Int. J. Morphol.,
40(6):1490-1496, 2022.

Investigation of the Relationship Between foot Deformities and Radiographic Measurements of the Talus and Calcaneus

Investigación de la Relación entre las Deformidades del Pie y las Mediciones Radiográficas del Talo y del Calcáneo

Busra Candan[1]; Ebru Torun[2] & Rumeysa Dikici[1]

CANDAN, B.; TORUN, E.; DIKICI, R. Investigation of the relationship between foot deformities and radiographic measurements of the talus and calcaneus. *Int. J. Morphol., 40(6)*:1490-1496, 2022.

SUMMARY: The weight of the body is transmitted to the foot through the subtalar joint and talus. Considering the important location of the talus and calcaneus, the morphological structures of these bones may affect the biomechanics of the subtalar joint. At the same time, the morphological structure of these bones is important in some common foot deformities. We aimed to investigate whether the various measurements of the talus and calcaneus are associated with different foot deformities in this study. In this study, radiography images of 158 (72 male and 86 female) patients within the mean age of 44 years were retrospectively examined. Eleven different measurements of the talus and calcaneus were obtained from the lateral and antero-posterior radiographs of the patients. A total of 158 patient's routine clinic radiographs were retrospectively assessed, which have calcaneal spur (n=63), hallux valgus (n=32) and control group (n=63). We determined that the body height of the calcaneus, maximum width of the head of the talus, minimum anterior width of the calcaneus were significantly different between calcaneal spur group and control group. Maximum length fibular malleolar facet of the talus was significantly different between age groups. And we determined that the calcaneal index was significantly different between hallux valgus group and control groups. Also all measurements were significantly different between males and females. As a result, some measurements that significantly determine the morphology of the talus and calcaneus were found to be significant between deformity groups and control groups. We think that our study will contribute to the literature as it is the first study in which the measurements obtained from the radiographic images of the talus and calcaneus are associated with foot deformities.

KEY WORDS: Calcaneus, morphology; Talus; Calcaneal spur; Hallux valgus.

INTRODUCTION

Plain radiograph is a widely used method because of their usability when medical evaluation of the foot is required. Calcaneal and talar morphology are critical in the understanding of human foot form and function, but few studies have examined the measurements of these bones taken from radiographs (Abreu *et al*., 2003). The talus and calcaneus are considered important elements in the structure, function and integrity of the human foot (Agoada, 2018). Body weight is distributed to the medial and lateral longitudinal arches of the foot via the subtalar joint and talus (Zhang *et al*., 2019). And the talus and calcaneus, which are part of the subtalar joint complex, are important bones in the formation of the medial and lateral arch and in maintaining foot posture (Prang, 2016). Given these features, the slightest structural changes in the talus and calcaneus due to foot deformities may affect the biomechanics of the subtalar joint (Prasad & Rajasekhar, 2019). The most common deformities in the foot area are plantar calcaneal spurs and hallux valgus. Calcaneal spurs are bony growths from calcaneal tuberculitis but there is no consistent definition in the literature (Abreu *et al*., 2003; Kirkpatrick *et al*., 2017). Hallux valgus is a complex and little-known common foot problem with a multifactorial cause and progression. It begins with lateral deviation of the big toe (hallux) and medial deviation of the first metatarsal (metatarsus primus varus) (Hecht & Lin, 2014). It can cause both pain and limitation of movement (Zirngibl *et al*., 2017). Standard views of the foot in radiographic evaluations

[1] Alanya Alaaddin Keykubat University, School of Medicine, Department of Anatomy, Alanya, Turkey.
[2] Alanya Alaaddin Keykubat University, School of Medicine, Department of Radiology, Alanya, Turkey.

Received: 2022-06-30 Accepted: 2022-07-26

usually include an anteroposterior (AP or dorsoplantar) view to assess from the transverse plane of the foot and a lateral (or lateromedial) view to assess from the sagittal plane, these images with the least distortion and closest to the true image (Agoada, 2018).

