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Original Article

Effect of toe contact condition during forward stepping on the ground reaction forces during turning movement

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Abstract. [Purpose] This study aimed to classify the plantar contact condition during forward stepping by focusing on the medial and lateral toes and to elucidate the relationship between the classification and turning movement. [Participants and Methods] The participants were 38 females. The plantar contact condition during forward stepping was evaluated for all participants, and the results were used for the group classification. In all the classified participants, the ground reaction force (GRF) during turning movement was measured. [Results] At sidestep (SS) and cross-step (CS), the peak medial-lateral GRF was significantly smaller in the medial floating toe (MFT) group than in the contact toe (CT) group. At SS, the peak times of the medial-lateral GRF in the MFT and lateral floating toe groups were significantly lesser than those in the CT group. At CS, the push-off peak time of the anterior-posterior GRF was significantly lesser in the MFT group than in the CT group. [Conclusion] The results of this study confirmed that each group classified according to the floating toe classification during forward stepping has different characteristics with respect to the ground reaction force during the turning movement, particularly the medial-lateral ground reaction force and its peak time.
Key words: Floating toe, Ground reaction force, Turning movement

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INTRODUCTION

The toes are located in front of the feet, therefore they are thought to be involved in the forward movement of the center of gravity (COG) and posture control at that position, and these also play an important role in dynamic situations[1, 2)].

The existence of "floating toe" where toe do not contact the surface is reported[3)]. Previous studies used floating toe evaluation at resting position; however, the usefulness of the evaluation in dynamic scenes has not been confirmed. The function of the toes is exerted more in the dynamic scene[4)], and we think that it must be evaluated and classified in the dynamic scene to clarify the characteristics of floating toes.

Turning is one of the fundamental components of mobility[5)], and the decline in turning movement ability is also related to falls[6)]. The turning movement is thought to require the movement of the COG and posture control, so that it is important to demonstrate the toe function. However no study has been conducted on the relationship between floating toe and turning movement. The purpose of this study was to evaluate and classify the plantar contact condition at the forward step by focusing on the medial and the lateral toes, and to clarify the relationship between the classification and the turning movement.

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PARTICIPANTS AND METHODS

The participants consisted of 38 healthy adult female (76 feet; mean age, 25.0 ± 2.1 years; height, 159.1 ± 5.0 cm; weight, 52.5 ± 5.5 kg). Furthermore, they had no lower extremity pathology and foot deformation that may have interfered with exercise within the past 6 months. In this study, we targeted only female, among whom the prevalence of foot deformation such as hallux valgus is higher than among men[7]. Ethical approval for this study was obtained from the ethics review committee of Gunma University (approval code: 2018-033). This study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all the participants, whose rights were protected.

In this study, evaluation of the plantar contact condition at the forward step was performed for all the participants, and group classification was performed based on the results. Especially, we classified based on the plantar contact condition of medial and lateral toe in forward step. After that, we measured the ground reaction force (GRF) and the peak time during turning movement for the classified participants.

We captured a video of the plantar contact condition with a self-built pedoscope (width: 50 cm, depth: 50 cm, height: 50 cm) and step platform (width: 120 cm, depth: 60 cm, height: 50 cm). A pedoscope is a device that captures the plantar contact condition by using a digital camera (EX-FC150, CASIO COMPUTER Co. Ltd.), with the participant standing on a tempered glass stage (Fig. 1)[8]. We evaluated the plantar contact condition by making the room as dark as possible, the participants could see the target point. Capturing was started when the posture stabilized with the feet 5 cm apart and capturing was finished when the feet were aligned with the forward step platform.

In the turning movement, the step distance was set as the trochanter malleolar distance. The target point was shown on the step platform. We conducted the measurements after having the participant practice adequately. Measurements were taken on both feet. The captured video was analyzed using the video analysis software Kinovea (0.8.25, Kinovea). First, we used the plantar contact condition at the resting stance. The anterior part from the anterior extremity of the medial longitudinal arch (MLA) was defined as the forefoot part, the part between the anterior and posterior extremities of the MLA was defined as the midfoot part, and the posterior part from the anterior extremity of the MLA was defined as the hindfoot part.

