Anthropometric evaluation of side, sex and age by radiological examination of the normal ankle joint among adult Egyptian population

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Wael Amin Nasr El-Din
Department of Anatomy, College of Medicine and Medical Science, Arabian Gulf University, Manama, Bahrain and Department of Human Anatomy and Embryology, Faculty of Medicine, Suez Canal University, Ismailia, Egypt
Mona Hassan Mohammed Ali
Department of Human Anatomy and Embryology, Faculty of Medicine, Suez Canal University, Ismailia, Egypt
Gisma Ahmed Madani
Department of Anatomy, Faculty of Medicine, National University - Sudan, Khartoum, Sudan, and
Islam Omar Abdel Fattah
Department of Human Anatomy and Embryology, Faculty of Medicine, Suez Canal University, Ismailia, Egypt

Abstract

Purpose – Sex and age estimation is important, particularly when information about the deceased is unavailable. There are limited radiological studies investigating side, sex and age differences in normal ankle morphometric parameters. The authors' goal was to evaluate different ankle joint morphometric measurements and document variations among Egyptians.

Design/methodology/approach – A prospective study was conducted throughout 23 months on 203 (100 males and 103 females) adult Egyptians, aged between 20-69 years old, who were referred for a plain x-ray of bilateral normal ankle joints.

Findings – Ankle parameters showed no statistical difference between both sides, except for tarsal width (TaW) which was significantly higher on right than left side (26.92 ± 2.66 vs 26.18 ± 2.65 mm). Males showed significantly higher morphometric values except for anteroposterior gap (APG) and talus height (TaH) which were significantly higher in females (2.29 ± 0.80 vs 1.80 ± 0.61 mm and 13.01 ± 1.68 vs 11.87 ± 1.91 mm, respectively). There was significant increase in tibial arc length, APG, distance of level of MTiTh from anterior limit of mortise, distance of level of MTiTh from vertex of mortise, sagittal distance between tibial and talar vertices and sagittal radius of trochlea tali arc in old age group compared to young one. A significant decrease in tibial width, malleolar width, TaW and TaH was noted in old age group compared to young one.

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Originality/value – Ankle joints of both sides are mostly symmetrical; however, there are significant differences in most morphometric values due to sex and age factors. These findings may be essential during side, sex and age determination.

Keywords Ankle joint, Egyptian population, Morphometry, Radiological, Anthropological, Estimation

Paper type Research paper

Introduction

Estimation of sex and age is more reliable in the case of an available complete skeleton for analysis (Abdel Moneim, Abdel Hady, Abdel Maaboud, Fathy, & Hamed, 2008). Nevertheless, in forensic cases, human skeletal remains are often damaged or incomplete, especially in a crime investigation or a mass disaster (Alkass *et al.*, 2010). In addition, it is highly accepted that skeletal morphometric parameters vary among different populations; thus, each population should have its own specific standards to allow more improvement in the accuracy of identification (Hayes, Tochigi, & Saltzman, 2006; Kuo *et al.*, 2008; Khanasuk, Itiravivong, Tangpronprasert, & Virulsri, 2011; Kwon *et al.*, 2014; Uzuner *et al.*, 2018; Garg *et al.*, 2022; Ghalawat, Sharma, Singh, & Malik, 2022).

Frequently, the skull, pelvis and long bones are damaged or absent, so the prediction of sex or age should be directed toward other parts of the skeleton. Nevertheless, the accuracy level of identification from other skeletal elements depends on their degree of difference (Abdel Moneim *et al.*, 2008). For example, in previous studies, foot skeletal components have been used for sex assessment, such as metacarpal bones (Zanella & Brown, 2003), and calcaneus and talus (Introna, Di Vella, Ampobasso, & Dragone, 1997). However, the availability of knowledge about the geographical origin or the ethnic group of the victim for the anthropologist is important before sex and age determination (Abdel Moneim *et al.*, 2008). Similarly, little data are available regarding the morphological variability of the human ankle regarding age and sexual dimorphism (Angthong *et al.*, 2020).

The measurement methods used for ankle morphometry are widely varying (Khanasuk *et al.*, 2011). Cadaveric specimens, radiographs, and computerized tomography images are mostly applied to obtain detailed ankle morphometric parameters (Han *et al.*, 2019).

Therefore, the purpose of the current study was to document the morphometric parameters of the human ankle joint obtained by x-ray radiographs regarding side, sex and age-based differences among Egyptians.

Methods

Study design

A prospective study was conducted on 203 subjects who met the criteria, including 100 males and 103 females with ages ranging from 20-69 years old. These cases were referred to the Radiology Department of Suez Canal University Hospital from the Orthopedic and Physiotherapy Clinics to perform ankle joint plain x-ray radiographs in the period between January 2020 and December 2021. This study was approved by the Research Ethics Committee of the Faculty of Medicine, Suez Canal University (approval No. 5046#). In addition, informed consent from the enrolled subjects was obtained. Only Egyptian subjects whose parents and grandparents are Egyptians with normal ankle joints were included in this study, while patients with a history of ankle joint surgery, fracture, tumor, inflammation, deformation or congenital anomaly were excluded from the study. Furthermore, low-quality radiographs were not utilized in this study.

Plain x-ray procedures

Ankle radiographs were obtained by using a radiographic image unit (GE Healthcare, Chicago, IL) set to 60 kVp and 6.3 mA at a distance of 110 cm. In anteroposterior radiographs, subjects stood with equal weight-bearing on both inverted feet, whereas in lateral views, subjects stood with equal weight-bearing on a support fixture and the cassette was held between both feet with the medial and lateral malleoli placed on each side of the cassette (Kwon *et al.*, 2014).

While taking x-ray radiographs, a metal rod with a known actual length was placed beside the ankle joint to use it for calibration during the morphometric analysis of the radiographic images. To ensure accurate calibration, this metal rod was applied at an angle of 90° to the horizontal ground surface.

All measurements were performed using ImageJ® software (Wayne Rasband NIH, Bethesda, MA, USA) by only one well-trained investigator to reduce the inter-observer bias. This investigator carried out the study measurements three times with at least a one-month interval between each to ensure minimal intra-observer bias and high repeatability of the morphometric procedures. The mean of these three measurements of each parameter was recorded.

Morphometric parameters

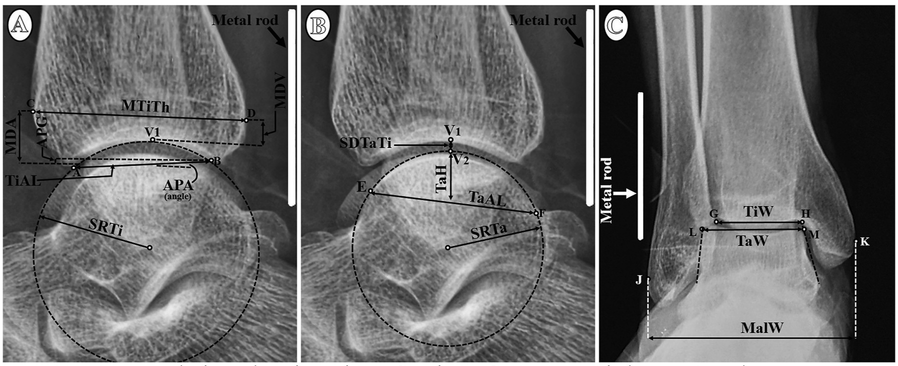
Radiographs were displayed on a picture archiving and communication system software program to perform the morphometric analysis of the components of the ankle joint (Stagni, Leardini, Ensini, & Cappello, 2005; Yurttas *et al.*, 2018) which are shown in Figure 1 and Table 1.

Evaluation of asymmetry

Percent directional asymmetry (%DA) was used for the assessment of the directional asymmetry in the tibial and talar measured parameters. It was calculated as follows:

$$\%\mathrm{DA} = (\mathrm{R} - \mathrm{L})/(1/2\,(\mathrm{R} + \mathrm{L})) \times 100\%$$

Where (L) is the left-side measurement, while (R) is the right-side measurement. The percent above zero means that there are right-side asymmetries, whereas the percent below zero means that there are left-side asymmetries.



