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Measurement of talar morphology in northeast Chinese population based on three-dimensional computed tomography

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Abstract

Morphological data of talus are important for the design of talar prostheses. The talar morphology of Chinese population has been rarely reported. This study adopted a three-dimensional (3D) measurement approach to provide accurate data for the anatomical morphology of talus in Northeast Chinese population and compared it with that of foreigners.

One hundred forty-six healthy subjects form Northeast China underwent computed tomography (CT) arthrography. 3D digital talar model was reconstructed and thirteen morphological parameters were measured through Mimics and Magics software. Length and breadth indexes of total talus, trochlea, medial and lateral malleolus articular surface were mainly selected. Statistical analysis was conducted by independent-samples and paired-samples *t* test through SPSS software.

All the indexes were normally distributed. No significant difference between left and right talus was identified in either males or females ($P > .05$). Most of the indexes showed significant sexual differences except the radian of lateral malleolus articular surface and the posterior breadth of trochlea ($P < .05$). The talar anatomy of Chinese subjects is different from the published data in other populations.

The promising approach adopted in this study addresses some inconvenience with previous conventional methods on cadaver specimens. The geometric parameters of talus in Chinese population differ from those in other populations. The talar measurements and morphology analysis in this study suggest that population characteristics should be taken into account. This study will provide references for the design of talar prostheses in Chinese population.

Abbreviations: 3D = three-dimensional, ABT = anterior breadth of trochlea, BLMAS = breadth of lateral malleolus articular surface, BMMAS = breadth of medial malleolus articular surface, CT = computed tomography, ICC = intraclass correlation coefficient, LLMAS = length of lateral malleolus articular surface, LMMAS = length of medial malleolus articular surface, MBT = middle breadth of trochlea, PBT = posterior breadth of trochlea, RLMAS = radian of lateral malleolus articular surface, RMMAS = radian of medial malleolus articular surface, TB = talar breadth, TH = talar height, TL = talar length, TV = talar volume.

Keywords: Chinese population, computed tomography, prosthesis, talar measurement, talus arthroplasty

1. Introduction

The talus bone is the connection between the ankle joint and the foot.[1] As the second largest tarsal bone in the foot, with 70% of the surface covered by a thin layer of articular cartilage, talus has no independent blood supply.[2] Thus, ischemic osteonecrosis is at high risk after injuries such as talar neck fracture, which could furthermore step into severe ankle arthritis.[3]

Treatment of osteonecrosis of the talus is quite challenging.[2] There are three main methods for this such as core decompression technique, tibiotalar arthrodesis technique, and talus arthroplasty. Core decompression technique can preserve joint

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JW, YL, and LZ contributed equally to this work and should be considered co-corresponding authors.

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mobility, but it is usually applied for early-stage patients.[4,5] Tibiotalar arthrodesis technique is suitable for almost all types of ankle arthritis, but it will cause ankylosis and short of the treated leg.[6] Talus arthroplasty has become the preferred form of surgical treatment for patients with end-stage ankle arthritis and the advantages include preservation of joint movement, a relatively short period of restricted weight bearing, rapid pain relief, and preservation of limb length.[7,8] Harnroongroj et al designed talar body prosthesis.[9,10] Later, Taniguchi et al treated Japanese patients with alumina ceramic total talar prosthesis that was designed through the data obtained by CT from the contralateral side and they reported that all patients had a satisfactory outcome.[2] Nevertheless, this Japanese custom-made prosthesis might not be applicable for Chinese due to the lack of comparisons of talar morphological sizes between Chinese and Japanese. Also, talar body and total talar prostheses of Chinese had rarely been reported. Hence, a size-suitable talar prosthesis for Chinese population is needed to be designed to treat osteonecrosis in Chinese patients and the design of talar prosthesis requires accurate morphological data of talus.

