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Original Article

Effects of increasing physical activity on foot structure and ankle muscle strength in adults with obesity

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Abstract. [Purpose] The purpose of this study was to examine the effects of increasing physical activity on foot structure and ankle muscle strength in adults with obesity and to verify whether the rate of change in foot structure is related to that in ankle muscle strength. [Subjects and Methods] Twenty-seven adults with obesity completed a 12-week program in which the intensity of physical activity performed was gradually increased. Physical activity was monitored using a three-axis accelerometer. Foot structure was assessed using a three-dimensional foot scanner, while ankle muscle strength was measured using a dynamometry. [Results] With the increasing physical activity, the participants' feet became thinner (the rearfoot width, instep height, and girth decreased) and the arch became higher (the arch height index increased) and stiffer (the arch stiffness index increased); the ankle muscle strength also increased after the intervention. Additionally, the changes in the arch height index and arch stiffness index were not associated with changes in ankle muscle strength. [Conclusion] Increasing physical activity may be one possible approach to improve foot structure and function in individuals with obesity.

Key words: Obesity, Foot structure, Ankle muscle strength

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INTRODUCTION

Obesity has become a global pandemic and is recognized as a primary public health concern in many countries. In addition to contributing to conditions such as cardiovascular diseases and diabetes[1, 2)], obesity is strongly related to lower extremity conditions such as ankle and foot pain[3–5)], which lower the quality of life (QoL) and increase the morbidity of obesity[6)].

Physical inactivity is considered a major contributor to the development and progression of overweight and obesity. A possible explanation for the association between obesity and physical inactivity is that excess weight has a negative impact on the biomechanical characteristics of the lower extremities[7, 8)]. With regard to the impact of obesity on the foot and ankle, obesity is reportedly associated with detrimental changes to foot structure and function[3, 9, 10)]. For instance, a recent systematic review, which analyzed 16 papers, reported that obesity is strongly related with planus (low-arched) foot structure, pronated dynamic foot function, and increased plantar pressure during walking[11)]. In addition, physical inactivity leads to poor muscle strength in individuals with obesity. A cross-sectional study indicated that adults with obesity generally had decreased physical activity (PA) and impaired knee strength compared to healthy counterparts[12)].

PA may be an effective measure to reduce weight, enhance lower extremity function, and improve QoL in individuals with obesity[13)]. However, to our knowledge, no systematic study has examined the effects of increasing PA on foot structure

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and function in adults with obesity. Therefore, the purpose of this study was to examine the effects of increasing PA on foot structure and ankle muscle strength in adults with obesity and to verify whether the rate of changes in foot structure is related to that of changes in ankle muscle strength. The results may be useful to better understand the association of PA with foot structure and function and to clarify whether PA is an effective approach to improve foot structure and increase ankle muscle strength in individuals with obesity.

SUBJECTS AND METHODS

Twenty-seven participants (gender, 15 males and 12 females; age, 53.07 ± 6.17 years; height, 166.75 ± 9.89 cm; weight, 75.35 ± 13.83 kg) were selected for this study. They met the following inclusion criteria: age between 30 and 64 years; a body mass index (BMI) exceeding 25.0 kg/m^2 (on the basis of domestic obesity guidelines)[14]; a stable weight for at least 3 months; no habit of regular exercise; and no current or previous lower extremity disorders or other neuromuscular or musculoskeletal disorders that affect the foot and ankle function. This study was conducted in accordance with the Helsinki Declaration, and the protocol was approved by the Ethics Committee of University of Tsukuba, Japan.

For 12 weeks, participants came to the University of Tsukuba three times a week for a 90-min PA session of increasing intensity. Each PA session comprised 10 min of warming up and stretching, 45 min of brisk walking and jogging, and 5 min of cooling down and stretching. In the first 4 weeks, the exercise intensity was set at 50–60% of the maximum heart rate, and it was gradually increased thereafter. In the last 4 weeks, the participants were finally exercising at 60–70% of the maximum heart rate. On rainy days, indoor exercise was performed using stationary cycling or stair stepping. In addition to the PA sessions at the university, participants were also encouraged to perform their preferred type of PA at home or work to the greatest possible extent.

PA was monitored using an accelerometer (HJA-350IT; Omron Healthcare, Kyoto, Japan), which was attached to the waist for over 7 consecutive days (including weekends), except when the participants slept or performed PAs in water. Depending on the intensity, PA was classified as low (LPA, 1.5–2.9 metabolic equivalents (METs)), moderate (MPA, 3.0–5.9 METs), vigorous (VPA, >6.0 METs), and moderate and vigorous (MVPA, >3.0 METs).

