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Original Research

Is obesity associated with foot structure and the strength of muscles that move the ankle in adult men?

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Abstract

Background and objective: Obesity is associated with several internal medicine diseases and also impacts the musculoskeletal system, particularly in the foot and ankle. Obesity potentially affects the foot structure and the strength of the muscles responsible for moving the ankle. The purpose of this study was to explore the association between obesity, foot structure and the strength of the muscles which move the ankle in adult men. **Material and methods**: 66 adult men were divided into a non-obese group (n = 19), an overweight group (n = 35) and an obese group (n = 12), based on each participant's body mass index (BMI). Foot structure was measured using a three-dimensional foot scanner and the strength of the muscles that move the ankle was assessed with a dynamometer. **Results**: The study demonstrated the height, width and girth indicators of the foot to be greater among those in the overweight and obese groups than participants in the non-obese group ($p < 0.05$) and positive relationships were discovered between BMI and instep height, forefoot and rearfoot width and forefoot and instep girth (r = 0.223–0.423, $p < 0.05$). The overweight and obese men exhibited lower strength in the muscles that move the ankle (peak torque per body weight) than the non-obese men ($p < 0.05$) and correlation analysis proved BMI to be positively associated with dorsiflexion peak torque at 30 and 120 °/s angular velocity (r = 0.385 and 0.310, $p < 0.05$) and negatively associated with plantarflexion, dorsiflexion, eversion and inversion peak torque per body weight at 30 °/s and 120 °/s angular velocity (r = –0.244–0.462, $p < 0.05$). **Conclusion**: The findings of the study show that the height, width, and girth of the foot are greater and the strength of the muscles responsible for moving the ankle is lower in overweight and obese men.

Keywords: Body mass index; Foot and ankle; Muscle strength; Musculoskeletal disorders; Obesity

1. Introduction

The global prevalence of people being overweight or obese has increased significantly in recent decades. According to statistics from the World Health Organization, more than 1.9 billion adults (39%) aged 18 years or older were deemed to be overweight in 2016. Of these, more than 650 million (13%) were categorised as obese [1]. Obesity is a noted public health concern and is linked to several internal medicine diseases, including diabetes, cardiovascular diseases and cancers [2,3] and also affects the musculoskeletal system, particularly the foot and ankle [4,5]. For example, a number of studies have demonstrated that obesity is an established risk factor for the development and progression of chronic foot and ankle diseases, including flat foot, tendinitis, plantar fasciitis, osteoarthritis and foot pain [6,7]. In addition, it has been reported that obese individuals have an increased likelihood of suffering from acute injuries including ankle sprains and fractures [8]. The association of obesity with foot and ankle disorders could lead to a decrease of general health-related quality of life and therefore increase morbidity related to obesity among both men and women [9].

Previous research has proven that being overweight or obese has a negative impact on children's foot structure and function [10,11]. Mauch *et al*. [12] claimed it is more likely that overweight children will develop flat and robust feet than underweight children. In addition to children, the relationship between flat feet and obesity was also discovered among adult Australians and Americans [13,14]. However, Atamturk [15] reported there to be no associations between flat feet or high-arched feet and body weight or body mass index (BMI) among Turkish individuals. Due to the conflicting results of these previous studies, further research is required to explore whether or not a relationship exists between obesity and foot structure.

Muscles around the foot and ankle play vital roles in maintaining a specific foot structure. Long-term morphologic changes to the foot are generally accompanied by changes in joint movement and muscle strength in the foot and ankle and insufficient muscle strength among obese individuals may be the reason for lower extremity musculoskeletal disorders, detrimental gait pattern and altered foot structure [16]. There is evidence that the occurrence and development of musculoskeletal disorders is associated with declining strength in the muscles in the foot and ankle [17]. To the best of our knowledge, although it has been documented that obesity can decrease grip strength and knee strength [18], there is no evidence proving an association between obesity and the strength of the muscles which move the ankle.

Table 1. Description of characteristics of the study participants.

