RELATIONSHIP BETWEEN DEFORMATION OF MEDIAL LONGITUDINAL ARCH AND KINETICS OF LOWER LIMBS DURING LONG - DISTANCE RUNNING

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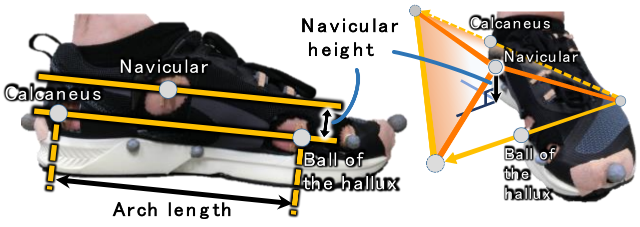
This study clarified the kinetic features of running motion associated with the change of the minimum value of arch height ratio. The subjects were seven male college students who had experience running 10km. By processing the shoes, deformation of the foot arch inside the shoe was measured. Kinematics and kinetics of the running motion were recorded for 5 conditions: In sequence (1) static standing posture, (2) 15 m running on the flat road, (3) 10 km running on the treadmill, (4) 15 m running on the flat road, (5) static standing posture. The results are presented for 3 contrasting subjects. 1) At the timing of the minimum value of arch height ratio (MAHR), inflection points were seen in the trajectory of COP. 2) At the timing of the MAHR, the joint torque around each axis of the ankle joint reached peak values. 3) It is considered that the running form and ankle joint torque at the timing of the MAHR affects the direction of toe off.

KEYWORDS: foot arch, long−distance running, recreational runner, injury prevention.

INTRODUCTION: In recent years, the number of recreational runners has increased remarkably. In many cases, running is stopped due to injuries in most of the recreational runners. The types of arch structure of human foot is classified into three types, medial longitudinal arch, transverse arch, and outer longitudinal arch. Decreasing the height of the medial longitudinal arch leads to a decrease in the shock absorbing ability during walking and running. The medial longitudinal arch height, which is the height from the ground to the navicular bone, is considered to be lowered during a long-distance running, and to be raised up to the original height after a sufficient rest of about 12 hours (Okado, Kobayashi, and Yokoe, 2009). However, the kinetics of running affecting these changes have not been clarified. The purpose of this study was to clarify the kinetic features of running motion associated with the change of the minimum value of arch height ratio.

METHODS: The subjects were seven male college students who had experience of running 10 km distance and were regular runners. The shoes (IGNITE-XT, PUMA) and socks were modified so that reflective markers could be affixed directly on the feet. A flat insole with no irregularities was inserted in the shoes. Figure 1 shows the sequence of the experiment. The trial was done in the sequence of (1) static standing posture, (2) 15 m running on flat road, (3) 10 km running on treadmill (ORK-5000SE, OHTAKE), (4) 15 m running on flat road, and (5) static standing posture. For data collection, three-dimensional coordinates of 51 reflective markers placed on a subject's body were recorded with a motion capture system (VICON MX+, Vicon Motion Systems, 250 Hz). In running on flat road, ground reaction forces in the left support phase was obtained with a force platform (9287, Kistler, 1000Hz). Determination of running speed was set to be a "somewhat hard" load on the Borg scale by running on the treadmill (running speed 12 ± 3 km/h). Figure 2 shows the shoe markers applied to the shoes and definition of the arch height ratio. The position of the reflective markers on the foot was

Figure 1: Experimental order.



$$\text{Arch height ratio}(\%) = \frac{\text{Navicular height [mm]}}{\text{Arch length [mm]}} \times 100$$

Figure 2: Definition of the arch height ratio.