Nowadays, cadaver specimens, radiographs, and CT images have been primarily applied to obtain detailed morphological data of talus. Cadaver specimens are difficult to obtain, which makes it hard and impractical to manage large scale studies.[11] Although, radiographs can be easily obtained from clinical cases, differences in posture and tube projection angles will cause substantial variability in structural variables.[12] By contrast, CT images are extremely consistent. It can be easily reconstructed to 3D model through computer software.[13] To the best of our knowledge, there have been few studies that have investigated Chinese talar morphological sizes. In this study, the accurate morphological data of talus was collected from a large cohort of 146 Chinese northeast healthy subjects by CT images and the talus was measured in both left and right sides. Also, the results were compared with other studies based on Chinese and other populations. The aim of this study was to provide accurate reference data for the anatomical morphology of talus and the design of talar prosthesis.

2. Materials and methods

The 75 male and 75 female Chinese northeast subjects attended in this study. One male and one female subjects were excluded due to the history of ankle fracture. Two female subjects were excluded due to the deformation caused by osteonecrosis or degeneration. At last, 74 male and 72 female subjects were adopted in this study. Their lower limbs were all scanned by CT.

Notification was issued that our hospital needed volunteers from Northeast China. Their ages must range from 20 to 60 years old. The inclusion criteria were listed as follows. The radiation of CT was informed to all these volunteers and every volunteer was compensated by 400 RMB. The tests were approved by the ethics committee of our hospital (No. 202 in 2018). This study was conducted in accordance with the principles outlined in the Declaration of Helsinki. Informed consent was obtained from all individual participants included in the study.

The inclusion criteria are as follows:

(1) Age: 20 to 60 years.
(2) Height: 165 to 185 cm (men) and 160 to 180 cm (women).
(3) Body mass index (BMI): $<28\,kg/m^2$.

Subjects with any of the followings will be excluded:

(1) History of fracture of ankle or foot.
(2) Deformation of ankle or foot caused by osteonecrosis or degeneration.
(3) Congenital malformation.

The information of subjects are as follows:

(1) Age: The average age of males was 34 (23–53) years. The average age of females was 29 (20–49) years.
(2) Height: The average height of males was 179 (168–185) cm. The average height of females was 168 (160–178) cm.
(3) Body mass index (BMI): The average BMI of males was 22.48 (19.37–27.76) kg/m^2. The average BMI of females was 21.16 (16.33–26.35) kg/m^2.

In the current study, CT scanning was performed by a TOSHIBA/Aquilion ONE scanner. After scanning, the CT images were exported to Mimics (v19.0, Materialise, Belgium)[13,14] in digital imaging and communications in medicine (DICOM) format. Through "threshold, region grow, edit masks, calculate 3D, and distance" functions in Mimics software, the images were reconstructed to 3D model. Then 9 indexes were measured in Mimics software. The 3D model was exported to Magics (v21.0, Materialise, Belgium) in stereolithography (STL) format. Through bounding cuboid function, the left 4 indexes were measured in Magics software. (Fig. 1)

In total, 13 indexes were measured. These included talar length (TL), talar breadth (TB), talar height (TH), talar volume (TV), length of medial malleolus articular surface (MMAS) (LMMAS), breadth of MMAS (BMMAS), radian of MMAS (RMMAS), length of lateral malleolus articular surface (LMAS) (LLMAS), breadth of LMAS (BLMAS), radian of LMAS (RLMAS), anterior breadth of trochlea (ABT), middle breadth of trochlea (MBT), and posterior breadth of trochlea (PBT). (Fig. 2)

2.1. Measurement of overall talus

TL, TB, and TH were measured through Bounding Rectangle function of measurement module in Magics software. TV is directly derived from its property in Magics software.

2.2. Measurement of MMAS

LMMAS: The distance between the most anterior point and the most posterior point of trochlea in MMAS.

BMMAS: The maximum breadth of trochlea in MMAS of trochlea which is perpendicular to LMMAS.

RMMAS: Use LMMAS and BMMAS to create a circle. Divide half LMMAS by radius and multiply the result by π, the final result is RMMAS.

2.3. Measurement of LMAS

LLMAS: The distance between the most anterior point and the most posterior point of trochlea in LMAS.

