The Journal of Foot & Ankle Surgery ■■ (2017) ■■–■■

Contents lists available at ScienceDirect

The Journal of Foot & Ankle Surgery

journal homepage: www.jfas.org

Original Research

Does Weight Reduction Affect Foot Structure and the Strength of the Muscles That Move the Ankle in Obese Japanese Adults?

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A R T I C L E I N F O

Level of Clinical Evidence: 4

Keywords:
ankle
dietary modification
3-dimensional foot scanner
foot
foot and ankle disorders
obesity

A B S T R A C T

Obesity is considered a major influential factor of foot structure and function. It has been reported to result in detrimental alterations of foot structure indicators and a decrease in muscle strength, which can lower the quality of life and increase the morbidity of obesity. The purpose of the present study was to determine the effect of weight reduction on foot structure and the strength of the muscles that move the ankle in obese adults. A total of 33 obese Japanese participants (mean body mass index 28.49 ± 2.87 kg/m^2) without an exercise habit participated in a 12-week dietary modification program. Their foot structure indicators were measured using a 3-dimensional foot scanner, and the strength of the muscles that move the ankle was assessed using a dynamometer. After the dietary modification, the mean body weight reduction was 7.49 ± 4.10 kg (9.38%; 77.82 ± 13.26 kg before and 70.33 ± 11.37 kg after; $p < .001$). The wide foot indicators, including the forefoot girth, rearfoot width, and instep girth, had decreased significantly ($p < .05$), and the decreases correlated positively with the weight reduction. Regarding the strength of the muscles that move the ankle, except for dorsiflexion, all the measured peak torque values per body weight had increased significantly ($p < .01$). These results suggest that the weight reduction induced by a 12-week dietary modification results in thinner feet and increased strength of the muscles that move the ankle.

Foot and ankle disorders are reported to affect approximately 24% of middle-age adults (>45 years old) (1) and 42% of older individuals (>60 years old) (2). A number of studies have revealed that foot and ankle disorders are positively associated with obesity (3–5). Furthermore, research has shown that obese adults have a greater prevalence of foot and ankle disorders compared, not only with normal-weight adults, but also with overweight adults (6). The presence of obesity combined with foot and ankle disorders is known to have a detrimental effect on gait and balance and on activities of daily living (7). These associations can also lower overall health-related quality of life and increase the morbidity related to obesity.

A possible explanation for the association of obesity with foot and ankle disorders is that the excess body weight causes detrimental alterations to foot structure and function (8). Previous cross-sectional studies have reached a consensus that obesity can affect the foot structure. Faria et al (9) indicated that excess body weight leads to collapse of the medial longitudinal arch, which adversely affects the functional capacity of the foot. In addition to arch height, foot length and width have been reported to increase significantly with increased body weight (10). Moreover, it is known that obesity is characterized by reduced muscle strength. Although to date no direct evidence has been reported, indirect evidence has suggested that obesity is associated with decreased strength of the muscles that move the ankle. It has also been shown that obesity has a detrimental effect on balance and ankle stability (11,12). Finally, the strength of the muscles that move the ankle is a strong predictor of balance and ankle stability (13).

Financial Disclosure: The research was sponsored by K.C. Wong Magna Fund in Ningbo University. The Pigeon Company (Tsukubamirai City, Ibaraki Prefecture, Japan) provided the 3-dimensional foot scanner and a technician to operate the device for the purposes of our investigation.

Conflict of Interest: None reported.

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https://doi.org/10.1053/j.jfas.2017.09.010

Weight reduction is an effective countermeasure to obesity-related health risks, and it can improve the quality of life in overweight and obese individuals (14,15). However, few systematic research studies have determined how weight reduction affects the foot structure and the strength of the muscles that move the ankle. Although 1 study designed a 3-month weight reduction program to investigate its influence on arch height and peak plantar pressures in obese adults (16), that study did not examine changes in other foot structural indicators, such as the width and girth, and also did not measure the strength of the muscles that move the ankle. Therefore, we undertook a prospective cohort study to examine the effect of weight reduction on foot structure and the strength of the muscles that move the ankle and to determine whether any changes in these outcomes correlated with the weight reduction in obese adults. Our aim was to better understand the association between weight gain and loss of foot structure and function and to clarify whether weight reduction can be an effective approach to improve foot structure and increase the strength of the muscles that move the ankle in obese individuals.

