

# Morphologic and Morphometric Variations of Calcaneus and Their Importance in Surgical Procedures

## Kalkaneusun Morfolojik ve Morfometrik Özelliklerinin Kalkaneus Cerrahisindeki Önemi

İpek ERGÜR, MD,<sup>a</sup>  
Can KOŞAY, MD,<sup>b</sup>  
Gülşah ZEYBEK, MD,<sup>a</sup>  
Amaç KIRAY, MD,<sup>a</sup>  
Ömer AKÇALI, MD,<sup>b</sup>  
Hamid TAYEFİ, MD<sup>a</sup>

Departments of  
<sup>a</sup>Anatomy,  
<sup>b</sup>Orthopedics and Traumatology  
Dokuz Eylül University  
Faculty of Medicine, İzmir

Geliş Tarihi/Received: 23.07.2009  
Kabul Tarihi/Accepted: 25.03.2010

Identify the date/place of congress of study  
presented: The 5th Asian-Pacific International  
Congress of Anatomist, Iran, 2008.

Yazışma Adresi/Correspondence:  
Gülşah ZEYBEK, MD  
Dokuz Eylül University,  
Faculty of Medicine,  
Department of Anatomy, İzmir,  
TÜRKİYE/TURKEY  
gulsah.zeybek@deu.edu.tr

**ABSTRACT Objective:** Calcaneus is the largest tarsal bone that supports talus and is frequently involved in fractures. The relation between talus and calcaneus is distorted in some disorders such as pes-equino varus or pes-plano valgus. A thorough knowledge of the anatomical variations of anterior and middle facets, sustentaculum tali and the sulcus in between them is essential in order to keep the osteotomy extra-articularly. Therefore, in this study, we aimed to describe detailed morphometry of calcaneus. **Material and Methods:** In this study, 80 calcanei (40 right, 40 left) from the collection of Dokuz Eylül University Department of Anatomy were used. The lengths of the bones were measured using vernier caliper which is sensitive to 0.01 mm, and thickness of the bones was measured using digital caliper with a sensitivity of 0.01 mm. In addition, medial angle of sustentaculum tali was measured by Image Tool on the digital photographs taken from the upper surface of the calcaneus. **Results:** In 38.7% of the cases, a sulcus (anterior calcaneal groove) was identified between middle and anterior facets. In 61.3%, there was no sulcus between the facets. In cases with a sulcus, a transverse line beginning from the middle of sulcus towards the lateral side (osteotomy line) was found to be average 13.3 mm posterior to the calcaneocuboid joint on a-verage. Between middle and posterior facets, four different morphologic types of posterior calcaneal groove were identified. The average depth of this groove was 2.3 mm. It was observed that the groove was funnel shaped in 40%, reverse funnel shaped in 3.9%, sandglass shaped in 35% and cylindrical in 21.3%. We detected 2.8 foramens on average in the posterior calcaneal grooves and 47.5% of these were localized at the 1/3 anterior region. Medial angulation of sustentaculum tali was 115 degrees on average. **Conclusion:** We believe that the results of this study are important for orthopedic surgeons who perform extraarticular osteotomy at distal calcaneus or deal with calcaneal fractures.