	Non-obese men (BMI <25.0)	Overweight men (25.0 ≤ BMI < 30.0)	Obese men (BMI ≥30.0)	Overall
Numbers (n)	19	35	12	66
Age (yrs)	52.95 ± 7.95	51.40 ± 9.34	49.00 ± 8.34	51.41 ± 8.76
Height (cm)	173.15 ± 5.84	169.48 ± 7.14	172.73 ± 4.17	171.13 ± 6.49
Weight (kg)	68.51 ± 9.07	77.65 ± 6.92*	96.07 ± 6.14$,§	78.37 ± 11.86
BMI (kg/m^2)	22.77 ± 2.09	27.02 ± 1.38*	32.18 ± 1.47$,§	26.73 ± 3.56

* represents significant differences between non-obese and overweight men.

$ represents significant differences between non-obese and obese men.

§ represents significant differences between overweight and obese men.

The human foot plays a vital role in the absorption of ground reaction forces, supporting body weight and maintaining postural balance when a person participates in weight-bearing activities or exercises. For overweight and obese individuals, excess body weight results in greater pressure on the feet, which can cause changes to the foot structure and function to a certain extent. Therefore, the purpose of this study was to explore the association between obesity, foot structure and the strength of the muscles that move the ankle in adult men. It was hypothesised that the foot is longer, wider and lower and the strength of the muscles that move the ankle is lower among obese men than in non-obese men.

2. Participants and methods

2.1 Participants

This research was conducted in the city of Ningbo between October 2018 and March 2019. Participants were recruited from communities close to Ningbo University by advertisements placed in local newspapers and the distribution of flyers about the study. Participants were chosen if they met the following eligibility criteria: (1) adult males aged between 30 and 65 years; (2) having no habit of regular exercise or inactivity (less than 150-minute moderate-vigorous activity per week according to the American Cancer Society [19]); and (3) having no current or previous lower extremity disorders affecting foot and/or ankle health. A total of 66 participants with a mean age of 51.41 ± 8.76 years took part in the study. They were divided into non-obese, overweight and obese groups according to their BMI (Table 1). Before measurements were taken, each participant read and signed an informed consent form. This study protocol was approved by the Ethics Committee of the university and complies with the Declaration of Helsinki.

2.2 Foot structure measurements

Traditional foot structure measuring methods include ink footprint, digital calliper and digital footprint. Compared to these methods, a three-dimensional surface scanning system, such as the leaser three-dimensional foot scanner that was used in this study, has been reported to offer better measurement precision and accuracy. In addition, another feature of the three-dimensional surface scanning system is time-saving, making it ideal for application in a great sample data test. Saghazadeh *et al*. [20] employed a three-dimensional foot scanner for determining foot posture, which indicated that the intraclass correlation coefficients of this device range from 0.94 to 0.99. In recent years, the majority of studies relating to foot structure have used the three-dimensional foot scanner [21,22] instead of the traditional measuring methods that were mentioned above.

A leaser three-dimensional foot scanner (FSN-2100, Dream GP Inc., Osaka, Japan) was employed for measuring foot structure information. A laser rotated on the rail around the foot calculated approximately 30,000 points, including the length, width, height and girth of the foot, which enabled the software to reconstruct the exact shape of each foot on the computer. Due to the higher accuracy and high efficiency of this method compared to conventional measurement methods, three-dimensional imaging technology is recommended for foot measurement and the collection of foot anthropometric data [23,24]. In this research, both left and right foot anthropometric data were measured in each participant in both sitting and bipedal standing positions with bare feet. Each measurement was completed in approximately 15 seconds.

Foot structure parameters were obtained automatically by using three-dimensional foot scanner analysis software (Fig. 1). The descriptions of the major parameters of foot structure have been described in greater detail in our previous study [16].

2.3 Muscle strength measurements

A Biodex System 4 Dynamometer with Biodex Advantage Software Package (Biodex Medical System Inc., Shirley, NY, USA) was used for measuring peak torque and peak torque per body weight in the right ankle. Plantarflexion and dorsiflexion (plantarflexion is the motion of moving the foot away from the leg and dorsiflexion is the opposite movement) and inversion and eversion (inversion is the movement whereby the sole of the foot is moved to face inwards and eversion is the opposite movement) were measured at a speed of 30 and 120 °/s angular velocity (Fig. 2).

