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Original Article

Plantar pressure differences among adults with mild flexible flatfoot, severe flexible flatfoot and normal foot when walking on level surface, walking upstairs and downstairs

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Abstract. [Purpose] This study observed the plantar pressure between flexible flatfoot and normal foot on different walking conditions to find out if flexible flatfoot needs the treatment and how the plantar pressure change while walking upstairs and downstairs. [Subjects and Methods] Fifteen adults with mild flexible flatfoot, fifteen adults with severe flexible flatfoot and fifteen adults with normal foot were examined while walking on a level surface, walking up and down 10 cm and 20 cm stairs. The max force and the arch index were acquired using the RSscan system. The repeated measures ANOVA was performed to analyze the data. [Results] Compared with normal foot, both max force and arch index of severe flatfoot were significantly increased on different walking conditions. When walking down 10 cm and 20 cm stairs, the plantar data of both normal foot and flatfoot were significantly increased. [Conclusion] The plantar pressure of severe flexible flatfoot were significantly larger than that of normal foot on different walking conditions. In addition, the arches of both normal foot and flatfoot were obviously deformed when walking downstairs. It is therefore necessary to be treated for severe flexible flatfoot to prevent further deformation.

Key words: Flexible flatfoot, Plantar pressure

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INTRODUCTION

Flexible flatfoot is a common disease in lower limb deformities[1)] that is characterized by the low medial longitudinal arch[2)]. It is the deformed structure of the foot bones[3)] that would cause calcaneal eversion, talar adduction with plantarflexion and dorsolateral forefoot subluxation. The plantar pressure distribution and the gait will be changed by the deformity of foot structure over the time[4)], potentially influencing the life of the patients.

There are two kinds of flatfoot: rigid flatfoot and flexible flatfoot[5)]. Regarding the former, the arch of the foot was always missing either in the weight-bearing position or non-weight-bearing position[6)] and it needs operation to restore the missing arch[7)]. As far as concerned the latter, the arch was missing only in the weight-bearing position, while in non-weight-bearing position, the arch is as the same as that of normal foot[8)]. Due to the arch's flexibility, the methods of the treatment and whether the flexible flatfoot needs the treatment, have always been controversial[9)].

Flexible flatfoot can be further divided into mild flexible flatfoot and severe flexible flatfoot[10)]. So far, previous studies did

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Table 1. Max force of 3 groups

Left foot	Group	Group	Mean difference	Std.error	Sig.(a)	95% confidence interval for difference(2)	
						Lower bound	Upper bound
	Mild	Mild					
		Severe	−90.5(*)	10.5	0.0	−111.6	−69.3
		Normal	7.7	10.5	0.5	−13.5	28.8
	Severe	Mild	90.5(*)	10.5	0.0	69.3	111.6
		Severe					
		Normal	98.1(*)	10.5	0.0	77.0	119.3
	Normal	Mild	−7.7	10.5	0.5	−28.8	13.5
		Severe	−98.1(*)	10.5	0.0	−119.3	−77.0
		Normal					
Right foot	Group	Group	Mean difference	Std.error	Sig.(a)	95% confidence interval for difference(2)	
						Lower bound	Upper bound
	Mild	Mild					
		Severe	−97.2(*)	9.3	0.0	−115.9	−78.5
		Normal	10.4	9.3	0.3	−8.4	29.1
	Severe	Mild	97.2(*)	9.3	0.0	78.5	115.9
		Severe					
		Normal	107.6(*)	9.3	0.0	88.8	126.3
	Normal	Mild	−10.4	9.3	0.3	−29.1	8.4
		Severe	−107.6(*)	9.3	0.0	−126.3	−88.8
		Normal					

Based on estimated marginal means.
*The mean difference is significant at the 0.05 level.
Mild: mild flexible flatfoot; Severe: severe flexible flatfoot; Normal: normal foot

not observe the plantar pressure of both kinds respectively and they had only focused on the plantar pressure of walking on the level surface[11, 12]. However, the differences between mild flexible flatfoot and severe flexible flatfoot, and how the plantar pressure changes while walking upstairs or downstairs has not been studied.

In this study, we examined the plantar pressure of mid flexible flatfoot, severe flexible flatfoot and normal foot while walking on a level surface, walking up and down 10 cm and 20 cm stairs to estimate how plantar pressure changed and further to find out if flexible flatfoot needs the treatment.

