introduction

The weight of the body is distributed through the talus to the medial and lateral longitudinal arches of foot via the subtalar joint. Given its importance, even the slightest of the structural variations in the talus or calcaneus may bear an effect on the biomechanics of the subtalar joint. Talus is the keystone in maintaining the medial longitudinal arch of the foot when it is abnormal may lead to flat foot. A high incidence of pes planus (flat foot) was reported in India through various studies. The incidence of flat foot ranged from 11.25 to 13.6% in the young adult Indian population as reported by various authors [1, 4].

Pes planus can be due to the structural constitution of the bones, tendons, and ligaments in the foot or may be acquired in the adulthood. It may result due to the laxity of the ligaments protecting the longitudinal arches [22].

Variant morphology of the articular facets in the talus and calcaneus in the subtalar joint may influence the range of movement of the subtalar joint, and may lead to the subtalar joint instability, ligamentous laxity, and arthritis [8, 12].

Osteotomy is one of the modalities for the correction of symptomatic idiopathic and non-idiopathic flatfoot deformity [20]. Osteotomies should be done carefully by passing between the anterior and middle articular facets without injuring the facets [11]. However, fused anterior and middle articular facets on the calcaneus bone make the planning of osteotomy difficult. Hence, various types of articular facets on the calcaneus and talus need to be studied to understand the common variations present in their articular surfaces.

The objective of the present study was to identify the common variants in the articular surfaces of the talus and calcaneus that are the important components of the medial longitudinal arch.

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Materials and methods

Materials

A total of 92 (right 48, left 44) dry unpaired tali and 49 (right 27 and left 22) dry unpaired calcanei of unknown gender were used for this study. The bones were obtained from the bone collection of the Department of Anatomy, JIPMER, India, between March and April 2018. The bones with any structural variations and damage were excluded from the study.

Methods

We have classified the calcaneus bone using the classification proposed by Bunning and Barnett.

Bunning and Barnett classified calcaneus into three types: (1) Type A calcaneus has three facets for the talus, anterior, middle, and posterior; (2) Type B has two facets—fused anterior and middle and a separate posterior facet; (3) Type C has a single facet (fused anterior, middle, and posterior facets) [9].

After typing the calcaneus, we have subtyped the bone using the classification proposed by Boyan et al. We have also typed the talus bone using the classification proposed by Boyan et al. Boyan et al. classified calcaneus and talus into three types based on the articular facets for each other. (1) Type A: the anterior and middle articulating facets were present separately, (2) Type B: there will be no separation between the anterior and middle articulating facets, while the posterior facet is separate, and (3) Type C: only one articulating facet was noted with no separation between the anterior, middle, and posterior articulating facets. Based on the distance between the anterior and middle articulating facets, Type A was further divided into the following subtypes: (1) Type A1: the distance between the anterior and middle articulating facets was < 2 mm, (2) Type A2: the distance between the anterior and middle articulating facets was 2–5 mm, and (3) Type A3: the distance between the anterior and middle articulating facets was > 5 mm. Based on the type of separation between facets, Type B was further divided into two subtypes: (1) Type B1: there was an incomplete separation between the anterior and middle facets; (2) Type B2: there was no separation between the anterior and middle facets [7].

After typing the calcaneus and talus, the incidence of each type was evaluated.

Measurement of morphometric parameters of the calcaneus

We have measured the following morphometric parameters of the calcaneus: (1) anteroposterior length of calcaneus, (2) transverse width of calcaneus (3) length of sulcus calcanei, (4) width of sulcus calcanei, and (5) depth of sulcus

calcanei. The anteroposterior length of the calcaneus is measured as the distance between the most anterior point on the anterior surface and the most posterior point on the posterior surface. The transverse width of the calcaneus is measured as the distance between a medial-most point on the medial surface and the lateral-most point on the lateral surface. The length of sulcus calcanei is measured as the distance between the anterior and posterior margins of the sulcus. The width of sulcus calcanei is measured as the distance between the medial margin and lateral margin of the sulcus. The depth of sulcus calcanei is measured as the distance between the base of the sulcus and its summit on the superior surface of the calcaneus.

Figures 1, 2, 3, 4, 5, 6, 7, 8 shows the calcaneus bones used and measurements that were taken in the present study.



Fig. 1 Collection of calcaneus used for this study



Fig. 2 Type A2 calcaneus



Fig. 3 Type A2 calcaneus measured by vernier caliper



Fig. 6 Type C calcaneus



Fig. 4 Type A3 calcaneus

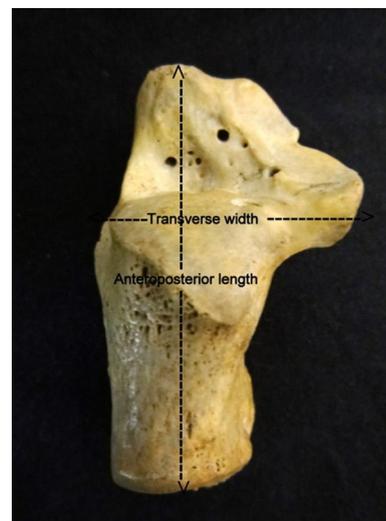


Fig. 7 Calcaneus: antero-posterior length and transverse width



Fig. 5 Type A3 calcaneus measured by vernier caliper



Fig. 8 Sulcus calcaneus: L—length and W—width

Measurement of morphometric parameters of the talus

We have measured the following morphometric parameters in the talus: (1) anteroposterior length of talus; (2) transverse width of talus; (3) length of sulcus tali; (4) width of sulcus tali; (5) depth of sulcus tali. The anteroposterior length of the talus is measured as the distance between the most anterior point on the anterior surface and the most posterior point on the posterior surface. The transverse width is measured as the distance between a medial-most point on the medial surface and the lateral-most point on the lateral surface. The length of sulcus tali is measured as the distance between the most medial end and the lateral end of the sulcus. The width of the sulcus tali is measured as the distance between the anterior margin and posterior margin of the sulcus. The depth of sulcus tali is measured as the distance between the base of the sulcus and its summit on the inferior surface of the talus.

Figures 9, 10, 11, 12, 13, 14 show the talus bones used and measurements that were taken in the present study.



Fig. 9 Collection of talus used for this study



Fig. 10 Type A1 talus



Fig. 11 Type B1 talus (incomplete separation between the anterior and middle facets)



Fig. 12 Type B2 talus (no separation between the anterior and middle facets)

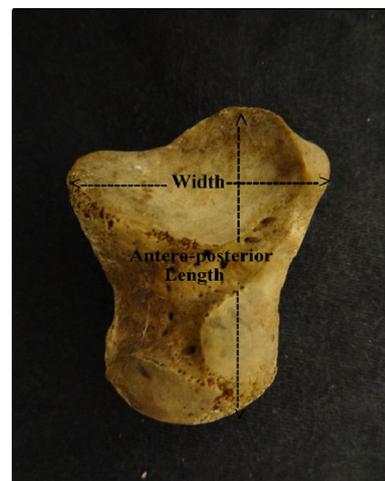


Fig. 13 Talus: antero-posterior length and transverse width

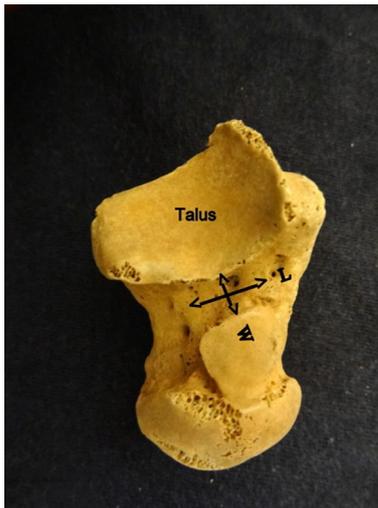


Fig. 14 Sulcus talus: L—length and W—width

All the measurements were done using a digital vernier caliper with a correction of 0.01 mm and repeated for three times to avoid measurement bias.