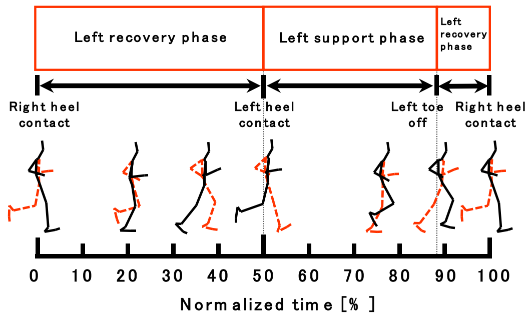


Figure 3: Analysis events and phases.

in accordance with the methods of a previous study (Takashima, 2003). A virtual foot sole was defined based on the three markers on the ball of hallux, ball of little toe, inner side of calcaneus directly attached on the foot. The length of the perpendicular line drawn from the navicular bone to the virtual foot sole was calculated to be the navicular bone height. The distance between the inner side of the calcaneus bone and the ball of the foot was defined as the arch length. The navicular bone height was divided by the arch length to calculate the arch height ratio. The minimum value of the arch height ratio in one cycle of running motion was assumed to be the minimum arch height ratio (MAHR). Based on the reflective markers affixed on the foot, a local coordinate system of the rear foot was constructed from the inner side and outside of the left calcaneus, and the left third metatarsal head. A local coordinate system of the forefoot from the left ball of the hallux and the little toe, and the left toe was constructed. Figure 3 shows analysis events and phases. In flat road running, two cycles of running motion from right heel contact to right heel contact was normalized with time over the force platform, and the average value was treated as a representative value. In treadmill running, running motion was measured every 1 km from the starting point (0 km point) to the 10 km point. Four cycles of running motion, with one cycle from right heel contact to the next right heel contact, were normalized with time and the average value was treated as a representative value. In this study, the left lower limb is taken as the analysis target, and when there is no left / right description, the result of the left lower limb is described.

RESULTS AND DISCUSSION: In the static standing posture before and after long distance running, average 0.58% the arch height ratio decreased for 6 of 7 subjects. This result seems to support the report of a previous study (Nigg, Cole, and Nachbauer, 1993). The change in MAHR before and after long-distance running was classified into three types; increasing (three subjects, typical example: subject B), decreasing (one subject, typical example: subject C), no changes (three subjects, typical example: subject E).

Figure 4 shows the arch height ratio at the 0 km point, the 5 km point, and the 10 km point of the long-distance running of three typical examples. The MAHR of subject B (Figure 4-a) during the support phase was 8.6% at 0 km point, 9.3% at 5 km point, and 9.7% at 10 km point. The MAHR increased at 5 km point and 10 km point compared with 0 km point. The MAHR of subject C (Figure 4-b) during the support phase at the 0 km point was 6.7%, the 5 km point was 6.3%, and the 10 km point was 5.9%. The MAHR decreased at 5 km point and 10 km point compared with 0 km point. The MAHR of subject E (Figure 4-c) during the support phase was 8.5% at 0 km point, 8.3% at 5 km point, and 8.5% at 10 km point. In all subjects, it is considered that the momentary arch stiffness increases at the time of the MAHR. The reason is that the arch was most deformed at the time of MAHR, compared with the arch height at the swinging phase.

Figure 5 shows the trajectory of the centre of pressure (COP) during the support phases of the left leg of the flat road running after a long-distance running. The characteristic events (foot flat, heel off, MAHR, ball of the hallux off, and toe off) are pointed on the trajectory.

The COP of subject B (Figure. 5-a, b) moved to the right from the heel off until the MAHR. After the timing of MAHR, COP moved forward. Subject B was taking off from the little toe. COP was located on the left side of the forefoot after long-distance running compared with before running.

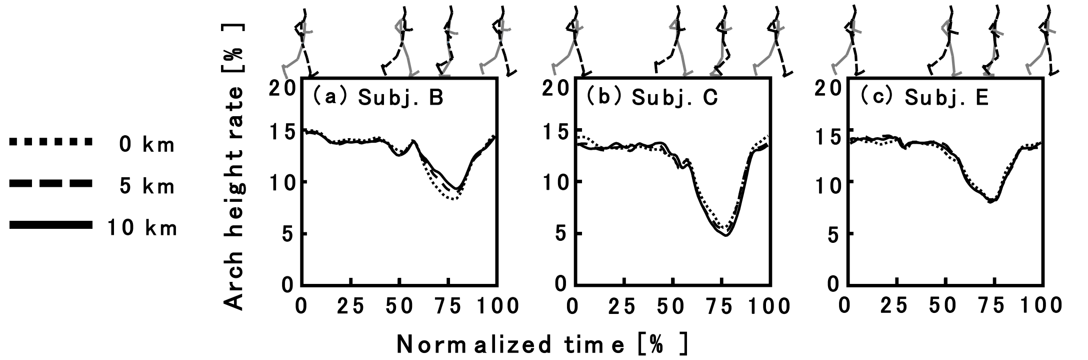


Figure 4: Arch height ratio while running at 0km, 5km, and 10km points on the treadmill.

