

Study on the foot shape characteristics of the elderly in China



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ABSTRACT

Background: With aging, the feet of the elderly above 60 years old in China present degenerative changes, deformities, and diseases, which significantly affect their daily activities.

Objectives: The authors aimed to study the morphological characteristics of the feet and identify the foot type according to size (length and width) and defect characteristics of elderly feet in China.

Methods: A convenient sample of 1000 subjects above 60 years old was recruited mainly in the regions of Shanghai, Shaanxi, Henan, Hebei, and Sichuan in China. Foot images were collected, and 800 (male 398, female 402) valid questionnaires were recovered. A total of 800 elderly subjects as the test group were invited to measure their foot sizes by means of a Footprint Collector (Tong Yuan Tang Health Management Limited, Qingdao in Shandong province). The foot type of the elderly was compared with that of the general adult Chinese population as the control group using the t-test for independent samples.

Results: Hallux valgus (46.9%) and flat foot (50.0%) were the most common foot shape deformities. The most frequent foot diseases were foot scaling (91.2%) and calluses (96.3%). The medial width of the first metatarsal-toe joint of the elderly was significantly higher (elderly female, 44.95 ± 4.86 mm; elderly male, 48.55 ± 4.94 mm) than that of the general adult population (adult female, 40.18 ± 3.43 mm; adult male, 43.22 ± 3.20 mm) ($p < 0.01$).

Conclusion: The foot length of the elderly was not significantly different from that of the general adult Chinese population. The width of the first metatarsal-toe joint in the forefoot of the elderly was significantly higher than that of the general adult Chinese population, which was consistent with the result that a high proportion of elderly subjects presented hallux valgus.

1. Introduction

In 2010, the results of a census in China showed that the number of Chinese people over 60 years of age had reached a total of 1.78 hundred million, which accounted for 13.26% of the total Chinese population. The results of the census show that a significant proportion of the Chinese population is in the elderly stage [1]. With increasing age, degenerative morphological changes and lesions occur in the feet of the elderly [2,3], such as diabetic foot [4], hallux valgus [5], overlapping toes, and claw toe [6], among others. The aging can lead to motor dysfunction, an increase in the risk of falls [7–9], and can seriously affect the daily activities of the elderly.

After reviewing the literature, the authors found that there are few studies on the foot type of the elderly in America, Japan, Australia, Korea, and others countries [10–14]. You and Zhang studied the data acquisition methods for the feet of the middle aged and elderly [15,16]. Li and Fei studied and identified the foot type of the elderly based on the length and width of their feet [17]. Shi studied the changes of

length and girth of the feet of the elderly with different exercise forms [18]. Li and Wang obtained foot data of Taiwanese adults using a 3-dimensional foot scanner, and found that there were three adult foot types in Taiwan [19]. Differences between feet related to sex have been reported, and significant differences in the foot sizes between male and female adults have been reported [20]. Asanka et al. measured the outline of the foot, and divided the foot into four types. They processed data through the methods of clustering and rotation analysis, and supplemented the morphological tissue characteristics of the foot for the design of footwear and shoe lasts [21]. Golightly et al. studied ethnic-related differences in the incidence of foot diseases, flatfoot deformity, and high arch foot, and obtained prevalent foot disease types among the subjects over the age of 50 [6].

In the present study, to evaluate the foot shape characteristics of the elderly in China, the authors collected the foot data of the elderly above 60 years of age mainly from Shanghai, Shaanxi, Henan, Hebei, and Sichuan in China. The foot types were evaluated by distributing questionnaires about elderly foot deformities, foot diseases, and motor

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dysfunctions. Seven images of foot shapes of the elderly were collected to research foot deformity characteristics, and the foot sizes of the elderly were measured to evaluate the changes in foot measurements. Finally, the survey results and the measurements were analysed subjectively and objectively. The present study provides information about the characteristics of the feet of the elderly in China. Moreover, our findings may provide useful information for the development of foot products or to improve footwear design for the elderly.