Results

Morphometry of calcaneus

The mean anteroposterior length of calcaneus was 75.30 ± 6.16 mm on the right side and 75.24 ± 5.10 mm on the left side, and the difference between the right side and the left side was statistically insignificant. The mean transverse width of calcaneus was 43.40 ± 3.59 mm on the right side, and 39.73 ± 5.10 mm on the left side, and the difference between the right side and the left side was statistically significant. The mean length of sulcus calcanei was 11.92 ± 1.34 mm on the right side and 10.61 ± 2.67 mm on the left side, and the difference between the right side and the left side was statistically significant. The mean width of sulcus calcanei was 5.70 ± 1.58 mm on the right side and 5.62 ± 1.93 mm on the left side, and the difference between the right side and the left side was statistically insignificant. The mean depth of sulcus calcanei was 2.21 ± 0.57 mm on the right side and 1.91 ± 0.60 mm on the left side, and the difference between the right side and the left side was statistically insignificant (Tables 1, 2).

The morphometric parameters of the calcaneus bone are summarized in Tables 3, 4, 5, 6, and 7.

Table 1 Classification of calcaneus based on the type of articulating facets

Parameters	Right, n (%)	Left, n (%)	Total, n (%)
Type A1	0 (0)	0 (0)	0 (0)
Type A2	2 (7.4)	0 (0)	2 (4.1)
Type A3	3 (11.1)	2 (9.1)	5 (10.2)
Type A4	1 (3.7)	1 (4.6)	2 (4.1)
Type B1	18 (66.7)	3 (13.6)	21 (42.9)
Type B2	2 (7.4)	16 (72.7)	18 (36.7)
Type C	1 (3.7)	0 (0)	1 (2.0)
Total	27 (55.1)	22 (44.9)	49 (100)

Bones are typed based on the classification given by Boyan et al. [7]
n number of calcaneus bones studied

Table 2 Classification of talus based on the type of articulating facet

Parameters	Right, n (%)	Left, n (%)	Total, n (%)
Type A1	0 (0)	1 (2.3)	1 (1.1)
Type A2	1 (2.1)	0 (0)	1 (1.1)
Type A3	0 (0)	0 (0)	0 (0)
Type A4	0 (0)	0 (0)	0 (0)
Type B1	24 (50)	30 (68.2)	54 (58.7)
Type B2	23 (47.9)	13 (29.5)	36 (39.1)
Type C	0 (0)	0 (0)	0 (0)
Total	48 (100)	44 (100)	92 (100)

Bones are typed based on the classification given by Boyan et al. [7]
n number of talus bones studied

Table 3 Anteroposterior length of calcaneus (in mm)

Side	Numbers	Range (mm)	Mean (mm)	SD (mm)
Right calcaneus	26	65.53–97.99	75.30	6.16
Left calcaneus	23	65.13–84.93	75.24	5.10

p value = 0.974

Table 4 Transverse width of calcaneus (in mm)

Side	Numbers	Range (mm)	Mean (mm)	SD (mm)
Right calcaneus	26	38.17–54.99	43.40	3.59
Left calcaneus	23	31.93–56.93	39.73	5.10

p value = 0.006

Table 5 Length of sulcus calcanei (in mm)

Side	Numbers	Range (mm)	Mean (mm)	SD (mm)
Right calcaneus	26	9.09–14.16	11.92	1.34
Left calcaneus	23	7.45–13.45	10.61	2.67

p value = 0.036

Table 6 Width of sulcus calcanei (in mm)

Side	Numbers	Range (mm)	Mean (mm)	SD (mm)
Right calcaneus	26	1.85–8.83	5.70	1.58
Left calcaneus	23	4.09–10.43	5.62	1.93

p value=0.884

Table 7 Depth of sulcus calcanei (in mm)

Side	Numbers	Range (mm)	Mean (mm)	SD (mm)
Right calcaneus	26	1.18–3.51	2.21	0.57
Left calcaneus	23	1.12–2.94	1.91	0.6

p value=0.077

The distribution of morphometric parameters of the calcaneus is depicted in the scatter diagrams (Figs. 15, 16, 17, 18, 19).

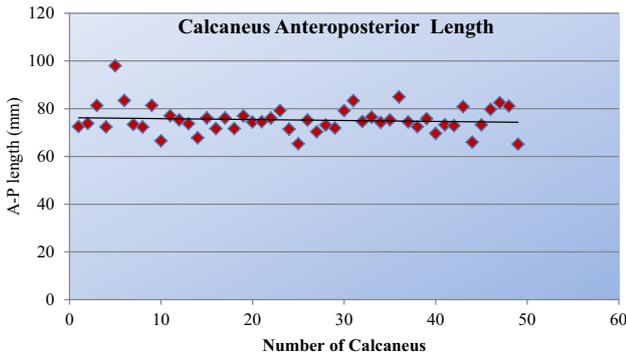


Fig. 15 Distribution of morphometry of calcaneus anteroposterior length (in mm)

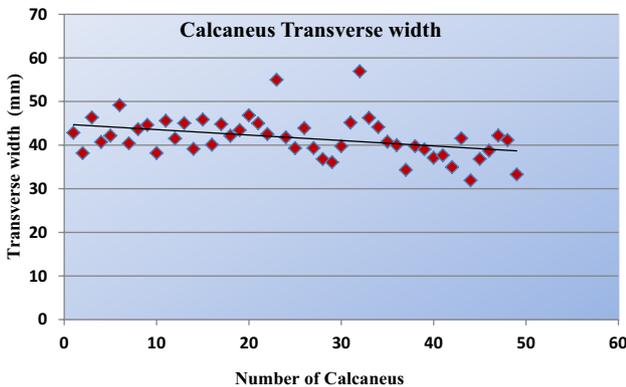


Fig. 16 Distribution of morphometry of calcaneus transverse width (in mm)

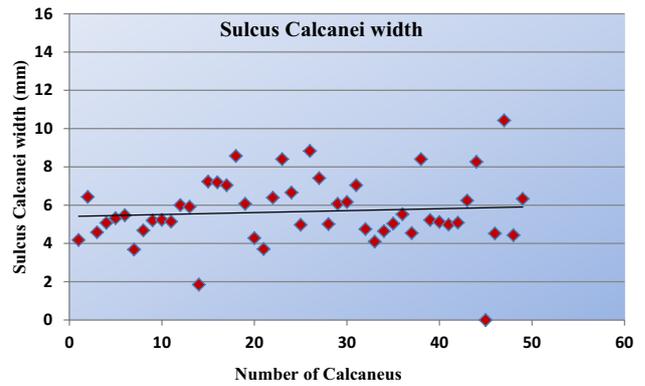


Fig. 17 Distribution of morphometry of sulcus calcanei width (in mm)