Note(s): *A*: Lateral view showing TiAL, SRTi, APG, APA, MTiTh, MDA and MDV parameters. *B*: Lateral view showing TaAL, SRTa, TaH, and SDTaTi parameters. *C*: Anteroposterior view showing TiW, TaW and MalW parameters. Scale bar = 25 mm
Source(s): Figure by authors

Figure 1. Radiographs of the ankle joint showing the measured morphometric parameters

(A) Lateral view (sagittal projection) parameters		
1	Tibial arc length (TiAL) (mm)	Distance between the most anterior (A) and the most posterior (B) points of the arc of the tibial mortise
2	Sagittal radius of the tibial mortise (SRTi) (mm)	Radius of the circle fitting the tibial mortise profile
3	Antero-posterior gap (APG) (mm)	Distance between the points (A) and (B) along the longitudinal axis of the tibia
4	Antero-posterior inclination angle of the tibial mortise (APA) (degrees)	Inclination angle between the A-B connecting line and the tibial antero-posterior axis
5	Maximal tibial thickness (MTiTh) (mm)	Distance between the most tibial anterior point (C) and the corresponding posterior point (D)
6	Distance of level of MTiTh from the anterior limit of the mortise (MDA) (mm)	Longitudinal distance between (A) and (C) points along the tibia
7	Distance of level of MTiTh from the vertex of the mortise (MDV) (mm)	Longitudinal distance between the vertex of tibial mortise (V1) and the point (C)
8	Trochlea tali length (TaAL) (mm)	Length of the line connecting the most anterior (E) and the most posterior (F) points of the trochlea tali sagittal arc
9	Sagittal radius of the trochlea tali arc (SRTa) (mm)	Radius of the circle fitting the trochlea tali arc points
10	Talus height (TaH) (mm)	Length of the longitudinal line connecting the vertex of trochlea tali (V2) and the line connecting the most anterior (E) and the most posterior (F) points of the trochlea tali sagittal arc
11	Sagittal distance between tibial and talar vertices (SDTaTi) (mm)	Distance between the vertex of the tibial mortise (V1) and trochlea tali vertex (V2)
(B) Anteroposterior view (frontal projection) parameters		
1	Tibial width (TiW) (mm)	Length of the internal line fitting between the two malleoli (between the G and H points)
2	Malleolar width (MalW) (mm)	Length of the line connecting the most medial point of the medial malleolus (K) and the most lateral point of the lateral malleolus (J)
3	Tarsal width (TaW) (mm)	Length of the line along the top of talar articular surface extending between the most medial (M) and the most lateral points (L) of the talar articular profile

Source(s): Table by authors

Table 1. Measured morphometric parameters of the ankle joint

A quantitative measure of directional asymmetry in each parameter was calculated by the percent absolute asymmetries (%AAs) to evaluate the degree of asymmetry, irrespective of its directionality, as follows:

$$\%AA = (\text{Max} - \text{Min})/(1/2\,(\text{Max} + \text{Min})) \times 100\%$$

Where (Max) is the maximum measurement, while (Min) is the minimum measurement (Auerbach & Ruff, 2006).

Statistical analysis

Data analysis was performed using Statistical Package for Social Sciences (SPSS) software version 27.0 for Windows (IBM Corp., Armonk, NY, USA). Data were expressed as means and standard deviations (SD), in addition to the maximal and minimal values. A paired sample Student's *t*-test was used to compare the means of morphometric values according to side variability. On the other hand, to test the sexual dimorphism, an unpaired *t*-test was performed. One-way analysis of variance (ANOVA) with Tukey *post-hoc* test was used to test the levels of statistical significance of the morphometric data according to the ages of the study subjects.

Regarding the %DAs and %AAs, their values were tested for normality using the Shapiro-Wilk test, which demonstrated the non-normal (non-parametric) distribution of their data. So, we evaluated the significance of the %DAs and %AAs using the Mann-Whitney *U*-test which is the non-parametric equivalent of the two-sample *t*-test.

Pearson's correlation coefficient was performed to evaluate the relations between different study variables. The difference between the data was considered significant when the two-tailed p value was ≤ 0.05. The intraclass correlation coefficient (ICC) was used to assess rating reliability by comparing the variability of the three values of each parameter recorded by the same investigator. ICC values were interpreted as follows: poor reliability <0.50; moderate reliability: 0.50-0.75; good reliability: 0.75-0.90 and excellent reliability >0.90 (Koo & Li, 2016).

Results

The numbers of male and female subjects according to the age groups were expressed in Table 2. The ICC values of all parameters ranged from 0.920-0.970, indicating excellent intra-observer reliability of all recorded measurements (Table 3). According to the side of the ankle joints, only TaW of the right side was significantly higher than the left (26.92 $\pm$ 2.66 vs 26.18 $\pm$ 2.65 mm) ($p = 0.005$). On the contrary, there was no statistical difference between other tibial or talar morphometric parameters on both sides of the ankle joints (Tables 4 and 5).

The evaluation of asymmetry revealed that there were right-sided asymmetries in all parameters except for TiAL, SRTi and TaAL in males and for TiAL, SRTi, TaAL and Taw in females where there were left-sided asymmetries (Tables 6 and 7). However according to the %AA assessment, only APG and TiW exhibited a significant asymmetrical directional bias comparing the males and females ($p = 0.042$ and 0.048, respectively) (Tables 8 and 9).

Regarding the sex, MTiTh, MDV, TiW, MalW, SRTi, TaAL, TaW, SDTaTi and SRTa were significantly higher in males than females (p < 0.001, <0.001, <0.001, <0.001, <0.001, = 0.024, <0.001, <0.001 and < 0.001, respectively), while APG and TaH were significantly higher in females than males ($p < 0.001$ for both). Nevertheless, there was no statistically significant difference between both sexes according to TiAL, APA and MDA (p = 0.080, = 0.946 and = 0.143, respectively) (Figure 2) (Tables 10 and 11).

Age group	Sex	N	Mean	SD
20-29	Male	17	24.24	2.60
	Female	22	24.77	2.83
30-39	Male	25	33.84	2.65
	Female	23	34.30	2.73
40-49	Male	22	44.68	2.74
	Female	21	44.29	2.76
50-59	Male	19	54.74	2.92
	Female	18	54.22	2.72
60-69	Male	17	64.47	2.59
	Female	19	63.95	2.67
Total	Male	100	44.39	2.70
	Female	103	44.31	2.74

Note(s): Abbreviations: N, number; SD, standard deviation
Source(s): Table by authors

Table 2. Distribution of individuals according to age and sex

Parameter	ICC of the left measurements	ICC of the right measurements
TiAL	0.967	0.964
APG	0.942	0.951
APA	0.968	0.943
MTiTh	0.963	0.923
MDA	0.920	0.931
MDV	0.959	0.949
TiW	0.960	0.952
MalW	0.971	0.970
SRTi	0.982	0.948
TaAL	0.945	0.945
TaW	0.965	0964
TaH	0.934	0.959
SDTaTi	0.953	0.921
SRTa	0.968	0.970

Note(s): The intra-observer reliability was evaluated using the intraclass correlation coefficient (ICC)
Source(s): Table by authors

Table 3.
The ICC values of the studied parameters

When age is considered, the values of TiAL, APG, APA, MDA, MDV, SDTaTi and SRTa were significantly higher in subjects aged between 60-69 years as compared to those aged between 20-29 years, while TiW, MalW, TaW and TaH were significantly lower in subjects aged between 60-69 years when compared to those aged between 20-29 years. Whereas there was no statistically significant difference between these two age groups according to MTiTh, SRTi and TaAL values (Figure 3) (Tables 12–15).

Pearson's correlation between the age and APA was positively high (n = 203, $r = 0.600$, $p < 0.001$), while this correlation was negatively high between the age and TaH (n = 203, $r = -0.531$, $p < 0.001$). On the other hand, MDA and SDTaTi were positively moderately correlated with age (n = 203, $r = 0.487$ and 0.361, $p = 0.165$ and < 0.001, respectively); nevertheless, the correlation between age and TaAL was moderately negative (n = 203, $r = -0.329$, $p < 0.001$). The other tibial and talar parameters were weakly correlated with age (the coefficient was smaller than 0.3 or greater than -0.3) (Figure 4).

According to the correlation among different study morphometric parameters, there were moderately significant positive correlations between TiW and Taw values (n = 406, $r = 0.654$, $p < 0.001$), and between APA and MDA values (n = 406, $r = 0.615$, $p < 0.001$). On the other hand, the correlations between other parameters were weak (Table 16).

Discussion

Part of forensic investigations may be implicated in identifying a decedent. Such identification is sometimes difficult, particularly when the human remains of the victim are fragmented, decomposed or mutilated (Rich, Dean, & Cheung, 2003).

As commonly reported, the most useful anatomic structures used for subject identification are the pelvis (Fornai *et al.*, 2021), long bones (Kiskira, Eliopoulos, Vanna, & Manolis, 2022), skull (Cappella *et al.*, 2022), teeth (Soundarya, Jain, Shetty, & Akshatha, 2021), chest (Kalbouneh *et al.*, 2021), and lumbar spine (Bozdag *et al.*, 2021). However, these elements may be unavailable due to their loss or destruction, so other body regions could be useful for that, such as the foot and ankle (Rich *et al.*, 2003).