Participants and Methods

The participants were recruited by 2 senior authors (Y.K. and K.T.) through advertisements in a local newspaper and flyers distributed locally in June 2015. Participants were selected if they met the following eligibility criteria: age 30 to 65 years, body mass index (BMI) of ≥25 kg/m^2 using the Japanese obesity guideline (17), no habit of regular exercise (≤150 minutes of moderate to vigorous activity weekly), stable weight for ≥3 months, and no current or previous lower extremity disorders or other neuromuscular or musculoskeletal disorders affecting foot and/or ankle health. A total of 41 potentially eligible obese individuals responded to our invitation to participate. Of these, 37 obese individuals (90.24%) met our inclusion criteria and engaged in a 12-week dietary modification program. Of the 37 participants, 1 (2.70%) was excluded from the analysis because of incomplete data, and 3 (8.11%) were unable to successfully complete the 12-week program for personal reasons, leaving 33 participants (89.19%) for the final analyses. Of the 33 participants, 21 were male (63.64%) and 12 were female (36.36%). Their mean age was 53.00 ± 10.18 years, and their mean BMI was 28.49 ± 2.87 kg/m^2 (Table 1). The ethics committee of our university approved the present study, which complied with the Declaration of Helsinki.

The 12-week weight-loss program mainly constituted dietary modification sessions (one 90-minute session each week), during which the participants were instructed how to restrict their energy intake scientifically and effectively to approximately 1680 kcal/day for males and 1200 kcal/day for females. The purpose of the dietary modification sessions was to help participants obtain a nutritionally well-balanced daily diet, using the Smart Diet (18), which has been used for >20 years by our research team. During the 12-week weight-loss program, each participant was required to record a detailed daily diary in which every food they ate was weighed and then transformed into calories. The daily diary was checked by experienced staff members, and instructional words of encouragement were provided as deemed indicated by the staff. Our past experience has shown the Smart Diet is safe and effective in reducing weight and forming healthy dietary habits. More detailed information related the Smart Diet has been reported previously by our research team (19). The intervention was performed by 5 of us (X.Z., T.T., B.K., Y.K., and K.O.).

Table 1
Foot structure characteristics in standing position before and after weight reduction (N = 33)

Characteristic	Before	After	Changes	*p Value**
Age (y)	53.00 ± 10.18	NA	NA	NA
Height (cm)	164.75 ± 8.55	NA	NA	NA
Weight (kg)	77.82 ± 13.26	70.33 ± 11.37	−7.49 ± 4.10	< .001
BMI (kg/m^2)	28.49 ± 2.87	25.83 ± 2.58	−2.66 ± 1.34	< .001
Foot length (mm)	244.05 ± 15.17	243.87 ± 15.15	−0.18 ± 1.68	.321
Forefoot girth (mm)	239.93 ± 12.94	238.28 ± 13.40	−1.65 ± 3.46	.012
Forefoot width (mm)	98.43 ± 6.07	98.00 ± 6.02	−0.43 ± 1.44	.085
Rearfoot width (mm)	65.49 ± 4.47	64.79 ± 4.88	−0.70 ± 1.94	.015
Ball of foot length (mm)	175.38 ± 11.18	175.23 ± 11.09	−0.15 ± 1.15	.270
Lateral ball of foot length (mm)	153.45 ± 9.78	153.33 ± 9.70	−0.13 ± 1.00	.299
Instep height (mm)	60.95 ± 5.44	60.50 ± 5.23	−0.45 ± 1.45	.096
Instep girth (mm)	246.51 ± 16.90	244.28 ± 15.39	−2.23 ± 3.86	.004
First toe angle (°)	11.13 ± 5.32	11.18 ± 5.04	0.05 ± 2.09	.449
Little toe angle (°)	13.47 ± 4.70	13.55 ± 4.49	0.08 ± 2.77	.918
Arch height index (ratio)	0.348 ± 0.030	0.346 ± 0.029	−0.002 ± 0.009	.214
Arch stiffness index (ratio)	0.898 ± 0.037	0.913 ± 0.031	0.015 ± 0.034	.026

Data presented as mean ± standard deviation.
Abbreviations: BMI, body mass index; NA, not applicable.
* Wilcoxon signed rank test.