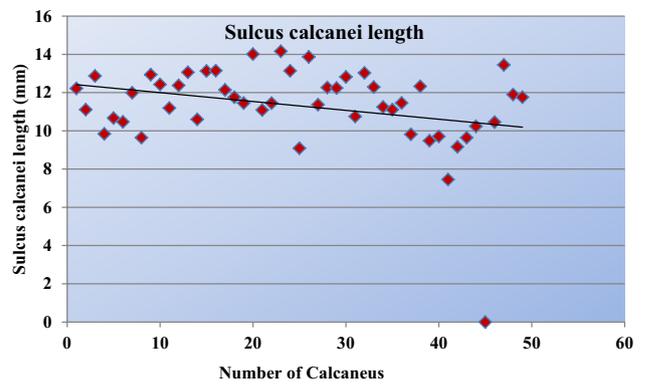


Fig. 18 Distribution of morphometry of sulcus calcanei length (in mm)

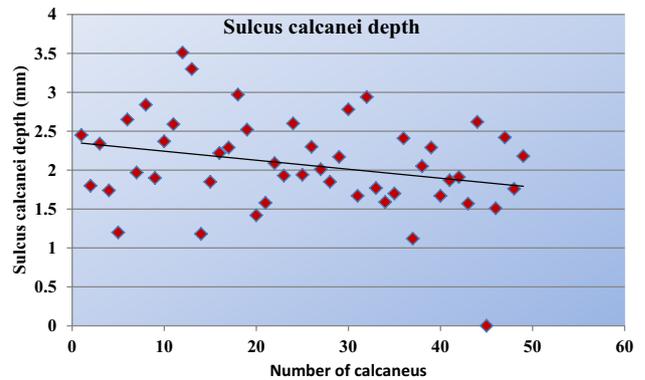


Fig. 19 Distribution of morphometry of sulcus calcanei depth (in mm)

The percentage distribution of various types of the calcaneus as per the classification of Boyan et al. is shown in Fig. 20.

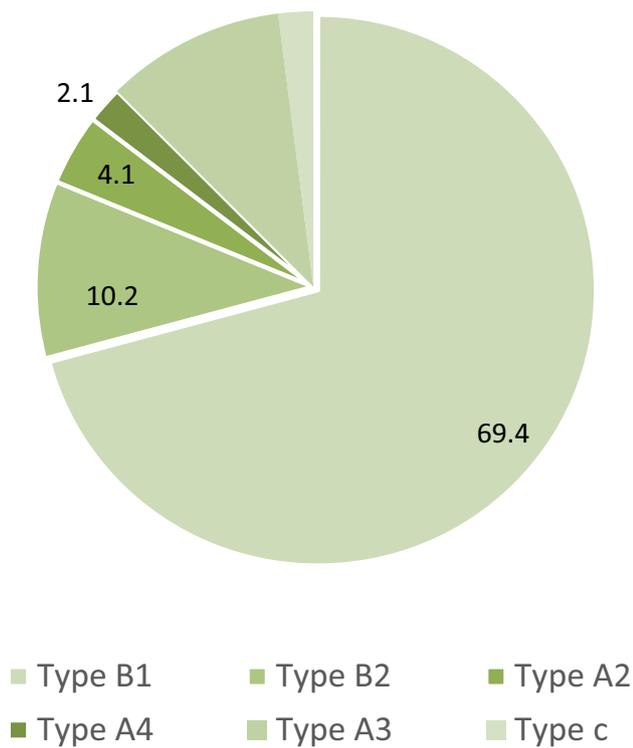


Fig. 20 Classification of calcaneus based on type of articulating facets

Morphometry of talus

The mean anteroposterior length of the talus was 50.51 ± 3.90 mm on the right side and 51.52 ± 4.16 mm on the left side, and the difference between the right side and the left side was statistically insignificant. The transverse width of the talus was 36.29 ± 2.94 mm on the right side and 36.92 ± 2.71 mm on the left side, and the difference between right side and the left side was statistically insignificant. The mean length of sulcus tali was 12.24 ± 2.87 mm on the right side and 10.53 ± 2.86 mm on the left side, and the difference between right side and left side was statistically significant. The mean width of sulcus tali was 5.65 ± 1.30 mm on the right side and 5.22 ± 1.49 mm on the left side, and the difference between right side and left side was statistically insignificant. The depth of sulcus tali was 3.97 ± 1.02 mm on the right side and 4.02 ± 1.08 mm on the left side, and the difference between right side and the left side was statistically insignificant.

The morphometric parameters of the talus bone are summarized in Tables 8, 9, 10, 11, and 12.

Table 8 Anteroposterior length of talus (in mm)

Side	Numbers	Range (mm)	Mean (mm)	SD (mm)
Right talus	48	43.13 – 58.32	50.51	3.90
Left talus	44	43.26–60.08	51.52	4.16

p value = 0.240

Table 9 Transverse width of talus (in mm)

Side	Numbers	Range (mm)	Mean (mm)	SD (mm)
Right talus	48	30.41–42.4	36.29	2.94
Left talus	44	33.93–43.25	36.92	2.71

p value = 0.293

Table 10 Length of sulcus tali (in mm)

Side	Numbers	Range (mm)	Mean (mm)	SD (mm)
Right talus	48	7.84–21.64	12.24	2.87
Left talus	44	5.65–17.26	10.57	2.91

p value = 0.007

Table 11 Width of sulcus tali (in mm)

Side	Numbers	Range (mm)	Mean (mm)	SD (mm)
Right talus	48	2.82–9.16	5.65	1.30
Left talus	44	2.85–9.19	5.27	1.51

p value = 0.201

Table 12 Depth of sulcus tali (in mm)

Side	Numbers	Range (mm)	Mean (mm)	SD (mm)
Right talus	48	2.04–6.18	3.97	1.02
Left talus	44	1.67–7.02	4.08	1.16

p value = 0.628

The distribution of morphometric parameters of the talus is depicted in the scatter diagrams (Figs. 21, 22, 23, 24, 25).

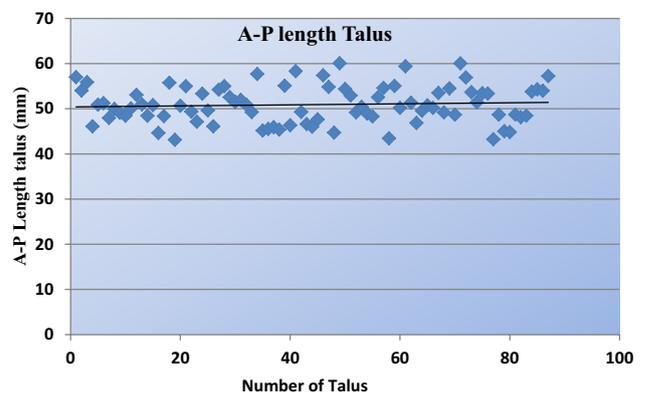


Fig. 21 Distribution of morphometry of talus anteroposterior length (in mm)

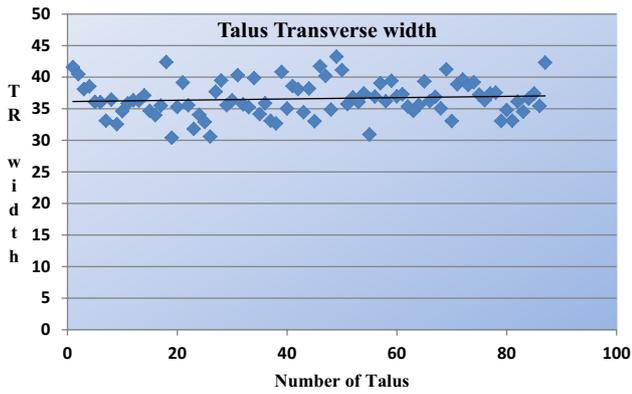


Fig. 22 Distribution of morphometry of talus transverse width (in mm)

