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Cluster Analysis of Normal Ankle Joint X-ray Morphology of Han Adults in Shaanxi Province, China

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Abstract: *To measure the X-ray morphological parameters of normal ankle joints of Han adults in Shaanxi province, and to summarize the two-dimensional morphological characteristics and categories of ankle joints. A total of 340 Han adults (170 males and 170 females) who met the criteria in Shaanxi Provincial People's Hospital from January 2018 to December 2023 were included in the study. Fifteen morphological parameters representing two-dimensional morphological features of the ankle joint were measured and calculated manually. Principal component analysis was used to analyze the measurement parameters, and the ankle joint morphology was clustered based on the extracted principal components. There were gender differences in the morphological parameters of the normal ankle joints of Han adults in Shaanxi province, and the parameters of males were higher than those of females ($P < 0.01$), the difference was statistically significant. Five principal component variables were extracted from the morphological parameters of male and female ankle joints of Han adults in Shaanxi province by principal component analysis, and the male and female ankle joints were classified into three types by cluster analysis. There are three types of ankle joint X-ray morphology of Han adults in Shaanxi province, and there are gender differences in ankle joint morphology.*

Keywords: *ankle joint; X-ray radiography; cluster analysis*

1. Introduction

Total ankle arthroplasty (TAA) is an effective treatment option for end-stage ankle arthritis caused by various etiologies, including osteoarthrosis of the talus. Still, there are no domestic artificial implants currently available for TAA. The artificial implants used in clinical practice are imported replacements based on the ankle morphological parameters of the Caucasian population in Western countries. In contrast, the ankle morphology of Chinese people differs from that of Caucasians. Implant mismatch can affect the surgical treatment effect and cause risks of surgical failure and serious postoperative complications [1-3]. There have been several studies on the measurement and analysis of ankle morphological parameters in China, all of which have shown that the ankle morphology of Chinese adults is significantly different from that of reported populations in other Western regions [4-7]. However, up to now, there have been no reports on the ankle joint morphological types of Chinese adults. This study explores the measurement and clustering analysis of the two-dimensional ankle morphology of Han adults in Shaanxi Province based on ankle X-ray images, providing a reference for the design and selection of domestic TAA prostheses.

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2. Data and Methods

2.1. General Information

A total of 340 Han adults in Shaanxi Province who underwent ankle joint X-ray examination in Shaanxi Provincial People's Hospital from January 2018 to December 2023 were selected as the study subjects. Six groups of X-ray data were selected from 18 to 30 years old (30 males and 30 females each), 31 to 40 years old (30 males and 30 females each), 41 to 50 years old (30 males and 30 females each), 51 to 60 years old (30 males and 30 females each), 61 to 70 years old (30 males and 30 females each), 71 to 85 years old (20 males and 20 females each), and their X-ray image data were obtained simultaneously. Among them, 170 were males, aged 18-86 years, average age 47.6 years, height 172.4±14.4cm; and 170 were females, aged 18-91 years, average age 49.5 years, height 161.2±15.8cm.

2.2. Inclusion and Exclusion Criteria

Inclusion criteria: (1) Age ≥18 years old; (2) The radiography reported no abnormality in the ankle joint; (3) Anterior and lateral X-ray images of the left ankle joint without weight bearing.

The exclusion criteria include: (1) The body position of the X-ray image of the ankle joint is not standard; (2) The X-ray images are not clear.

This study was approved by the Ethics Committee of Shaanxi Provincial People's Hospital (Approval number: 2023K-S038).

2.3. X-ray Photography of the Ankle Joints

The Philips multi-function whole body Digital X-ray machine (brand: Philips, model: Digital Diagnosis, origin: Netherlands) in the Department of Radiology of Shaanxi Provincial People's Hospital was used for ankle joint photography. The tube voltage was 63kV, the tube current was 8mA, and the X-ray source was 110cm from the ankle joint. When taking the anterior image of the ankle joint, the subject was required to lie supine on the examination bed, the lower limb was naturally abduction without weight bearing, the sole of the foot was in the rotation neutral position, the X-ray bundle was vertically focused on the center of the medial and lateral ankles, and the exposure range was from the lower half of the calf to the sole of the foot.