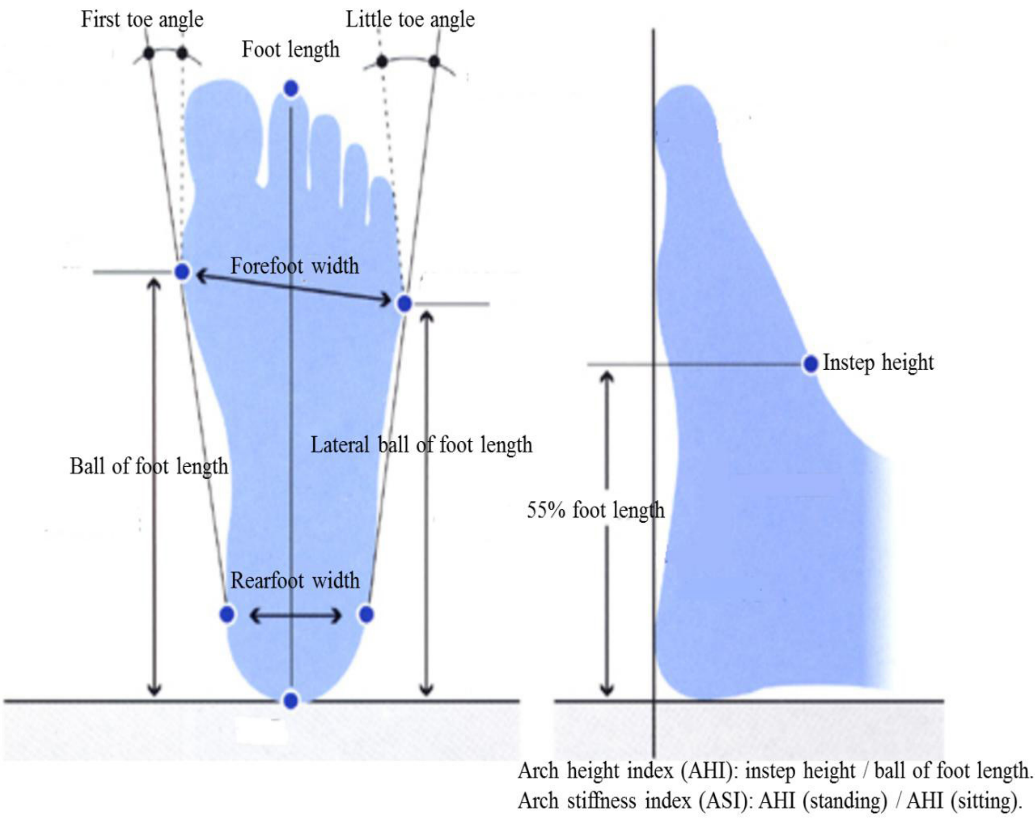

Fig. 1. The descriptions of major indicators of foot structure.

Table 2. Differences of right foot structure in bipedal standing position among different BMI groups by one-way ANOVA test followed by Bonferroni-Dunn post-hoc test.

Variables	Non-obese men	Overweight men	Obese men	p values
Foot length (mm)	254.07 ± 11.12	250.10 ± 13.93	252.95 ± 7.98	0.814
Forefoot girth (mm)	237.67 ± 10.12	246.04 ± 10.56*	249.45 ± 9.61$	0.028
Forefoot width (mm)	99.43 ± 4.48	103.66 ± 5.11*	104.34 ± 4.27$	0.088
Rearfoot width (mm)	63.04 ± 5.59	67.28 ± 3.26*	67.75 ± 3.53$	0.013
Ball of foot length (mm)	182.71 ± 8.06	179.78 ± 10.20	181.82 ± 5.79	0.838
Lateral ball of foot length (mm)	159.76 ± 7.05	157.31 ± 8.94	159.06 ± 5.07	0.958
Instep height (mm)	61.58 ± 3.60	65.21± 4.82*	66.09 ± 4.49$	0.045
Instep girth (mm)	243.90 ± 11.42	255.35 ± 11.60*	258.61 ± 11.30$	0.010
First toe angle (degrees)	9.44 ± 3.69	10.59 ± 4.04	7.85 ± 4.08	0.851
Little toe angle (degrees)	15.20 ± 3.71	14.47 ± 5.76	13.86 ± 3.83	0.900
Arch height index (ratio)	0.342 ± 0.022	0.353 ± 0.033	0.367 ± 0.030$	0.068
Arch stiffness index (ratio)	0.912 ± 0.034	0.914 ± 0.034	0.921 ± 0.028	0.874