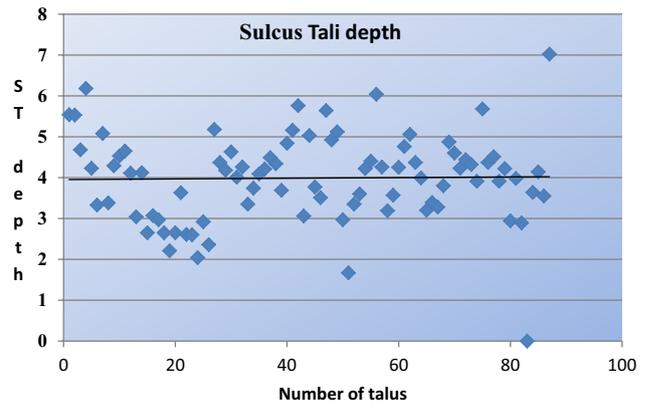


Fig. 25 Distribution of morphometry of sulcus tali depth (in mm)

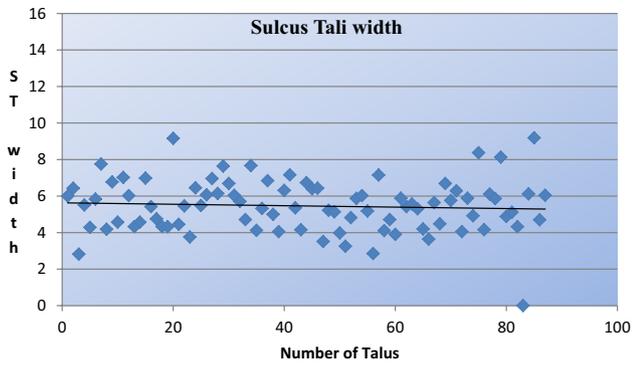


Fig. 23 Distribution of morphometry of sulcus tali width (in mm)

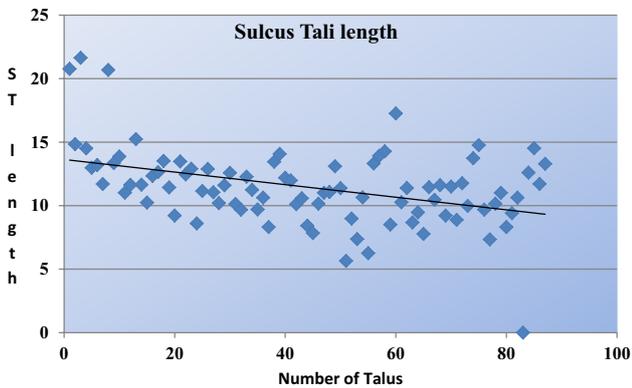


Fig. 24 Distribution of morphometry of sulcus tali length (in mm)

The percentage distribution of various types of the talus as per the classification of Boyan et al. is shown in Fig. 26.

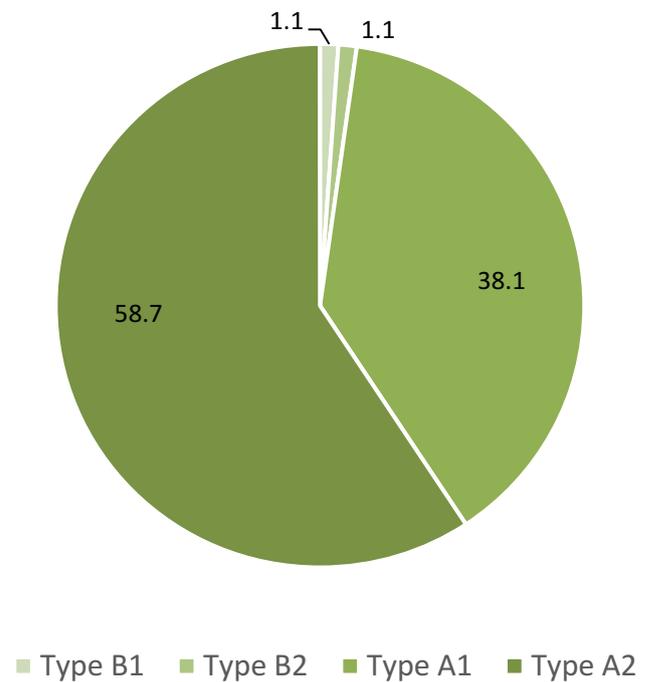


Fig. 26 Classification of talus based on articulating facets

Discussion

For identifying the joint pathologies and planning, the surgical treatment needs an accurate analysis of the structure of the joint. The morphometric data of talus and calcaneus can be used to prepare a database that can be used as landmarks for clinical exploration and research [6]. Structural variations of articular surfaces of talus and calcaneus affect the torque stability of the foot while walking [6]. The articular facets of talus and calcaneus show racial differences in different populations [9, 13, 20].

Classification of calcaneus by Bunning and Barnett

Bunning and Barnett classified the calcaneus based on the talar articular facets into three types: A, B, and C. In Type A, there are three facets for talus; Type B has two facets; Type C has a single facet for articulation with the talus [9].

Sharada et al. classified the talar articular facets on calcaneus bone into Type 1, Type 2, Type 3, and Type 4.

Type 1 has anterior and middle articular facets for talus. Type 2 has anterior, middle, and posterior articular facets for talus. Type 3 has two articular facets, where the anterior facet was present on the sustentaculum tali. Type 4 has a single articular facet for talus. Type 1 was further subclassified into Type 1a and Type 1b, where Type 1a had a non-constricted facet and Type 1b had a constricted anterior facet for talus. However, Type 1a of Sharada et al. is similar to the Type B2 classification of Boyan et al. and Type 1b of Sharada et al. is similar to the Type B1 classification of Boyan et al. [7, 23].

Anjaneyulu et al. had classified the articular facets on calcaneus bone into Type A, Type B, Type C, and Type D. Type A is further classified into Type A1, Type A2, and Type A3. In Type A1, the anterior and middle articular facets are separated by less than 2 mm distance. Type A has separated anterior and middle facet. Type B has an articular facet on the sustentaculum tali and the anterior articular facet being absent. Type C has anterior and middle articular facets that are continuous. Type D has an anterior, middle, and posterior talar articular facets that are continuous as a single articular facet. However, Type C and Type D described by Anjaneyulu et al. are similar to the Type B and Type C classification given by the Boyan et al. Type C1 and C2 of Anjaneyulu et al. are similar to Type B1 and B2 of Boyan et al. [2, 7].

Common classification of talus and calcaneus bones by Boyan et al.