**Key Words:** Calcaneus; fractures, bone; bone lengthening; anatomy

**ÖZET Amaç:** Kalkaneus talusu destekleyen ve kırıklarına sıklıkla rastlanan en büyük tarsal kemiktir. Talus ve kalkaneus arasındaki ilişki pes-equino varus ve pes-equino valgus gibi bazı patolojilerde bozulabilir. Kalkaneusun ön ve orta eklemler yüzleri arasında anterior kalkaneal oluğun bulunması ekstraartiküler osteotomiye gerçekleştirmede esastır. Bu özellikleri nedeniyle, çalışmamız da kalkaneusun detaylandırılmış morfometrisini ortaya koymayı amaçladık. **Gereç ve Yöntemler:** Bu çalışmada Dokuz Eylül Üniversitesi Anatomi Anabilim Dalı koleksiyonunda bulunan 80 kalkaneus (40 sağ, 40 sol) kemiği kullanılmıştır. Kemiklerin uzunluğu 0,01mm hassasiyetindeki kumpas ile, kalınlığı da dijital kumpas ile ölçülmüştür. Sustentaculum tali'nin iç köşesi de kalkaneusun üst yüzeyinden alınan dijital fotoğraflarla, görüntü araçları programı kullanılarak ölçülmüştür. **Bulgular:** Kemiklerin %38.7'sinde, orta ve ön yüzleri arasında bir sulcus (ön kalkaneal oluk) tespit edilmiştir. Bu sulcus kemiklerin %61.3'ünde tespit edilmemiştir. Sulcus bulunan kemiklerde, kalkaneocuboid eklemin arkasında ortalama 13.3 mm olan, sulcusun ortasından başlayıp dış yüzü (osteotomi çizgisi) boyunca devam eden çapraz bir hat bulunmuştur. Orta ve arka yüzler arasında dört farklı tipte posterior kalkaneal oluk tespit edilmiştir. Bu oluğun derinliği ortalama 2.3 mm idi. Bu olukların %40'ının huni, %3.8'inin ters huni, %35'inin kum saati, %21.3'ünün de silindirik şeklindeki olduğu gözlenmiştir. Kalkaneusların posterior kalkaneal oluklarında ortalama 2.8 foramen olduğu saptandı. Bu deliklerin de %47.5'i oluğun 1/3 anterior parçasında yerleşim göstermekteydi. Sustentaculum tali'nin medial açılması ortalama 115° olarak ölçüldü. **Sonuç:** Çalışma sonuçlarının distal kalkaneusta ekstraartiküler osteotomi yapan ya da kalkaneus kırıkları ile uğraşan ortopedi ve travmatoloji uzmanları için önemli olacağını düşünmekteyiz.

**Anahtar Kelimeler:** Kalkaneus; kırıklar, kemik; kemik uzatma; anatomi

doi:10.5336/medsci.2009-14722

Copyright © 2011 by Türkiye Klinikleri

Türkiye Klinikleri J Med Sci 2011;31(1):15-21

The calcaneus or the heel bone is placed at the back of the foot. The calcaneus is the largest tarsal bone and functions as a lever for the gastrosoleus complex and provides vertical support for the body weight and for the lateral arc of the foot. Calcaneal fractures may deteriorate these functions to some extent causing walking impairments.<sup>1-5</sup>

Calcaneus is one of the strongest bones of the foot and is used for sex determination in forensic medicine and in archaeology.<sup>6</sup>

The calcaneus transmits most of the body weight from talus to the ground. The sustentaculum tali is the part of the calcaneus supporting the head of talus.<sup>7</sup> Sustentaculum tali is kept stable by interosseous and deltoid ligaments. Primary longitudinal fractures of the posterior facet may cause damage on this supporting structure by cleaving the sustentaculum tali. Such fractures may also cause plantar vascular, neural damages and flexor tendon ruptures.<sup>8,9</sup>

Superior surface of the calcaneus, which articulates with talus, has three facets. Posterior facet is the largest one with a convex shape. Middle facet is concave and rests on the sustentaculum tali. Third one, anterior facet, is concave and generally exists confluent with the mid facet. Anterior surface also articulates with os cuboideum.<sup>7,10,11</sup> Between the middle and the posterior facets lies the calcaneal groove. In this study, the groove between the middle and posterior facets of calcaneus is referred as posterior calcaneal groove. The posterior calcaneal groove displays a number of nutritive foramina belonging to vascular structures. Calcaneal fractures involving the posterior calcaneal groove may cause massive hemorrhage due to rich vascular supply of this region, however avascular necrosis, that is frequently seen in scaphoid and femoral head fractures is not encountered in this region. Therefore, morphology and morphometry of the posterior calcaneal groove are of great importance in calcaneal fractures that account for approximately 2% of all fractures.