* represents significant differences between non-obese and overweight men.

$ represents significant differences between non-obese and obese men.

Before measuring, two to three minutes of warm-up exercise were performed by each participant under the guidance of an experienced staff member, with focus on the ankle joint. At the same time, an isokinetic dynamometer was set and positioned based on the manufacturer's recommendations. Participants were then seated in the Biodex chair with two straps to stabilise the trunk and hip. For each participant, the dynamometer, knee pad and positioning chair were adjusted to ensure full alignment between the midline of the foot and the midline of the patella and to ensure that the lower shank was parallel to the floor. The dynamometer orientation, tile and seat orientation were maintained at 90, 0 and 90 degrees during the plantarflexion to dorsiflexion test and at 0, 70 and 90 degrees during the eversion to in-

Table 3. Bivariate correlation coefficients (Pearson correlation coefficients) between BMI and parameters of right foot structure in bipedal standing position.

	Foot length	Forefoot girth	Forefoot width	Rearfoot width	Ball of foot length	Lateral ball of foot length
r	0.035	0.330	0.196	0.385	0.032	0.031
p	0.778	0.007	0.114	0.001	0.800	0.806
	Instep height	Instep girth	First toe angle	Little toe angle	Arch height index	Arch stiffness index
r	0.292	0.423	–0.069	–0.171	0.223	–0.065
p	0.018	<0.001	0.579	0.169	0.042	0.603

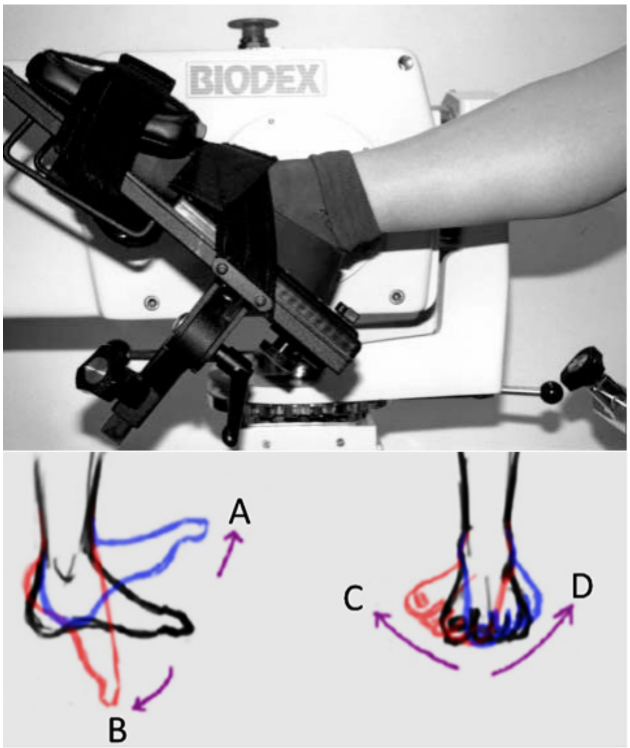

Fig. 2. The descriptions of measurements of the strength of muscles that move the ankle. (A) Plantarflexion. (B) Dorsiflexion. (C) Inversion. (D) Eversion.

version test. A range of motion was used for determining the start and stop angles for each participant based on their active range of motion. Once an explanation of the testing procedure was provided to participants, one submaximal repetition was given in order for them to become familiar with the testing procedure, then a test consisting of three maximal repetitions at a speed of 30 °/s and 120 °/s angular velocity for plantarflexion to dorsiflexion and eversion to inversion were performed. During testing, verbal encouragement was offered to each participant. The highest muscular force output at any moment during a repetition was defined as peak torque (Nm) and peak torque per body weight (Nm/kg × 100%). In order to limit measurement variability, all measurements were performed by the same tester on all 66 participants.