Due to their protected nature in footwear, the feet and ankles usually escape the effects of trauma other than the rest of the body. Additionally, footwear not only slows down the process of disarticulation but also helps in the retention and preservation of foot and ankle

Table 4. Relation among tibial parameters according to the side

Parameter	Left ankle (n = 203) Mean	SD	Min	Max	Right ankle (n = 203) Mean	SD	Min	Max	Total (n = 406) Mean	SD	Min	Max	*p* value
TiAL (mm)	29.00	3.68	20.40	38.65	28.79	3.69	21.01	40.14	28.90	3.68	20.40	40.14	0.564
APG (mm)	2.04	0.63	0.84	4.22	2.07	0.85	0.24	5.94	2.05	0.75	0.24	5.94	0.626
APA (degrees)	3.44	1.46	1.10	7.95	3.71	1.50	1.04	8.06	3.58	1.48	1.04	8.06	0.065
MTiTh (mm)	40.79	3.36	34.28	49.57	40.91	3.27	34.18	48.60	40.85	3.31	34.18	49.57	0.736
MDA (mm)	10.65	4.61	5.12	24.13	10.92	4.62	5.26	24.99	10.79	4.61	5.12	24.99	0.546
MDV (mm)	4.89	1.41	2.03	8.28	5.07	1.35	2.58	7.90	4.98	1.38	2.03	8.28	0.180
TiW (mm)	28.13	2.01	22.59	32.94	28.44	1.89	22.97	34.80	28.29	1.95	22.59	34.80	0.112
MalW (mm)	59.04	4.79	48.05	67.60	59.61	4.94	46.33	68.47	59.33	4.87	46.33	68.47	0.229
SRTi (mm)	22.99	2.47	16.82	29.99	22.80	1.87	18.18	27.85	22.89	2.19	16.82	29.99	0.373

Note(s): Values are presented as means, SD, minimum (Min) and maximum (Max). Statistical analysis was performed by paired student's *t*-test
Source(s): Table by authors

Table 5.
Relation among talar parameters according to the side

Parameter	Left ankle (n = 203) Mean	SD	Min	Max	Right ankle (n = 203) Mean	SD	Min	Max	Total (n = 406) Mean	SD	Min	Max	*p* value
TaAL (mm)	37.63	2.46	29.31	44.71	37.23	2.69	31.15	45.83	37.43	2.59	29.31	45.83	0.118
TaW (mm)	26.18	2.65	20.33	33.29	26.92	2.66	22.02	32.78	26.55	2.68	20.33	33.29	0.005
TaH (mm)	12.42	1.83	7.63	16.93	12.47	1.94	8.01	16.16	12.45	1.89	7.63	16.93	0.784
SDTaTi (mm)	2.40	0.65	1.01	4.55	2.48	0.65	1.00	4.89	2.44	0.65	1.00	4.89	0.221
SRTa (mm)	21.09	1.22	17.96	24.71	21.11	1.35	17.69	24.92	21.10	1.28	17.69	24.92	0.863

Note(s): Values are presented as means, SD, minimum (Min) and maximum (Max). Statistical analysis was performed by paired student's *t*-test
Source(s): Table by authors

Parameter	Male (n = 100) Mean	SD	Female (n = 103) Mean	SD	Total (n = 203) Mean	SD	p value
TiAL	−0.79	0.09	−0.66	0.07	−0.73	0.07	0.692
APG	1.66	0.13	1.31	0.11	1.48	0.16	0.693
APA	7.57	1.27	7.55	1.21	7.56	1.23	0.661
MtiTh	1.01	0.09	0.33	0.02	0.67	0.07	0.700
MDA	2.49	0.29	2.52	0.31	2.50	0.28	0.528
MDV	3.74	0.32	3.46	0.35	3.60	0.37	0.183
TiW	1.20	0.14	1.09	0.11	1.15	0.16	0.139
MalW	0.94	0.06	0.96	0.08	0.95	0.07	0.391
SRTi	−0.84	0.07	−0.82	0.1	−0.83	0.09	0.298

Note(s): Values are presented as means and SD. Statistical analysis was performed by Mann–Whitney U-test
Source(s): Table by authors

Table 6. %DAs of tibial parameters according to the sex

Parameter	Male (n = 100) Mean	SD	Female (n = 103) Mean	SD	Total (n = 203) Mean	SD	p value
TaAL	−1.06	0.06	−1.21	0.08	−1.14	0.08	0.132
TaW	2.77	0.19	−6.49	0.42	−1.86	0.18	0.003
TaH	0.34	0.04	0.46	0.07	0.40	0.09	0.693
SDTaTi	3.01	0.53	3.60	0.56	3.31	0.62	0.349
SRTa	0.09	0.01	0.10	0.01	0.09	0.01	0.731

Note(s): Values are presented as means and SD. Statistical analysis was performed by Mann–Whitney U-test
Source(s): Table by authors

Table 7. %DAs of talar parameters according to the sex

Parameter	Male (n = 100) Mean	SD	Female (n = 103) Mean	SD	Total (n = 203) Mean	SD	p value
TiAL	0.57	0.05	0.67	0.07	0.62	0.06	0.275
APG	1.52	0.18	1.13	0.13	1.32	0.16	0.042
APA	1.30	0.13	1.52	0.16	1.41	0.18	0.211
MTiTh	0.37	0.05	0.24	0.06	0.30	0.04	0.318
MDA	1.00	0.01	1.31	0.02	1.16	0.03	0.073
MDV	1.03	0.04	1.15	0.05	1.09	0.06	0.627
TiW	0.43	0.07	0.23	0.03	0.33	0.19	0.048
MalW	0.31	0.05	0.37	0.05	0.34	0.06	0.762
SRTi	0.39	0.04	0.45	0.06	0.42	0.05	0.184

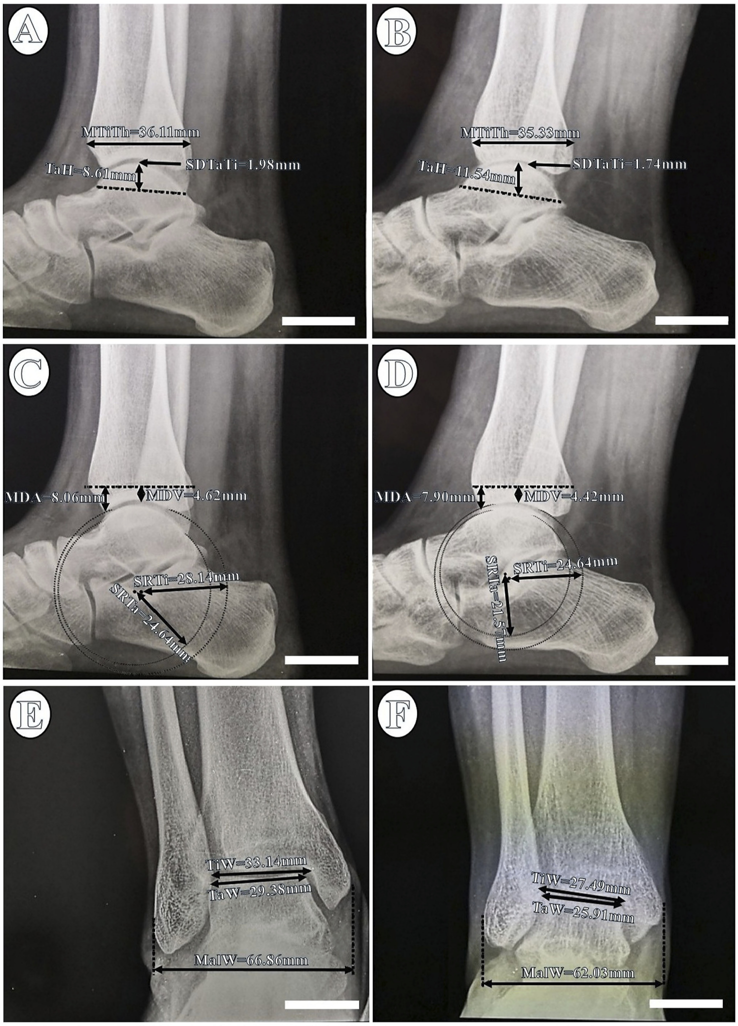
Note(s): Values are presented as means and SD. Statistical analysis was performed by Mann–Whitney U-test
Source(s): Table by authors

Table 8. %AAs of tibial parameters according to the sex

Parameter	Male (n = 100) Mean	SD	Female (n = 103) Mean	SD	Total (n = 203) Mean	SD	p value
TaAL	0.39	0.03	0.43	0.06	0.41	0.05	0.729
TaW	0.49	0.05	0.30	0.02	0.39	0.04	0.182
TaH	0.69	0.06	0.64	0.08	0.67	0.07	0.829
SDTaTi	1.15	0.07	1.54	0.09	1.35	0.07	0.491
SRTa	0.34	0.03	0.29	0.04	0.32	0.04	0.695

Note(s): Values are presented as means and SD. Statistical analysis was performed by Mann–Whitney U-test
Source(s): Table by authors

Table 9. %AAs of talar parameters according to the sex



Note(s): *A* and *C*: Lateral views of the male. *B* and *D*: Lateral views of the female. *E*: Anteroposterior view of the male. *F*: Anteroposterior view of the female. Scale bar = 25 mm
Source(s): Figure by authors

Figure 2.
Radiographs of ankle joints of adult male and female aged 35 years old showing a comparison between their morphometric values

bones. Furthermore, footwear adds a degree of protection from taphonomic alteration, e.g. animal scavenging, thus preserving the integrity of the pedal skeleton (Davies, Hackman, & Black, 2014).

