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Original Research

Alignment of the rearfoot and foot pressure patterns of individuals with medial tibial stress syndrome: A cross-sectional study

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ABSTRACT

Objective: To compare the rearfoot alignment (leg-heel angle, LHA) during standing and walking, and foot pressure during walking between individuals with medial tibial stress syndrome (MTSS) and asymptomatic individuals participating in daily sports.
Design: A cross-sectional study.
Setting: Research laboratory.
Participants: MTSS (18 legs) and control (15 legs) participants.
Main outcome measures: The LHA in the frontal plane during walking and standing; partial foot pressures expressed as the percentage of body weight (%PFP); and transverse width of the center of pressure (COP) path expressed as the percentage of foot width (%Trans) on walking.
Results: The LHA while walking was significantly higher in MTSS individuals, whereas the LHA while standing was not significantly different. The %PFPs of medial metatarsal areas were significantly higher in MTSS patients, whereas the %Trans was significantly lower.
Conclusions: In individuals with MTSS, the LHA is similar to controls while standing but higher (more everted) while walking while there is higher pressure under the medial metatarsal areas and the COP is more medial. Rearfoot malalignment in individuals with mild to moderate MTSS can be detected on walking, even if the alignment on standing is normal.

1. Introduction

Medial tibial stress syndrome (MTSS) is a common sports injury of the lower limb characterized by “pain and discomfort in the legs from repetitive running on hard surfaces or forceful excessive use of the foot flexors (American Medical Association, 1966).” Recently, MTSS has been described as an overuse injury or repetitive-stress injury of the shin area. Various stress reactions of the tibia and surrounding musculature occur when the body is unable to heal properly in response to repetitive muscle contractions and tibial strain (Galbraith & Lavallee, 2009). Several potential causes of MTSS have been described (Messier & Pittala, 1988; Moen et al., 2012); excessive rearfoot pronation due to excessive eversion or valgus (Messier & Pittala, 1988; Viitasalo & Kvist, 1983; Yates & White, 2004) or repeated tractions of the ankle plantar flexors caused by high eversion angle of the rearfoot probably affecting the muscular origin of the tibia (Detmer, 1980; Garth & Miller, 1989; Saxena, O'Brien, & Bunce, 1990). To evaluate rearfoot alignment, leg-heel angle (LHA) is widely used for individuals with MTSS (Lee and Hertel, 2012a; 2012b; Wen, Puffer, & Schmalzried, 1998).

Considering the risk factors for the onset and exercise-induced pain of individuals with MTSS, evaluation of running in high-risk individuals may be important. However, studies of rearfoot alignment in individuals with MTSS during running have been limited, with only the Achilles tendon angle and maximum speed of eversion having been examined by videography (Niina, Egawa, Ikegame, & Torii, 2002; Viitasalo & Kvist, 1983) or high-speed

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cinematography (Messier & Pittala, 1988). Since the evaluation of alignment on running requires more precise equipment for measurement, they may be difficult. Several studies have investigated alignment of athletes with MTSS in the standing position such as high value of the navicular drop test (Moen et al., 2012), high Achilles tendon angle (Viitasalo & Kvist, 1983), and the pronated foot as defined by the foot posture index (Yates & White, 2004). In contrast, Rathleff et al. (2012) using video camera reported that feet with MTSS had abnormal alignment on walking even if normal on standing.

The reasons for these different results have not yet been clarified. The condition of walking in individuals with MTSS should be investigated.

Furthermore, the foot pressure pattern has been used to examine walking characteristics in several conditions such as osteoarthritis of the knee (Saito et al., 2013). However, in individuals with MTSS, studies of foot pressure pattern have been limited. Normal foot posture in the standing position in five individuals (Nagano, Ono, Hirose, Kurosaka, & Ishikawa, 1996) and abnormal foot pressure during running measured by force plate (Brund et al., 2017; Sharma, Golby, Greeves, & Spears, 2011) have been previously reported. Since abnormal rearfoot alignment may affect the foot pressure pattern (Lee & Hertel, 2012a; 2012b; Oh et al., 2013) and taping or insoles are frequently used to correct alignment in MTSS patients in the clinical setting (Loudon & Dolphino, 2010; Okubo & Shimazu, 1992), elucidating the characteristics of foot pressure on walking in individuals with MTSS is important.

In most previous studies, the grade of symptoms of MTSS was not well documented; in fact, many individuals with mild or moderate symptoms of MTSS participate in daily sports exercises (Noh et al., 2015; Raissi, Cherati, Mansoori, & Razi, 2009). With this in mind, we hypothesized that individuals with mild MTSS would show abnormal rearfoot alignment and foot pressure pattern during walking, even if these were normal during standing. The purpose of this study was to examine the rearfoot alignment and foot pressure pattern on walking and standing of individuals with mild MTSS participating in daily sports exercise.