2. Subjects and methods

2.1. Subjects

The present study was approved by the ethical committee of Graduate School of Shaanxi University of Science and Technology. All the study subjects provided written informed consent prior to participation in the present study.

The subjects in this study are the elderly over 60 years old as the test group, mainly from Shanghai, Shaanxi, Henan, Hebei, and Sichuan in China. Questionnaires were sent to all the study subjects, considering the places where the elderly population can regularly be found, such as the park and residential quarters, among others. There were 800 elderly subjects (male 398 and female 402) recruited as test subjects whose feet were in good state without any congenital or acquired disease. The demographic characteristics of the study subjects are shown in Table 1. The general adult Chinese population was used as the control group. The average data (foot sizes) for 10,000 adult Chinese subjects (control group) from 34 provinces in China in the 1970s were used for comparisons with the data from the test group.

2.2. Questionnaires and foot shape collection

Questionnaires about foot deformities, foot diseases, and other foot-related questions were distributed. The researchers were divided into three groups. Each group was responsible for distributing the questionnaires. Seven visual images of foot shapes of the elderly were collected (before, after, left, right, above, below, and at 45°) using a high-definition camera. There were eight groups of investigators, and the number of questionnaires issued by each group was 120. The male to female ratio was 1:1. the authors recovered 800 valid questionnaires. All of the answers and collected feet images were classified.

2.3. Foot pattern research method

The foot sizes of the elderly were obtained by manual measurement in the barefoot state. The footprints and foot contour of elderly subjects were obtained by a Footprint Collector (the acquisition principle for screen printing) (Tong Yuan Tang Health Management Limited, Qingdao in Shandong province), as well as foot marks (ankle, tarsal convex points, waist, boat-shaped bend points). The height and the girth of the foot of the elderly were measured by movable square and leather tape measurements. The left and right feet were measured for

Table 1
Demographic characteristics of the elderly subjects and the general adult population in China.

	Test groups		Control groups	
	Elderly female (n = 402)	Elderly male (n = 398)	Adult female (n = 5000)	Adult male (n = 5000)
Age (years)	63.7 ± 4.9	66.2 ± 9.0	22.2 ± 1.5	21.9 ± 0.9
Height (m)	1.58 ± 0.06	1.66 ± 0.54	1.63 ± 0.07	1.76 ± 0.07
BMI (kg/m ²)	23.9 ± 2.6	24.2 ± 3.1	20.7 ± 2.1	21.0 ± 2.0

Data are presented as mean ± SD.
BMI, body mass index.

Table 2
Foot diseases among the elderly.

	Elderly male (n = 398)	Elderly female (n = 402)
Total	398 (100%)	402 (100%)
Senile plaques	303 (76.1%)	132 (32.8%)
Scaling	350 (87.9%)	380 (94.5%)
Ulcerations	260 (65.3%)	270 (67.2%)
Calluses	380 (95.5%)	390 (97.0%)
Clavus	360 (90.5%)	320 (79.6%)
Callosus	254 (63.8%)	300 (74.6%)
Nail ringworm	50 (12.6%)	73 (18.2%)
Paronychia	30 (7.5%)	23 (5.7%)
No disease	46 (11.6%)	40 (10.0%)

Table 3
Foot deformities among the elderly.

	Elderly male (n = 398)	Elderly female (n = 402)
Total	398 (100%)	402 (100%)
Claw toes	50 (12.6%)	73 (18.2%)
Overlapping toes	30 (7.5%)	120 (29.9%)
Webbed toes	50 (12.6%)	60 (14.9%)
Hallux valgus	123 (30.9%)	253 (62.9%)
Toe deformities	30 (7.5%)	56 (13.9%)
Flat foot	189 (47.5%)	211 (52.5%)
High arch	69 (17.3%)	88 (21.9%)
No deformity	60 (15.1%)	46 (11.4%)

Table 4
Motor dysfunction among the elderly.