SUBJECTS AND METHODS

The study protocol was approved by the Institutional Review Board of The First Affiliate Hospital of Xi'an Jiaotong University. All the participants signed the written informed consent prior to the study participation.

Fifteen college students with mild flexible flatfoot, fifteen college students with severe flexible flatfoot and fifteen college students with normal foot were subjected to collecting the footprints by RSscan force plate. All the subjects were female students and there was no significant difference between flatfoot and normal foot in age, height, weight and foot length. None of the participants had suffered from any lower limb diseases in the past 6 months. For the normal foot, the arch was always present either in weight-bearing position or non-weight-bearing position. The footprint ratio of solid and hollow area is 1/2. For the flatfoot, the arch was present only in non-weight-bearing position and it was flattened in weight-bearing position. For mild flexible flatfoot, the footprint ratio of solid and hollow area is more than1/1 and less than 2/1, for severe flexible flatfoot, the ratio is more than 2/1.

Before the measurement, all the subjects need to take off their shoes, wear the unified socks and do the walking exercises at the speed of one step per second. Then the subjects were firstly told to walk on the level RSscan force plate; then, they were instructed to walk up or walk down 10 cm or 20 cm stairs on the instrument respectively. The max force and arch index of the foot were recorded by the RSscan system on those walking conditions. To ensure the accuracy, data were measured 3 times and an average was obtained. At last, the repeated measures ANOVA with a level of significance of $p<0.05$ was performed using spss 13.0. The 95% confidence intervals (CIs) ($p<0.05$) was considered statistically significant.

An RSscan force plate (RS-footscan 7 USB2 gait) with an area of 40 × 50 cm, including 4 sensors in each square centime-

Table 2. Arch index of 3 groups

Left foot	Group	Group	Mean difference	Std.error	Sig.(a)	95% confidence interval for difference(2)	
						Lower bound	Upper bound
	Mild	Mild					
		Severe	−3.93(*)	0.39	0.00	−4.73	−3.14
		Normal	0.79	0.39	0.05	0.00	1.59
	Severe	Mild	3.93(*)	0.39	0.00	3.14	4.73
		Severe					
		Normal	4.73(*)	0.39	0.00	3.93	5.52
	Normal	Mild	−0.79	0.39	0.05	−1.59	0.00
		Severe	−4.73(*)	0.39	0.00	−5.52	−3.93
		Normal					
Right foot	Group	Group	Mean difference	Std.error	Sig.(a)	95% confidence interval for difference(2)	
						Lower bound	Upper bound
	Mild	Mild					
		Severe	−4.46(*)	0.28	0.00	−5.02	−3.91
		Normal	0.39	0.28	0.17	−0.17	0.95
	Severe	Mild	4.46(*)	0.28	0.00	3.91	5.02
		Severe					
		Normal	4.85(*)	0.28	0.00	4.29	5.41
	Normal	Mild	−0.39	0.28	0.17	−0.95	0.17
		Severe	−4.85(*)	0.28	0.00	−5.41	−4.29
		Normal					

Based on estimated marginal means.
*The mean difference is significant at the 0.05 level.
Mild: mild flexible flatfoot; Severe: severe flexible flatfoot; Normal: normal foot

ter, was used to measure the dynamic data of max force and arch index on different walking conditions. When the subject was walking on the force plate, the foot was divided into 10 parts automatically including toe 1, toe 2–5, first metatarsal, second metatarsal, third metatarsal, forth metatarsal, fifth metatarsal, mid foot, medial heel and lateral heel.

In addition, there is a main difference of plantar pressure in midfoot region between a normal foot and a flatfoot. For the normal foot, the main load-bearing regions include the metatarsal area and the heel area, but for the flatfoot, it not only includes the metatarsal and heel areas, but also includes the midfoot[13]. In other words, it is the pressure of midfoot that differs the flatfoot from normal foot. Therefore, we only focused on the data of mid foot.

This study measured two kinds of dynamic data, max force and arch index. With the progression of the disease, the arch will become flat further result in an increase of max force[14] and arch index[15]. Max force, with the unit of Newton, is defined as the maximum of plantar pressure of one part of the foot[16]. Arch index, a proportion of the midfoot area and the whole foot area, is useful in determining the prevalence of flatfoot and possibly predicting pathologic foot conditions[17].