2.4. Measurement Method

The research data were selected and imported into the medical image analysis software Digimizer 6.4.0 in DICOM format, and 12 ankle joint morphological parameters were measured and 3 morphological parameters were calculated using the measurement tool according to the method described in reference [8]. The measurement indexes were respectively measured by two trained senior radiologists using image measurement tools in the imaging diagnosis workstation. The measurements were taken twice at an interval of one week, and the average values of the measured data were taken.

2.5. Measurement and Observation Indicators[7]

(1) Anteroposterior gap (APG): the vertical distance between the most anterior point and the last point of the ankle points along the longitudinal axis of the tibia. (2) Tibial arc length (TiAL): the linear distance from the first point to the last point of the ankle hole. (3) Anteroposterior inclination angle of the mortise (APA): the angle between the most anterior point and the last point of the ankle points and the anteroposterior and posterior axis of the tibia. (4) Maximal tibial thickness (MTiTh): length between the most anterior point of the lower tibia and the corresponding posterior point along the anterior and posterior axis of the tibia. (5) Distance of level of MTiTh from the anterior limit of the mortise (MDA): the distance between the anterior point of the ankle points and the thickest plane of the lower segment of the tibia along the tibia longitudinal axis. (6) Distance of MTiTh from the vertex of the mortise (MDV) : the vertical distance between the apex of the ankle point and the thickest plane of the lower tibia along the longitudinal axis of the tibia. (7) Trochlea tail length (TaAL): the length of the line between the most advanced and last points of the talar trochlea. (8) Sagittal radius of the trochlea tali arc (SRTa): the distance from the center of the arc of talar trochlea to the trochlea of talar. (9) Tibial width (TiW): The tangential line of the top of the ankle hole intersects with the inside of the inner and outer ankle, and the length between the two intersection points is the ankle hole width. (10) Tarsal width (TaW): The tangent

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line of the apex of the talus intersects the inner and outer edge of the talus on the orthogram, and the length between the intersection points is the width of the talus. (11) Height of the talar tenon (Th): the vertical distance between the sagittal apex of talar trochlea and the most advanced point of talar trochlea parallel to the ground line. (12) Malleolar width (MalW): the distance between the outermost point of the external ankle and the innermost point of the medial ankle along the transverse axis of the tibia. (13) MTiTh/TiW: the ratio of MTiTh to TiW. (14) TaAL/TaW: the ratio of TaAL to TaW. (15) MalW/TiW: the ratio of MalW to TiW.

2.6. Statistical Analysis

SPSS 22.0 statistical analysis software was used to represent the measurement data consistent with normal distribution. Independent sample *t* test and one-way analysis of variance were used for inter-group comparison. Principal component analysis was performed on the measurement index results of male and female ankle joints respectively, and K-means clustering analysis was performed after the component matrix was rotated.

3. Results

3.1. Comparison of the Measurement Results of Morphological Parameters

Inter-group comparison of the mean values of morphological parameters of normal ankle joints X-ray images and gender of 340 Han adults in Shaanxi province is shown in Table 1. There were significant differences in 15 morphological parameters between male and female ($P < 0.01$).

Table 1: Comparison of the measurement results of morphological parameters of normal ankle joints X-ray images between males and females($\bar{x} \pm S$)

Morphological Parameters	Male (n=170)	Female (n=170)	t-value	P-value
APG(mm)	5.76±1.38	4.27±1.02	11.21	<0.01
APA(°)	10.15±2.48	8.49±2.47	6.52	<0.01
TiAL(mm)	29.84±2.67	24.96±2.16	17.94	<0.01
MTiTh(mm)	42.64±2.22	38.13±2.49	16.54	<0.01
MDA(mm)	10.16±1.43	9.60±0.99	4.05	<0.01
MDV(mm)	8.02±1.16	7.24±1.06	6.59	<0.01
SRTa(mm)	22.27±3.39	17.91±1.72	14.45	<0.01
Tiw(mm)	34.45±2.34	35.51±2.02	-4.10	<0.01
MalW(mm)	67.34±3.71	62.01±3.39	14.44	<0.01
TaW(mm)	30.99±2.23	29.71±1.83	5.56	<0.01
TaAL(mm)	34.97±2.62	31.47±2.11	13.13	<0.01
Th(mm)	9.59±1.04	9.12±0.96	4.45	<0.01
MalW/TiW	1.96±0.13	1.74±0.09	16.64	<0.01
MTiTh/TiW	1.24±0.08	1.07±0.07	17.46	<0.01
TaAL/TaW	1.13±0.11	1.06±0.08	6.48	<0.01

3.2. Results of Principal Component Analysis

The principal component analysis was performed on 15 morphological parameters of anterior and lateral ankle joint X-ray images of Han adults in Shaanxi Province. 80.06% of the data variation could be explained when the male ankle joint morphological parameters component was 5 (Figure 1), and 84.57% of the data variation could be explained when the female ankle joint morphological parameters component was 5 (Figure 2). After rotation of the component matrix, the five components of male and female ankle joints are shown in Table 2 and Table 3 respectively.