There are various surgical approaches described for the correction of incorrect articulation between

facets of calcaneus and talus, like pes-equino varus, pes-plano valgus or flat-foot. Calcaneal-lengthening is the most popular one of these methods and was first implemented by Dillwyn Evans on patients with pes-plano valgus foot deformity resulting from poliomyelitis. Evans noticed his patients' shorter medial arc compared to longer lateral arc and performed calcaneal lengthening to get normal hindfoot, midfoot and forefoot alignment. In the original procedure of calcaneal lengthening, osteotomy is performed 1.5 cm proximal of and in parallel to the calcaneocuboid joint.<sup>12,13</sup> Evans' calcaneal lengthening osteotomy technique is modified and popularized by Mosca.<sup>13</sup> In the symptomatic pes-plano valgus patients, Mosca performed transverse calcaneal lengthening osteotomy from lateral towards medial of the groove between the anterior and the middle facets of the subtalar joint.<sup>12,13</sup>

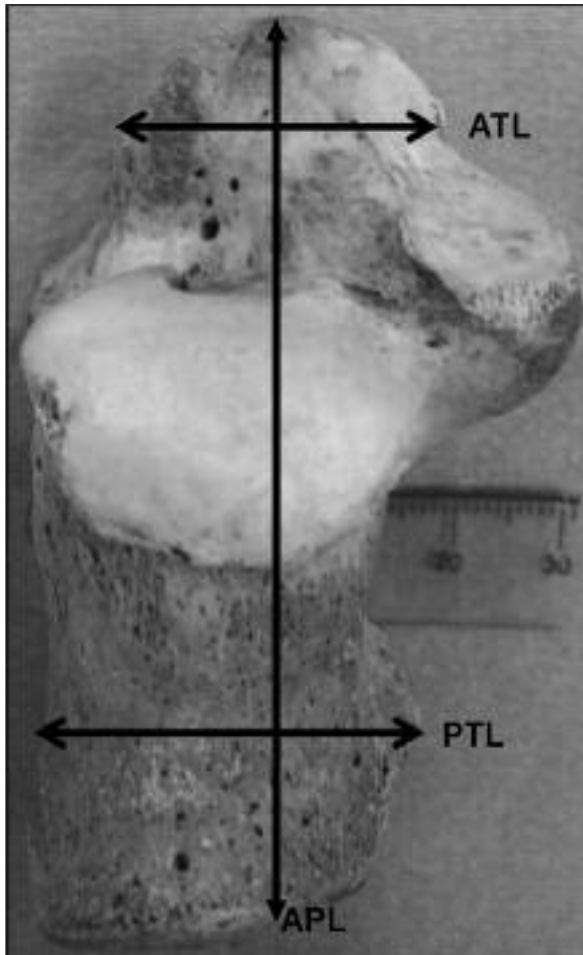
The groove between anterior and middle facets that is observed in some bones was named as anterior calcaneal groove. Anatomical properties of the anterior facets, middle facets, sustentaculum tali and interarticular groove (anterior calcaneal groove) are important to perform calcaneal lengthening extra-articularly.

Although our study is anthropological, we assessed anterior-posterior length and medial-lateral width of each calcaneus in our collection to evaluate whether our results were in accordance with other studies.

Therefore, in the present study, we aimed to accomplish detailed morphologic and morphometric measurements of the anterior, posterior and middle facets of the superior surface of calcaneus, sustentaculum tali and posterior calcaneal groove.

## MATERIAL AND METHODS

We used 40 right and 40 left dry calcanei from the collection of Department of Anatomy, Dokuz Eylül University, İzmir, Turkey. The age and gender were not assessed in this study. The part in front and behind sustentaculum tali and the medial-lateral distance in both anterior and posterior areas were measured by a vernier caliper (sensitive to 0.01 mm). Medial-lateral distance of the part in front of



**FIGURE 1:** Anteroposterior length and anterior and posterior largest transverse length for calcaneus.

APL: Anteroposterior length, ATL: anterior transverse length, PTL: posterior transverse length.

sustentaculum tali was named as anterior width, and the distance of the part behind the sustentaculum tali was called as posterior width. (Figure 1). From lateral to medial, 1/3 anterior, 1/3 middle and 1/3 posterior widths of posterior calcaneal groove (Figure 2) and posterior calcaneal groove depth (Figure 3) were measured using Mitutoyo digital caliper, with a sensitivity of 0.01 mm.