We focused on the max force of mid foot and the arch index. All the data were divided into 3 groups: mild flexible flatfoot, severe flexible flatfoot and normal foot. Each group was further divided into 5 conditions: walking on a level surface, walking up 10 cm stairs, walking up 20 cm stairs, walking down 10 cm stairs, walking down 20 cm stairs.

RESULTS

The significant differences were found in max force and arch index between severe flexible flatfoot and normal foot ($p<0.01$), and between severe flexible flatfoot and mild flexible flatfoot ($p<0.01$). While there was no significant difference between mild flexible flatfoot and normal foot in both data ($p>0.05$) (Tables 1 and 2).

In addition, there was no intersection of the 95% CIs of both data between severe flexible flatfoot and normal foot on 5 different walking conditions. Furthermore, no intersection of arch index could be found between mild flexible flatfoot and normal foot when walking downstairs. However, there was an intersection between mild flexible flatfoot and normal foot in both data when walking on the level surface and walking upstairs (Tables 3 and 4).

Furthermore, the 95% CIs of downstairs of both data did not intersect with any other walking conditions not only in flatfoot but also in normal foot (Tables 3 and 4).

Table 3. Max force of 5 walking conditions

Left foot	Group	Conditions	Mean difference	Std.error	95% confidence interval for difference(2)	
					Lower bound	Upper bound
	Mild	Level	191.9	5.7	179.6	202.4
		Up 10 cm stairs	182.6	6.2	170.2	195.0
		Up 20 cm stairs	182.7	6.0	170.5	194.9
		Down 10 cm stairs	236.6	9.5	217.4	255.8
		Down 20 cm stairs	285.9	12.7	260.3	311.5
	Severe	Level	285.2	5.7	273.8	296.7
		Up 10 cm stairs	274.0	6.2	261.6	286.4
		Up 20 cm stairs	268.7	6.0	256.5	280.9
		Down 10 cm stairs	330.0	9.5	310.8	349.2
		Down 20 cm stairs	373.2	12.7	347.6	398.8
	Normal	Level	188.7	5.7	177.2	200.1
		Up 10 cm stairs	176.8	6.2	164.4	189.2
		Up 20 cm stairs	178.4	6.0	166.2	190.6
		Down 10 cm stairs	230.8	9.5	211.6	250.0
		Down 20 cm stairs	265.9	12.7	240.3	291.5
Right foot	Group	Conditions	Mean difference	Std.error	95% confidence interval for difference(2)	
					Lower bound	Upper bound
	Mild	Level	192.4	5.6	181.1	203.8
		Up 10 cm stairs	184.8	5.8	173.1	196.6
		Up 20 cm stairs	183.0	5.7	171.5	194.5
		Down 10 cm stairs	242.0	8.1	225.6	258.3
		Down 20 cm stairs	293.6	10.5	272.3	314.8
	Severe	Level	291.7	5.6	280.4	303.1
		Up 10 cm stairs	282.8	5.8	271.1	294.6
		Up 20 cm stairs	280.3	5.7	268.8	291.9
		Down 10 cm stairs	337.1	8.1	320.7	353.4
		Down 20 cm stairs	389.7	10.5	368.5	411.0
	Normal	Level	187.7	5.6	176.3	199.0
		Up 10 cm stairs	177.9	5.8	166.2	189.7
		Up 20 cm stairs	179.5	5.7	168.0	191.0
		Down 10 cm stairs	232.7	8.1	216.4	249.1
		Down 20 cm stairs	266.1	10.5	244.8	287.3

Mild: mild flexible flatfoot; Severe: severe flexible flatfoot; Normal: normal foot

The results implied that the plantar pressure of severe flexible flatfoot were significantly larger than that of normal foot. Although there was no difference between mild flexible flatfoot and normal foot when walking on the level surface and walking upstairs, the arch index of mild flexible flatfoot did differ from the normal foot when walking downstairs. Additionally, the arches of both normal foot and flatfoot were obviously deformed when walking down 10 cm and 20 cm stairs.

DISCUSSION

The results showed that the max force and arch index of severe flexible flatfoot were significantly increased, which was in accordance with previous studies[18–21].

As the foot arch of severe flexible flatfoot was not steady enough, the height of the foot arch would be lower in load-bearing-position[22] and the structure of the foot bones was deformed[23], which increased the max force and arch index.