Despite the use of the ankle joint in forensic investigations, which has been previously involved in medical and forensic literature (Steele *et al.*, 1976; Singh *et al.*, 1975; Rich, 2000; Rich *et al.*, 2002), only a few studies have investigated the geometrical measurements of the ankle joint, and the common techniques for these measurements were plain x-ray, CT scan and MRI (Khanasuk *et al.*, 2011).

Table 10. Relation among tibial parameters according to the sex

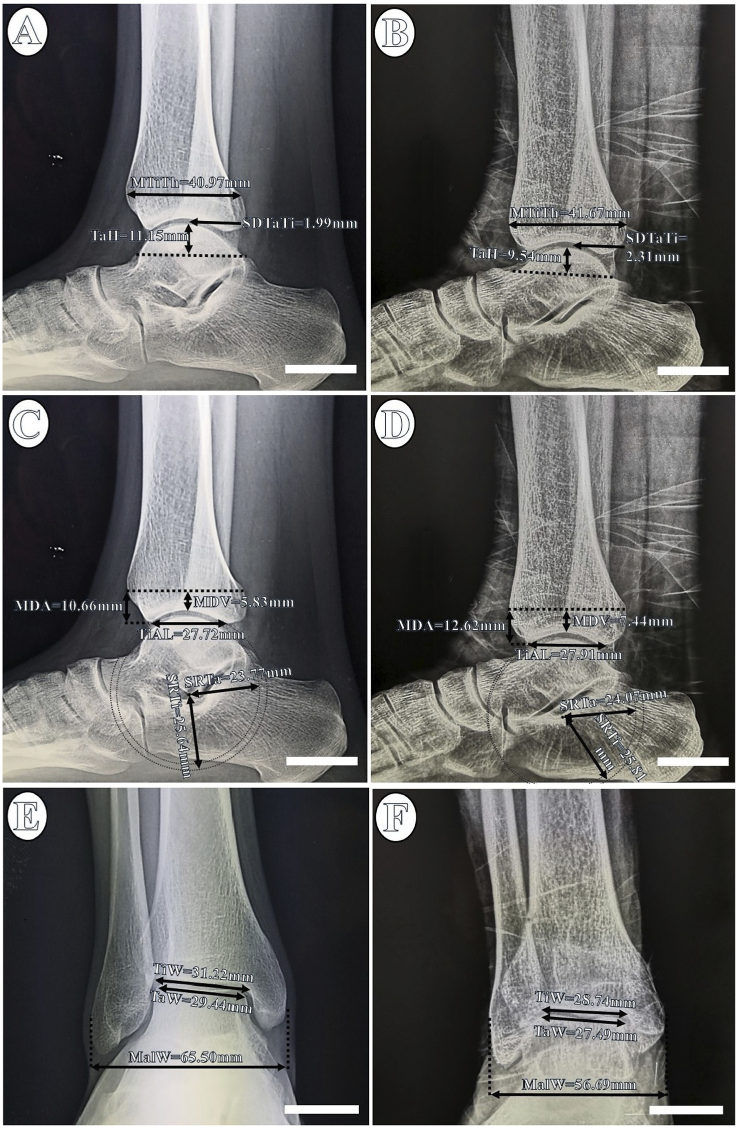
Parameter		Male (n = 200) Mean	SD	Min	Max	Female (n = 206) Mean	SD	Min	Max	Total (n = 406) Mean	SD	Min	Max	p value
TiAL (mm)	Left	29.33	3.68	21.38	37.97	28.67	4.10	19.30	39.07	28.90	3.68	20.40	40.14	0.080
	Right	29.10	3.69	21.01	37.83	28.48	4.35	19.35	38.73					
	Total	29.22	3.00	20.40	36.84	28.58	4.23	20.72	40.14					
APG (mm)	Left	1.79	0.61	0.73	4.02	2.28	0.71	1.42	5.84	2.05	0.75	0.24	5.94	<0.001
	Right	1.82	0.73	0.52	5.17	2.31	0.84	1.70	5.33					
	Total	1.80	0.61	0.24	3.96	2.29	0.80	1.05	5.94					
APA (degrees)	Left	3.43	1.45	1.09	5.31	3.44	1.70	1.12	8.02	3.58	1.48	1.04	8.06	0.946
	Right	3.70	1.47	1.13	5.12	3.71	1.78	1.07	8.11					
	Total	3.57	1.10	1.10	5.42	3.58	1.79	1.04	8.06					
MTiTh (mm)	Left	42.26	3.52	34.07	49.67	39.05	1.89	33.82	43.03	40.85	3.31	34.18	49.57	<0.001
	Right	42.69	3.33	33.98	49.32	39.18	1.71	33.98	42.85					
	Total	42.63	3.51	34.18	49.57	39.12	1.90	34.28	43.72					
MDA (mm)	Left	10.32	2.32	5.10	15.32	10.98	5.93	5.06	24.26	10.79	4.61	5.12	24.99	0.143
	Right	10.58	2.40	5.36	15.97	11.26	5.95	5.14	25.03					
	Total	10.45	2.47	5.26	15.37	11.12	5.98	5.12	24.99					
MDV (mm)	Left	5.25	1.38	2.54	8.05	4.54	1.33	2.01	7.57	4.98	1.38	2.03	8.28	<0.001
	Right	5.45	1.34	2.73	8.34	4.70	1.30	2.16	7.94					
	Total	5.35	1.35	2.65	8.28	4.62	1.32	2.03	7.89					
TiW (mm)	Left	28.91	2.45	22.36	34.61	27.35	1.11	24.25	30.53	28.29	1.95	22.59	34.80	<0.001
	Right	29.26	2.38	22.75	34.98	27.65	1.05	24.63	30.87					
	Total	29.09	2.31	22.59	34.80	27.51	1.06	24.41	30.76					
MalW (mm)	Left	61.19	4.27	50.44	68.31	56.95	4.36	46.26	67.21	59.33	4.87	46.33	68.47	<0.001
	Right	61.77	4.34	50.07	68.74	57.50	4.46	46.72	67.79					
	Total	61.48	4.31	50.11	68.47	57.23	4.45	46.33	67.68					
SRTi (mm)	Left	23.82	2.23	17.92	29.98	22.17	2.08	15.37	27.31	22.89	2.19	16.82	29.99	<0.001
	Right	23.62	2.08	21.61	28.67	21.99	1.88	18.53	26.17					
	Total	23.72	2.10	18.79	29.99	22.08	1.96	16.82	27.24					

Note(s): Values are presented as means, SD, minimum (Min) and maximum (Max). Statistical analysis was performed by unpaired student's t-test
Source(s): Table by authors