The supporting leg in the forward step was analyzed. The moment when the midfoot and hindfoot separated and the forefoot attained contact was taken as the timing of analysis. At this timing, we defined as the contact toe (CT) group the feet with all toes in contact or whose floating toes were improved by toe-off. Likewise, at this timing, the feet whose big toes and second toes were clearly in partial and unclear contact and showed no improvement by toe-off were defined medial floating-toe (MFT) group. Furthermore, the feet whose the fifth toes were clearly in partial and unclear contact and showed no improvement by toe-off were defined as the lateral floating-toe (LFT) group. In the case where the floating toes were compoundly present on the medial and fifth toes, the influence of the medial toe is prioritized and included in the MFT group. The contact clarity or unclarity was judged by comparing with the contact condition of other parts with reference to a previous research[8]. Unclear videos and included floating toes among the excluded target toes were excluded from the classification. Unclear videos or floating toes among the toes other than the target toes were excluded from the classification.

The GRF measurement in the turning movement was performed using the Force Platforms (MG-2090, ANIMA) at a frequency of 100 Hz. The starting position in this measurement was set at 50% of the trochanter malleolar distance from the force platform. At the cue of the examiner, the participant performed a step forward and grounded the support leg to the force platform, and stepped forward the opposite leg in the direction of 30°. The turning movement has 2 kinds. The steps in the direction of the swing leg 30° on the same side and the step toward 30° on the opposite side were defined as side step (SS) and cross step (CS), respectively. In addition each step distance was defined as 75% of the trochanter malleolar distance. The step direction and distance were specified by the tape affixed to the floor. We instructed the participants to perform the turning movement at the optimum speed and sufficient practice so that they could be grounded at the prescribed placement. Furthermore, we instructed them not to pivot the supporting leg in SS and CS. The measurement was made on both feet, and the step sequences were randomly decided. Measurement was performed twice, and the second measurement value was adopted.

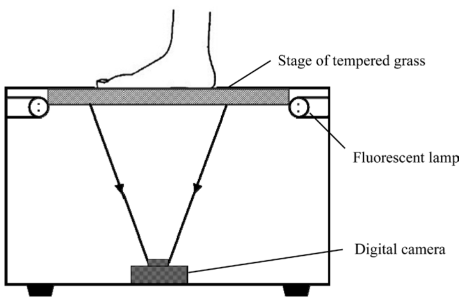

Fig. 1. Shooting situation in self-build Pedoscope.

For the GRF, the vertical component force (z), anterior-posterior component force (y), and medial-lateral component force (x) of the supporting leg were calculated. The vertical GRF has two peak values the first peak (Fz1) corresponding to the heel contact and the second peak (Fz2) corresponding to the push-off. The vertical GRF is plus for the upward direction and minus for the downward direction. The anterior-posterior GRF has two peak values the first peak value (Fy1) corresponding to the braking force and the second peak value (Fy2) corresponding to the accelerating force. The anterior-posterior GRF is plus for the anterior direction and minus for the posterior direction. For the medial-lateral GRF, a peak value (Fx) corresponding to push-off phase was adopted. The medial-lateral GRF is plus for the medial direction and minus for the lateral direction. The GRF was normalized by body weight. In addition, the time to reach each peak value (Fz1, Fz2, Fy1, Fy2 and Fx) was normalized by each stance phase time, and the values were set as Fz1T, Fz2T, Fy1T, Fy2T and FxT.

Statistical analysis was performed using SPSS version 25.0 for Windows. For the classification based on the plantar contact condition at the forward step, the intra-rater reliability was calculated. Measurement was made three times, first time and 1 hour and 1 week after first time, and examined using intraclass correlation coefficient (ICC) using three measured values. Furthermore, the GRF measurement results among the 3 groups of the CT, MFT, and LFT groups were compared. The Shapiro Wilk test was used to assess the normality of data. As a result, as normality was not recognized, the Kruskal Wallis test was performed, and multiple comparison test was performed for items for which significant difference was recognized. The significant level of the analyses was set at 5%.