2. Participants and methods

2.1. Participants

Forty athletes from colleges in the Akita prefecture in Japan were recruited in the present study; all participants exercised at least three times a week for several years. The participants were divided into MTSS and control groups according to the presence of the symptoms of MTSS. The diagnosis of MTSS was made according to the criteria reported by Yates and White (2004) (Table 1), with legs determined as MTSS if they satisfied all items. In cases of bilateral MTSS, the more painful side was examined. Foot deformities and abnormal knee alignment were confirmed. Neither was observed in all participants. In addition, participants who had a history of musculoskeletal disorders except for MTSS were also excluded in the present study. In the control group, we randomly selected one leg to be examined.

The review board of our institution approved the study (Akita University Graduate School of Medicine and Faculty of Medicine: No. 1158) and written informed consent for the collection and use of the information was obtained from all respondents in accordance with the Declaration of Helsinki.

Table 1
Inclusion criteria (Yates & White, 2004).

① Exercise-induced pain in the leg on the posteromedial tibial border
② No exercise-induced sensory impairment or other symptoms
③ Pain on palpation of the posteromedial tibia for at least 5 cm
④ 2–3 cm localized pain is treated as atigue fracture
⑤ Tenderness, Radiating and Discomfort
⑥ Irregularities of the surface
⑦Symptoms present for at least 2 weeks

2.2. Evaluation of pain

Pain associated with MTSS was classified according to the grading system reported by Walsh (1990, pp. 251–258), as follows: Grade 1, pain after exercise; Grade 2, pain during exercise, not interfering with movement; Grade 3, pain during exercise, interfering with movement; and Grade 4, chronic pain at rest.

2.3. Analysis during standing

Deformities of the feet and alignment of the lower limbs. Existence of foot deformities, including flat foot having navicular index more than 6.7 (Roth, Roth, Jotanovic, & Madarevic, 2013), hallux valgus having hallux angle more than 15° (Coughlin, 1997; Nix, Russell, Vicenzino, & Smith, 2012), and spread foot having spread angle more than 15° (Shimizu, Nagai, Genda, & Obinata, 2013), and abnormal knee alignments, including genu varus, were examined by physical inspection, palpation, measurement by tape measure, and standard goniometer before the below-mentioned measurements.

Leg-heel angle (LHA). The LHA is formed by the center line of the distal third of the posterior aspect of the lower leg and the median line of the posterior aspect of the calcaneus. The angle on one-leg standing position was measured by the standard goniometer and the electronic goniometer (SG110; Biometrics Ltd., Gwent, UK). We confirmed that the angles of these two measurements were of the same value. The electronic equipment was fixed with tape (COACH; Johnson & Johnson, New Brunswick, NJ) on the posterior side of the lateral malleolus parallel to the long axis of the fibula according to the previously reported method (Moriguchi, Sato, & Gil Coury, 2007) (Fig. 1). The center of the superior sensor of the equipment was set 17 cm superiorly to the lateral malleolus, and the center of the inferior sensor was set 3 cm inferiorly to the malleolus.

2.4. Analysis during walking

Foot pressure. Foot pressure measurements were performed on a flat, 16-m walking course at a comfortable walking speed. The flexible, pressure-sensitive sheet of the foot pressure measurement system (F-Scan II; Nitta Corp., Osaka, Japan) was used as the insoles of the trial shoes (Shin-Nipponkyoiku shoes; Fig. 2). The F-Scan II consists of pressure-sensitive sheets and a personal computer system, and the path of the COP, foot-printed area, and foot pressures of each part of the foot were recorded automatically while the participants walked on the course 3 times for measurement, after 1 or 2 practice walks. The values obtained were averaged over the 3 trials. The sampling frequency was 100 Hz.

The two following parameters were obtained: (1) partial foot-pressure per body weight (%PFP; Fig. 3). The foot-print area during gait was divided into the heel, central, metatarsal, hallux, and lateral toes according to the average foot length of healthy individuals (Saito et al., 2013). The most posterior 34.5% of the foot-printed area was defined as the heel part, the next 24% and 26.5% were defined as the central and metatarsal parts, respectively, and the anterior 15% was defined as the toes. The medial 22% of the toe part was defined as the hallux and the lateral 78% as the lateral toes. The metatarsal part was subdivided into the first, second, third,

Fig. 1. Appearance of the fixed electronic goniometer for measurement of the leg-heel angle.