BLMAS: The maximum breadth of trochlea in LMAS of trochlea which is perpendicular to LLMAS.

RLMAS: Use LLMAS and BLMAS to create a circle. Divide half LLMAS by radius and multiply the result by π, the final result is RLMAS.

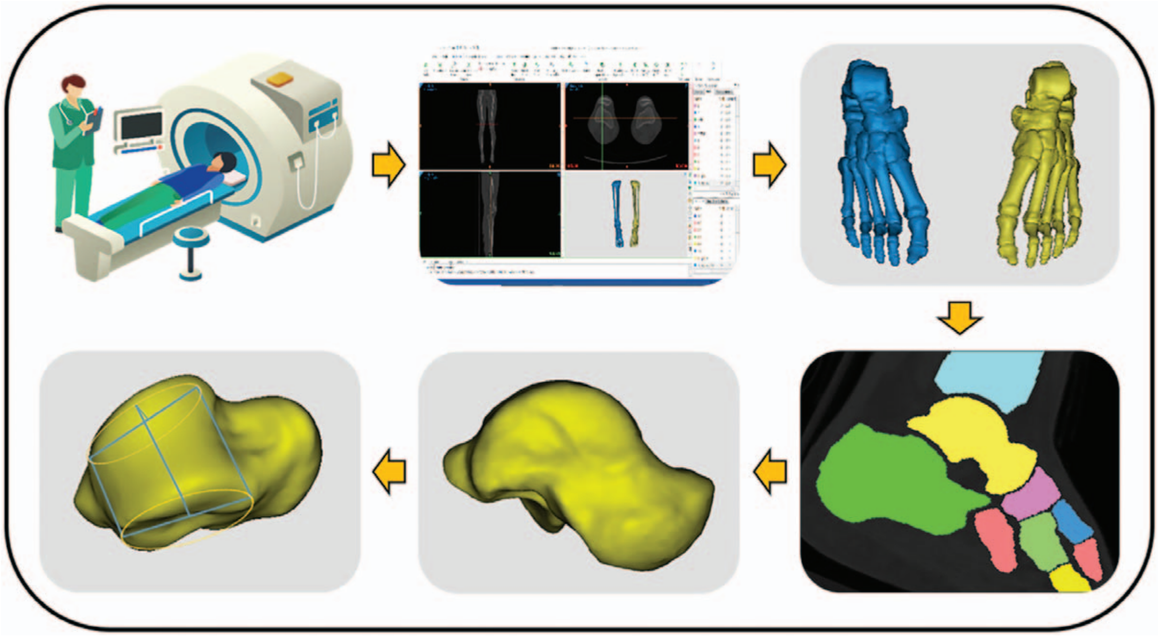

Figure 1. Flow diagram to illustrate the process from CT scan to measurement. The subjects' lower limbs were scanned by CT and the CT images were reconstructed to 3D model through Mimics software. Nine indexes were measured in Mimics software and the left four indexes were measured in Magics software.