A three-dimensional laser foot scanner (FSN-2100; Dream GP, Osaka, Japan) was used to measure foot structure information. Among the many indicators of foot structure, the arch height index and arch stiffness index are especially useful for evaluating the arch and foot. The arch height index is defined as the instep height divided by the length of the ball of the foot[15]. The arch stiffness index, which is a measure of arch flexibility, is defined as the ratio between the standing arch height index and the sitting arch height index[16]. An arch height index close to 0 indicates a lower arch, and an arch stiffness index close to 1 indicates a stiffer arch.

A Biodex System 4 Dynamometer (Shirley, NY, USA) was used to assess ankle muscle strength at an angular velocity of 30°/s. In keeping with the manufacturer's recommendations, the dynamometer orientation, tilt, and seat orientation were set at 90°, 0°, and 90°, respectively, during the plantar flexion to dorsiflexion test and at 0°, 70°, and 90°, respectively, during the eversion to inversion test. After the participants performed submaximal repetitions to familiarize themselves with the test procedures, they performed a test comprising 3 maximal repetitions, both plantar to dorsiflexion and eversion to inversion. During ankle muscle strength evaluation, the greatest muscle force output at any moment during the repetitions was recorded as the peak torque (Nm) and peak torque per kilogram body weight (Nm/kg*100%).

In consideration of the assumption of independence in the statistical analysis, only data pertaining to the structure and ankle muscle strength of the right foot were entered in the main analyses. Because the Shapiro-Wilk test showed that the data of foot structure and ankle muscle strength were not normally distributed, the Wilcoxon signed rank test was used to compare differences in these data before and after the PA intervention. Then, partial correlations adjusted for age were used to determine the relationship between the rates of changes in foot structure and ankle muscle strength with increasing PA. All data were analyzed using SPSS version 22.0, and $p<0.05$ was considered significant.

RESULTS

Compared to their baseline values, MPA, VPA, and MVPA increased significantly ($p<0.01$). Foot structure indicators such as the foot length, rearfoot width, length of the ball of the foot, and instep girth reduced remarkably ($p<0.05$), while the instep height, arch height index and arch stiffness index increased significantly ($p<0.05$) (Table 1). Moreover, the plantar flexion peak torque increased significantly ($p<0.05$), although the dorsiflexion, eversion, and inversion peak torques remained unchanged. In contrast, the values of plantar flexion, dorsiflexion, and eversion peak torque per kilogram body weight increased remarkably ($p<0.05$) (Table 2). Additionally, neither the rate of change in the arch height index nor that in the arch stiffness index was significantly associated with the rate of changes in ankle muscle strength (Table 3).

DISCUSSION

The main findings of this study were that the feet became shorter (the foot length and length of the ball of the foot decreased), thinner (the instep girth and rearfoot width decreased), higher (the instep height and arch height index increased),

Table 1. Foot structure characteristics before and after intervention (n=27)

	Before	After
Age (yrs)	53.07 ± 6.17	
Weight (kg)	77.05 ± 14.67	75.35 ± 13.83**
BMI (kg/m^2)	27.42 ± 4.14	26.82 ± 3.89**
Low PA (min/d)	244.77 ± 69.37	247.95 ± 67.01
Moderate PA (min/d)	44.79 ± 20.90	62.77 ± 21.51**
Vigorous PA (min/d)	1.55 ± 3.37	14.29 ± 10.35**
Moderate and vigorous PA (min/d)	46.34 ± 22.67	77.06 ± 26.08**
Foot length (mm)	247.43 ± 14.21	246.53 ± 14.26*
Forefoot girth (mm)	237.36 ± 15.78	237.62 ± 14.29
Forefoot width (mm)	97.25 ± 6.48	97.46 ± 6.22
Rearfoot width (mm)	63.8 ± 6.02	63.08 ± 5.59**
Ball of foot length (mm)	177.8 ± 10.31	177.23 ± 10.41*
Lateral ball of foot length (mm)	155.57 ± 9.02	155.08 ± 9.11
Instep height (mm)	60.72 ± 6.18	61.52 ± 6.42*
Instep girth (mm)	243.31 ± 18.63	241.73 ± 18.05*
First toe angle (degree)	10.05 ± 4.37	10.56 ± 4.85
Little toe angle (degree)	13.87 ± 5.14	13.67 ± 5.88
Arch height index (ratio)	0.342 ± 0.029	0.347 ± 0.031*
Arch stiffness index (ratio)	0.906 ± 0.039	0.928 ± 0.032**