Terms	Number (n = 800)	Proportion (%)
Lumbago	72	9.0
Leg numbness	96	12.0
Unable in lower limbs	128	16.0
Knee joint pain	24	3.0
Heel pain	8	1.0
Dizziness in gait	64	8.0
Procrastination	72	9.0
Toe-out	152	19.0
Unbalance	40	5.0
O-type leg	21	2.6
No motor dysfunction	120	15.0

“Unable” means no strength in the lower limbs. “Procrastination” means that it is too slow and hard to lift the feet in whole gait.

comparative analysis of elderly subjects. The length, width, hallux valgus angle, ratio of the width of footprints to that of the foot contour, and the number and position of the plantar of the foot were obtained from the subjects’ foot prints. Length and width as the basic data and other parameters as the defect data were combined to identify the foot type of the elderly. Then, the results of comparative analysis between the foot type of the elderly and that of the general adult population in China were evaluated to study the change in the foot shape characteristics of the elderly.

Table 5
Elderly female foot length type.

Foot length (mm)	215	220	225	230	235	240	245	250	255	260
Number	16	24	56	64	91	61	36	31	17	4
Portion (%)	4.0	6.0	14.02	16.04	23.07	15.07	9.0	8.0	4.0	1.00

“Number” is the number of subjects and “Portion” is the proportion of the subjects.

Table 6
Elderly male foot length type.

Foot length (mm)	235	240	245	250	255	260	265	270	275	280	285	290
Number	20	32	56	72	56	60	44	28	8	11	5	8
Portion (%)	5.0	8.0	14.0	18.0	14.0	15.0	11.0	7.0	2.00	3.0	1.00	2.00

“Number” is the number of subjects and “Portion” is the proportion of the subjects.

Table 7
Comparison of the foot length according to foot type of the elderly and that of the general adult population in China.

Length of foot (mm)	Female adults (n = 5000)	Elderly female (n = 400)	p	Male adults (n = 5000)	Elderly male (n = 400)	p
Foot length	232.11 ± 10.10	235.34 ± 10.52	0.064	252.1 ± 10.91	255.55 ± 13.67	0.127
T1 convex point	208.44 ± 0.58	212.73 ± 0.09	0.429	225.1 ± 0.58	232.26 ± 11.55	0.061
T5 end	190.98 ± 1.11	197.55 ± 14.9	0.530	207.46 ± 6.77	214.68 ± 10.31	0.330
T5 convex point	181.49 ± 0.58	183.83 ± 14.36	0.629	196.67 ± 1.71	200.21 ± 10.79	0.080
M1 convex point	168.96 ± 0.94	168.75 ± 9.01	0.056	183.22 ± 2.00	183.89 ± 11.24	0.092
M5 convex point	149.02 ± 0.91	149.63 ± 8.38	0.052	161.21 ± 0.97	163.40 ± 11.29	0.109
Tarsal bone point	128.81 ± 0.50	121.61 ± 14.55	0.222	139.17 ± 2.52	132.76 ± 9.61	0.108

Data are presented as mean ± SD. “n” is the number of subjects.

Table 8
Comparison of the foot width according to foot type of the elderly and that of the general adult population in China.

Width of foot (mm)	Female adults (n = 5000)	Elderly female (n = 400)	p	Male adults (n = 5000)	Elderly male (n = 400)	p
Basic width	93.1 ± 2.32	96.23 ± 8.35	0.179	102.8 ± 4.46	104.35 ± 6.63	0.075
Medial M1	40.18 ± 3.43	44.95 ± 4.86	< 0.001	43.22 ± 3.20	48.55 ± 4.94	< 0.001
Lateral M5	52.92 ± 3.82	51.57 ± 4.21	0.054	59.38 ± 2.71	55.80 ± 4.78	0.283
Lateral waist	43.03 ± 2.31	42.25 ± 4.67	0.075	48.33 ± 2.64	46.29 ± 5.72	0.277
Heel centre	63.56 ± 3.03	66.38 ± 5.40	0.001	68.84 ± 4.06	71.29 ± 5.97	0.038

Data are presented as mean ± SD. “n” is the number of subjects.

Table 9
Hallux valgus angle among the elderly.