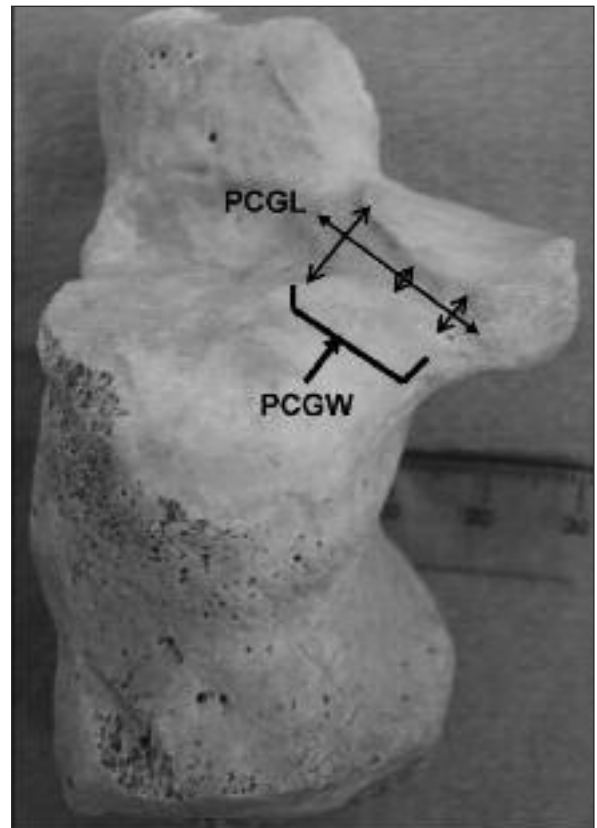
The angle between medial calcaneal border and posterior margin of the sustentaculum tali was measured. After the photographs of all the calcaneal bones had been taken from the top, the angle formed at the intersection point of the sagittal line along the medial edge of the calcaneus and the posterior edge of the sustentaculum tali was measured

one by one using UTHSCSA Image Tool Windows version 3.00 (Figure 4)

The length and the thickness of the sustentaculum tali of each calcaneus were measured separately. In anatomical position, medial-lateral distance between the most medial part of sustentaculum tali and posterior calcaneal groove was measured. In addition, at the middle of this distance the thickness between upper and lower surface of sustentaculum tali was measured (Figure 4).

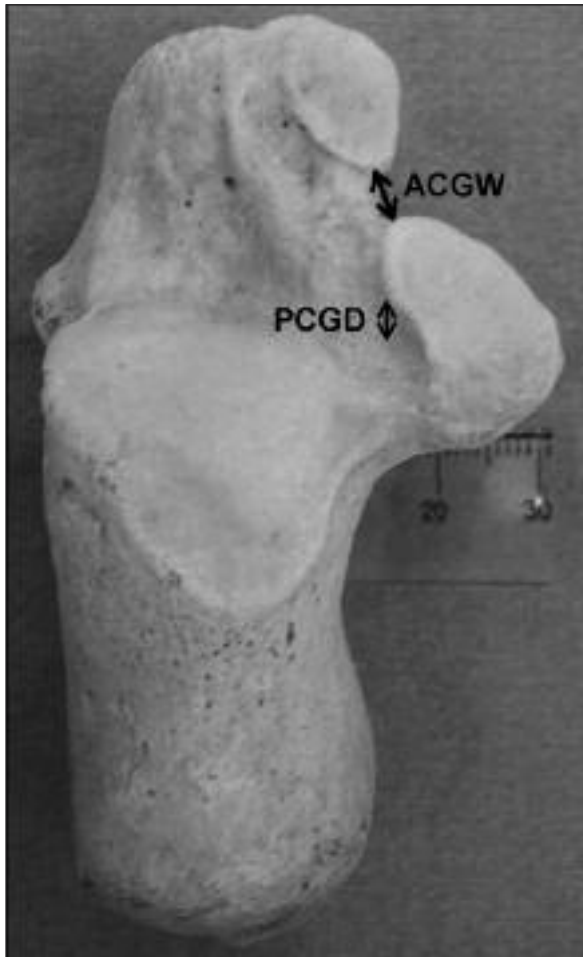
Anterior calcaneal groove was investigated between facies articularis talaris anterior (FTA) and facies articularis talaris media (FTM). Distance between two facets was measured in subjects with groove. Distance between transverse line crossing this sulcus and calcaneocuboid joint was also measured (Figure 3).