2.4 Statistical analysis

During the data analysis process, only the right side foot structure and muscle strength information were analysed to avoid a breach of the assumption of independence in the dataset, as with the previous study [25]. A one-way ANOVA test was used for determining any differences in foot structure parameters and the strength of muscles responsible for moving the ankle in non-obese, overweight and obese male groups, followed by a Bonferroni-Dunn post-hoc test. Next, Pearson's bivariate correlation analysis was used to conduct an exploration of the associations between BMI, foot structure parameters and the strength of the muscles that move the ankle. Cohen's guidelines [26] were also used for determining the effect size (small = 0.1, medium = 0.3, large = 0.5). In all data analysis, a *p*-value of less than 0.05 was considered statistically significant. The data were analysed using the Statistical Package for Social Sciences version 22.0 (SPSS, IBM Corp., Armonk, NY, USA).

3. Results

The results of the differences in foot structure parameters in non-obese, overweight and obese men can be seen in Table 2. The length and angle indicators of the foot, including foot length, ball of foot length, lateral ball of foot length and first and little toe angle, were found to exhibit no differences ($p > 0.05$), whereas the height, width and girth indicators, including instep height, forefoot and rearfoot width and forefoot and instep girth, were found to be greater among those in the overweight and obese groups than in the non-obese group. Furthermore, the results of the correlation analysis demonstrate the existence of positive relationships between BMI and instep height, forefoot and rearfoot width and forefoot and instep girth (r ranged from 0.223 to 0.423, $p < 0.05$; Table 3).

Table 4 shows the results of the differences of the parameters for the strength of muscles that move the ankle in the non-obese, overweight and obese groups. With peak torque, obese men only had a statistically larger dorsiflexion peak torque at both 30 °/s and 120 °/s angular velocity compared to non-obese men ($p < 0.05$). With peak torque per body weight, lower plantarflexion, dorsiflexion, eversion and inversion values were observed at 30 or 120 °/s angular velocity in overweight and obese men ($p < 0.05$).

Table 4. Differences of the strength of muscles that move the ankle among different BMI groups by one-way ANOVA test followed by Bonferroni-Dunn post-hoc test.

Variables	Non-obese men	Overweight men	Obese men	*p* values
Peak torque (Nm)				
Plantarflexion at 30 °/s	80.25 ± 27.13	81.99 ± 27.92	83.56 ± 34.44	0.951
Dorsiflexion at 30 °/s	28.90 ± 5.26	30.33 ± 4.79	34.47 ± 5.40$	0.013
Eversion at 30 °/s	20.21 ± 3.63	18.94 ± 6.09	21.25 ± 5.66	0.405
Inversion at 30 °/s	25.18 ± 7.88	24.53 ± 8.63	26.52 ± 7.29	0.827
Plantarflexion at 120 °/s	50.60 ± 18.71	49.97 ± 18.92	53.84 ± 23.17	0.839
Dorsiflexion at 120 °/s	17.39 ± 3.42	18.69 ± 5.21	21.38 ± 3.69$	0.062
Eversion at 120 °/s	13.26 ± 2.30	12.94 ± 4.39	14.68 ± 2.75	0.365
Inversion at 120 °/s	17.54 ± 5.03	16.79 ± 5.08	18.73 ± 4.55	0.499
Peak torque per body weight (Nm/kg × 100%)				
Plantarflexion at 30 °/s	118.14 ± 40.28	106.14 ± 35.88	85.43 ± 32.55$	0.061
Dorsiflexion at 30 °/s	42.34 ± 5.69	39.18 ± 5.79*	35.55 ± 4.41$	0.006
Eversion at 30 °/s	29.75 ± 5.07	24.31 ± 6.80*	21.78 ± 5.01$	0.001
Inversion at 30 °/s	36.91 ± 9.94	31.78 ± 9.87	27.29 ± 7.14$	0.024
Plantarflexion at 120 °/s	74.65 ± 27.69	64.48 ± 24.35	54.93 ± 21.63$	0.100
Dorsiflexion at 120 °/s	25.57 ± 4.53	24.13 ± 6.41	22.10 ± 3.46	0.238
Eversion at 120 °/s	19.53 ± 3.31	16.61 ± 4.66*	15.16 ± 2.60$	0.008
Inversion at 120 °/s	25.79 ± 7.18	21.51 ± 5.47*	19.31 ± 4.32$	0.008