Table 11.
Relation among talar parameters according to the sex

Parameter		Male (n = 200)				Female (n = 206)				Total (n = 406)				p value
		Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	
TaAL (mm)	Left	37.92	2.41	30.67	45.66	37.39	2.22	28.72	44.67	37.43	2.59	29.31	45.83	0.024
	Right	37.52	2.69	30.95	45.71	36.94	2.46	28.96	44.46					
	Total	37.72	2.73	31.65	45.83	37.14	2.41	29.31	42.42					
TaW (mm)	Left	27.78	2.53	20.05	33.65	25.78	1.49	21.21	29.61	26.55	2.68	20.33	33.29	<0.001
	Right	28.56	2.71	20.16	32.97	24.16	1.54	21.93	28.69					
	Total	28.19	2.64	20.33	33.29	24.97	1.52	21.28	28.84					
TaH (mm)	Left	11.85	1.87	7.32	15.63	12.98	1.62	8.16	16.11		1.89	7.63	16.93	<0.001
	Right	11.89	1.96	7.76	15.21	13.04	1.71	8.33	16.02					
	Total	11.87	1.91	7.63	15.57	13.01	1.68	8.21	16.93	12.45				
SDTaTi (mm)	Left	2.62	0.64	1.31	4.74	2.18	0.56	0.95	4.07		0.65	1.00	4.89	<0.001
	Right	2.70	0.67	1.29	4.91	2.26	0.59	0.11	4.12					
	Total	2.66	0.66	1.28	4.89	2.22	0.57	1.00	4.07	2.44				
SRTa (mm)	Left	21.44	1.39	17.97	24.88	20.76	1.09	17.76	23.59		1.28	17.69	24.92	<0.001
	Right	21.46	1.56	17.53	24.95	20.78	0.99	17.51	23.78					
	Total	21.45	1.41	17.91	24.92	20.77	1.04	17.69	23.69	21.10				

Note(s): Values are presented as means, SD, minimum (Min) and maximum (Max). Statistical analysis was performed by unpaired student's t-test
Source(s): Table by authors



Note(s): *A* and *C*: Lateral views of the male aged 28 years old. *B* and *D*: Lateral views of the male aged 68 years old. *E*: Anteroposterior view of the male aged 28 years old. *F*: Anteroposterior view of the male aged 68 years old. Scale bar = 25 mm
Source(s): Figure by authors

Figure 3. Radiographs of ankle joints showing a comparison between two males of 28 and 68 years old according to their morphometric values

As previously reported by Stagni *et al.* (2005) in Italy, all measured ankle morphometric values were higher than our reported results. Also, according to Kwon *et al.* (2014), all ankle parameters in the Korean population were higher than our results except for MTiTh

Parameter		20-29 (n = 39) Mean ± SD	30-39 (n = 48) Mean ± SD	40-49 (n = 43) Mean ± SD	50-59 (n = 37) Mean ± SD	60-69 (n = 36) Mean ± SD
TiAL (mm)	Left	28.02 ± 1.71	29.92 ± 2.88^{a}	28.79 ± 4.29^{a,b}	27.81 ± 2.33^{b}	32.13 ± 4.95^{a,b,c,d}
	Right	27.84 ± 1.62	29.80 ± 1.62^{a}	28.59 ± 4.40^{a,b}	27.67 ± 2.19^{b}	31.63 ± 4.8 ^{a,b,c,d}
	Total	27.93 ± 1.62	29.86 ± 2.83^{a}	28.69 ± 4.29^{a,b}	27.74 ± 2.41^{b}	31.88 ± 4.79^{a,b,c,d}
APG (mm)	Left	0.95 ± 0.27	1.61 ± 0.57^{a}	1.62 ± 0.41^{a}	1.66 ± 1.16^{a}	3.01 ± 0.59^{a,b,c,d}
	Right	1.01 ± 0.31	1.63 ± 0.62^{a}	1.70 ± 0.52^{a}	1.72 ± 1.25^{a}	3.09 ± 0.61^{a,b,c,d}
	Total	0.98 ± 0.26	1.62 ± 0.57^{a}	1.66 ± 0.62^{a}	1.69 ± 1.26^{a}	3.05 ± 4.86^{a,b,c,d}
APA (degrees)	Left	1.92 ± 0.39	3.26 ± 0.11^{a}	4.05 ± 0.66^{a,b}	4.12 ± 0.68^{a,b}	4.32 ± 2.01^{a,b}
	Right	2.14 ± 0.52	2.52 ± 0.83^{a}	4.33 ± 0.71^{a,b}	4.44 ± 0.79^{a,b}	4.60 ± 2.32^{a,b}
	Total	2.03 ± 0.43	2.89 ± 0.97^{a}	4.19 ± 0.66^{a,b}	4.28 ± 0.78^{a,b}	4.46 ± 2.17^{a,b}
MTiTh (mm)	Left	43.66 ± 3.39	41.28 ± 2.99^{a}	40.70 ± 1.60^{a}	43.92 ± 3.97^{b,c}	43.21 ± 1.52^{b,c}
	Right	43.80 ± 3.95	41.36 ± 3.08^{a}	40.88 ± 1.78^{a}	44.10 ± 4.11^{b,c}	43.37 ± 1.64^{b,c}
	Total	43.73 ± 3.97	41.32 ± 3.11^{a}	40.79 ± 1.79^{a}	44.01 ± 4.05^{b,c}	43.29 ± 1.54^{b,c}
MDA (mm)	Left	8.43 ± 1.39	8.33 ± 2.91	6.28 ± 0.99^{a,b}	12.39 ± 1.03^{a,b,c}	16.22 ± 6.13^{a,b,c,d}
	Right	8.61 ± 1.61	8.45 ± 2.37	6.52 ± 0.87^{a,b}	12.69 ± 1.26^{a,b,c}	16.58 ± 5.72^{a,b,c,d}
	Total	8.52 ± 1.57	8.39 ± 2.83	6.40 ± 0.98^{a,b}	12.54 ± 1.16^{a,b,c}	16.40 ± 5.91^{a,b,c,d}
MDV (mm)	Left	5.53 ± 1.19	4.81 ± 1.56^{a}	4.86 ± 0.80^{a,b}	5.00 ± 1.06^{c}	6.05 ± 0.79^{a,b,c,d}
	Right	5.67 ± 1.44	5.03 ± 1.71^{a}	5.10 ± 0.62^{a,b}	5.24 ± 1.35^{c}	6.21 ± 0.93^{a,b,c,d}
	Total	5.60 ± 1.36	4.92 ± 1.62^{a}	4.98 ± 1.12^{a,b}	5.12 ± 1.19^{c}	6.13 ± 0.84^{a,b,c,d}
TiW (mm)	Left	28.66 ± 1.51	30.01 ± 1.88^{a}	29.61 ± 0.86^{a,b}	29.17 ± 2.31^{b,c}	26.95 ± 1.05^{a,b,c,d}
	Right	28.90 ± 1.56	30.31 ± 1.97^{a}	30.05 ± 1.02^{a,b}	30.05 ± 2.06^{b,c}	27.19 ± 1.31^{a,b,c,d}
	Total	28.78 ± 1.52	30.16 ± 1.98^{a}	29.83 ± 3.09^{a,b}	29.61 ± 2.11^{b,c}	27.07 ± 1.15^{a,b,c,d}
MalW (mm)	Left	62.25 ± 5.69	62.12 ± 3.73	59.43 ± 3.16^{a,b}	64.83 ± 4.43^{a,b,c}	57.50 ± 4.38^{a,b,c,d}
	Right	62.81 ± 5.81	62.62 ± 3.59	60.05 ± 2.98^{a,b}	65.39 ± 4.19^{a,b,c}	57.80 ± 4.11^{a,b,c,d}
	Total	62.53 ± 5.66	62.37 ± 3.63	59.74 ± 3.08^{a,b}	65.11 ± 4.22^{a,b,c}	57.65 ± 4.24^{a,b,c,d}
SRTi (mm)	Left	23.80 ± 1.50	24.70 ± 1.63^{a}	25.12 ± 2.73^{a}	22.12 ± 1.69^{a,b,c}	23.26 ± 1.66^{b,c,d}
	Right	23.62 ± 1.46	24.54 ± 1.58^{a}	24.9 ± 2.99^{a}	22.04 ± 1.61^{a,b,c}	23.10 ± 1.59^{b,c,d}
	Total	23.71 ± 1.53	24.62 ± 1.58^{a}	25.01 ± 2.81^{a}	22.08 ± 1.67^{a,b,c}	23.18 ± 1.61^{b,c,d}

Note(s): Values are mean ± SD. $^{a}p < 0.05$ vs 20–29 age group, $^{b}p < 0.05$ vs 30–39 age group, $^{c}p < 0.05$ vs 40–49 age group and $^{d}p < 0.05$ vs 50–59 age group. Statistical analysis was performed by ANOVA, followed by Tukey's *post hoc* test
Source(s): Table by authors

Table 12. Relation among the male tibial parameters according to the age groups

(39.3 mm), TaAL (35.3 mm) and TaH (10.5 mm) which were lower than the values of the current study (40.9, 37.4 and 12.5 mm, respectively). In contrast, ankle joint measurements were lower than our ones with a Thai study conducted by Khanasuk *et al.* (2011), except for TiW (29.3 mm) and TaW (28.0 mm) which were higher than the results of the present study (28.3 and 26.6 mm, respectively).