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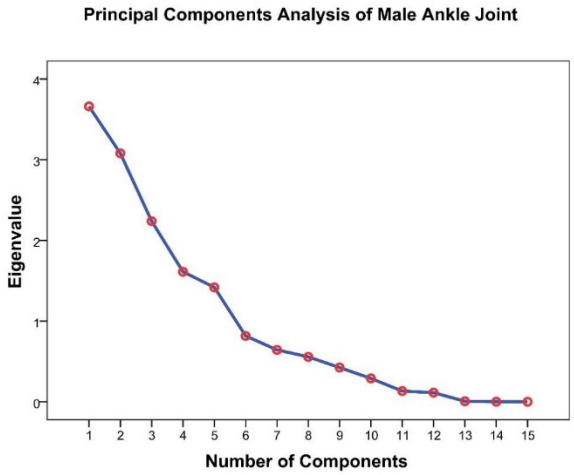

Figure 1: Scatter plot of principal component analysis for morphological parameters in X-ray images of male ankle joints.

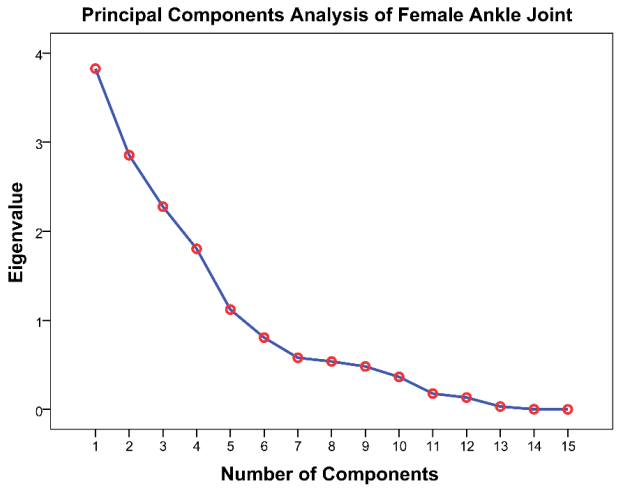

Figure 2: Scatter plot of principal component analysis for morphological parameters in X-ray images of female ankle joints.

Table 2: The rotated component matrix of the principal component analysis of the morphological parameters of the male ankle joint X-ray images.

Parameters	Components				
	1	2	3	4	5
TiW	0.952				
TaW	0.917				
TaAL/TaW	-0.782				
MTiTh/TiW	-0.722				
MalW/TiW	-0.687			0.518	
APG		0.693		-0.508	
MTiTh		0.682			
TiAL		0.658			
SRTa		0.500			
MDV			0.788		
MDA			0.755		
MalW		0.509		0.612	
APA				-0.592	
TaAL		0.575			0.619
Th					0.513

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Table 3: The rotated component matrix of the principal component analysis of the morphological parameters of the female ankle joint X-ray images.

Parameters	Components				
	1	2	3	4	5
APG					0.932
APA					0.944
TiAL	0.559		0.513		
MTiTh	0.747				
MDA				0.893	
MDV				0.894	
SRTa					
TiW		-0.760			
MalW	0.833				
TaW	0.730				
TaAL			0.834		
Th			0.799		
MalW/TiW		0.912			
MTiTh/TiW		0.923			
TaAL/TaW			0.834		

3.3. Analysis of Clustering Results

The extracted principal components were used to perform K-means clustering for male and female ankle joint X-ray images. The male completed 3 categories clustering after 8 iterations and the female completed 3 categories clustering after 10 iterations.The results of one-way ANOVA showed statistically significant differences between the five principal components extracted from male and female ankle parameters, as shown in Table 4 and Table 5. All 170 male samples were valid clustering cases, which could be clustered into 3 types.The difference of 14 parameters in the inter-group comparison of mean morphological parameters of different categories was statistically significant ($P < 0.01$) (Table 6). And all 170 female samples were valid clustering cases, which could be clustered into 3 types.The difference of 11 parameters in the inter-group comparison of morphological parameters of different categories was statistically significant ($P < 0.01$) (Table 7).