Abbreviation: °/s, degrees per second.

* represents significant differences between non-obese and overweight men.

$ represents significant differences between non-obese and obese men.

Table 5. Bivariate correlation coefficients (Pearson correlation coefficients) between BMI and parameters of the strength of muscles that move the ankle.

Peak torque (Nm)	Plantarflexion at 30 °/s	Dorsiflexion at 30 °/s	Eversion at 30 °/s	Inversion at 30 °/s
r	0.069	0.385	0.076	0.119
p	0.582	0.001	0.544	0.341
	Plantarflexion at 120 °/s	Dorsiflexion at 120 °/s	Eversion at 120 °/s	Inversion at 120 °/s
r	0.119	0.310	0.118	0.140
p	0.341	0.011	0.346	0.263
Peak torque per body weight (Nm/kg × 100%)	Plantarflexion at 30 °/s	Dorsiflexion at 30 °/s	Eversion at 30 °/s	Inversion at 30 °/s
r	–0.313	–0.455	–0.462	–0.320
p	0.011	<0.001	<0.001	0.009
	Plantarflexion at 120 °/s	Dorsiflexion at 120 °/s	Eversion at 120 °/s	Inversion at 120 °/s
r	–0.244	–0.253	–0.436	–0.360
p	0.049	0.040	<0.001	0.003

Abbreviation: °/s, degrees per second.

In addition, correlation analysis showed BMI to be positively associated with dorsiflexion peak torque at 30 and 120 °/s angular velocity (r = 0.385 and 0.310, $p < 0.05$) and negatively associated with plantarflexion, dorsiflexion, eversion and inversion peak torque per body weight at 30 and 120 °/s angular velocity (ranged from –0.244 to –0.462, $p < 0.05$), as can be seen in Table 5.

4. Discussion

The aim of this cross-sectional study was to establish whether or not an association exists between obesity, foot structure and the strength of muscles which move the ankle in adult men. The primary findings were that the height, width and girth indicators of the foot were greater in the overweight and obese groups than in the non-obese group and positive relationships were discovered between BMI and instep height, forefoot and rearfoot width and forefoot and instep girth. Overweight and obese men exhibited lower strength in the muscles that move the ankle (peak torque per body weight) than non-obese men and correlation analysis showed BMI to be positively associated with dorsiflexion peak torque at 30 °/s and 120 °/s angular velocity (r = 0.385 and 0.310, $p < 0.05$) and negatively associated with plantarflexion, dorsiflexion, eversion and inversion peak torque per body weight at 30 °/s and 120 °/s angular velocity.

Based on the height of the arch, foot arch can be divided into high-arched, normal and low-arched. Bodyweight may affect arch height [25]. Cimolin *et al*. [27] noted there to be a marked difference among the foot types of obese and non-obese adolescents. They observed the percentage of obese individuals with flat foot, cavus foot and normal foot to be 70%, 20% and 10% respectively. However, in non-obese men, 25% of people had flat foot, 25% had cavus foot and 50% had normal foot. In this study, arch height index and arch stiffness index were used for evaluating the height and flexibility of the foot (a value of the arch height index close to 0 indicated a low-arch foot and an arch stiffness index close to 1 indicated a stiff-arched foot). The results revealed that obese men had a higher arch than non-obese individuals in this study, which is consistent with previous research [28]. Inconsistent study results may be attributed to participants from different races and age groups or the fact that different foot structure measuring methods were employed. In addition, further findings from our study showed that height, width and girth indicators, including instep height, forefoot and rearfoot width and forefoot and instep girth, to be greater among the overweight and obese men groups than in the non-obese men group. Similar findings were also made by Price and Nester [29], who indicated the feet to be significantly wider in obese men than in healthy and overweight men. These results may offer an explanation as to why obese men had larger feet than their non-obese counterparts.