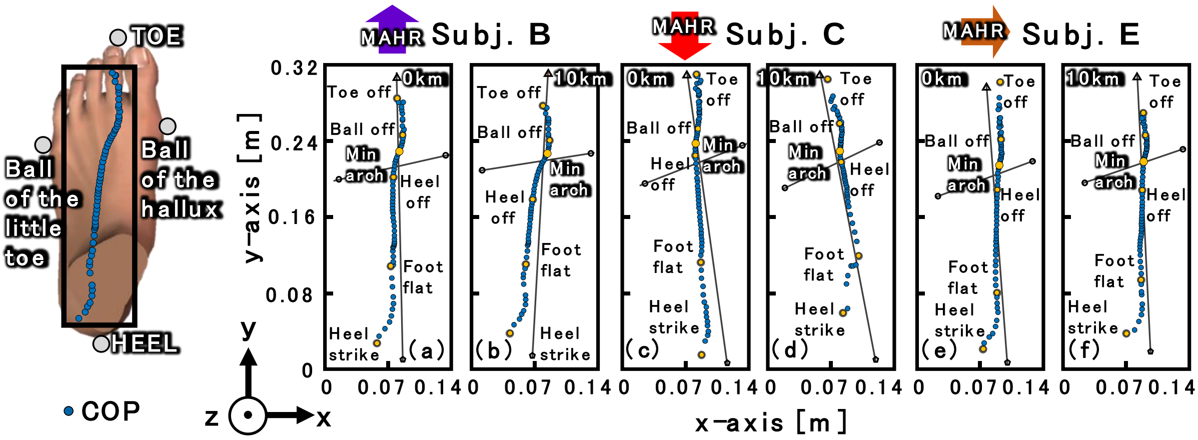


Figure 5: Trajectory of COP during support phase on the flat surface.