Boyan et al. had studied the talus and calcaneus and had given a common classification for talus and calcaneal

articulation based on their articular facets and the distance between them. They have broadly classified the talocalcaneal articular facets into Types A, B, and C similar to the Bunning and Barrett, and they further subclassified the talocalcaneal articulations based on the communication between the articulating facets into Types A1, A2, A3, and A4. In Type A1, the distance between the anterior and middle articular facet for talus was less than 2 mm. In Type A2, the distance between the anterior and middle articular facets was 2–5 mm. In Type A3, the distance between the anterior and middle articular facets was greater than 5 mm. Bunning and Barnett described that Type A4 has only one articular facet on the calcaneus for talus (observation of Type A4 in their study: talus 0%, calcaneum 3.5%). Type B was further classified into Type B1 and B2; Type B1, where there was an incomplete separation between the anterior and middle articular facets, and Type B2, where there was no separation between the anterior and middle articular facets. Type C has a single large articular facet, which is due to the fusion of the anterior, middle, and posterior talocalcaneal articular facets [7, 9].

Lacunae in the classification proposed by Boyan et al.

Boyan et al. while describing the Type A4 did not elaborate on whether the middle articular facet was totally absent or if the anterior and middle facets are fused together. If it is the latter case, then the fused anterior and middle facets will be classified under the subtype B2 as mentioned by Bunning and Barnett, and Boyan [7, 9]. Hence, further elaborate description of Type A4 is necessary to discern the talocalcaneal articular facets from Type B2.

Findings of incidence of calcaneus by various authors

Among the broad types of talus and calcaneus, Boyan et al. found that Type B was the commonest type (61.6%) [7]. In their study of adult calcanei, Bunning and Barnett have reported that the Indian population has 78% incidence of Type B and the African population had 63% of Type B calcaneus [9]. Sharada et al. observed that 67% of the bones were of Type B [23]. Minimol et al. had found that 74% of the calcaneus included in the study were of Type B [19]. In the present study done using adult dry calcanei of south Indian Population, we observed that the Type B was more common (79.6%). The results of

the present study (Type B) are similar to Bunning and Barnett, Boyan et al., Sharada et al., and Minimol et al. [7, 9, 19, 23].

Among the subtypes, Boyan et al. reported that the subtype B2 was the more common type (35.4%) followed by Type B1 (26.1%) [7]. Minimol et al. reported that Type B1 (40%) is more common than Type B2 (34%) subtype [19]. Anjaneyulu et al. described that Type B1 (43%) was more common than Type B2 (19%) [2]. In the present study, Type B1 (42.9%) was found to be the most common type followed by Type B2 (36.7%). The findings in the present study are similar to Anjaneyulu et al. and Minimol et al. and differ from that of the Boyan et al. From the above findings, it is evident that, in Indian population, calcaneus bone belonging to Type B is most common variety, along with the subtype B1, where there is an incomplete separation of anterior and middle talar articular facets on calcaneus.

Confusion regarding the classification of the calcaneus

There are many classifications of calcaneus bone based on the articular facets of the talus that are followed by various authors, which are often overlapping and confusing. Certain features of the Talar articular facets were not included in the original classification proposed by Boyan et al. Certain types of Boyan classification such as Type B and Type C are interpreted as Type C and Type D by Anjaneyulu et al. Type A and Type B of Boyan et al.'s classification are similar to Type 2 and Type 1 of Sharada et al., respectively [2, 7, 23]. Such differences in the terminology used for classification that is often interchanged by various authors create confusion to the clinicians, anthropologists, and forensic specialists, while the classification of the types of calcaneus bone is based on the talar articular surfaces.

After reviewing the classifications proposed by Bunning and Barnett, Boyan et al., Sharada et al., and Anjaneyulu

et al., we propose a modified Boyan classification of talar articular facets of calcaneus that is simple and comprehensive.

Proposed modification of Boyan's classification of calcaneus bone is based on talar articular facets

- | | |
|---------|--|
| Type A | Three separate articular facets. Anterior, middle, and posterior talar articular facets on the calcaneus. |
| Type A1 | Distance between anterior and middle talar articular facets < 2 mm. |
| Type A2 | Distance between anterior and middle talar articular facets 2–5 mm. |
| Type A3 | Distance between anterior and middle talar articular facets > 5 mm. |
| Type B | Two articular facets. Anterior and middle are fused; posterior is separate. |
| Type B1 | Incomplete separation of anterior and middle facets (partially fused, constricted). |
| Type B2 | No separation of anterior and middle articular facets (fused completely, non-constricted). |
| Type B3 | Absent anterior articular facet; middle facet present on the superior surface of sustentaculum tali posterior. |
| Type B4 | Absent middle articular facet; anterior and posterior facets are present. |
| Type C | Single articular facet. Anterior, middle, and posterior talar articulating facets are fused. |

Figure 27 shows the schematic line diagram for the proposed modification of Boyan et al.'s classification.