BMI was discovered to be negatively associated with plantarflexion, dorsiflexion, eversion and inversion peak torque per body weight at 30 °/s and 120 °/s angular velocity. When the Biodex System 4 Dynamometer was used to examine the strength of muscles that move the ankle in this study, 30 °/s and 120 °/s angular velocities were chosen for measuring peak torque and peak torque per body weight. An angular velocity of 30 °/s showed a slow velocity defining muscle strength and 120 °/s denoted a fast velocity representing muscle power. It was reported that an angular velocity of greater than 120 °/s had a potential risk of injuries and was also difficult to perform [30]. Another reason for the utilisation of these two angular velocities was that they had been employed in previous, comparable studies. In addition, they have proven to be reliable [31,32].

Tsiros *et al*. [33] proved the existence of the relationship between adiposity and knee joint strength in their study of children, observing the peak torque to be higher and the peak torque per body weight to be lower among obese than among healthy, non-obese children. Similar results were obtained by another researcher in a study of adults [34]. Although several studies relating to muscle strength, such as grip strength and knee muscle strength [18,34], have been conducted, comparatively little research has been conducted on the way in which obesity impacts the strength of the muscles that move the ankle [9]. In this study, it was observed that overweight and obese men had lower strength in the muscles that move the ankle (peak torque per body weight) than non-obese men and a weak-to-moderate negative relationship was observed between BMI and peak torque per body weight. Weaker muscle strength around the ankle joint increases the likelihood of foot injuries and disorders [16]. It was reported that it is more likely that individuals with lower foot and ankle muscle strength will experience foot pain and disability [17]. Therefore, increasing strength in the muscles around the ankle joint could help obese individuals avoid foot injuries and disorders.

This study had some limitations. Firstly, during the data analysis process, only the right foot was chosen for measuring foot structure and the strength of the muscles that move the ankle. However, some differences were found between the feet due to bilateral asymmetry that was caused by the dominant foot [35]. Another limitation is that this study is a cross-sectional study and the causal association between obesity, foot structure and the strength of the muscles that move the ankle cannot be revealed. Thirdly, the sample size was not large enough, which may be a barrier to popularising the research results. Finally, whether the participants did or did not have flat feet was not checked. Therefore, the prevalence rate of flat feet presenting among non-obese, overweight and obese men was not determined by this study.

5. Conclusions

To summarise, this study has demonstrated the height, width and girth indicators of the foot to be greater among the overweight and obese groups than the non-obese group and weak-to-moderate positive correlations were discovered between BMI and foot structure parameters. Overweight and obese men had lower strength in the muscles that move the ankle (peak torque per body weight) than non-obese men and a weak-to-moderate negative relationship was observed between BMI and the strength of the muscles that move the ankle (peak torque per body weight). We contend that the height, width and girth of the foot are greater and the strength of the muscles responsible for moving the ankle is lower in overweight and obese men. The findings of this study may be helpful in better understanding the mechanism behind the association between obesity and foot and ankle disorders or injuries. It may also be useful in helping physical therapists increase the strength of the muscles in the foot and ankle to prevent and treat foot and ankle disorders or injuries.

Author contributions

XZ, JY and FH are contributed in study design, manuscript writing, and submission; ZZ is contributed in study design and data analysis; FH and ZZ are contributed in manuscript writing and data collecting. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

All participants gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the study protocol was reviewed and approved by the Human Ethics Board of Ningbo University (approval number: RAGH20181012).

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Conflict of interest

The authors declare no conflict of interest.

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