Previous study had already estimated the plantar pressure of flatfoot when walking on a level surface[18–21]. However, it has not been examined how the plantar pressure changes when walking upstairs and downstairs. In this study, the max force and arch index of severe flexible flatfoot were significantly larger than that of normal foot not only when walking on a level

Table 4. Arch index of 5 walking conditions

Left foot	Group	Conditions	Mean difference	Std.error	95% confidence interval for difference(2)	
					Lower bound	Upper bound
	Mild	Level	27.0	0.3	26.5	27.6
		Up 10 cm stairs	27.0	0.3	26.3	27.6
		Up 20 cm stairs	26.8	0.3	26.2	27.5
		Down 10 cm stairs	30.4	0.3	29.8	31.0
		Down 20 cm stairs	32.1	0.4	31.3	32.8
	Severe	Level	31.5	0.3	30.9	32.1
		Up 10 cm stairs	31.2	0.3	30.5	31.8
		Up 20 cm stairs	31.2	0.3	30.5	31.9
		Down 10 cm stairs	33.3	0.3	32.7	33.9
		Down 20 cm stairs	35.8	0.4	35.0	36.5
	Normal	Level	26.8	0.3	26.2	27.4
		Up 10 cm stairs	26.5	0.3	25.8	27.1
		Up 20 cm stairs	26.4	0.3	25.8	27.1
		Down 10 cm stairs	29.2	0.3	28.6	29.7
		Down 20 cm stairs	30.5	0.4	29.7	31.2
Right foot	Group	Conditions	Mean difference	Std.error	95% confidence interval for difference(2)	
					Lower bound	Upper bound
	Mild	Level	26.7	0.2	26.2	27.2
		Up 10 cm stairs	26.6	0.3	26.1	27.1
		Up 20 cm stairs	26.5	0.3	26.0	27.0
		Down 10 cm stairs	30.9	0.2	30.5	31.5
		Down 20 cm stairs	32.0	0.2	31.6	32.5
	Severe	Level	31.9	0.2	31.5	32.4
		Up 10 cm stairs	31.3	0.3	30.8	31.8
		Up 20 cm stairs	31.2	0.3	30.7	31.7
		Down 10 cm stairs	34.5	0.2	34.1	34.9
		Down 20 cm stairs	36.2	0.2	35.7	36.6
	Normal	Level	26.7	0.2	26.2	27.2
		Up 10 cm stairs	26.4	0.3	25.9	26.9
		Up 20 cm stairs	26.4	0.3	25.9	26.9
		Down 10 cm stairs	29.9	0.2	29.5	30.4
		Down 20 cm stairs	31.3	0.2	30.9	31.8

Mild: mild flexible flatfoot; Severe: severe flexible flatfoot; Normal: normal foot

surface, but also when walking upstairs and downstairs. This result indicated that the structure of severe flexible flatfoot was deformed badly[24] due to the instability of its foot arch[25].

The largest values of max force and arch index were in walking down 20 cm stairs, the second largest ones were in walking down 10 cm stairs, which may be due to the fact that the plantar pressure will be influenced not only by the body weight but also by the acceleration of gravity when a person walks downstairs[26]. Therefore, with the increase of the gravity, the plantar pressure would increase as well.

According to this study, the data of both normal foot and flexible flatfoot were obviously larger when walking downstairs, illustrating that the arches of both normal foot and flatfoot were apparently deformed whenever walking down 10 cm stairs or 20 cm stairs. As the arch of normal foot needs certain elasticity to protect plantar vessels and nerves from compression[27], the arch could be influenced by the impact of downstairs. The arch of flatfoot were more easily influenced due to the weak stability[28]. In other words, it is harmful to the foot arch when walking downstairs. This is important because people prefer to taking a lift when walking upstairs, as for downstairs, as long as the floor is not much high, they would rather walk downstairs than wait for the lift.

The plantar pressure of severe flexible flatfoot were significantly larger than that of normal foot not only when walking on

a level surface but also when walking upstairs and downstairs. Additionally, the arch of both normal foot and flexible flatfoot were deformed whenever walking down 10 cm or 20 cm stairs. Therefore, adults with severe flexible flatfoot may need treatment to prevent further deformation. However, further studies are necessary to analyze the plantar pressure of adults with flatfoot in other areas in the future.

Conflict of interest

The authors declare that there have no conflicts of interest.

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