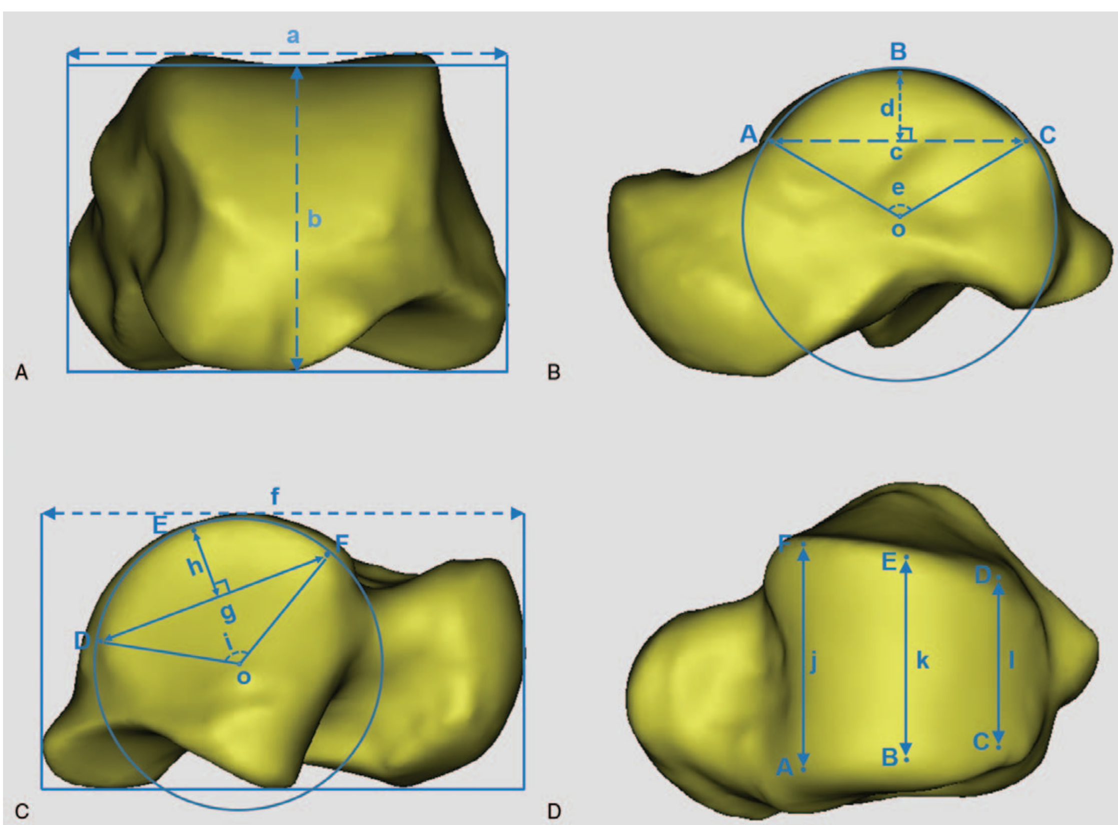

Figure 2. Indications of the indexes measured in this study. A: View of the talus from posterior aspect showing talar breadth (a) and talar height (b). B: View of the talus from medial aspect showing length of medial malleolus articular surface (c), breadth of medial malleolus articular surface (d), and radian of medial malleolus articular surface (e). C: View of the talus from lateral aspect showing talar length (f), length of lateral malleolus articular surface (g), breadth of lateral malleolus articular surface (h), and radian of lateral malleolus articular surface (i). D: View of the talus from superior aspect showing the anterior breadth of trochlea (j), middle breadth of trochlea (k), and posterior breadth of trochlea (l).

Table 1

Inter-observer and intra-observer reliability estimated by intraclass correlation coefficient (ICC).

Factor	ICC A1-A2	ICC B1-B2	ICC A1-B1	ICC A2-B2
TL	0.957	0.966	0.933	0.929
TB	0.955	0.948	0.943	0.951
TH	0.973	0.969	0.931	0.938
LMMAS	0.957	0.985	0.917	0.926
BMMAS	0.973	0.968	0.942	0.991
RMMAS	0.956	0.981	0.921	0.926
LLMAS	0.961	0.966	0.933	0.942
BLMAS	0.963	0.971	0.962	0.977
RLMAS	0.825	0.847	0.865	0.884
ABT	0.977	0.984	0.967	0.968
MBT	0.969	0.968	0.961	0.962
PBT	0.984	0.984	0.974	0.982

ABT = anterior breadth of trochlea, BLMAS = breadth of lateral malleolus articular surface, BMMAS = breadth of medial malleolus articular surface, LLMAS = length of lateral malleolus articular surface, LMMAS = length of medial malleolus articular surface, MBT = middle breadth of trochlea, PBT = posterior breadth of trochlea, RLMAS = radian of lateral malleolus articular surface, RMMAS = radian of medial malleolus articular surface, TB = talar breadth, TH = talar height, TL = talar length.

2.4. Measurement of trochlea

ABT: The distance between the most anterior point of trochlea in MMAS and the most anterior point of trochlea in LMAS.