In this study, we aimed to investigate whether the various measurements which we obtained by examining the lateral and anteroposterior radiographs of the talus and calcaneus are associated with different foot deformities.

MATERIAL AND METHOD

This study was a retrospective, observational study. From January 2018 to December 2020, 158 (72 male and 86 female) lateral and anteroposterior radiographs of the talus and calcaneus were included in this study. After taken ethical approval, all observations were taken electronically on radiographs viewed on a PACS. Patients with complete records and anteroposterior and lateral x-rays of both feet were included. All patients who had a previous amputation and were suspected of having cancer in the affected foot or ankle were excluded from the study. Age, sex, limb side, and diagnosis made by the specialist physician were noted. A total of anteroposterior and lateral foot radiographs of 158 patient's routine clinic radiographs were retrospectively assessed, which have calcaneal spur (n=63), hallux valgus (n=32) and control group (n=63).

Talus radiographic Measurements

Lateral View Measurements:

Maximum height of the body of the talus (MaxHBTAL): The distance between the most superior point of the trochlear lateral surface and the most inferior point of the lateral process of the talar body at the apex (Fig. 1A) (Agoada, 2018).

Maximum length fibular malleolar facet of the talus (MaxLFMTAL): The distance between the most anterior aspect of the lateral malleolar facet and the most posterior aspect of the lateral malleolar facet (Fig. 1B) (Agoada, 2018).

Maximum talar length (MaxLTAL): The distance between the most posterior point of the posterolateral tubercle and the most anterior point of the talus. If a prominent spur, or an os trigonum is present, then measurements are taken, including the spur or os trigonum in the measurement (Fig. 1C) (Agoada, 2018).

The talus index was calculated by taking the ratio of MaxHBTAL measurement to MaxLTAL measurement.

AP View Measurements

Maximum width of the head of the talus (MaxWHTAL): The distance between the most medial and the most lateral points of the head of the talus (Fig. 2A) (Agoada, 2018).

Maximum length of the head and neck of the talus (MaxLHNTAL): A straight line is drawn parallel to the lateral margin of the talar neck. A second line is drawn perpendicular to the first, traversing the widest point of the talar neck at the lateral margin (where it flares out to become continuous with the body). MaxLHNTAL is measured as the distance between the most anterior aspect of the head and the second line drawn, perpendicular to that line (Fig. 2B) (Agoada, 2018).

Minimum width of the neck of the talus (MinWNTALx) definition: The shortest distance between the medial and lateral margins of the talar neck, perpendicular to the long axis of the lateral margin. The measured line is drawn between the narrowest point on the lateral margin and where it traverses the medial margin (Fig. 2C) (Agoada, 2018).

Calcaneus radiographic measurements:

Lateral View Measurements

Maximum length of the calcaneus (MLCAL): The distance between the most anterior point of the calcaneus and the most posterior point of the calcaneal tuberosity, measured roughly parallel to the long axis of the calcaneus (Fig. 3A) (Agoada, 2018).

Body height of the calcaneus (BHCAL): The greatest projected height, measured from the most inferior point of the calcaneal tuberosity to the most superior point of the posterior articular facet. Measurement is taken from a line extended distally from the plantar aspect of the calcaneal tuberosity, parallel to the long axis of the calcaneus. BHCAL is measured perpendicular to this line. (Fig. 3B) (Agoada, 2018).

Minimum anterior height of the calcaneus (MinAHCAL): The minimal distance between the superior and inferior margins at the anterior aspect of the calcaneus, posterior to the articular face for the cuboid. The measurement is taken as a straight line drawn from the most superior point of the inferior margin to the superior margin of the lateral surface of the anterior calcaneus, perpendicular to the long axis of the calcaneus (Fig. 3C) (Agoada, 2018).

Minimum body height of the calcaneus (MinBHCAL): The minimum distance between the superior margin of the calcaneus posterior to the posterior articular facet superiorly, and the line representing the most superior point of the inferior margin of the lateral surface, anterior to the calcaneal tuberosity (Fig. 3D) (Agoada, 2018).

Fig. 1. Lateral view measurements of the talus.