Table 4: One-way ANOVA for principal component clustering of morphological parameters of the male ankle joint X-ray images($x \pm S$)

Principal Component	Clustering		Error		F-value	P-value
	Mean Square	df	Mean Square	df		
1	17.917	2	0.797	167	22.469	0.000
2	20.918	2	0.761	167	27.470	0.000
3	17.076	2	0.807	167	21.147	0.000
4	15.151	2	0.831	167	18.243	0.000
5	32.477	2	0.623	167	52.127	0.000

Table 5: One-way ANOVA for principal component clustering of morphological parameters of the female ankle joint X-ray images($\bar{x} \pm S$)

Principal Component	Clustering		Error		F-value	P-value
	Mean Square	df	Mean Square	df		
1	13.484	2	0.850	167	15.855	0.000
2	36.386	2	0.576	167	63.146	0.000
3	13.398	2	0.852	167	15.734	0.000
4	12.119	2	0.867	167	13.981	0.000
5	8.623	2	0.909	167	9.489	0.000

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Table 6: The inter-group comparison of mean morphological parameters of different categories of male ankle joint X-ray images($\bar{x} \pm S$)

Parameters	Category			F-value	P-value
	1 (n=55)	2 (n=45)	3 (n=70)		
APG	6.21±1.23	6.01±1.22	5.23±1.43	9.578	0.000
APA	11.06±2.31	10.50±2.15	9.22±2.52	9.982	0.000
TiAL	30.01±2.60	29.93±2.20	29.64±3.01	0.329	0.720
MTiTh	41.62±1.92	42.30±1.67	43.68±2.32	16.243	0.000
MDA	9.58±1.04	10.02±1.01	10.70±1.71	10.868	0.000
MDV	7.74±1.04	7.71±1.11	8.45±1.16	8.824	0.000
SRTa	23.49±3.34	22.65±3.55	21.07±2.93	8.992	0.000
TiW	34.65±1.99	32.67±1.85	35.44±2.23	25.072	0.000
MalW	65.60±3.28	65.92±2.68	69.63±3.41	30.539	0.000
TaW	31.04±1.80	29.29±1.63	32.04±2.20	27.721	0.000
TaAL	33.42±2.03	37.37±1.65	34.66±2.46	43.585	0.000
Th	9.30±1.19	10.22±0.82	9.40±0.87	13.094	0.000
MalW/TiW	1.89±0.13	2.02±0.11	1.96±0.11	13.818	0.000
MTiTh/TiW	1.20±0.07	1.29±0.08	1.23±0.07	18.795	0.000
TaAL/TaW	1.09±0.73	1.27±0.06	1.08±0.07	122.173	0.000

Table 7: The inter-group comparison of mean morphological parameters of different categories of female ankle joint X-ray images($\bar{x} \pm S$)

Parameters	Category			F-value	P-value
	1 (n=49)	2 (n=66)	3 (n=55)		
APG	4.16±0.99	4.36±1.04	4.27±1.02	0.516	0.598
APA	8.36±2.76	8.77±2.48	8.28±2.18	0.677	0.510
TiAL	24.30±2.34	25.02±1.68	25.47±2.39	3.957	0.021
MTiTh	39.16±2.05	36.35±1.83	39.34±2.30	40.282	0.000
MDA	10.23±0.87	8.75±0.62	10.06±0.71	74.084	0.000
MDV	7.73±0.95	6.44±0.76	7.76±0.86	47.941	0.000
SRTa	17.15±1.57	17.83±1.71	18.67±1.56	11.533	0.000
TiW	34.07±1.53	35.20±1.81	37.18±1.39	50.6878	0.000
MalW	62.09±2.71	60.24±2.65	64.03±3.60	23.628	0.000
TaW	28.72±1.34	29.01±1.47	31.45±1.32	63.881	0.000
TaAL	31.33±2.16	31.24±1.84	31.87±2.36	1.477	0.231
Th	9.11±1.03	9.20±0.97	9.03±0.88	0.442	0.644
MalW/TiW	1.82±0.81	1.71±0.87	1.72±0.79	28.870	0.000
MTiTh/TiW	1.15±0.66	1.03±0.62	1.05±0.07	54.472	0.000
TaAL/TaW	1.09±0.79	1.08±0.73	1.01±0.72	17.110	0.000