MBT: The distance between the highest point of trochlea in MMAS and the highest point of trochlea in LMAS.

PBT: The distance between the most posterior point of trochlea in MMAS and the most posterior point of trochlea in LMAS.[15]

2.5. Statistics

The SPSS software (v21.0, IBM, America) was used to conduct statistical analysis. Normal distribution of each index was tested. The measurement was conducted by 2 researchers and every index was measured twice by each researcher. One researcher is an attending physician and the other is a resident physician. These 2 researchers have been trained for anatomic and radiologic research. The average of the 4 measurements is the final result and the data was presented by mean ± standard deviation of each index. Inter-observer and intra-observer reliability were estimated by intraclass correlation coefficient (ICC). The comparison between left and right talus in either males or females of this study was analyzed through paired-samples *t* test. The comparison between male and female subjects of this study was analyzed through independent-samples *t* test. The comparison between this study and other studies was analyzed by independent-samples *t* test. The *P* value less than .05 was considered significant.

3. Results

3.1. Inter-observer and intra-observer reliability

The ICC of each variable was in the range of its 95% confidence interval (CI) (Table 1).

None of the tests were statistically significant for any of the variables, therefore, there were no differences between or within observers. Statistically acceptable coefficients of reproducibility could be obtained.

3.2. Overall measurement

TL, TB, TH, and TV were normally distributed in the entire cohort as well as both male and female subgroups. All the indexes were significantly larger in males than females ($P < .05$). No significant difference between left and right talus in either males or females was identified ($P > .05$). (Table 2)

3.3. MMAS measurement

LMMAS, BMMAS, and RMMAS were normally distributed in the entire cohort as well as both male and female subgroups. LMMAS and BMMAS were significantly larger in males than females ($P < .05$). Whereas the RMMAS was significantly larger in females (72.76° ± 3.98°) than males (74.73° ± 4.04°) ($P < .05$). No significant difference between left and right talus in either males or females was identified ($P > .05$). (Table 2 and Fig. 3)

3.4. LMAS measurement

LLMAS, BLMAS, and RLMAS were normally distributed in the entire cohort as well as both male and female subgroups. LLMAS

Table 2

Comparison of indexes of talus.

Indexes	Male/L Mean ± SD	Female/L Mean ± SD	*P*	Male/R Mean ± SD	Female/R Mean ± SD	*P*
TL (mm)	61.54 ± 2.69	54.45 ± 2.51	.01	61.89 ± 2.81	54.19 ± 2.44	.01
TB (mm)	44.02 ± 2.71	39.78 ± 1.76	.01	43.58 ± 2.64	39.67 ± 1.88	.01
TH (mm)	33.76 ± 1.70	29.67 ± 1.24	.01	33.89 ± 1.78	29.70 ± 1.20	.01
Volume (cm^3)	40.87 ± 5.18	26.07 ± 3.01	.01	41.01 ± 5.36	25.89 ± 2.99	.01
LMMAS (mm)	36.02 ± 2.36	30.23 ± 1.69	.01	36.21 ± 2.12	30.61 ± 1.65	.01
BMMAS (mm)	10.13 ± 0.91	8.85 ± 0.81	.01	9.98 ± 1.11	8.81 ± 0.94	.01
RMMAS (°)	72.62 ± 3.75	74.85 ± 3.91	.01	72.89 ± 4.21	74.61 ± 4.17	.01
LLMAS (mm)	30.57 ± 2.32	24.22 ± 1.23	.01	30.13 ± 2.21	24.48 ± 2.07	.01
BLMAS (mm)	10.82 ± 1.03	8.79 ± 0.94	.01	10.74 ± 0.99	9.24 ± 0.85	.01
RLMAS (°)	84.24 ± 2.63	84.47 ± 2.98	.35	84.52 ± 3.01	86.23 ± 2.54	.07
ABT (mm)	31.61 ± 2.21	28.43 ± 1.26	.01	31.82 ± 1.96	28.76 ± 1.58	.01
MBT (mm)	29.49 ± 1.62	25.51 ± 1.37	.01	29.71 ± 1.92	25.39 ± 1.62	.01
PBT (mm)	23.77 ± 2.54	23.89 ± 1.79	.73	24.39 ± 3.01	23.81 ± 2.69	.23