Hallux valgus angle classification (°)	Number (female, n = 402)	Ratio (%) (female)	Number (male, n = 398)	Ratio (%) (male)
Total	402	100	398	100
0–15	168	41.8	186	46.7
15–20	93	23.0	91	22.8
20–25	50	12.4	52	13.2
25–30	43	10.6	38	9.6
30–35	24	6.1	17	4.2
35–50	24	6.1	14	3.6

Table 10
Ratio of the width of the footprint to that of the foot contour in the most concave region of the midfoot.

Proportion (%)	Number (n = 800)	Ratio (%)
0–10	18	2.2
10–20	2	0.2
20–30	0	0
30–40	68	8.5
40–50	351	43.9
50–60	261	32.7
60–70	53	6.6
70–80	27	3.4
80–90	18	2.2
90–100	2	0.2

2.4. Measurement method

The measurement of foot deformity mainly referred to significant changes of the foot shape. The main research methods included a qualitative analysis and quantitative measurement. Qualitative analysis was performed through the observation and analysis of the seven visual images collected. Quantitative analysis was performed by the way of measurement to quantify and to study the defects of the foot, such as hallux valgus foot, high arch foot, flat foot, and foot plate calluses.

2.5. Statistical analysis

Statistical analyses were performed using the SPSS system 19.0 software. The t-test for independent samples was applied to determine whether differences in the foot types between the elderly and the general adult population in China were significant. Statistical significance was set at $p < 0.05$.

3. Results

The proportions of different foot deformities in all the study subjects are listed as the number of subjects with different foot type. The survey results of the elderly foot lesions showed that skin lesions and nail lesions were the most common foot diseases (Table 2). The results of the foot deformity survey showed that the forefoot was the mainly affected area of the foot, especially, hallux valgus and toe deformity (Table 3). The results of the motor dysfunction survey showed that toe-out gait, weakness, procrastination, and unbalanced gait were the most common motor dysfunctions among the elderly (Table 4).

The evaluation of the foot type was mainly focused on foot length

Table 11
Number and ratios of foot plantar calluses.

Number of foot plantar calluses	Number (n = 800)	Ratio (%)
0	149	18.6
1	120	15.0
2–3	164	20.5
Above 4	65	8.1
No calluses	302	37.8

(Tables 5–7) and width (Table 8), and a comparative analysis between the elderly and the general adult population in China in terms of feet length and feet width was also made. The indicators of deformity included hallux valgus angle (Table 9), ratio of the width of the footprint to the width of the foot contour in the midfoot (Table 10), and number and position of plantar calluses (Table 11).

4. Discussion

4.1. Survey results of the foot characteristics of the elderly

4.1.1. Survey results of foot diseases

The results of the survey on foot diseases among the elderly showed that 89% of the elderly above 60 years of age had foot lesions, mainly

skin and nail lesions. Foot skin lesions mainly included calluses and corns, scaling, corpus callosum, and ulcer (Fig. 1a–f). The most common foot diseases were scaling (91.2%) and calluses (96.3%). The less common foot diseases were calluses (85.1%) and calluses (69.3%), 66.3% of the subjects had ulcerations (Fig. 1g) (Table 2). It was reported that 30% of foot ulcers were caused by keratinized skin disease, including corns and calluses [2]. In the literature, the fundamental cause of dry skin, skin scaling, and even keratinization was the loss of hydrating function of the skin, and glycoprotein was also proposed to promote skin hydrating function, which can be released from microcapsules to improve the skin aging problem [22].

4.1.2. Survey results of foot deformities

Foot deformity data of the elderly showed that 86.8% of the feet of the elderly over the age of 60 years had deformities. Many elderly subjects had two or more deformities of the toes. The proportions of claw toe, overlapping toes, webbed toes (the adjacent toes become webbed because of the compression caused by the first toe), hallux valgus, and other toe deformities (diabetic foot toe amputation, natural short toes, deformity of hallux valgus) (Fig. 2a–g) were 15.4%, 18.8%, 13.8%, 46.9%, and 10.8% respectively. Furthermore, 50.0% of elderly people had flat foot, which proves that fallen arch was the most common foot deformity in the elderly (Fig. 3a–c) (Table 3). It is reported that high arch foot causes the foot contact area to decrease, which can lead to high forefoot pressure, so that the toes develop claw



Fig. 1. Foot diseases.