In our study, number of the foramens in the posterior calcaneal groove and in the sinus tarsi re-



**FIGURE 2:** Length of posterior calcaneal groove and width of anterior, middle and posterior 1/3.

PCGL: Posterior calcaneal groove length, PCGW: Posterior calcaneal groove width.



**FIGURE 3:** Width of anterior calcaneal groove between anterior and middle facets and depth of posterior calcaneal groove.

ACGW: Anterior calcaneal groove width, PCGD: Posterior calcaneal groove depth.

gion was also evaluated. SPSS 11.0 program was used for frequency analysis of the data.

Posterior calcaneal groove was named according to its shape: funnel-shaped (Figure 5A), reverse funnel-shaped (Figure 5B), sandglass shaped (Figure 5C) and cylindrical (Figure 5D).

## RESULTS

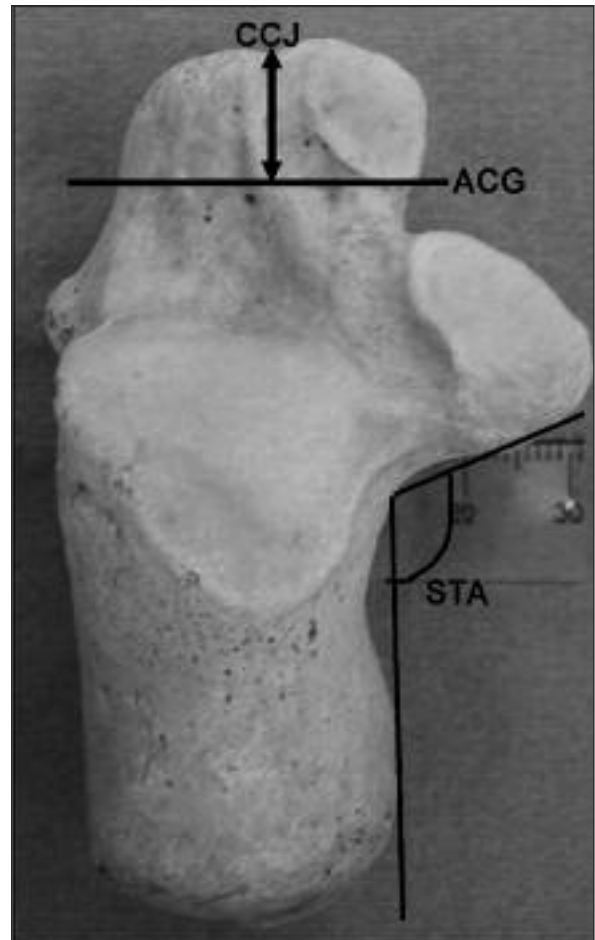
The mean anteroposterior length of calcaneus was 74.7 mm, anterior and posterior transverse lengths were 32.8 and 32.6 mm respectively (Table 1).

The mean widths of the 1/3 anterior, 1/3 middle and 1/3 posterior parts of posterior calcaneal groove were 10.8, 6.7 and 8.5 mm, respectively (Table 2). The mean calcaneal groove depth was 2.3 mm (min: 0.5 mm, max: 4.6 mm).

The angle formed by sustentaculum tali and the sagittal line along the medial edge of the calcaneus was on average  $115^\circ$  (min:  $94^\circ$ , max:  $135^\circ$ ).

The mean medial-lateral length and thickness of sustentaculum tali were found as 12.6 and 10.2 mm, respectively (Table 3).