Kuo *et al.* (2014) in Taiwan concluded that ankle measurements are higher than our results regarding APG (3.6 vs 2.1 mm), APA (7.4 vs 3.6°), MTiTh (42.0 vs 40.9 mm), MDA (11.4 vs 10.9 mm), MalW (63.1 vs 59.3 mm) and SDTaTi (4.5 vs 2.4 mm), while lower for TiAL (28.4 vs 28.9 mm) and TaH (11.9 vs 12.5 mm) values.

In accordance with our results, an American study by Hayes *et al.* (2006) reported that the mean SRTa was 20.7 mm which is slightly lower than that of the present study (21.1 mm ± 1.3 mm) (Table 17). In another study performed by Fessy, Carret, and Béjui (1997) in France, TiAL and TaAL were slightly higher than our results (30.8 vs 28.9 and 38.5 vs 37.4 mm, respectively).

The presence of bilateral asymmetry is considered normal in the human body. This may be attributable to both genetic and environmental factors (Krishan & Kanchan, 2016). In

Parameter		20-29 (n = 39) Mean ± SD	30-39 (n = 48) Mean ± SD	40-49 (n = 43) Mean ± SD	50-59 (n = 37) Mean ± SD	60-69 (n = 36) Mean ± SD
TaAL (mm)	Left	37.74 ± 1.89	40.43 ± 1.91^{a}	36.60 ± 1.97^{a,b}	36.21 ± 2.68^{a,b}	37.87 ± 2.66^{b,c,d}
	Right	37.52 ± 1.94	40.15 ± 1.75^{a}	36.36 ± 1.71^{a,b}	36.87 ± 2.39^{a,b}	37.45 ± 2.64^{b,c,d}
	Total	37.63 ± 1.81	40.29 ± 1.84^{a}	36.48 ± 1.87^{a,b}	36.54 ± 2.54^{a,b}	37.66 ± 2.65^{b,c,d}
TaW (mm)	Left	28.11 ± 2.73	29.25 ± 2.89^{a}	28.17 ± 1.37^{b}	28.43 ± 2.05	25.14 ± 1.21^{a,b,c,d}
	Right	28.65 ± 2.85	30.05 ± 3.01^{a}	28.99 ± 1.48^{b}	29.27 ± 2.44	25.84 ± 1.42^{a,b,c,d}
	Total	28.38 ± 2.77	29.63 ± 2.98^{a}	28.51 ± 1.42^{b}	28.88 ± 2.33	25.52 ± 1.34^{a,b,c,d}
TaH (mm)	Left	12.57 ± 2.04	13.80 ± 0.74^{a}	11.61 ± 1.32^{a,b}	10.67 ± 0.84^{a,b,c}	10.62 ± 1.85^{a,b,c}
	Right	12.67 ± 2.09	13.78 ± 0.79^{a}	11.63 ± 1.21^{a,b}	10.69 ± 0.89^{a,b,c}	10.66 ± 1.91^{a,b,c}
	Total	12.62 ± 2.06	13.79 ± 0.79^{a}	11.62 ± 1.27^{a,b}	10.68 ± 0.86^{a,b,c}	10.64 ± 1.85^{a,b,c}
SDTaTi (mm)	Left	2.28 ± 0.51	2.60 ± 0.35^{a}	2.23 ± 0.41^{b}	2.96 ± 0.68^{a,b,c}	2.95 ± 0.69^{a,b,c}
	Right	2.36 ± 0.57	2.76 ± 0.43^{a}	2.31 ± 0.49^{b}	3.04 ± 0.77^{a,b,c}	3.11 ± 0.79^{a,b,c}
	Total	2.32 ± 0.53	2.68 ± 0.35^{a}	2.27 ± 0.46^{b}	3.00 ± 0.74^{a,b,c}	3.03 ± 0.77^{a,b,c}
SRTa (mm)	Left	21.22 ± 0.83	21.31 ± 0.67	20.35 ± 0.88^{a,b}	21.63 ± 1.55^{c}	22.67 ± 1.17^{a,b,c,d}
	Right	21.26 ± 0.91	21.31 ± 0.69	20.39 ± 0.85^{a,b}	21.69 ± 1.61^{c}	22.69 ± 1.15^{a,b,c,d}
	Total	21.24 ± 0.84	21.31 ± 0.67	20.37 ± 0.85^{a,b}	21.66 ± 1.57^{c}	22.68 ± 1.16^{a,b,c,d}

Note(s): Values are mean ± SD. $^{a}p < 0.05$ vs 20–29 age group, $^{b}p < 0.05$ vs 30–39 age group, $^{c}p < 0.05$ vs 40–49 age group and $^{d}p < 0.05$ vs 50–59 age group. Statistical analysis was performed by ANOVA, followed by Tukey's *post hoc* test
Source(s): Table by authors

Table 13. Relation among the male talar parameters according to the age groups

addition, the additional stress and strain on the dominant side of the body could also increase the incidence of this asymmetry (Gutnik *et al.*, 2015).

A previous study conducted by Islam *et al.* (2014) using CT scan images for assessment concluded that there are small percent differences between the morphometric parameters of the left and right talus bones, supporting the fact that the tali of both sides are geometrically symmetrical based on the measurement of talus bone surface area and volume. The same results, but based on gross cadaveric assessment, were previously reported by Angthong *et al.* (2020) who reported that there are no statistical differences between left and right tali morphometric values, also according to both surface area and volume; however, they found that the talar dome height, middle trochlear width and posterior trochlear width of the right side were significantly higher than those of the left. In the present study, tali on both sides were symmetrical except for TaW of the right side which, was higher than the left (26.92 vs 26.18 mm). On the other hand, no statistical difference was found in this study between all other morphometric parameters of the left and right ankle joints.

Starting from the age of puberty, sex differences become apparent in bone growth. So, men develop greater bone size and higher bone mass compared to women. Recent findings attributed to the traditional concept of sex hormones are the chief regulators of this sexual dimorphism of the skeleton (Callewaert, Sinnesael, Gielen, Boonen, & Vanderschueren, 2010).

In the current study, MTiTh, MDV, TiW, MalW, SRTi, TaAL, TaW, SDTaTi and SRTa were significantly higher in males, while only APG and TaH were higher in females. According to APG, these results are in agreement with the findings of an Italian study by Stagni *et al.* (2005) who found that only APG and APA were significantly higher in females than males (2.7 vs 2.6 mm and 5.5 vs 4.7°, respectively). Furthermore, in accordance with our results, higher values of SRTa, MTiTh, TiW, MalW and TaW in male subjects were recorded by Khanasuk *et al.* (2011) in Thailand.

Kuo *et al.* (2014) in Taiwan and Uzuner *et al.* (2018) in Turkey found that MalW values were also higher in males. In contrast, both Khanasuk *et al.* (2011) and Kuo *et al.* (2014) reported that

Table 14. Relation among the female tibial parameters according to the age groups