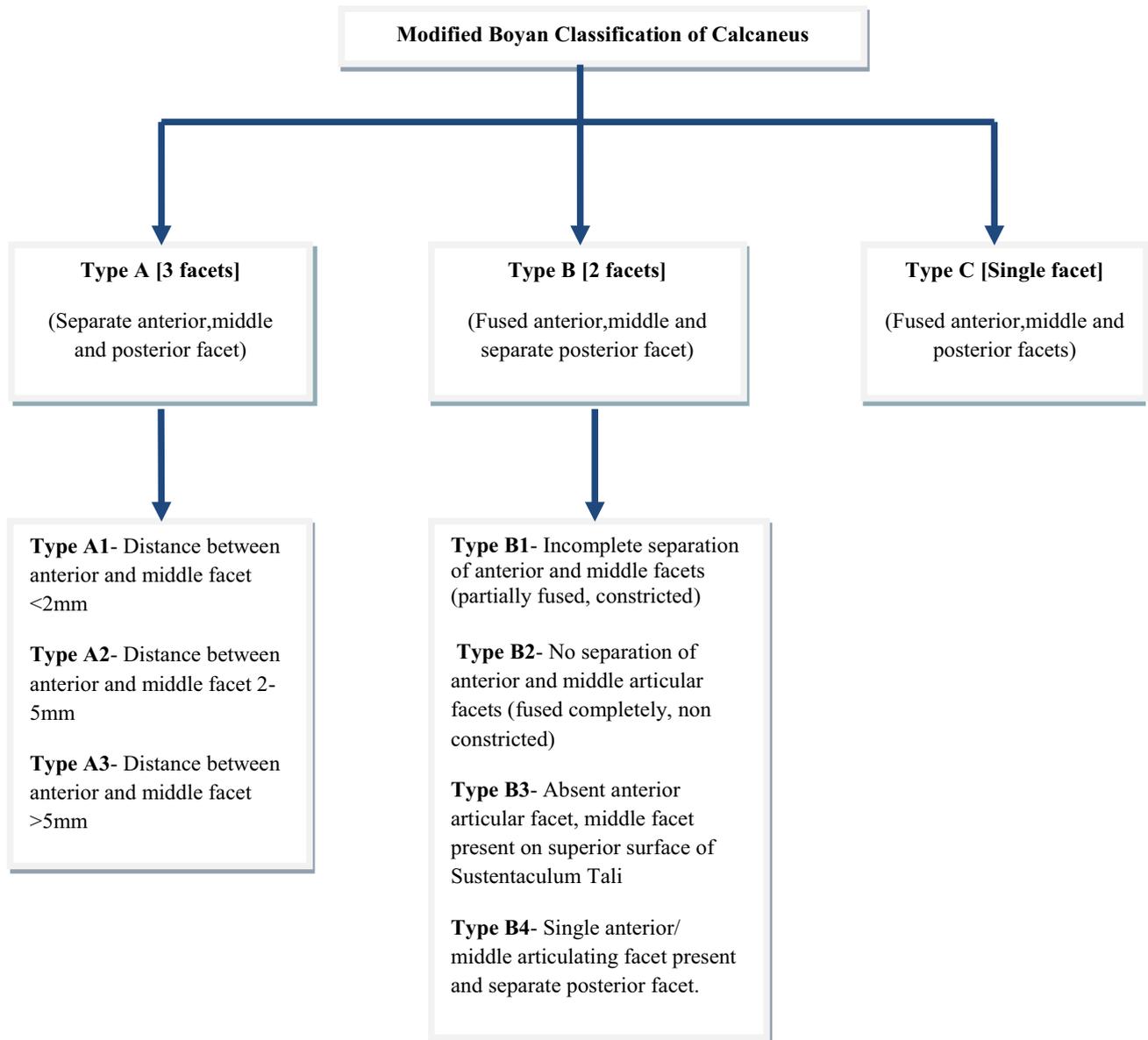


Fig. 27 Modified Boyan classification of calcaneus

Morphometric parameters of the calcaneus

The mean anteroposterior length of the calcaneus observed in the present study is similar to that of the Boyan et al. [7]. The mean transverse width of the calcaneus observed in the present study is almost similar to the results obtained by Koshy et al. [16]. The mean width of the sulcus calcanei is

almost similar to the observations made by Jung et al. and Boyan et al. [7, 14]. However, the mean depth of the sulcus calcanei observed in the present study is different from the observations reported in the earlier studies, and the mean length of the sulcus calcanei observed in the present study was significantly different from the observations reported in earlier studies (Fig. 28).

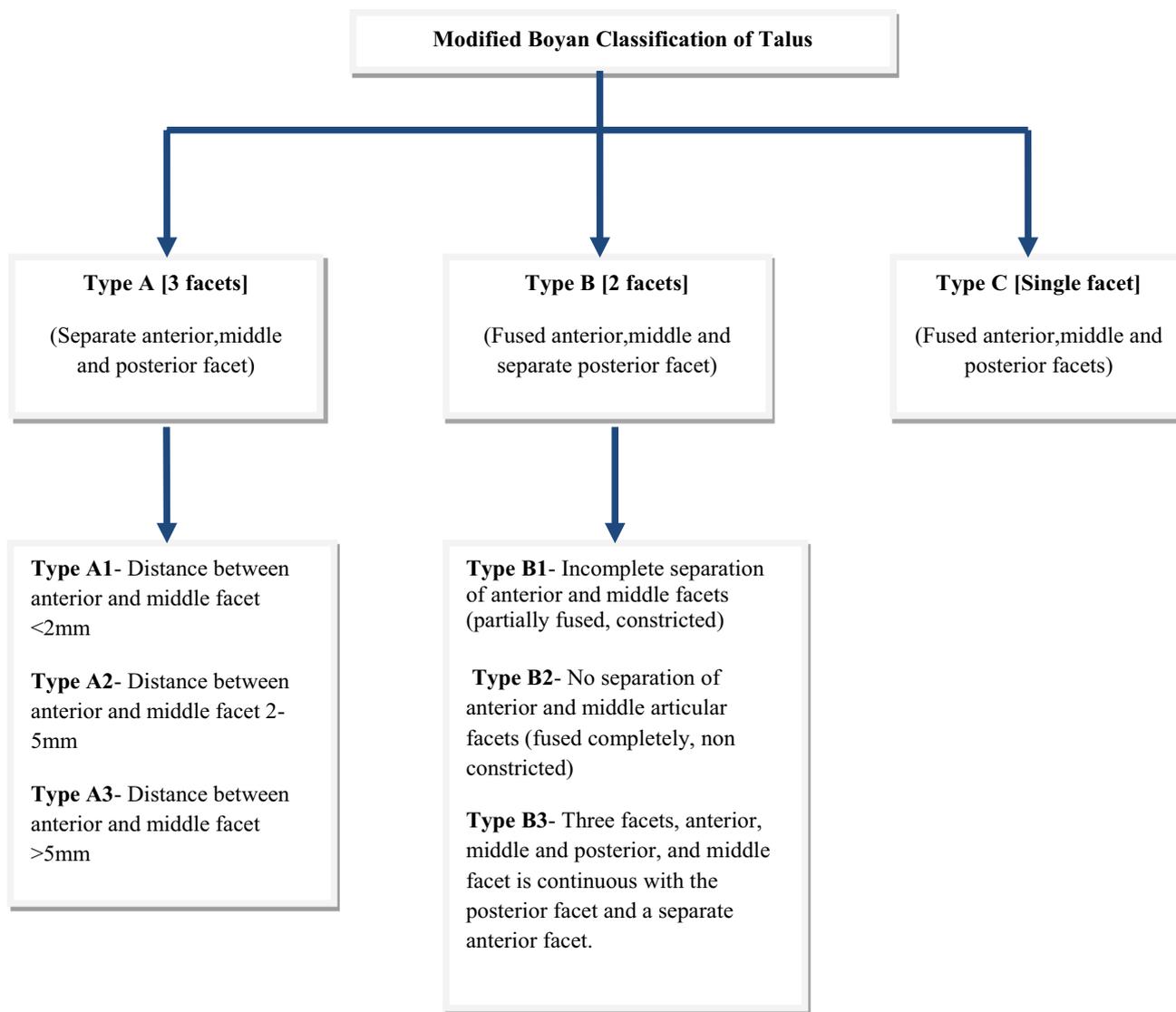


Fig. 28 Modified Boyan classification of talus

Table 13 Comparison of the different classifications proposed by Kaur et al. and Boyan et al.

Kaur et al. [13]	Boyan et al. [6]
Type I	Type B2
Type II and III	Type B1
Type IV	Type A
Type VA	Type C
Type VB	No equivalent

Bones are typed based on the classification given by Boyan et al. [7]

Comparison of morphometric parameters of the calcaneus of the present study with studies by other authors is summarized in Tables 13 and 14.

Talus

The type and number of articulating surfaces on the talus and their variations may predispose to the diseases such as arthritis [12]. Boyan et al. studied the talus and classified the talus based on the articular surfaces into broad Types A, B, and C, and subtypes based on the communication between the articulating facets into subtype A1, A2, A3 and subtype B1, B2 and type C.

The classification proposed by Boyan et al. is widely used and largely accepted for classifying the talus [7]. However, certain other authors had deviated from this classification and followed a different classification. Kaur et al. had classified calcaneal articulating facets of talus into five types: Types I, II, III, IV, and V. Type I has a

Table 14 Comparison of morphometric parameters of calcaneus (mean \pm 2 SD) of the present study with other studies (in mm)

Authors	Population	Anteroposterior length (mm)	Transverse width (mm)	Width of sulcus calcanei (mm)	Length of sulcus calcanei (mm)	Depth of sulcus calcanei (mm)
Koshy [14]	Indians ($n=110$)	73.6 ± 5.7	40.8 ± 4.6	21.1 ± 2.4	31.9 ± 3.5	3.4 ± 0.9
Uygur [24]	Turkish ($n=221$)	77.7 ± 5.65	47.5 ± 4.2	6.15 ± 2.7	30.4 ± 3.1	2.55 ± 0.7
Jung [12]	Korean ($n=118$)	–	–	5.16 ± 1.16	–	–
Boyan [6]	Turkish ($n=57$)	75.88 ± 6.1	44.8 ± 4.09	5.98 ± 1.09	32.33 ± 2.99	4.21 ± 0.93
Present study	Indian ($n=92$)	75.27 ± 11.24	41.56 ± 8.7	5.66 ± 3.51	11.30 ± 4.01	1.91 ± 0.6