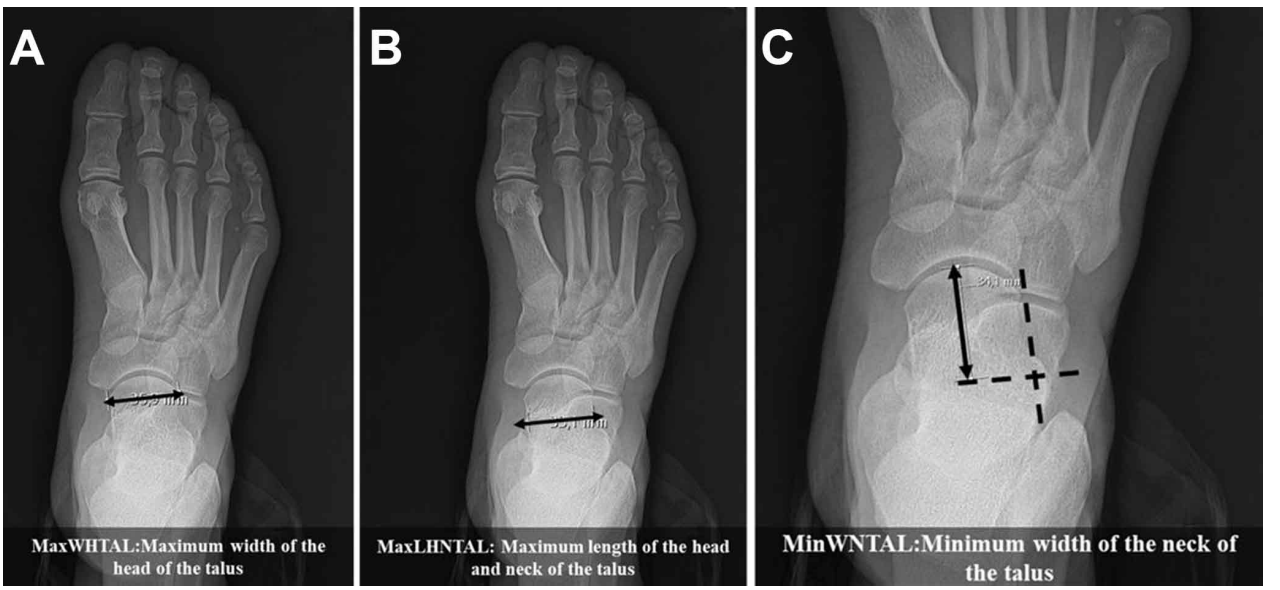

Fig. 2. Anteroposterior view measurements of the talus.