Parameter		20-29 (n = 39) Mean ± SD	30-39 (n = 48) Mean ± SD	40-49 (n = 43) Mean ± SD	50-59 (n = 37) Mean ± SD	60-69 (n = 36) Mean ± SD
TiAL (mm)	Left	27.38 ± 1.71	29.92 ± 2.88^{a}	28.15 ± 4.29^{a,b}	27.17 ± 2.33^{b}	31.49 ± 4.95^{a,b,c,d}
	Right	27.20 ± 1.62	28.52 ± 1.62^{a}	27.95 ± 4.40^{a,b}	27.03 ± 2.19^{b}	30.99 ± 4.8 ^{a,b,c,d}
	Total	27.29 ± 1.64	29.22 ± 2.86^{a}	28.05 ± 4.25^{a,b}	27.10 ± 2.48^{b}	31.24 ± 4.72^{a,b,c,d}
APG (mm)	Left	1.44 ± 0.27	2.10 ± 0.57^{a}	2.11 ± 0.41^{a}	2.15 ± 1.16^{a}	3.50 ± 0.59^{a,b,c,d}
	Right	1.50 ± 0.31	2.12 ± 0.62^{a}	2.19 ± 0.52^{a}	2.21 ± 1.25^{a}	3.58 ± 0.61^{a,b,c,d}
	Total	1.47 ± 0.27	2.11 ± 0.59^{a}	2.15 ± 0.61^{a}	2.18 ± 1.22^{a}	3.54 ± 1.88^{a,b,c,d}
APA (degrees)	Left	1.93 ± 0.39	3.27 ± 0.11^{a}	4.06 ± 0.66^{a,b}	4.13 ± 0.68^{a,b}	4.33 ± 2.01^{a,b}
	Right	2.15 ± 0.52	2.53 ± 0.83^{a}	4.34 ± 0.71^{a,b}	4.45 ± 0.79^{a,b}	4.61 ± 2.32^{a,b}
	Total	2.04 ± 0.47	2.90 ± 0.94^{a}	4.20 ± 0.64^{a,b}	4.29 ± 0.79^{a,b}	4.47 ± 2.15^{a,b}
MTiTh (mm)	Left	40.15 ± 3.39	37.77 ± 2.99^{a}	37.19 ± 1.60^{a}	40.41 ± 3.97^{b,c}	39.71 ± 1.52^{b,c}
	Right	40.29 ± 3.95	37.85 ± 3.08^{a}	37.37 ± 1.78^{a}	40.59 ± 4.11^{b,c}	39.87 ± 1.64^{b,c}
	Total	40.22 ± 3.95	37.81 ± 3.19^{a}	37.28 ± 1.82^{a}	40.50 ± 4.01^{b,c}	39.79 ± 1.53^{b,c}
MDA (mm)	Left	9.10 ± 1.39	9.00 ± 2.91	6.95 ± 0.99^{a,b}	13.06 ± 1.03^{a,b,c}	16.89 ± 6.13^{a,b,c,d}
	Right	9.28 ± 1.61	9.12 ± 2.37	7.19 ± 0.87^{a,b}	13.36 ± 1.26^{a,b,c}	17.25 ± 5.72^{a,b,c,d}
	Total	9.19 ± 1.54	9.06 ± 2.87	7.07 ± 1.02^{a,b}	13.21 ± 1.14^{a,b,c}	17.07 ± 5.84^{a,b,c,d}
MDV (mm)	Left	4.80 ± 1.19	4.08 ± 1.56^{a}	4.13 ± 0.80^{a,b}	4.27 ± 1.06^{c}	5.32 ± 0.79^{a,b,c,d}
	Right	4.94 ± 1.44	4.30 ± 1.71^{a}	4.37 ± 0.62^{a,b}	4.51 ± 1.35^{c}	5.48 ± 0.93^{a,b,c,d}
	Total	4.87 ± 1.37	4.19 ± 1.69^{a}	4.25 ± 1.11^{a,b}	4.39 ± 1.14^{c}	5.40 ± 0.86^{a,b,c,d}
TiW (mm)	Left	27.08 ± 1.51	28.43 ± 1.88^{a}	28.03 ± 0.86^{a,b}	27.59 ± 2.31^{b,c}	25.37 ± 1.05^{a,b,c,d}
	Right	27.32 ± 1.56	28.73 ± 1.97^{a}	28.47 ± 1.02^{a,b}	28.47 ± 2.06^{b,c}	25.61 ± 1.31^{a,b,c,d}
	Total	27.20 ± 1.55	28.58 ± 1.96^{a}	28.25 ± 3.04^{a,b}	28.03 ± 2.18^{b,c}	25.49 ± 1.17^{a,b,c,d}
MalW (mm)	Left	58.00 ± 5.69	57.87 ± 3.73	55.18 ± 3.16^{a,b}	60.58 ± 4.43^{a,b,c}	53.25 ± 4.38^{a,b,c,d}
	Right	58.56 ± 5.81	58.37 ± 3.59	55.80 ± 2.98^{a,b}	61.14 ± 4.19^{a,b,c}	53.55 ± 4.11^{a,b,c,d}
	Total	58.28 ± 5.64	58.12 ± 3.67	55.49 ± 3.09^{a,b}	60.86 ± 4.26^{a,b,c}	53.40 ± 4.22^{a,b,c,d}
SRTi (mm)	Left	22.16 ± 1.50	23.06 ± 1.63^{a}	23.48 ± 2.73^{a}	20.48 ± 1.69^{a,b,c}	21.62 ± 1.66^{b,c,d}
	Right	21.98 ± 1.46	22.90 ± 1.58^{a}	23.26 ± 2.99^{a}	20.40 ± 1.61^{a,b,c}	21.46 ± 1.59^{b,c,d}
	Total	22.07 ± 1.54	22.98 ± 1.59^{a}	23.37 ± 2.84^{a}	20.44 ± 1.62^{a,b,c}	21.54 ± 1.67^{b,c,d}

Note(s): Values are mean ± SD. $^{a}p < 0.05$ vs 20–29 age group, $^{b}p < 0.05$ vs 30–39 age group, $^{c}p < 0.05$ vs 40–49 age group and $^{d}p < 0.05$ vs 50–59 age group. Statistical analysis was performed by ANOVA, followed by Tukey's *post hoc* test

Source(s): Table by authors

TiAL values are similar in both sexes, while the current study showed no statistical difference between male and female values according to TiAL (Table 17). As noted, the wide variability of values of ankle joint parameters among various studies could be due to different methods of evaluation.

Advances in medicine promoted increased life spans that led to the increased development of extensive lower extremity alteration due to significant musculoskeletal system changes that occur with aging, especially in post-menopausal women. For example, with age, bones lose their strength and rigidity; in addition, they become more brittle. Furthermore, joints and surrounding soft tissue become less flexible and weaker (Lee & Mulder, 2009).

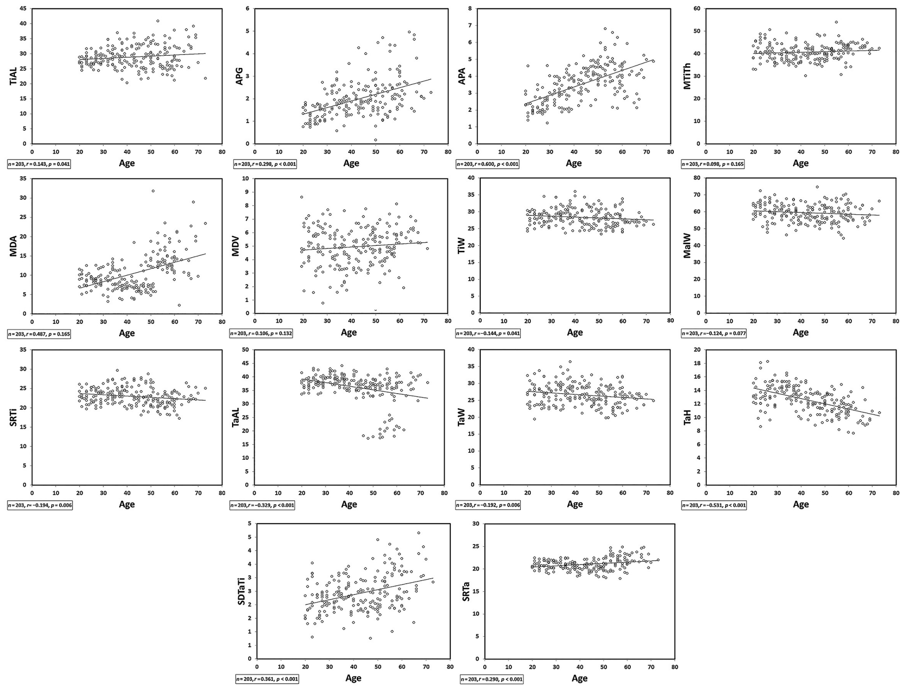
In this study, TiAL, APG, APA, MDA, MDV, SDTaTi and SRTa were significantly higher in old age as compared to subjects aged 20-29 years, and significantly higher TiW, MalW, TaW and TaH values were noted in the subjects aged 20-29 years compared to those aged 60-69 years, indicating that ankle joint measurements are highly affected by age.

In addition to different methods of evaluation, the different number of involved subjects or different enrolled populations according to their ethnicity, age and sex could be the cause of the variability of the results of various studies.