Bones are typed based on the classification given by Boyan et al. [7]

n number of calcaneus bones studied

Table 15 Comparison of morphometric parameters of talus (mean \pm 2 SD) of the present study with other studies (in mm)

Authors	Population	Anteroposterior length (mm)	Transverse width (mm)	Width of sulcus tali (mm)	Length of sulcus tali (mm)	Depth of sulcus tali (mm)
Koshy [14]	Indians ($n=70$)	52.8 ± 5.8	37.9 ± 3.5	27.8 ± 4.4	38 ± 4.1	6.9 ± 1.05
Lee [18]	Korean ($n=140$)	53.9 ± 3.2	40.48 ± 2.46	–	–	–
Jung [12]	Korean ($n=118$)	–	–	4.76 ± 1.0	–	–
Boyan [6]	Turkish ($n=57$)	51.78 ± 4.09	39.41 ± 3.31	5.65 ± 1.57	21.36 ± 3.19	5.69 ± 1.18
Present study	Indians ($n=49$)	51.02 ± 8.06	36.61 ± 5.65	5.44 ± 2.79	11.41 ± 5.78	4.00 ± 2.18

n number of talus bones studied

single facet on the plantar surface of the head of the talus. Type II shows the single calcaneal facet on the plantar surface of talus divided by a ridge into two parts. Type III has two calcaneal facets on the plantar surface of talus divided partly by a ridge and partly by a groove. Type IV has the two calcaneal facets on the plantar surface of talus separated by a non-articular groove. Type V is divided into two subtypes: VA has a large calcaneal facet formed by the fusion of anterior and middle facets, and is fused with posterior calcaneal facet, and VB has three calcaneal facets, anterior, middle, and posterior, and middle facet is continuous with the posterior facet, while the anterior facet is separate [15].

Similarities and deficiencies in the classification used by Kaur et al. with that of Boyan et al. are summarized in Table 15.

In the classification used by Kaur et al., there are no equivalents of Types A1, A2, A3, and A4 of Boyan classification. However, Kaur et al. had proposed a new classification item called VB. In this, the talus has three calcaneal facets, anterior, middle, and posterior, and the middle facet is continuous with the posterior facet, while the anterior facet is separate [7, 15].

We propose a modification of classification proposed by Boyan et al. Apart from the Types A1, A2, A3, B1, B2, and C, a new Type B3 can be included in Boyan et al.

classification, where among the anterior, middle, and posterior calcaneal facets on the talus, the middle facet fuses with the posterior facet. This addition of a new item in the classification improves the classification.

Findings by various authors' talus incidence

Boyan et al. found that the Type B talus was the most common type (98.3%), and among the subtypes, B1 was the most common (55.9%) followed by Type B2 (42.4%) [7]. In a study done by Barbaix et al. in the Belgian population, there was a slightly higher occurrence of Type A (39%) than the present study which might be a characteristic feature in European populations (Table 16). The relatively higher incidence of Type A calcaneus among the European population was noted [3].

Muthukumaravel et al., in their study on talus, had followed the classification proposed by Saadeh et al. and found out that Type B2 (65.82%) was more common than Type B1 (33.33%) [21].

Garg et al. reported in their study on talus had followed the classification proposed by Kaur et al. and reported that Type B1 (49.7%) was more common than Type B2 (39%) [13].

Jung et al. studied the Korean population and reported that Type B (46.6%) is more common than Type C (42.4%)

Table 16 Comparison of classification of calcaneus based on the types of articulating facets of the present study with other studies

Authors	Population	Type A%	A1%	A2%	A3%	A4%	B%	B1%	B2%	C%
Bunning and Barnett [8]	Africans (n = 492)	36	–	–	–	–	63	–	–	0.8
Bunning and Barnett [8]	British (n = 194)	67	–	–	–	–	33	–	–	0
Bunning and Barnett [8]	Indians (n = 78)	17	–	–	–	–	61	–	–	0
Campos and Pellico [10]	Spaniards (n = 176)	46	3	21	16	6	54	29	25	0
Uygur [24]	Turkish (n = 221)	39.4	4.1	13.1	17.2	5	58.4	25.4	33	2.2
Anjeneyulu [2]	Indians (n = 100) (North East)	–	10	10	11	5	–	43	19	24.1
Sharada [19]	Indians (n = 300) (South)	28.6	5.33	13.66	9.66	3	67	50.3	16.6	1.33
Jung [12]	Korean (n = 118)	–	39	0	0	0	–	32	28.8	0
Boyan [6]	Turkish (n = 57)	–	8.7	12.4	13.9	3.5	–	26.1	35.4	0
Present study	Indians (n = 92)	16.4	0	4.1	10.2	2.1	81.6	69.4	12.2	2.1

Bones are typed based on the classification given by Boyan et al. [7]

n number of calcaneus bones studied

[14]. In the present study, Type B1 (58.7%) was common than Type B2 (39.1%) in the study population. The present study findings are similar to the incidence reported by Garg et al. and Boyan et al. [7, 13].

Morphometric parameters of the talus

The mean anteroposterior length of the talus observed in the present study is similar to the observation made by Boyan et al. The mean transverse width of the talus observed in the present study is almost similar to that of the Koshy et al. The mean width of the sulcus tali observed in the present study is similar to that of the Boyan et al. However, the depth of the sulcus tali observed in the present study is different from the observations made by the other authors, and the mean length of the sulcus tali observed in the present study is significantly different from the observations made by earlier studies.

The comparison of morphometric parameters observed in the present study with that of the earlier studies is summarized in Table 17.

The mean depth and the mean length of the sulcus calcanei and sulcus tali on the calcaneus and talus bones, respectively, are significantly different from the earlier studies done in Indian population and other Asian population. When the

talus articulates with the calcaneus, the sulcus calcanei and sulcus tali together form sinus tarsi which are occupied by the talocalcaneal and cervical interosseous ligaments. The reason for the increased length and the width of both sulcus calcanei and sulcus tali is not immediately clear from the data obtained in the present study. An increased width of the sulcus tali and sulcus calcanei observed in the present study may be due to the excessive force exerted on the subtalar joint while squatting in the Indian population. However, the effect of squatting on the subtalar joint should be investigated further to confirm the same.

Embryology of talus and calcaneus

The first appearance of subtalar joint starts at around 8th week, during which the talus and calcaneus appear as cartilaginous precursors separated by mesenchymal tissue. At 9th week, cavitation of subtalar joint starts with posterior part developing quickly than anterior aspect. At 10th week, posterior part fully formed with anterior and medial aspects also developed. At the 11th week, sinus tarsi and tarsal canal were fully developed. By 14th week, the subtalar joint and sinus tarsi were completely formed along with its

Table 17 Comparison of classification of talus based on articulating facets of the present study with other studies

	Population	Type A%	A1%	A2%	A3%	A4%	B%	B1%	B2%	C%
Barbaix E [3]	Belgians (n = 122)	39	–	–	–	–	49	–	–	11
Bilodi [5]	Indians (n = 240)	–	5	0	0	10	–	50	16.6	18.4
Lee JY [17]	Koreans (n = 76)	–	9.2	0	0	30.3	–	28.9	31.6	0
Jung [12]	Koreans (n = 118)	–	11	0	0	0	–	46.6	42.4	0
Boyan N [6]	Turkish (n = 57)	–	0	1.7	0	0	–	55.9	42.4	0
Present study	Indians (n = 49)	2.2	1.1	1.1	0	0	96.8	58.7	38.1	0

Bones are typed based on the classification given by Boyan et al. [7]

n number of talus bones studied

articulating facet and capsuloligamentous structures. The subtalar joint shows considerable variations among patients [11].