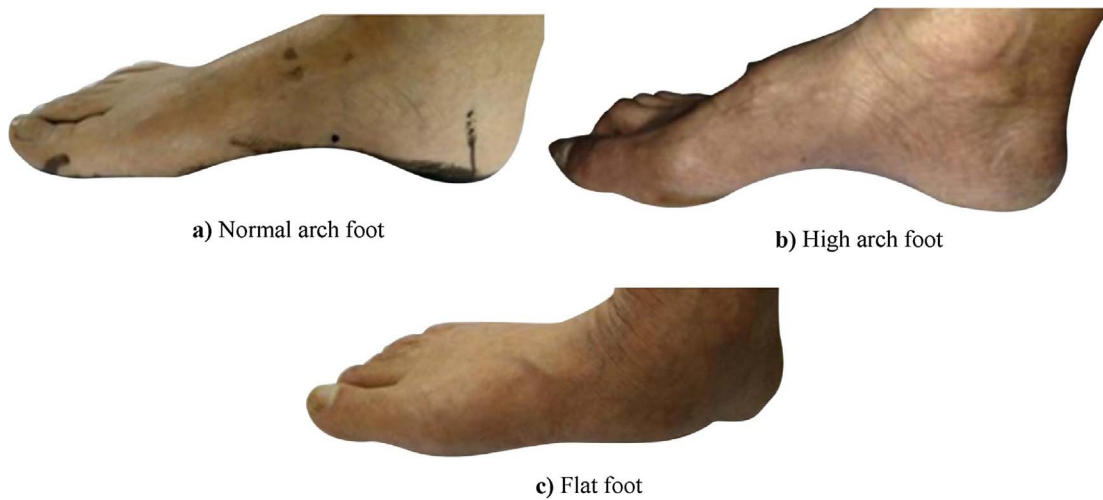


Fig. 2. Foot deformities.

a) Claw toes b)Overlapping toes c) Paste toes d)Hallux valgus



e) Deformity of hallux valgus f)Diabetic foot toe amputation g)Natural short toe



a) Normal arch foot

b) High arch foot

c) Flat foot

Fig. 3. Foot arch.

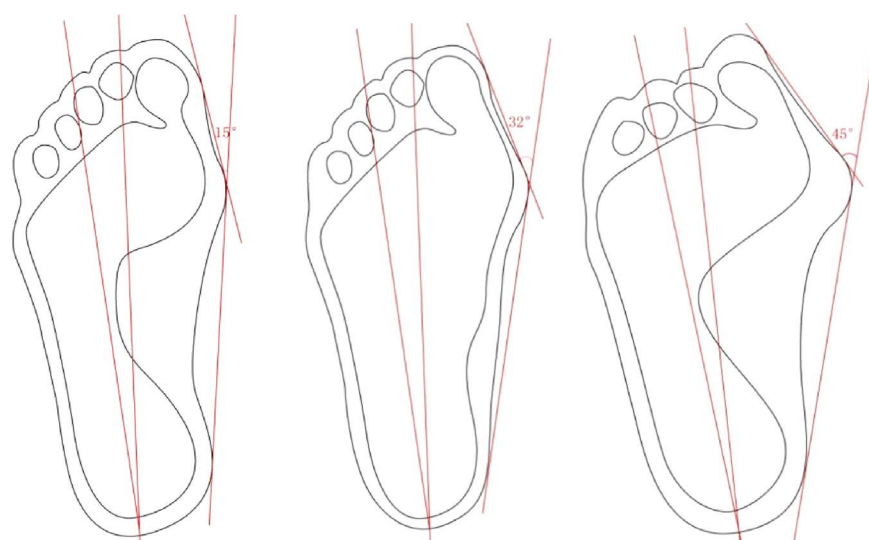


Fig. 4. Hallux valgus.

a) Mild hallux valgus b) Moderate hallux valgus c) Severe hallux valgus

deformity [23]. Factors such as obesity, age, sex differences, related diseases, diabetic foot, and rheumatoid arthritis can also lead to foot arch collapse [24]. It is reported that 83% (58% male, 25% female) of elderly subjects above 65 years of age with a history of wearing high-heeled shoes develop hallux valgus [25].