ABT = anterior breadth of trochlea, BLMAS = breadth of lateral malleolus articular surface, BMMAS = breadth of medial malleolus articular surface, LLMAS = length of lateral malleolus articular surface, LMMAS = length of medial malleolus articular surface, MBT = middle breadth of trochlea, PBT = posterior breadth of trochlea, RLMAS = radian of lateral malleolus articular surface, RMMAS = radian of medial malleolus articular surface, TB = talar breadth, TH = talar height, TL = talar length.

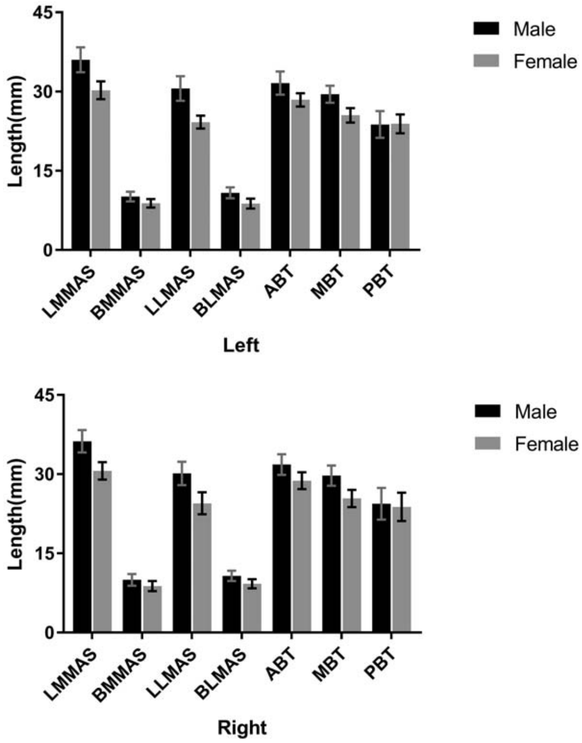

Figure 3. Comparisons between males and females in LMMAS, BMMAS, LLMAS, BLMAS, ABT, MBT, and PBT. Error bars denote SDs. ABT = anterior breadth of trochlea, BLMAS = breadth of lateral malleolus articular surface, BMMAS = breadth of medial malleolus articular surface, LLMAS = length of lateral malleolus articular surface, LMMAS = length of medial malleolus articular surface, MBT = middle breadth of trochlea, PBT = posterior breadth of trochlea.

and BLMAS were significantly larger in males than females ($P < .05$). Whereas there was no significant difference between males (84.38° ± 2.82°) and females (85.35° ± 2.76°) in RLMAS ($P > .05$). No significant difference between left and right talus in either males or females was identified ($P > .05$). (Table 2 and Fig. 3)

3.5. Trochlea articular surface measurement

ABT, MBT, and PBT were normally distributed in the entire cohort as well as both male and female subgroups. ABT and MBT were significantly larger in males than females ($P < .05$). However, there was no significant difference between males (24.08 ± 2.78 mm) and females (23.85 ± 2.24 mm) in PBT ($P > .05$). No significant difference between left and right talus in either males or females was identified ($P > .05$). (Table 2 and Fig. 3)

4. Discussion

There have been several ways to acquire accurate talar anatomical morphology such as cadaver specimens, radiographs and conventional CT.[3,13,16] Cadaver specimens were most commonly adopted. Whereas measurements by cadaver specimens are bound to be associated with some disadvantages. Cadaver specimens are costly and different to obtain. Moreover, bones require extensive preparation.[11] Radiographs easily obtained from clinical cases will have variability in structural parameters due to the differences in posture and tube projection angles.[12] By contrast, CT is convenient and CT images can be easily acquired, stored, and reconstructed from two-dimensional to 3D model.[17,18] It is also convenient to measure perimeter, area, and radian of bones on CT images. Engelke et al used CT to assess bone structure.[19] In the current study, the geometric parameters of talus were measured in Chinese northeast subjects by using CT arthrography.