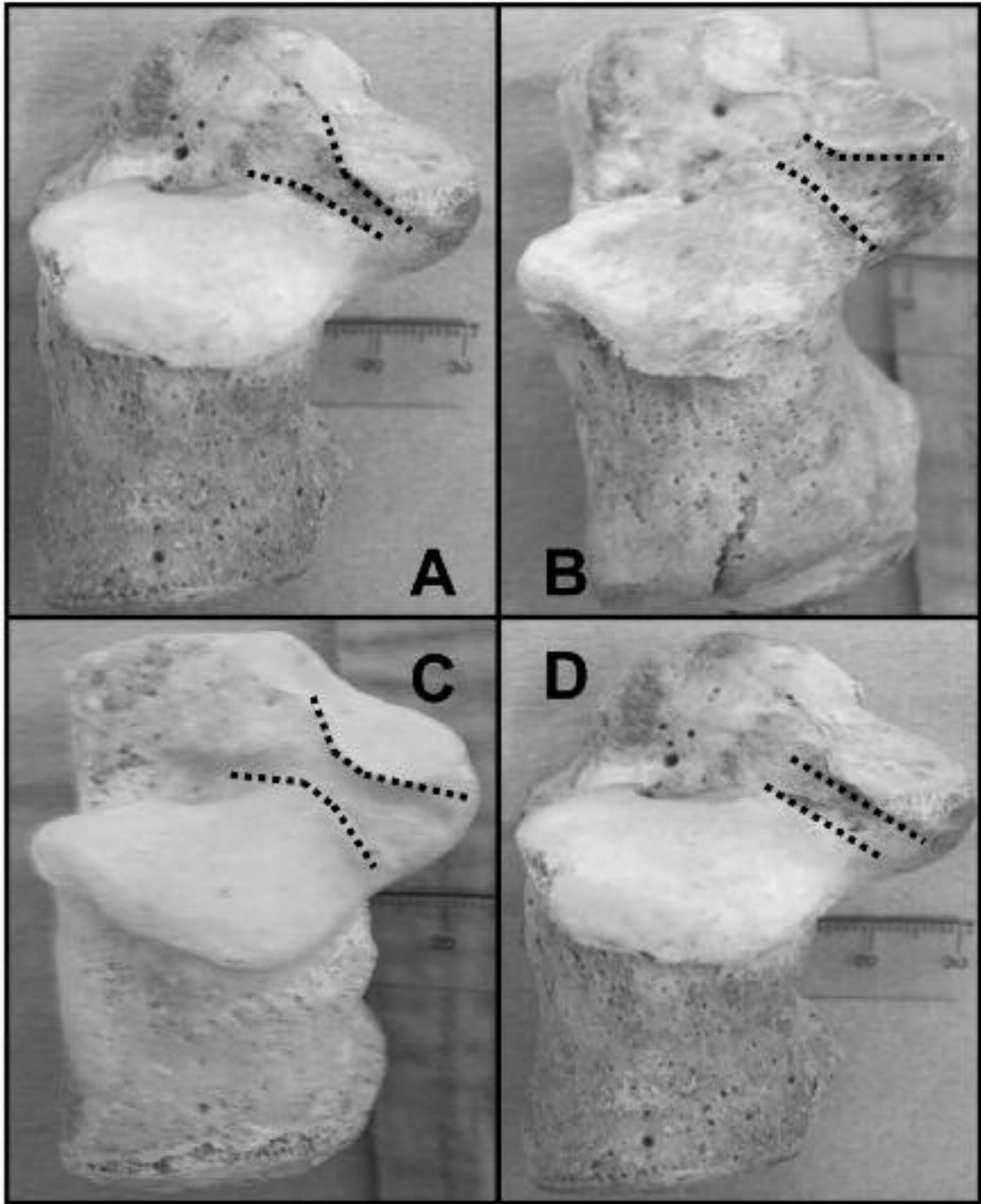
In 38.7% of the calcaneus bones, we found an anterior calcaneal groove between FTA and FTM. The mean width of this groove was 1.8 mm (min: 1.2 mm- max: 2.8 mm). In the subjects having the groove between FTA and FTM, the mean distance between transverse line crossing the groove and calcaneocuboid joint was 13.3 mm (min: 8.9 mm- max: 17.5 mm).



**FIGURE 4:** The angle between medial calcaneal border and posterior margin of the sustentaculum tali; The distance between transverse axis through anterior calcaneal groove and calcaneocuboid joint.

CCJ: calcaneocuboid joint, ACG: anterior calcaneal groove, STA: Sustentaculum tali angle.