Clinical aspects

The flat foot (pes planus) is one of the common disorders of the foot with a prevalence of 13.6% among Indian adults [1]. The mainstay treatment for correcting flatfoot deformity is calcaneal lengthening osteotomy (or) triple C (calcaneo–cuboid–cuneiform) osteotomy. In corrective osteotomies, the articulating surfaces on the talus and calcaneus bones should be preserved [11]. While correcting the deformities of the flat foot by means of ‘triple arthrodesis’, the knowledge about the morphology of the articular facets is necessary to plan adequate denuding of the articular surfaces of subtalar joints along their articular cartilages [13]. The bones with three facets’ morphology require excess denuding of the articular facets compared to the bones with absent anterior or middle facets. Brukner reported that the subtalar joint with a separate anterior and middle facet configuration is more stable than the other types [8]. However, in the present study, Type B2 was observed to be more common, where the anterior and middle facets are fused with each other. This may be the reason for the inherent instability of the subtalar joint and which may further precipitate flat foot when combined with other factors. Verhagen found that arthritic lipping occurs less frequently in sustentaculum tali having separate anterior and middle facets than other types. He found that individuals with a long continuous facet and only medial facet morphology pose a greater risk for subtalar joint instability than two facet configurations. These findings reveal the importance of knowing the sustentaculum tali facet morphology [8, 12].

In conclusion, the classification of the calcaneus and talus needs to be comprehensive for it to be adopted by all the authors studying the talus and calcaneus. In the present study, we found that the talus and the calcaneus bones belonging to the Type B2 are more common than types. Knowledge about the common types of articular facets present in talus and calcaneus will help in planning the treatment strategies for correctives surgeries of flat foot or arthritis of subtalar joints. The morphometric parameters of talus and calcaneus calculated in the present study can be used as a guide for osteotomies in South Indian adult population. Similar studies on the morphology of the talus and calcaneus bones in different races will add to the knowledge base of the anatomy of the subtalar joint.

References

1. Aenumulapalli A, Kulkarni MM, Gandotra AR (2017) Prevalence of flexible flat foot in adults: a cross-sectional study. *J Clin Diagn Res* 11(6):AC17–AC20. <https://doi.org/10.7860/JCDR/2017/26566.10059>
2. Anjaneyulu K, Philips C, Tamang BK et al (2014) Patterns of talar articulating facets in adult human calcanei from north-east India and their clinical correlation. *Asian J Med Sci* 5(4):89–93
3. Barbaix P, Roy V, Clarys JP (2000) Variations of anatomical elements contributing to subtalar joint stability: intrinsic risk factors for post-traumatic lateral instability of the ankle? *Ergonomics* 43(10):1718–1725. <https://doi.org/10.1080/001401300750004122>
4. Bhoir T, Anap DB, Diwate A (2014) Prevalence of flat foot among 18–25 years old physiotherapy students: cross sectional study. *Indian J Basic Appl Med Res* 3(4):272–278
5. Bilodi AK (2006) Study of calcaneal articular facets in human tali. *Kathmandu Univ Med J* 4(1):75–77
6. Bonnel F, Teissier P, Maestro M, Ferre B, Toullec E (2011) Biometry of the bone components in the talonavicular joint: a cadaver study. *Orthop Traumatol Surg Res* 97 (6):S66–S73 <https://doi.org/10.1016/j.otsr.2011.06.005>
7. Boyan N, Ozsahin E, Kizilkanat E, Soames R, Oguz O (2016) Morphometric measurement and types of articular facets on the talus and calcaneus in an Anatolian population. *Int J Morphol* 34(4):1378–1385
8. Brukner J (1987) Variations in the human subtalar joint. *J Orthop Sports Phys Ther* 8(10):489–494
9. Bunning PS, Barnett CH (1965) A Comparison of adult and foetal talocalcaneal articulations. *J Anat* 99(1):71–76
10. Campos FF, Pellico LG (1989) Talar articular facets (faciesarticularestales) in human calcanei. *Acta Anat* 134:124–127
11. Canavese F, Dimeglio A, Bonnel F (2017) Postoperative CT-scan reconstruction of the calcaneus following lateral calcaneal lengthening osteotomy for flatfoot deformity in children. Is the surgical procedure potentially associated with subtalar damage? *Foot Ankle Surg* <https://doi.org/10.1016/j.fas.2017.05.005>
12. Drayer-Verhagen F (1993) Arthritis of the subtalar joint associated with sustentaculum tali facet configuration. *J Anat* 183:631–634
13. Garg R, Babuta S, Mogra K et al (2015) Modifications on dorsum of neck of talus (squatting facets and trochlear extensions) in Indians. *Acta Med Int* 2(1):100–104
14. Jung MH et al (2015) Types of subtalar joint facets. *Surg Radiol Anat* 37:629–638. <https://doi.org/10.1007/s00276-015-1472-1>
15. Kaur M, Kalsey G, Laxmi V (2014) Morphological classification of tali on the basis of calcaneal articular facets. *PB J Orthop* 12(1):57–60
16. Koshy S, Vettivel S, Selvaraj KG (2002) Estimation of length of calcaneum and talus from their bony markers. *Forensic Sci Int* 129(3):200–204
17. Lee JY, Jung MH, Lee JS, Choi BY et al (2012) Types of calcaneal articular facets of the talus in Korean. *J Phys Anthropol* 25(4):185–192
18. Lee UY, Han SH, Park DK et al (2012) Sex determination from the talus of Koreans by discriminant function analysis. *J Forensic Sci* 57(1):166–171
19. Mini MP, Nazmeen S, Haritha KN (2012) Morphological study on patterns of talar articular facets of human calcanei. *Int J Med Clin Res* 3(3):136–139
20. Moraleda L, Salcedo M, Bastrom TP et al (2012) Comparison of the calcaneo–cuboid–cuneiform osteotomies and the calcaneal lengthening osteotomy in the surgical treatment of symptomatic flexible flatfoot. *J Pediatr Orthop* 32(8):821–829

21. Muthukumaravel N, Ravichandran D, Melani RS (2011) Human calcaneal facets for the talus: patterns and clinical implications. *J Clin Diagn Res* 5(4):791–794
22. Riccio I, Gimigliano F, Gimigliano R et al (2009) Rehabilitative treatment in flexible flatfoot: a perspective cohort study. *Chir Organ Mov* 93(3):101–107
23. Sharada R, Sneha K, Gupta C, Shakuntala RP, Rairam GB (2012) Non-metrical study of the pattern of talar articular facets in south Indian dry calcanei. *Surg Radiol Anat* 34:487–491. <https://doi.org/10.1007/s00276-012-0939-6>
24. Uygur M, Atamaz F, Celik S, Pinar Y (2009) The types of talar articular facets and morphometric measurements of the human calcaneus bone on Turkish race. *Arch Orthop Trauma Surg* 129(7):909. <https://doi.org/10.1007/s00402-008-0729-0>