In total, 13 indexes of talus were measured. 10 indexes were significantly larger in males than females ($P < .05$). Only RMMAS, RLMAS, and PBT showed differences. In this study, the RMMAS was significantly larger in females than males ($P < .05$). There was no significant difference in PBT and RLMAS between males and females ($P > .05$). Different physiological structures between males and females may be the main cause to the result of PBT. Through our observation, there is much cartilage on the posterior part of talus especially in males. The cartilage would weaken the bone identification on CT images, which would affect the measurement accuracy of PBT. While designing talus prosthesis, the above differences between males and females should be taken into account or the mismatch will be caused.[10] Islam et al used Mimics software to analyze the geometric symmetry of human talus bones and found that the left and right talus of 11 subjects differed by less than 7.5%.[20] In this study, left and right side of talus showed strong property of symmetry, which was consistent with the findings of Islam et al. Thus, for talus replacement surgery, the geometric shape of the contralateral talus bone can be adopted as a reference.

Table 3 shows the comparison with other studies.[12,15,21] (Table 3 and Fig. 4) Kazuhiro measured relevant variables in Japanese population by examining cadaver specimens and he reported that talar length, breadth and height were 50.70 ± 2.60

Table 3

Comparison with other studies in talar length, breadth, and height.

	Author	Present study		Kazuhiro		Peckmann et al		Shereen et al		Ma et al	
	Population	Chinese		Japanese		Greeks		Egyptian		Chinese	
Sex	Variables	n	Mean ± SD	n	Mean ± SD	n	Mean ± SD	n	Mean ± SD	n	Mean ± SD
Male	TL (mm)	74	61.72 ± 2.75	72	50.70 ± 2.60	81	60.98 ± 3.93	67	61.25 ± 3.72	33	53.78 ± 3.62
	TB (mm)	74	43.80 ± 2.68	72	40.70 ± 2.35	81	42.25 ± 2.58	67	41.97 ± 2.07	33	41.50 ± 2.98
	TH (mm)	74	33.83 ± 1.74	72	29.45 ± 2.00	81	32.78 ± 2.10	67	36.95 ± 3.27	33	26.89 ± 1.77
Female	TL (mm)	72	54.32 ± 2.48	71	45.80 ± 2.50	71	53.88 ± 2.90	43	53.27 ± 5.24	32	48.86 ± 2.63
	TB (mm)	72	39.77 ± 1.82	71	36.75 ± 1.80	71	37.63 ± 2.07	43	37.86 ± 3.58	32	36.47 ± 2.02
	TH (mm)	72	29.69 ± 1.22	71	26.70 ± 1.55	71	29.33 ± 2.16	43	33.81 ± 3.67	32	24.32 ± 1.61

TB = talar breadth, TH = talar height, TL = talar length.

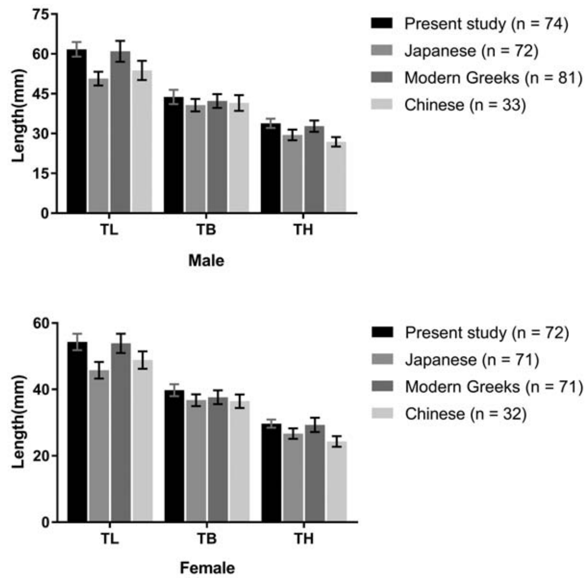

Figure 4. Comparisons of different studies in TL, TB, and TH. Error bars denote SDs. TL: talar length, TB: talar breadth, TH: talar height.