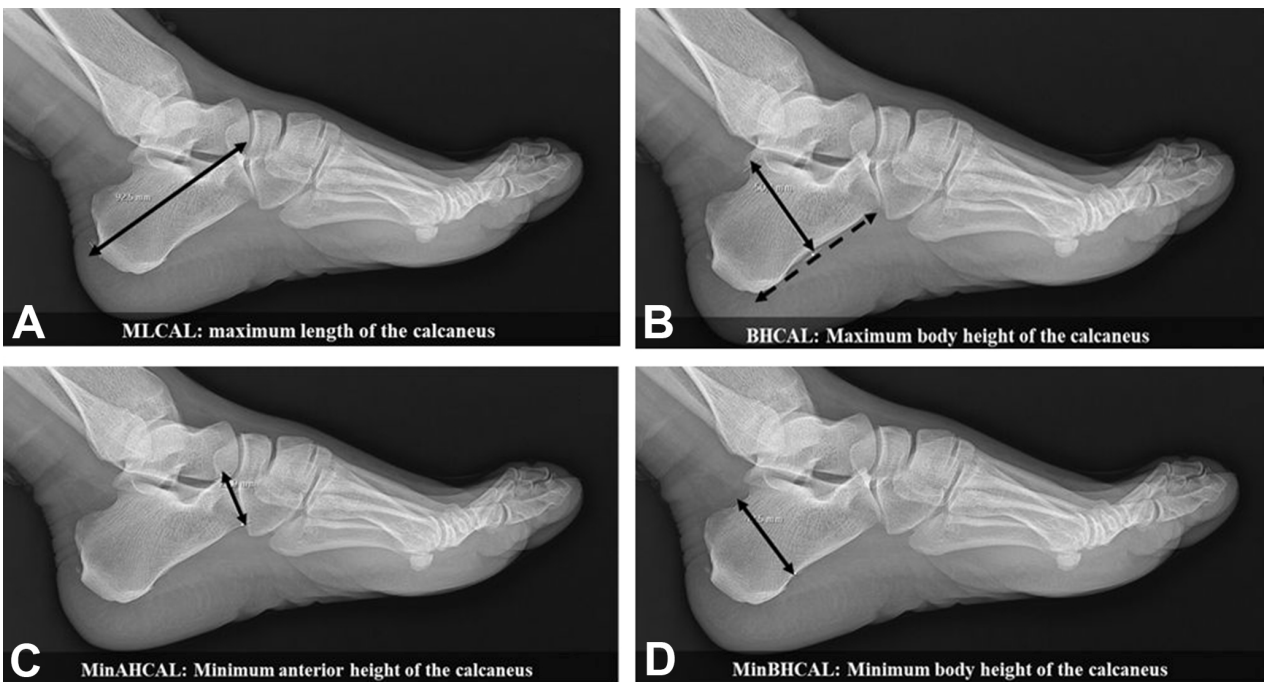

Fig. 3. Lateral view measurements of the calcaneus.

AP View Measurements

Minimum anterior width of the calcaneus (MinAWCAL): The distance between the medial and lateral margins of the calcaneus, at the level of the cuboid articular facet. However, since the medial and lateral margins of the calcaneus maybe difficult to identify, this measurement is taken as the distance between the most medial and most lateral points of the calcaneal articular surface on the cuboid (Fig. 4) (Agoada, 2018).

Fig. 4. Anteroposterior view measurement of the calcaneus.

The calcaneal index was calculated as the ratio of the MinBHCAL measurement to the MLCAL measurement.

Statistical analysis: SPSS 21.0 program was used for statistical analysis. The mean, standard error mean (SEM), minimum and maximum values of all measurements were calculated. "Kolmogorov-Smirnov" and "Shapiro-Wilk" tests were performed and histogram graphs were examined to determine whether the data were suitable for normal distribution. Significance tests were performed between sex groups, age groups, and diagnostic groups. In the evaluation of the parameters, Mann-Whitney U test was used for those that did not show normal distribution, and independent samples test was used for those that did. A "p" value below 0.05 was considered statistically significant in all analyzes ($p<0.05$).

RESULTS

In our study, 158 foot radiographs were studied. Name, age, sex, limb side, and diagnosis group of the individuals were recorded from the PACS system. The radiographic measurements were taken from 86 female and 72 male patients. The mean age of the patients was 44 (min. 20-max.82). The patient groups to be measured were determined as with calcaneal spur (63), with hallux valgus (32), and without deformity in their feet (63). Eleven different measurements of the talus and calcaneus were obtained from the lateral and antero-posterior radiographs of the patients. The mean±SEM, minimum and maximum values of the talus and calcaneus measurements (Table I) were determined. Also measurement parameters were evaluated according to sex. The difference between sexes was significant for all measurements ($p<0.05$).

Table I. Descriptive statistics of talus and calcaneus radiography measurements (mm).