4.1.3. Footprint pictures

The hallux valgus angle (hallux valgus is defined as an angle between the first phalanx and the first metatarsal greater than 15° [25]) (Fig. 4a–c, Red line marker), the number and position of plantar calluses (Fig. 5a–b, Red line marker), and the identification of high arch and flat foot (Fig. 6a–b, Red line marker) are shown in footprints. Relevant research showed that there was a significant difference ($p < 0.01$) in the contact area of the midfoot between a high arch foot and normal foot [23].

4.2. Survey results of motor dysfunction decline in the elderly

The results of foot motor function decline showed that 85.0% of the elderly had backache pain, leg numbness, gait weakness, knee joint

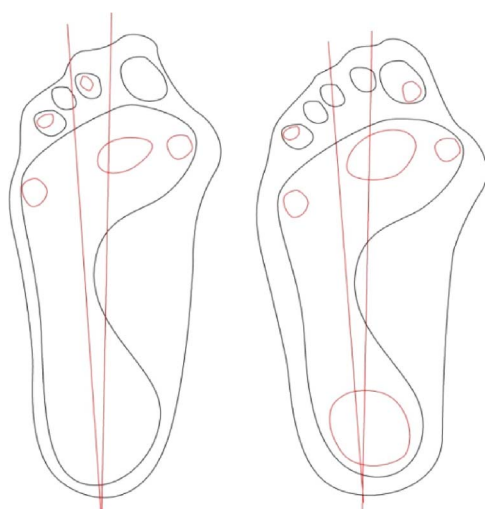
pain, heel pain, dizziness, sluggish gait, gait imbalance (easy to fall), the toe-out gait, procrastination, and weakness. Among these, the proportion of subjects with toe-out gait was the highest at 19.0% (Table 4).

4.3. Foot type pattern in the elderly

4.3.1. Foot size database

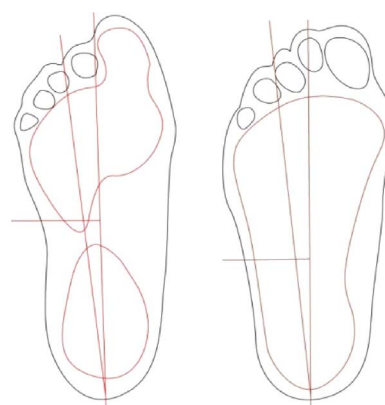
4.3.1.1. Length. The foot length of most elderly male subjects ranged from 255 mm to 260 mm, and that of elderly female subjects ranged from 235 mm to 240 mm (Tables 5 and 6). Compared to the foot length of general adult population in China, the foot length of elderly male subjects was higher by 3.45 mm and that of elderly female subjects was higher by 3.23 mm. For all foot types, the foot length of the elderly was longer than that of the general adult population in China, except for the length of the tarsal bone (Table 7). It was mentioned in the literature that there was no significant difference between the foot length of the elderly and that of the general adult population in China [26].

4.3.1.2. Width. Compared with the foot width of the general adult population in China, the foot width of the elderly was higher by about 3 mm, and the medial width of the first metatarsophalangeal (M1) joint was higher by about 4.5 mm. Compared with the basic foot width of the



a) Moderate calluses b) Severe calluses

Fig. 5. Calluses.



a) High arch foot b) Flat foot

Fig. 6. Foot arch deformities.

general adult population in China, the basic foot width was higher by 1.55 mm among elderly male subjects and 3.13 mm among elderly female subjects. The medial width of the M1 of the elderly was greater by 5.33 mm in elderly male subjects and 4.77 mm in elderly female subjects when compared with that of the general adult population in China. The lateral width of the foot waist of the elderly was less than that of the general adult population in China. The lateral width of the fifth metatarsophalangeal remained unchanged. The width of the heel of the elderly was higher than that of the general adult population in China by about 3 mm (Table 8). Significant differences ($p < 0.01$) in the basic foot width of the elderly and that of the general adult population in China have been reported [26], and the results of the present study are consistent with this previous finding.