**FIGURE 5:** A: Funnel-shaped calcaneal groove; B: Reverse funnel shaped calcaneal groove; C: Sandglass-shaped calcaneal groove; D: Cylinder-shaped calcaneal groove.

We detected 2.8 foramina on average in posterior calcaneal groove and 47.5% of these were located at the 1/3 anterior region (Table 4). There were 3.5 foramina on average in the sinus tarsi.

When the shape of the posterior calcaneal groove taken into consideration, 40% were determined as a funnel, 3.8% were like a reverse funnel, 35% were sandglass-shaped and 21.3% were cylindrical.

**TABLE 1:** Anterior-posterior length, anterior and posterior lengths of calcaneus.

Calcaneus	Min	Max	Mean	Standart deviation
Anterior posterior length	62.2 mm	85.7 mm	74.7 mm	5.8
Anterior transvers length	24.2 mm	42.9mm	32.8 mm	3.8
Posterior transvers length	24.6 mm	44.7 mm	32.6 mm	4.0

**TABLE 2:** Width of posterior calcaneal groove.

	Min	Max	Mean	Standart deviation
Posterior calcaneal groove anterior 1/3 width	5.7 mm	15.6 mm	10.8 mm	2.5
Posterior calcaneal groove middle 1/3 width	4.0 mm	11.5 mm	6.7 mm	1.8
Posterior calcaneal groove posterior 1/3 width	3.7 mm	16.4 mm	8.5 mm	2.3

**TABLE 3:** Thickness and length sustentaculum tali.

	Min	Max	Mean	Standart deviation
Sustentaculum tali thickness	8.1 mm	13.7 mm	10.2 mm	2.2
Sustentaculum tali length	9.8 mm	15.6 mm	12.6 mm	3.7

**TABLE 4:** Number of foramina in posterior calcaneal groove.

Number of foramina in posterior calcaneal groove	Min	Max	Mean	Standart deviation
1/3 anterior	2	6	3.8	2.1
1/3 middle	1	5	2.4	1.8
1/3 posterior	0	2	1.8	1.0

## DISCUSSION

Koshy et al.<sup>8</sup> evaluated bony markers of calcaneus. They calculated average measurements of anteroposterior length as 73.6 mm, transverse width as 40.8 mm, length and width of the sustentaculum tali as 20.7 mm and 10.8 mm, respectively, and length, width and depth of the posterior calcaneal groove as 31.9 mm, 21.1 mm and 3.4 mm, respectively. These fragmentary measurements were used to estimate the total anteroposterior length of the calcaneus.<sup>8</sup> In our study, anteroposterior length of the calcaneal bones was measured 74.7 mm on average, anterior transverse width as 32.8 on average mm, posterior width as 32.6 mm. The medial-lateral length of sustentaculum tali was 12.6 mm on average. The supero-inferior thickness of calcaneus at sustentaculum tali was 10.2 mm. The mean widths at 1/3 anterior, 1/3 middle and 1/3 posterior parts of posterior calca-

neal groove were measured as 10.8 mm, 6.7 mm and 8.5 mm, respectively. The mean posterior calcaneal groove depth was 2.3 mm.

There are various correction methods for pes-planovalgus, pes-equinovarus or flat foot pathologies which occur due to subtalar disjoining problems. In most of the subtalar joints, the sulcus between the anterior and middle calcaneal facets is the site for the extra-articular calcaneal lengthening osteotomy. In a study performed by Ragab et al.,<sup>13</sup> 37% of calcanei were noted as Type A, in which the sulcus lied between the anterior and middle calcaneal facets, 12% were called as transitional type, where the anterior and middle facets were united as they were bridged over, and in 6% anterior facets were not found at all. It is emphasized that in the transitional types, osteotomy may cause minimal articular degeneration and in cases without anterior facets, extra-articular calcaneal

lengthening may be performed only if the mid facet is located towards distal part of the calcaneus.<sup>13</sup>