Measurements of Talus	Min.	Max.	Mean±SEM	Agoada, 2018
Maximum Length (maxLTAL)	54.50	79.70	64.71±0.41	62.45±0.80
Maximum Body Height (maxHBTAL)	28.30	44.90	34.96±0.29	33.16±0.44
Maximum length fibular malleolar facet (maxLFMTAL)	26.50	49.30	37.65±0.31	32.83±0.38
Maximum width talar head (maxWHTAL)	28.10	47.60	35.53±0.27	31.92±0.44
Minimal width talar neck (minWNTAL)	22.20	40.50	30.75±0.24	27.75±0.44
Maximum length talar head and nec (maxLHNTAL)	13.30	40.60	22.57±0.27	24.54±0.46
MaxHBTAL/MaxLTAL (Talus-index)	0.46	0.74	0.54±0.003	0.53
Maximum length (MLCAL)	22.40	103.90	86.88±0.69	86.75±0.91
Body height (BHCAL)	41.00	84.00	50.32±0.41	50.50±0.77
Minimum body height (minBHCAL)	33.30	56.20	40.86±0.29	38.98±0.52
Minimum anterior height (minAHCAL)	18.90	35.60	25.21±0.23	23.08±0.30
Minimum anterior width (minAWCAL)	18.30	32.70	25.39±0.25	23.01±0.28
MinBHCAL/ MLCAL (Calcaneal-index)	0.39	1.73	0.47±0.09	0.44

The patients were divided into groups according to their age; group-1 (20-40), group-2 (40-60) and group-3 (60 and above). A significant difference was found between group-1 and group-2 for MaxLFMTAL value. No significant difference was found in terms of age groups for other measurements. No positive correlation was found between the increase in age and the measurements. Also all measurements were evaluated separately between the diagnostic groups (Table II). A significant difference was found between the control group and calcaneal spur groups for BHCAL, maxWHTAL, and minAWCAL measurements ($p<0.05$) (Fig 5). The calcaneus index ratio was found to be significantly different between the control group and the hallux valgus group ($p<0.001$) (Fig. 6).

Table II. Comparisons of radiography measurements of talus and calcaneus between groups (mm) (Mean±SEM).

Measurements	Healthy Group	Calcaneal Spur Group	Hallux Valgus Group
Maximum Length (maxLTAL)	64.27±0.8	65.34±0.6	64.17±0.8
Maximum Body Height (maxHBTAL)	35.02±0.4	35.10±0.4	34.34±0.9
Maximum length fibular malleolar facet (maxLFMTAL)	37.67±0.5	37.46±0.4	38.17±0.6
Maximum width talar head (maxWHTAL)	34.76±0.4	36.28±0.4	35.60±0.4
Minimal width talar neck (minWNTAL)	30.21±0.3	31.24±0.4	30.86±0.4
Maximum length talar head and neck (maxLHNTAL)	23.01±0.5	22.51±0.3	21.79±0.4
MaxHBTAL/MaxLTAL (Talus-index)	0.54±0.005	0.53±0.04	0.53±0.11
Maximum length (MLCAL)	86.20±0.84	87.39±1.32	87.46±1.48
Body height (BHCAL)	49.42±0.52	51.48±0.76	49.66±0.83
Minimum body height (minBHCAL)	40.73±0.47	41.34±0.45	39.85±0.68
Minimum anterior height (minAHCAL)	25.26±0.36	25.33±0.34	24.72±0.67
Minimum anterior width (minAWCAL)	24.90±0.33	26.01±0.45	25.16±0.55
MinBHCAL/ MLCAL (Calcaneal-index)	0.57±0.004	0.62±0.05	0.56±0.008