PA: physical activity. *p<0.05, **p<0.01

Table 2. Ankle muscle strength before and after intervention

	Before	After
Peak torque (Nm)		
Plantar flexion (Nm)	60.03 ± 31.71	68.24 ± 25.65*
Dorsiflexion (Nm)	24.24 ± 9.58	25.20 ± 10.59
Eversion (Nm)	16.96 ± 5.03	18.00 ± 5.20
Inversion (Nm)	23.02 ± 9.05	22.92 ± 7.75
Peak torque per body weight (%)		
Plantar flexion (%)	83.80 ± 37.72	98.80 ± 30.38*
Dorsiflexion (%)	33.41 ± 9.19	35.62 ± 11.29*
Eversion (%)	23.93 ± 5.61	26.21 ± 6.63*
Inversion (%)	32.34 ± 9.96	33.47 ± 9.97

*p<0.05

Table 3. Correlation between the rate of changes in the arch height index and arch stiffness index and that of changes in the ankle peak torque per kilogram body weight adjusted for age

Δ Arch height index	Δ Plantar flexion	Δ Dorsiflexion	Δ Eversion	Δ Inversion
r	−0.05	0.07	−0.17	−0.09
Δ Arch stiffness index	Δ Plantar flexion	Δ Dorsiflexion	Δ Eversion	Δ Inversion
r	0.02	0.03	−0.06	0.28

and stiffer (the arch stiffness index increased) with increasing PA. Further, the peak torque per kilogram body weight of all ankle muscles, except the invertor, increased with the increasing PA intervention. Additionally, it seems that the changes in foot structure and ankle muscle strength associated with increasing PA were independent of each other.

The presence of a lower arch is reportedly related to increased body weight or BMI[17, 18]. It is known that obesity is always accompanied by decreased PA. However, increasing PA may have a positive impact on arch structure and function in individuals with obesity. One study[19] found that PA increased the arch height in school-aged children with obesity, but this observation may have been confounded by the regular growth and development of children. The findings of the present study further proved that increasing PA alone significantly enhanced arch height. Additionally, arch stiffness, whose value reduces in the case of soft-tissue injuries of the foot and ankle[20], was also found to improve remarkably after PA intervention. On the basis of these results, it is suggested that the structure of the arch has reversible characteristics, and low PA may be one of the important reasons underlying the detrimental changes in arch structure and function in individuals with obesity.

On the other hand, a cross-sectional study reported that children with obesity generally have fatter feet than age- and gender-matched children with normal body weight[21]. Another study investigated the association of body weight with foot parameters in 872 adults and found that BMI is related positively to foot indicators such as height, width, and girth[22]. In the present study, as expected, foot indicators such as the rearfoot width, instep height, and girth reduced significantly with increasing PA in adults with obesity. Taken together, the results indicate that increasing PA can make the feet of individuals with obesity thinner. Therefore, increasing PA should be recommended to such individuals for improving arch and foot structure.

It is widely accepted that obesity is associated with decreased muscle strength[12, 23]. With regard to the effects of obesity on ankle muscle strength, a previous study showed that compared to individuals of normal weight, adults with obesity are more likely to have reduced ankle muscle strength, which is related to declined functioning of the ankle and foot, instability of the ankle joint[24], and even sprains[25]. However, the present study found that almost all indicators of ankle muscle strength adjusted for body weight increased with the increasing PA intervention. This suggests that the improved ankle muscle strength induced by increasing PA may improve the function of ankle and foot in individuals with obesity.

This study has some limitations that should be acknowledged. Although foot structure characteristics were measured, the pathological bone deformation of flat foot was not investigated. Therefore, it was not clear whether increasing PA can improve arch height in individuals with flat foot. In addition, since only middle-aged adults (30–64 years) were involved in the study, it is not known whether the research findings are equally applicable to children and older adults. Further studies need to be conducted to examine these aspects.

In conclusion, the results of the present study indicate that with increasing PA, the feet become thinner and arches become higher and stiffer; further, ankle muscle strength increased. Additionally, the changes in arch height and arch stiffness are not associated with changes in ankle muscle strength. Increasing PA may be one possible approach to improve foot structure and function in individuals with obesity.

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