Gupta et al.<sup>14</sup> examined talar articular facets of the calcanei and described four different types. In 67% of the cases, there was no facet on the sustentaculum tali which extended onto the antero-medial corner of the distal part of the calcaneus (Type 1). In 26% of the cases, two articular facets were described; one placed on the distal part of the calcaneus and the other placed on the sustentaculum tali (Type 2). In 5% of the cases one single facet was very well defined on the sustentaculum tali (Type 3). In 2% of cases, one single facet was defined extending onto the antero-medial corner of the distal portion of the calcaneus and this facet designated continuity with the posterior talar facet of the calcaneus (Type 4).<sup>14</sup> In our study, we found a sulcus between FTA and FTM in 38.7% of our calcanei. The mean width of this sulcus was 1.8 mm and was placed 13.3 mm away from the calcaneocuboid joint.

In this study, by evaluating the number and the intensity of the vascular foramina of the posterior calcaneal groove, we tried to clarify the regions

of the groove which might cause heavy bleeding in calcaneal fractures. We detected 2.8 foramina on average in the posterior calcaneal groove and 47.5% of these were at the 1/3 anterior region. Average 3.5 foramina on average in the sinus tarsi.

## CONCLUSION

Anterior calcaneal groove was identified in 38.7% of all cases. This may be an important finding as calcaneal lengthening osteotomy is described ideally to be through this sulcus.

Another important finding of this study is that the distance between the sulcus and calcaneocuboid joint was 13.3 mm and the width of the sulcus was 1.8 mm.

Having the knowledge of these measurements is of utmost importance from a surgical point of view for a precise and correct osteotomy.

Forty seven point five percent of the vascular foramina are located at the 1/3 of anterior part of the posterior calcaneal groove. It should be kept in mind that fractures of this region may cause excessive hemorrhage.

## REFERENCES

- Barei DP, Bellabarba C, Sangeorzan BJ, Benirschke SK. Fractures of the calcaneus. *Orthop Clin North Am* 2002;33(1):263-85, x.
- Juliano P, Nguyen HV. Fractures of the calcaneus. *Orthop Clin North Am* 2001;32(1):35-51, viii.
- Rammelt S, Zwipp H. Calcaneus fractures: facts, controversies and recent developments. *Injury* 2004;35(5):443-61.
- Sanders R. Displaced intra-articular fractures of the calcaneus. *J Bone Joint Surg Am* 2000;82(2):225-50.
- Lawrence SJ, Singhal M. Open hindfoot injuries. *J Am Acad Orthop Surg* 2007;15(6):367-76.
- Murphy AM. The calcaneus: sex assessment of prehistoric New Zealand Polynesian skeletal remains. *Forensic Sci Int* 2002;129(3):205-8.
- Standing S. Pelvic girdle and lower limb. In: William A, lead editor. *Gray's Anatomy*. 39<sup>th</sup> ed. Spain: Churchill Livingstone; 2005. p. 1512-3.
- Koshy S, Vettivel S, Selvaraj KG. Estimation of length of calcaneum and talus from their bony markers. *Forensic Sci Int* 2002;129(3):200-4.
- Lin PP, Roe S, Kay M, Abrams CF, Jones A. Placement of screws in the sustentaculum tali. A calcaneal fracture model. *Clin Orthop Relat Res* 1998;(352):194-201.
- Kinik H. [Surgical management of intra-articular calcaneal fractures]. *Turkiye Klinikleri J Surg Med Sci* 2007;3(39):49-57.
- Netter FH. The netter collection of medical illustration. *Musculoskeletal system*. Volume: 8, Part I: Anatomy, physiology, and metabolic disorders. Elsevier Saunders 11th ed. Ankara: Güneş Tıp Kitapevleri; 2009. p.117-9.
- Mosca VS. Calcaneal lengthening for valgus deformity of the hindfoot. Results in children who had severe, symptomatic flatfoot and skewfoot. *J Bone Joint Surg Am* 1995;77(4):500-12.
- Ragab AA, Stewart SL, Cooperman DR. Implications of subtalar joint anatomic variation in calcaneal lengthening osteotomy. *J Pediatr Orthop* 2003;23(1):79-83.
- Gupta SC, Gupta CD, Arora AK. Pattern of talar articular facets in Indian calcanei. *J Anat* 1977;124(Pt 3):651-5.