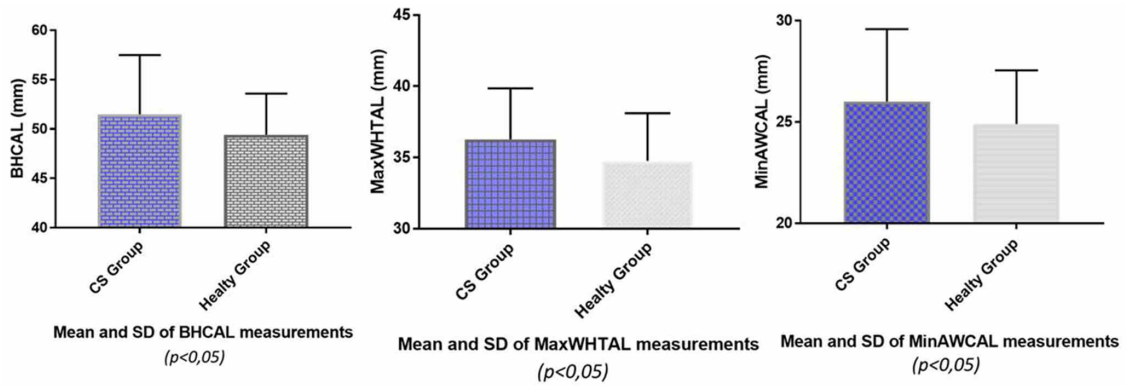

Fig. 5. Parameters significantly different between calcaneal spur and control groups.

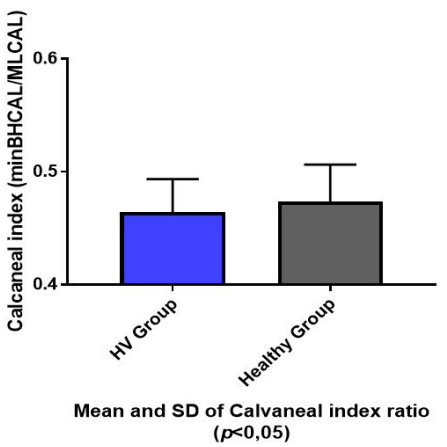

Fig. 6. Parameters significantly different between hallux valgus and control groups.

DISCUSSION

In this study, we searched for the answer to the question of whether the dimensions of the tarsal bones in the foot could be related to foot deformities. A significant difference was found between group-1 and group-2 for MaxLFMTAL value. A significant difference was found between control group and calcaneal spur groups in terms of BHCAL, maxWHTAL and minAWCAL measurements ($p<0.05$) (Fig. 5). The calcaneus index ratio was found to be significantly different between the control group and the hallux valgus group ($p<0.001$) (Fig. 6). According to the literature, there are several ways to obtain the correct

dimensions of the tarsal bones. Cadaveric specimens, radiographs and CT images are widely adopted study materials (Li *et al*., 2015) However, measurements made with cadaver samples can be associated with some disadvantages. Obtaining cadaver specimens is costly and different. Moreover, bones require extensive preparation. Radiographs are easier and more trouble-free, giving clear information (Han *et al*., 2019) Gathering quantitative information about these bones from radiographic images of the feet of living humans will aid in understanding the relationship of morphological variation of these tarsal elements to identifiable foot types in modern humans, something that cannot currently be safely accomplished using isolated foot bones (DeSilva *et al*., 2013; Agoada, 2018). The dimensions of the tarsal bones differ according to sex (Moraleda *et al*., 2012). Talus and calcaneus dimensions differed between the sexes in our study as well. The measurements with the talus and calcaneus obtained in our study are consistent with the measurements reported in Agoada's study in 2018 (Table 1) (Agoada, 2018). It is known that the calcaneus and talus are important bones in the formation of the arch of thefoot (Murley *et al*., 2009; Agoada & Kramer, 2020). Using radiographs, Agoada & Kramer (2020) reported that during weight bearing, a longer calcaneal height relative to the length of the calcaneus (calcaneal index) may be positively correlated with foot arch height, and may be associated with a higher foot arch height.

In our study, the calcaneal index was found to be significantly different between hallux vagus and control groups ($p<0.001$). The reason we could not look at the correlation of the calcaneal index and the arch height of the foot, is that our radiographs are not load-bearing and we cannot measure the foot arch height reliably. Also, in a study by Agoada & Kramer (2020), all variables related to the height of the talus, including the talus index, were not correlated with foot arch height. And in this study, also such a significant relationship was not found (Agoada & Kramer, 2020). As an explanation for these current and historical findings, studies have shown that high curvature of the foot is associated with an increase in the calcaneal index, suggesting that a higher calcaneus is seen in the higher hind feet (Murley *et al*., 2009). In contrast, the low arch of the foot is associated with an increase in the calcaneus-first metatarsal angle (ie, the angle formed by the lower surface of the calcaneus and a line parallel to the midshaft dorsum). Therefore, a longer talus may suggest a lower arch of the foot (Murley *et al*., 2009). Thus, a longer calcaneus due to an increased calcaneal index ratio may be a positive factor for a higher arch height, while a longer talus due to an increased calcaneal-first metatarsal angle may be a negative factor for a higher arch height. In summary, the height of the calcaneus, not the talus, can play an important role in increasing the arch of the foot (Murley *et al*., 2009). The study by Suga *et al*. (2020) suggested that while a longer calcaneus indicates potentially longer forelimb and hindfoot bones and higher arch height, it may be an important morphological factor for achieving superior sprint performance. They argued that their findings could improve our understanding of the importance of foot morphology on athletic performance in athletes (Suga *et al*., 2020).