RESULTS

Two feet with unclear video or floating toe identified from among the toes other than the target toe were excluded. The target of this study were 74 feet. As a result of the floating toe classification at the forward step, the CT group included 38 feet (mean age, 24.6 ± 2.1 years; height, 158.4 ± 4.1 cm; body weight, 41.0 ± 5.5 kg) and the MFT group included 13 feet height, 160.5 ± 3.5 cm; body weight, 55.3 ± 4.5 kg), and the LFT group included 23 feet (mean age, 25.5 ± 1.8 years; height, 159.4 ± 6.7 cm; body weight, 53.0 ± 5.0 kg). The ICC (1.1) for the floating toe classification at the forward step was 0.882 and confidence interval is 0.833–0.920.

The results of the GRF during turning movement in each group are shown in Tables 1 and 2. At the SS, Fx in the MFT group (14.5 ± 1.7%) was significantly smaller than that in the CT group (16.3 ± 2.5%). Furthermore, FxT in the MFT (81.8 ± 2.6%) and LFT groups (82.1 ± 3.7%) were significantly smaller than that in the CT group (84.0 ± 1.9%). At the CS, Fx in the MFT group (−14.2 ± 2.3%) was significantly smaller than that in the CT group (−16.1 ± 2.1%). Furthermore, Fy2T in the MFT group (87.7 ± 1.6%) was significantly smaller than that in the CT group (89.2 ± 1.6%). No significant difference was observed in the other items.

DISCUSSION

In this study, floating toe classification at the forward step was performed on the basis of the plantar contact evaluation. As a result, the medial and lateral toes in the forward step were found to have partial or unclear contact. The ICC (1.1) of this classification is 0.882 and has an almost perfect reliability according to the Landis standard[9].

The occurrence of floating toes has been reported in subjects with a wide range of age from children to adults[3, 10, 11],

Table 1. The result of peak ground reaction forces and peak time during sidestep in each group (%)

		CT group n=38	MFT group n=13	LFT group n=23
GRF	Fz1	103.7 ± 5.3	101.5 ± 8.0	103.2 ± 6.5
	Fz2	117.2 ± 12.3	113.5 ± 7.4	115.1 ± 8.4
	Fy1	−5.5 ± 1.6	−5.7 ± 1.5	−5.4 ± 1.2
	Fy2	18.2 ± 3.0	17.1 ± 2.3	17.1 ± 2.9
	Fx	16.3 ± 2.5*	14.5 ± 1.7*	15.5 ± 3.1
Peak time	Fz1T	31.2 ± 3.4	31.6 ± 3.3	31.7 ± 2.8
	Fz2T	79.8 ± 2.8	78.4 ± 2.5	78.2 ± 3.1
	Fy1T	18.4 ± 4.2	20.6 ± 3.8	19.2 ± 4.9
	Fy2T	87.4 ± 4.7	88.0 ± 1.9	88.1 ± 1.1
	FxT	84.0 ± 1.9***	81.8 ± 2.6**	82.1 ± 3.7*

CT: contact toe; MFT: medial floating-toe; LFT: lateral floating-toe; Fz1, Fz2: first and second peak of vertical ground reaction force (GRF); Fy1, Fy2: first and second peak of anterior-posterior GRF; Fx: first peak (push-off) of medial-lateral GRF; Fz1T, Fz2T, Fy1T, Fy2T, FxT: the time to reach each peak value.
Differences were compared multiple comparison test. *$p<0.05$, **$p<0.01$.

Table 2. The result of peak ground reaction forces and peak time during crossstep in each group (%)

		CT group n=38	MFT group n=13	LFT group n=23
GRF	Fz1	105.0 ± 5.9	102.1 ± 7.5	105.2 ± 7.5
	Fz2	113.7 ± 6.1	109.4 ± 8.8	111.0 ± 9.3
	Fy1	−5.3 ± 1.6	−4.9 ± 1.7	−4.8 ± 0.9
	Fy2	17.7 ± 2.2	16.3 ± 2.5	17.2 ± 2.2
	Fx	−16.1 ± 2.1*	−14.2 ± 2.3*	−15.2 ± 3.0
Peak time	Fz1T	33.1 ± 3.2	34.5 ± 3.4	33.4 ± 3.1
	Fz2T	81.0 ± 2.4	78.6 ± 4.9	81.1 ± 2.5
	Fy1T	19.1 ± 5.4	22.6 ± 3.8	19.7 ± 6.1
	Fy2T	89.2 ± 1.6*	87.7 ± 1.6*	88.3 ± 1.6
	FxT	88.3 ± 1.9	87.3 ± 1.6	87.8 ± 1.7