4. Conclusions

The measurement techniques of human skeletal morphology mainly include cadaver specimen measurement, two-dimensional imaging measurement based on X-ray imaging, and three-dimensional imaging measurement based on CT reconstruction [9]. The data obtained from cadaver measurement can reflect the human skeletal morphological parameters accurately, but the amount of data obtained is very small, and it lacks important measurement parameters for prosthesis design and surgical plan formulation [10]. The measurement based on X-ray images and CT images is mainly carried out by doctors by using measurement and analysis software such as distance, angle, and other measurement tools. Among them, the three-dimensional measurement of CT images can avoid the influence of anatomical structure overlap on measurement in two-dimensional X-ray images, and the measurement results are closest to the true anatomical morphology of the human skeleton [11]. However, CT is not the preferred imaging examination method for ankle joint disease screening in clinical practice, and X-ray examination still has the advantage of easy access for obtaining a large number of imaging data for quantitative analysis. The X-ray measurement method is more reproducible than CT and is widely used. In this study, the standard

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ankle joint X-ray images and measurement methods were used to measure and analyze the two-dimensional morphology of the ankle joint in 340 adults, and the results showed that there were gender differences in ankle joint morphology, consistent with previous research results, suggesting that total ankle joint prosthesis design needs to consider gender factors.

The X-ray morphological measurement of the ankle joint includes distance-based and angle-based measurement indexes, which are used to obtain quantitative data on the ankle bone anatomical structures such as the ankle cavity, calcaneus, and tibiofibular joint. Obtaining these data is very important for the selection and design of TAA prostheses and the formulation of surgical plans before surgery [12]. The morphological measurement methods used in previous studies were mainly used for the formulation of treatment plans and outcome assessment for ankle fractures [7]. The 15 morphological parameters used in this study can provide a more comprehensive understanding of the anatomical features of the ankle bone structures and are mainly used for the design and selection of TAA prostheses. In addition, principal component analysis (PCA) can objectively reflect the combined contribution of each observation parameters and the mutual relationship between different research subjects [13]. In this study, the 15 morphological parameters measured on the lateral and anterior-posterior X-ray images of the ankle joints of Han Chinese adults in Shaanxi Province of China were subjected to PCA. When the principal components were 5, it could explain more than 80% of the data variation in both men and women and had statistically significant contributions to clustering, indicating that the extracted principal components can be reliably used to classify the morphology of the ankle joint after conversion.

Cluster analysis is a research method that groups data objects according to similarity based on the information describing objects and their relationships found in data. It can overcome the subjectivity dependent on the experience and professional knowledge of artificial experts and is widely used in data mining and medical image analysis applications [14,15]. The K-means clustering results show that all male and female samples are effective clustering cases, and the two-dimensional morphological characteristics of the ankle joints of both males and females can be grouped into three types. The design basis of TAA prostheses includes key points such as the structural material, mechanical, fixation, and biomechanics of the prostheses, in which determining the size and type of the prosthesis is an important step. Designing TAA prostheses that meet the anatomical parameters of Chinese people is very important for the efficacy of TAA prostheses replacement, and at the same time, clustering real-world population data can guide the standardization and production of the prostheses when it is not possible to individually customize the prostheses according to the anatomical parameters of the patient's ankle joints.

In this study, the inter-group comparison results of the mean values of three types of ankle joint morphological parameters of Han adults in Shaanxi province of China showed that 14 out of 15 measurement parameters for males and 11 out of 15 for females have statistically significant differences between the types, indicating that clustering is effective, and the types obtained have reference value for guiding the design of TAA prostheses.

The main limitations of this study are as follows: (1) A single-center study and the sample size for measurement and analysis is still small; (2) No correlation analysis was conducted between the measurement data and other relevant information of the observed objects. The next research content includes: (1) developing an automatic method for measuring the morphological parameters of the ankle joint using artificial intelligence technology; (2) conducting a multi-center, multi-ethnic, large-sample measurement in different regions of northwest China.

In summary, this study measured and clustered the morphological parameters of the ankle joints in Han adults in Shaanxi Province of China, and found that there were gender differences in the two-dimensional morphology of the ankle joints. The three types of ankle joints and the mean values of the type parameters proposed in this study have certain reference values for the design of total ankle prostheses.

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