4.3.2. Measurement of foot deformity

4.3.2.1. Hallux valgus foot. Hallux valgus by quantitative indicators is the angle between the first metatarsal and first phalanx. The results showed that 46.9% of elderly subjects had hallux valgus (the medial tangent in the first toe angle is greater than or equal to 15°). A hallux valgus angle of $15\text{--}20^\circ$ was the most common among elderly male subjects (22.8%) and elderly female subjects (23.0%) (Table 9). The larger the angle, the more serious the hallux valgus foot deformity. Hallux valgus can cause foot movement dysfunction and increase the risk of falls in the elderly [7,27].

4.3.2.2. The ratio of midfoot printing to the foot contour width. The evaluation index of high arches and flat foot is the ratio of the width of the footprint to the width of the contour in the most concave region of the midfoot. A ratio greater than $1/3$ is defined as flat foot. The results of the ratios of the width of the footprint to that of the foot contour in the midfoot showed that in 44% of the elderly subjects, the ratio ranged from 40% to 50%, and the less common ratio was 50–60% (Table 10). In the literature, severe flat feet can trigger foot eversion [28]. The cause of flat foot is dysfunction of the posterior tibial muscle, which generates arch collapse and longitudinal arch, and leads to longer foot. Flat foot morphology is the main cause of foot length increase among elderly subjects [29].

4.3.2.3. The number and position of foot plantar calluses. The survey result of foot plantar calluses showed that 96.3% of the elderly had calluses on the foot plantar surface. The calluses were mainly located on the position of the first, second, and fifth metatarsal heads and the first toe. Thirty-three percent of elderly subjects had 2–3 calluses and 13% had up to 4 calluses on the foot plantar surface (Table 11). According to the degree of skin keratosis, calluses can be classified as callus, corns, and dry skin [30].

4.3.3. Limitations

One of the limitations of the present study is the relatively small sample size. As the study subjects were limited to those from a few provinces of China, the findings cannot be generalized to the entire Chinese elderly population, and thus cannot be applied to the design of elderly footwear entirely. Further research in a larger sample size, including subjects from all the provinces of China is warranted.

5. Conclusions

The foot lesions of the elderly mainly comprised foot skin lesions and nail lesions. The foot deformities were mainly at the forefoot, among which hallux valgus morphology and toe deformity were the most common. Compared with the foot length of the general adult population in China, elderly subjects had a greater foot length, length of the outer convex point of the toe, and length of the outward convex points of the fifth toes. There were no significant differences in the length of other characteristic sites between the two groups. Compared with the foot width of the general adult population in China, the medial

width of the M1 joint and the width of heel of the elderly were higher, with a significant difference in the medial width of the M1 joint between both groups ($p < 0.01$).

Brief summary

What is already known:

- People over 60 years of age tend to develop motor dysfunction in their lower limbs and feet.
- Foot shape deformity can lead to foot diseases and change in foot size.
- Foot diseases and foot deformities significantly affect the activities of daily living.

What this study adds:

- Hallux valgus and flat feet were the most common foot shape deformities among the elderly in China. Among the foot diseases in the elderly in China, the most common were scaling and calluses.
- There was no significant difference in the foot length of the elderly and that of the general adult population in China; however, the width of the first metatarsal-toe joint in forefoot was significantly higher among the elderly.
- The results of measurement of foot deformity confirmed that foot degenerative changes can trigger foot diseases in the elderly Chinese population.

Author contributions

Xiang Dong Luo: study design, data acquisition, interpretation of data, final approval.

Chao-Hua Xue: study design, critical revision of the article, final approval.

Yan Li: study design, data acquisition, manuscript revision, final approval.

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Conflict of interest

None declared.

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