Parameter		20-29 (n = 39) Mean ± SD	30-39 (n = 48) Mean ± SD	40-49 (n = 43) Mean ± SD	50-59 (n = 37) Mean ± SD	60-69 (n = 36) Mean ± SD
TaAL (mm)	Left	37.16 ± 1.89	39.85 ± 1.91[a]	36.02 ± 1.97[a,b]	35.63 ± 2.68[a,b]	37.29 ± 2.66[b,c,d]
	Right	36.94 ± 1.94	39.57 ± 1.75[a]	35.78 ± 1.71[a,b]	36.29 ± 2.39[a,b]	36.87 ± 2.64[b,c,d]
	Total	37.05 ± 1.85	39.71 ± 1.83[a]	35.90 ± 1.82[a,b]	35.96 ± 2.53[a,b]	37.08 ± 2.63[b,c,d]
TaW (mm)	Left	24.90 ± 2.73	26.02 ± 2.89[a]	24.89 ± 1.37[b]	25.25 ± 2.05	21.94 ± 1.21[a,b,c,d]
	Right	25.44 ± 2.85	26.82 ± 3.01[a]	25.71 ± 1.48[b]	26.09 ± 2.44	22.64 ± 1.42[a,b,c,d]
	Total	25.17 ± 2.74	26.42 ± 2.92[a]	25.30 ± 1.45[b]	25.67 ± 2.39	22.29 ± 1.31[a,b,c,d]
TaH (mm)	Left	13.71 ± 2.04	14.94 ± 0.74[a]	12.75 ± 1.32[a,b]	11.81 ± 0.84[a,b,c]	11.76 ± 1.85[a,b,c]
	Right	13.81 ± 2.09	14.92 ± 0.79[a]	12.77 ± 1.21[a,b]	11.83 ± 0.89[a,b,c]	11.80 ± 1.91[a,b,c]
	Total	13.76 ± 2.04	14.93 ± 0.74[a]	12.76 ± 1.25[a,b]	11.82 ± 0.89[a,b,c]	11.78 ± 1.88[a,b,c]
SDTaTi (mm)	Left	1.84 ± 0.51	2.16 ± 0.35[a]	1.79 ± 0.41[b]	2.52 ± 0.68[a,b,c]	2.51 ± 0.69[a,b,c]
	Right	1.92 ± 0.57	2.32 ± 0.43[a]	1.87 ± 0.49[b]	2.60 ± 0.77[a,b,c]	2.67 ± 0.79[a,b,c]
	Total	1.88 ± 0.56	2.24 ± 0.38[a]	1.83 ± 0.43[b]	2.56 ± 0.71[a,b,c]	2.59 ± 0.72[a,b,c]
SRTa (mm)	Left	20.54 ± 0.83	20.63 ± 0.67	19.67 ± 0.88[a,b]	20.95 ± 1.55[c]	21.98 ± 1.17[a,b,c,d]
	Right	20.58 ± 0.91	20.63 ± 0.69	19.71 ± 0.85[a,b]	21.01 ± 1.61[c]	22.00 ± 1.15[a,b,c,d]
	Total	20.56 ± 0.85	20.63 ± 0.69	19.69 ± 0.81[a,b]	20.98 ± 1.53[c]	21.99 ± 1.12[a,b,c,d]

Note(s): Values are mean ± SD. [a]$p < 0.05$ vs 20–29 age group, [b]$p < 0.05$ vs 30–39 age group, [c]$p < 0.05$ vs 40–49 age group and [d]$p < 0.05$ vs 50–59 age group. Statistical analysis was performed by ANOVA, followed by Tukey's *post hoc* test
Source(s): Table by authors

Table 15.
Relation among the female talar parameters according to the age groups



Source(s): Figure by authors

Figure 4.
Scatter plots showing the correlations between age and the different anthropometric parameters

Table 16.
Relationships among the studied morphometric variables

	TiAL	APG	APA	MTiTh	MDA	MDV	TiW	MalW	SRTi	TaAL	TaW	TaH	SDTaTi	SRTa
TiAL	1	−0.023	0.406**	0.396**	0.425**	0.111*	−0.123*	−0.113*	0.251**	0.275**	−0.062	0.219**	0.113*	0.015
APG	−0.023	1	0.299**	−0.079	0.218**	0.205**	−0.091	−0.138**	−0.187**	−0.104*	−0.086	0.035	−0.137**	−0.226**
APA	0.406**	0.299**	1	0.452**	0.615**	0.041	0.001	−0.148**	<0.001	0.108*	0.012	−0.121*	0.128**	0.019
MTiTh	0.396**	−0.079	0.452**	1	0.262**	0.358**	−0.069	−0.151**	−0.078	0.146**	−0.172**	−0.270**	0.259**	0.488**
MDA	0.425**	0.218**	0.615**	0.262**	1	0.418**	−0.005	−0.128**	−0.268**	0.168**	−0.142**	−0.174**	0.233**	0.329**
MDV	0.111*	0.205**	0.041	0.358**	0.418**	1	0.044	0.083	−0.083	−0.036	0.082	−0.222**	0.140**	0.186**
TiW	−0.123*	−0.091	0.001	−0.069	−0.005	0.044	1	0.427**	0.063	0.375**	0.654**	0.080	0.158**	0.163**
MalW	−0.113*	−0.138**	−0.148**	0-.151**	−0.128**	0.083	0.427**	1	0.055	0.055	0.499**	−0.214**	0.096	0.043
SRTi	0.251**	−0.187**	<0.001	−0.078	−0.268**	−0.083	0.063	0.055	1	0.238**	0.241**	0.234**	−0.076	−0.099*
TaAL	0.275**	−0.104*	0.108*	0.146**	0.168**	−0.036	0.375**	0.055	0.238**	1	0.210**	0.485**	0.071	0.162**
TaW	−0.062	−0.086	0.012	0-.172**	−0.142**	0.082	0.654**	0.499**	0.241**	0.210**	1	0.012	0.056	−0.044
TaH	0.219**	0.035	−0.121*	−0.270**	−0.174**	−0.222**	0.080	−0.214**	0.234**	0.485**	0.012	1	−0.206**	−0.282**
SDTaTi	.113*	−0.137**	0.128**	0.259**	0.233**	0.140**	0.158**	0.096	−0.076	0.071	0.056	−0.206**	1	0.351**
SRTa	0.015	−0.226**	0.019	0.488**	0.329**	0.186**	0.163**	0.043	−0.099*	0.162**	−0.044	−0.282**	0.351**	1

Note(s): **. Correlation is significant at the 0.01 level (two-tailed)
*. Correlation is significant at the 0.05 level (two-tailed)
Source(s): Table by authors

Author	Stagni *et al.* (2005)		Hayes *et al.* (2006)			Khanasuk *et al.* (2011)		Kuo *et al.* (2014)		Kwon *et al.* (2014)		Uzuner *et al.* (2018)		Present study	
Year of publication	2005		2006			2011		2014		2014		2018		2022	
Country	Italy		United states			Thailand		Taiwan		Korea		Turkey		Egypt	
Method of assessment	Plain x-ray		Multi-detector CT scan			MRI		Cadaveric CT scan		Plain x-ray		Plain x-ray		Plaine x-ray	
Number of subjects	M = 23 F = 13		M = 11 F = 10			M = 11 F = 21		M = 32 F = 26		M = 57 F = 43		M = 134 F = 140		M = 100 F = 103	
Age of subjects (year old)	15-76		30-50			20-60		–		18-85		10-85		20-69	
		M	F	T	T	T	M	F	T	T	M	F	M	F	T
Mean of studied arameters	TiAL	33.1	28.0	31.4	–	26.1	29.4	26.1	28.4	29.2	–		29.2	28.6	28.9
	APG	2.6	2.7	2.7	–	–	3.9	2.9	3.6	4.2	–		1.8	2.3	2.1
	APA	4.7	5.5	5.0	–	–	6.1	6.6	7.4	8.2	–		3.6	3.6	3.6
	MTiTh	42.2	38.3	41.4	–	36.2	42.5	40.8	42.0	39.4	–		42.6	39.1	40.9
	MDA	12.2	10.4	11.5	–	–	11.8	10.5	11.4	12.4	–		10.5	11.1	10.8
	MDV	9.3	7.7	8.7	–	–	4.5	2.9	4.0	10.0	–		5.4	4.6	5.0
	TiW	33.6	28.6	31.9	–	29.3		–		31.1	33.8	29.9	29.1	27.5	28.3
	MalW	71.0	63.5	69.0	–	58.5	64.5	59.9	63.1	67.6	66.6	58.1	61.5	27.2	59.3
	SRTi		–		–	–	27.3	23.5	26.1	23.3	–		23.7	22.1	22.9
	TaAL	43.6	37.9	41.7	–	31.7	32.7	31.2	32.3	35.3	41.2	37.7	37.7	37.1	37.4
	TaW	31.5	28.3	30.4	–	28.0	21.5	19.4	20.9	30.5	–		28.2	25.0	26.6
	TaH		–		–	–	11.5	11.8	11.9	10.5	–		11.9	13.0	12.5
	SDTaTi		–		–	–	4.7	4.0	4.5	–	–		2.7	2.2	2.4
	SRTa	24.5	21.1	23.4	20.7	18.1	20.5	21.4	20.8	21.5	–		21.5	20.8	21.1

Note(s): Abbreviations: M, male; F, female; T, total. All measurement parameters are by mm except for APA id by degrees
Source(s): Table by authors

Table 17.
Comparison between the findings of the current and previous studies

Conclusion

The findings of this study among Egyptians recorded valuable details of morphometric ankle parameters that may be helpful during the identification of the side, sex and age in unknown subjects, especially when other more reliable body regions for this identification are lost or damaged.

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Corresponding author
Wael Amin Nasr El-Din can be contacted at: waela@agu.edu.bh