The foot anthropometric data were measured using a 3-dimensional foot scanner (FSN-2100; Dream GP, Inc., Osaka, Japan). Owing to the accuracy and efficiency of this form of measurement, application of 3-dimensional imaging technology to collect foot anthropometric data has been recommended (20). The foot anthropometric data were measured in both sitting and bipedal standing positions for each participant. Each participant was instructed to sit on a chair with their feet bare and then to place the right foot on a specified location inside the foot scanner. The participant was also instructed to keep the lower leg, from the knee to the ankle, perpendicular to both the thigh and the floor with their hands at their sides. A laser rotated on a rail about foot measured the length, width, height, and girth, allowing the 3-dimensional foot scanner analysis software to rebuild an exact replica of the foot on the computer. After measurement in the sitting position, a same measurement was taken with the participant in the bipedal standing position. Foot structural indicators were obtained automatically using the foot scanner analysis software as follows:

1. Foot length: the most posterior point of the calcaneus to the anterior point of the most protruding toe
2. Forefoot width: the distance between the most medial point (protrusion) of the first metatarsophalangeal (MTP) joint and the most lateral point (protrusion) of the fifth MTP joint
3. Forefoot girth: the circumference over the first and fifth MTP joint
4. Rearfoot width: the widest section of the heel (calcaneus)
5. Ball of foot length: the most posterior point of the calcaneus on the foot end normal line and the first MTP joint protrusion
6. Lateral ball of foot length: the most posterior point of the calcaneus to the ball of fifth MTP joint
7. Instep height: the highest point at the longitudinal section of the 55% foot length
8. Instep girth: the circumference of the longitudinal section of the 55% foot length
9. First toe angle: the angle between the big toe and the ball of the first MTP joint
10. Little toe angle: the angle between the little toe and the ball of the fifth MTP joint
11. Arch height index (AHI): instep height/ball of foot length
12. Arch stiffness index (ASI): the AHI at standing divided by the AHI at sitting

The AHI and ASI are frequently used indicators in evaluating the arch and foot. The AHI, introduced by Williams and McClay (21) is used to assess the arch height, defined as the instep height divided by the ball of the foot length. The ASI was defined as the ratio of the standing AHI to the sitting AHI and was developed by Richards et al (22) to evaluate arch flexibility. An AHI of 0 indicates a low arch height (0 height) and an ASI close to 1 represents a stiff arch, with an ASI approaching 0 indicating a flexible arch. The measurements were conducted by 3 of us (X.Z., M.T., and K.I.).

Isokinetic muscle strength was measured using a Biodex System 4 Dynamometer with the Biodex Advantage Software Package (Biodex Medical System Inc., Shirley, NY). Plantarflexion, dorsiflexion, inversion, and eversion were measured at a speed of 30°/second angular velocity, in accordance with the manufacturer's recommendations. The rationale for selecting this angular velocity was that it has been frequently used in published reports, has been shown to produce reliable information, and a greater angular velocity indicates the potential risk of injury and is difficult to perform when measuring the strength of the muscles that move the ankle (23).

Before the test, 2 to 3 minutes of warm-up exercises were performed by each participant, under the guidance of a staff member (B.K.). Next, the participant was instructed to sit on the dynamometer chair; 2 straps were used to stabilize the hip and trunk. For each participant, the dynamometer, knee pad, and positioning chair were adjusted to align the midline of the foot with the midline of the patella and to ensure that the lower leg was parallel to the horizontal substrate. The dynamometer orientation, tilt, and seat orientation were set at 90°, 0°, and 90° during the plantarflexion to dorsiflexion test and at 0°, 70°, and 0° during the eversion to inversion test. The range of motion used was in accordance with each participant's active range of motion. After 1 submaximal repetition, allowed for the participant to become familiar with the testing procedure, the test, consisting of 3 maximal repetitions for plantarflexion to dorsiflexion or eversion to inversion, was performed. The greatest muscular force output at any moment during a repetition was defined as the peak torque (Nm), and peak torque per body weight (Nm/kg × 100%) was used to define the strength of the muscles that moved the ankle. To limit the variability of measurements, the same tester (X.Z.) executed all measurements for the 33 participants.

Considering the independence of assumption of statistical analysis, only the right foot structure and muscle strength data were selected for the main analyses. Because the indicators for the foot structure and the strength of the muscles that move the ankle