CT: contact toe; MFT: medial floating-toe; LFT: lateral floating-toe; Fz1, Fz2: first and second peak of vertical ground reaction force (GRF); Fy1, Fy2: first and second peak of anterior-posterior GRF; Fx1: first peak (push-off) of medial-lateral GRF; Fz1T, Fz2T, Fy1T, Fy2T, Fx1T: the time to reach each peak value. Differences were compared multiple comparison test. *$p<0.05$.

and reports on the relationship with body functions and abilities in floating toes are also scattered[3, 8]. Most of the floating toe evaluations so far are judged only by the evaluation at the static standing condition and the presence or absence of foot contacts. However, each toe has different functions[1, 2, 4]. In addition, that the center of pressure of the support leg during starting walk movement is in the direction of the first metatarsal area and the big toe in the late stance phase[12]. Even in the forward step, movement of the COG is thought to be toward the forefoot part including the toes, and exercise of the toe functions is important. Therefore, in this research, from the plantar contact evaluation at the forward step, considering the function of each toe, distinguish between the medial toe including the big and second toes and the lateral toe, including the fifth toe, we classified the floating toes classification. As a result, the feet were classified in MFT and LFT groups.

Different characteristics were confirmed among the three groups including the CT group in the GRF during the turning movement. The MFT group had significantly lower Fx values at the SS and CS than the CT group. Even in the LFT group, the Fx values at the SS and CS tended to be slightly lower but no significant difference was confirmed. In the turning movement used in this study, the COG must be moved from the posterior direction to the side, and the push-off to the side plays an important role in this movement. In addition, non-contact of the big toe was reported to be related to the decrease COG movement ability to the front side[2]. Furthermore, the big toe was reported to have greater contribution to walking and dynamic posture control than the other toes, from the magnitude of the load amount and the like[1, 2, 4].

From this, the function of the big toe is considered to be also important in the turning movement. It can be predicted that the toes are contributing to the COG movement and the posture control by being in contact with the ground, and the MFT group is expected to be non-contact and to have dysfunction of the big toe during motion. Thus, the side push-off is considered to have decreased.

In the peak GRF time at the SS, FxT was significantly decreased in the MFT and LFT groups as compared with that in the CT group. Moreover, Fy2T in the MFT group was significantly decreased in the CT group as compared with that in the CT group. This clarified that the timing of the push-off in the floating toe group, especially the MFT group, tends to be faster than that in the CT group. The peak GRF time in this study was normalized by the stance period, so the earlier push-off peak time means that the time from the push-off to the end of the stance phase is long. It is conceivable that the push-off force is not used for moving the COG efficiently because the interval from push-off to the end of the stance phase is long. The toes function by contact with the ground to enhance the propulsive force and posture control during the forward movement of the COG. In this way, the forward transfer ability of the COG is reduced in both floating toe groups, especially the MFT group. It is considered that push-off is performed in a state where the movement of the COG is not sufficiently performed.

In addition, the push-off at the time of CS is performed in the fifth metatarsal, but the function of the big toe is important for forward transfer of the COG. Therefore, Fx decreased in the MFT group even at CS.

From the results of this study, we confirmed that each group classified by the floating toe classification at the forward step has different characteristics with respect to the GRF value of the turning movement, particularly the medial-lateral GRF and its peak time. From this, we can conclude that the floating toe classification focusing on the medial and lateral toes was useful for functional evaluation. However, the limitation of this research is that it only measured GRF; thus, each joint motion, muscle activity, and so on must be analyzed for a more detailed examination. In addition, in the classification used in this study, we classified the state of toe contact by visual examination or as clear or unclear. We think that a quantitative evaluation method must be considered in the future as well.

Conflicts of interest

None.

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