mm, 40.70 ± 2.35 mm, and 29.45 ± 2.00 mm in males respectively.[15] In the current study, TL, TB and TH are 61.72 ± 2.75 mm, 43.80 ± 2.68 mm, and 33.83 ± 1.74 mm in males respectively. The significant difference also occurred in the comparison of females. The results suggest that total talar sizes are substantially larger in Chinese population than those in Japanese population. Due to the significant differences in sizes, the current Japanese total talar prostheses do not adequately cover the range of talar dimensions in our Chinese cohort. While designing Chinese talar prosthesis, the prosthesis of Japanese could merely be adopted as a reference. Peckmann et al measured talar morphology in Greek population through cadaver specimens.[21] Their total talar sizes were smaller than those of the current Chinese subject groups. Compared with our Chinese subjects, TL and TB were smaller and TH was larger in the study of Egyptian people reported by Shereen et al, who obtained their values by examining cadaver specimens.[22] The above comparisons are evidences that Asian populations have different osseous anatomy compared with other populations.[23–25] Combined with those of previous studies, findings in the current study indicate that there is substantial variation in the morphological parameters of the talus between different ethnic groups and different area, even within Asian. The variation further emphasizes the essentiality to measure talar morphology of Chinese population for designing Chinese talar prostheses.

To the best of our knowledge, there have been few studies that have investigated Chinese talar morphological sizes. Ma et al have measured the morphology of talus in Chinese population through CT images.[12]Table 3 shows the comparison with their study. TL, TB, and TH in males and females in this study were all larger than those reported in their research. TV in this study is 40.94 ± 5.27 cm^3 in males and 25.98 ± 3.00 cm^3 in females. TV in the study of Ma et al were 37.87 ± 6.69 cm^3 in males and 26.95 ± 5.73 cm^3 in females.[12] TV in males of this study was larger than that in the study of Ma et al. Whereas, TV in females of this study was smaller than that in the study of Ma et al. The significant difference in the results may be due to differences in methodology between studies. In that research, the length, width, and height of the talus were determined based on different apexes identified in the CT layers. While in the current study, bounding cuboid function in Magics software was used to create a cuboid to cover the talus. The cuboid will change its form as the talus rotates. And then the talar position was adjusted until its inferior surface contacted with the inferior surface of the cuboid by 3 apexes. Thus, the length and breadth of the cuboid were respectively the length and breadth of the talus. Besides, subjects in the current study are from Northeast China where people have a greater level of average height. In the study of Ma et al, subjects are from north China where people have a middle level of average height. The significant difference of results between two groups in Chinese may be caused by the different methods and sources of subjects.

This study has several limitations, including comparisons with other studies that adopted different methods. When multiple cohorts are combined, variability in the methodology used in the individual studies could weaken the statistical significance. Our technique using 3D CT from healthy subjects addresses some inconvenience with previous conventional methods. The subjects in the current study are all from Northeast China and this situation did not allow us to determine whether there are regional differences in talar dimensions within China. Although subjects in the study of Ma et al are from north China, the method adopted in their study is not the same as that of the current study. Additional studies of different populations with the same methodology can further clarify ethnic differences in talar morphology.

5. Conclusion

Our study provided precise measurements of talar morphology and revealed significant variations in the morphometric characteristics of talus in different ethnic groups and different genders. These data could have important relevance with regard to talar prosthetic design.

Author contributions

Conceptualization: Qing Han, Lei Zhong.
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Funding acquisition: Jincheng Wang.
Investigation: Fei Chang.
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Resources: Jincheng Wang.
Software: Yang Liu.
Supervision: Fei Chang, Jincheng Wang.
Writing – original draft: Yang Liu.
Writing – review & editing: Qing Han, Lei Zhong.

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