CONCLUSION

As a result, our study showed that the measurements we obtained from the talus and calcaneus radiographs were statistically different from in male and female sexes, in line with the literature. When we evaluated the parameters about calcaneus, the measurements that were found to be significantly different between the calcaneal spur group and the control group were maximum body height of calcaneus (BHCAL) and minimal anterior width of the calcaneus min (AWCAL). Also calcaneal index was found to be significantly different between the hallux valgus group and control group ($p<0.05$). MaxWHTAL which is one measurement of the talus was significantly different between calcaneal spur group and control groups ($p<0.05$). In our literature review, we could not find any other study in which measurements obtained from radiographic images of the talus and calcaneus were associated with foot deformities. In this sense, our research is a first and we think that its results will contribute to the literature.

Limitation. More radiographic images are required to determine clinical relevance. Having an equal number of patient groups will increase the accuracy of the results.

Ethics approval. This study was performed in line with the principles of the Declaration of Helsinki. This study was approved by the Non-Interventional Clinical Research Ethics Committee (Decision No: 2020:20–10). This study was approved by the Non-Invasive Clinical Research Ethics Committee (Decision No: 2020:20–10).

CANDAN, B.; TORUN, E.; DIKICI, R. Investigación de la relación entre las deformidades del pie y las mediciones radiográficas del talo y el calcáneo. *Int. J. Morphol., 40(6)*:1490-1496, 2022.

RESUMEN: El peso del cuerpo se transmite al pie a través de la articulación subtalar y el talo. Teniendo en cuenta la importante ubicación del talo y el calcáneo, las estructuras morfológicas de estos huesos pueden afectar la biomecánica de la articulación subtalar. Al mismo tiempo, la estructura

morfológica de estos huesos es importante en algunas deformidades comunes del pie. Nuestro objetivo fue investigar si las diversas medidas del talo y el calcáneo están asociadas con diferentes deformidades del pie en este estudio. Se examinaron retrospectivamente imágenes radiográficas de 158 pacientes (72 hombres y 86 mujeres) con una edad promedio de 44 años. Se obtuvieron once medidas diferentes del talo y el calcáneo a partir de las radiografías lateral y anteroposterior de los pacientes. Se evaluaron retrospectivamente un total de 158 radiografías clínicas de rutina de los pacientes, los cuales tenían espolón de calcáneo (n=63), hallux valgus (n=32) y grupo control (n=63). Determinamos que la altura del cuerpo del calcáneo, el ancho máximo de la cabeza del talo, el ancho anterior mínimo del calcáneo fueron significativamente diferentes entre el grupo con espolón calcáneo y el grupo control. La longitud máxima de la faceta maleolar fíbular del talo era significativamente diferente entre los grupos de edad. También determinamos que el índice calcáneo fue significativamente diferente entre el grupo de hallux valgus y los grupos controles. Además, todas las medidas fueron significativamente diferentes entre hombres y mujeres. Como resultado, algunas medidas que determinan la morfología del talo y el calcáneo resultaron significativas entre los grupos de deformidad y los grupos controles. Estimamos que nuestro estudio contribuirá a la literatura debido a que es el primer reporte en el que las medidas obtenidas de las imágenes radiográficas del talo y el calcáneo se asocian con deformidades del pie.