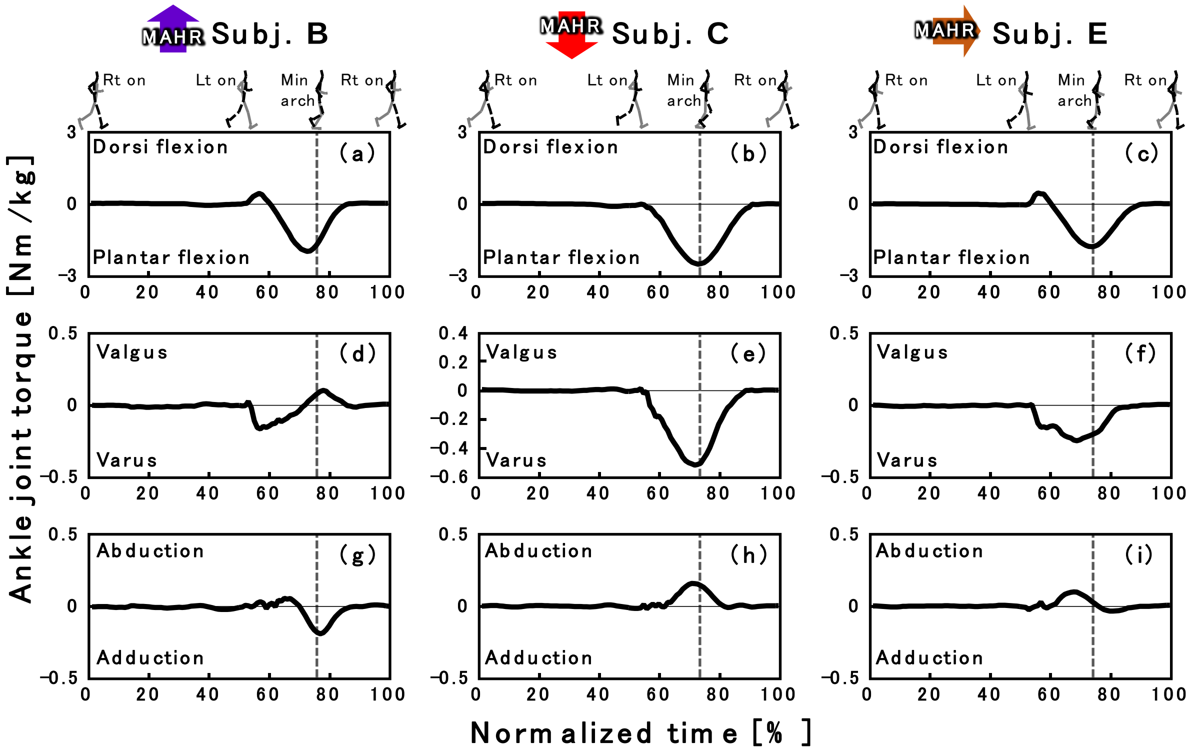


Figure 6: Ankle joint torque while running on the flat surface. 6-a, b, and c show ankle joint dorsiflexion / plantar flexion torque. 6-d, e, and f show ankle joint valgus / varus torque. 6-g, h, and i show ankle joint abduction / adduction torque.

The COP of subject C (Figure 5-c, d) moved to the left from the heel off until the MAHR. After the timing of MAHR, the COP moved forward. Subject C was taking off from the ball of hallux. COP was located on the right side of the forefoot after a long-distance running compared with before running. The toe of subject C was facing outward than other subjects.

The COP of subject E (Figure 5-e, f) moved forward from the heel off until the MAHR. After the timing of MAHR, the COP moved slightly to the right. Subject E was taking off from the middle of toe. In the forefoot after a long-distance running, the position of the COP termination had hardly changed. The COP was located on the centre side of the forefoot before and after a long-distance running.

Figure 6 shows the ankle joint torque of three typical subjects. The dotted line shows the time when the arch height ratio of each subject reached minimum value. In the subject B, whose MAHR was increased, the timing of maximum value of ankle joint valgus and adduction torque (Figure 6-d, g) and MAHR is nearly simultaneous. In the subject C, whose MAHR was decreased, the timing of maximum value of ankle joint varus and abduction torque (Figure 6-e, h) and MAHR is nearly simultaneous. In addition, in the subject C and E, the timing of maximum value of ankle joint plantar flexion torque (Figure 6-b, c) and MAHR is nearly simultaneous.

The subject B grounded the left foot to the left relative to the position of the center of gravity with the toe slightly facing inward than other subjects (Figure 5-a, b). It is considered that the momentary arch stiffness increases at the timing of the MAHR. Because the arch deforms to its maximum with one cycle at the timing of the MAHR. Furthermore, even in previous study, it is said that the foot stiffness increases with arch deformation at the timing of toe off in walking (Elfman H, 1960). It is considered that similar movements also occur in running motion. Therefore, it is considered that subject B was likely to exert ankle joint valgus, adduction, and plantar flexion torque by such movement. It is inferred that those joint torque affect the direction of movement of COP and result in taking off toward the little toe. It is said that callus is formed for sustained mechanical compression (Otsuki, 1997). It is thought that such a running form may cause the formation of a callus near the ball of little toe due to the repeated loading.

The subject C grounded the left foot to the right relative to the position of the center of gravity with the hip joint slightly externally rotated. It is considered that the momentary arch stiffness increases at the timing of the MAHR. Therefore, it is considered that the subject C was likely to exert the ankle joint varus, abduction, and plantar flexion torque by such movement. It is inferred that those joint torques affect the direction of movement of COP and result in taking off toward the first toe. It is thought that such a running form may cause the formation of a callus near the ball of hallux due to the repeated loading (Otsuki, 1997).

The timing of MAHR is not only the point where the arch height ratio reaches minimum value but also the peak value of the torque around each axis of the ankle joint. Therefore, the MAHR is considered to be an important determinant of whether the COP progresses in the direction of the inside or the outside of the forefoot.

CONCLUSION: The important results of this study are as follows: (1) At the timing of the MAHR, inflection points were seen in the trajectory of COP; (2) At the timing of the MAHR, the joint torque around each axis of the ankle joint reached peak values; (3) It is considered that the running form and ankle joint torque at the timing of the MAHR affects the direction of toe off.

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