PALABRAS CLAVE: Calcáneo; Morfología; Talo; Espolón calcáneo; Hallux valgo.

REFERENCES

Abreu, M. R.; Chung, C. B.; Mendes, L.; Mohana-Borges, A.; Trudell, D. & Resnick, D. Plantar calcaneal enthesophytes: new observations regarding sites of origin based on radiographic, MR imaging, anatomic, and paleopathologic analysis. *Skeletal Radiol., 32(1)*:13-21, 2003.

Agoada, D. & Kramer, P. A. Radiographic measurements of the talus and calcaneus in the adult pes planus foot type. *Am. J. Phys. Anthropol., 171(4)*:613-27, 2020.

Agoada, D. The relationship between linear osteological and radiographic measurements of the human calcaneus and talus. *Anat. Rec. (Hoboken), 301(1)*:21-33, 2018.

DeSilva, J. M.; Holt, K. G.; Churchill, S. E.; Carlson, K. J.; Walker, C. S.; Zipfel, B. & Berger, L. R. The lower limb and mechanics of walking in Australopithecus sediba. *Science, 340(6129)*:1232999, 2013.

Han, Q.; Liu, Y.; Chang, F.; Chen, B.; Zhong, L. & Wang, J. Measurement of talar morphology in northeast Chinese population based on three-dimensional computed tomography. *Medicine (Baltimore), 98(37)*:e17142, 2019.

Hecht, P. J. & Lin, T. J. Hallux valgus. *Med. Clin. North Am., 98(2)*:227-32, 2014.

Kirkpatrick, J.; Yassaie, O. & Mirjalili, S. A. The plantar calcaneal spur: a review of anatomy, histology, etiology and key associations. *J. Anat., 230(6)*:743-51, 2017.

Li, J.; Zhang, H.; Yin, P.; Su, X.; Zhao, Z.; Zhou, J.; Li, C.; Li, Z.; Zhang, L. & Tang, P. A new measurement technique of the characteristics of nutrient artery canals in tibias using materialise's interactive medical image control system software. *Biomed Res. Int., 2015*:171672, 2015.

Moraleda, L.; Salcedo, M.; Bastrom, T. P.; Wenger, D. R.; Albinana, J. & Mubarak, S. J. 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)*:821-9, 2012.

Murley, G. S.; Menz, H. B. & Landorf, K. B. A protocol for classifying normal- and flat-arched foot posture for research studies using clinical and radiographic measurements. *J. Foot Ankle Res., 2*:22, 2009.

Prang, T. C. The subtalar joint complex of Australopithecus sediba. *J. Hum. Evol., 90*:105-19, 2016.

Prasad, S. A. & Rajasekhar, S. S. S. N. Morphometric analysis of talus and calcaneus. *Surg. Radiol. Anat., 41(1)*:9-24, 2019.

Suga, T.; Terada, M.; Tanaka, T.; Miyake, Y.; Ueno, H.; Otsuka, M.; Nagano, A. & Isaka, T. Calcaneus height is a key morphological factor of sprint performance in sprinters. *Sci. Rep., 10(1)*:15425, 2020.

Zhang, Y. J.; Du, J. Y.; Chen, B.; Jin, R. L.; Hu, J. G. & Lin, X. J. Correlation between three-dimensional medial longitudinal arch joint complex mobility and medial arch angle in stage II posterior tibial tendon dysfunction. *Foot Ankle Surg., 25(6)*:721-6, 2019.

Zirngibl, B.; Grifka, J.; Baier, C. & Gotz, J. Hallux valgus: Etiology, diagnosis, and therapeutic principles. *Orthopade, 46(3)*:283-96, 2017.

Corresponding author:
Busra Candan, PhD
Assist. Prof.
Alanya Alaaddin Keykubat University
School of Medicine Department of Anatomy
Alanya
TURKEY

E-mail: busra.candan@alanya.edu.tr

Ebru Torun Orcid id: 0000-0003-0879-5285
Busra Candan Orcid id: 0000-0002-5138-5583
Rumeysa Dikici Orcid id: 0000-0003-3144-8740