Fig. 2. Pressure-sensitive sheets of the foot pressure measurement system.

fourth, and fifth metatarsal parts. Subsequently, the %PFP of each part was calculated as the average value during the stance phase, expressed as the percentage of the participant's body weight. (2) %Trans (Fig. 4). The transverse width of the COP path from the most medial to the most lateral point was measured, and the %Trans was expressed as the percentage of the transverse width to the maximum foot width (Saito et al., 2013). All lengths were measured using the measuring system built in F-Scan II.

LHA during walking (Fig. 5). The LHA during walking was continuously recorded on the 16-m flat pathway using an electronic goniometer as described above, during comfortable walking speed. To determine the phases of heel contact and heel off, a foot sensor (Flexi Force; Nitta Corp.) working during pressure was affixed to the heel. The maximum values of the LHA at the heel contact and heel off phases were measured, and the values obtained were averaged over the 3 trials. The sampling rate adopted for the electrical goniometer was 100 Hz.

2.5. Data analysis

All statistical analyses were performed using SPSS Statistics version 18.0 (IBM, Armonk, NY). Prior to analysis, all data were assessed for normality according to the result of the Shapiro-Wilk test. As data were not normally distributed, the comparison between the MTSS and control groups was assessed using the nonparametric Mann-Whitney *U* test. Statistically significant level was set at $p = 0.05$.

3. Results

3.1. Participants

In the 40 participants, 7 were excluded, since they had histories of musculoskeletal disorders. No participant had any foot deformity or abnormal knee alignment. Consequently, 33 athletes were enrolled in the present study. The MTSS group comprised of 18 individuals. Thirteen of the 18 individuals had bilateral MTSS lesions, whereas the remaining 5 had unilateral MTSS. In the 33 individuals, 15 individuals without any sign of MTSS were classified as the control group. Age, sex, body height and weight, and sports of both groups are shown in Table 2.

3.2. Evaluation of pain

In the 18 legs of the MTSS group, 7 and 11 legs were classified as

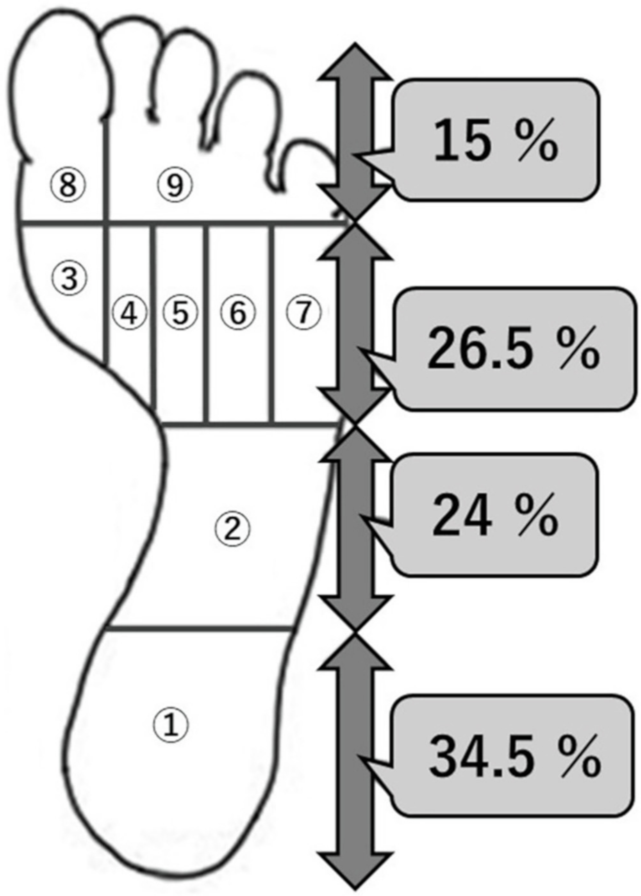

Fig. 3. Partial foot pressure (%PFP). The foot-printed area is divided into the ① heel, ② central, ③ first metatarsal, ④ second metatarsal, ⑤ third metatarsal, ⑥ fourth metatarsal, ⑦ fifth metatarsal, ⑧ hallux, and ⑨ and lateral toes. The %PFP of each part is calculated as the average value during the stance phase of each step, as a percentage of the body weight.

Grades 1 and 2, respectively, and there were no Grade 3 or 4 legs. None of the participants in the control group had any lower leg pain.

3.3. Analysis during standing

LHA during standing. The LHA during one-leg standing position did not significantly differ between the MTSS and control groups (7.4 ± 1.6° vs. 7.3 ± 1.7°, $P = 0.8$).

3.4. Analysis during walking

Foot pressure. (1) %PFP. The %PFP of the first, second, and third metatarsal areas of the MTSS group were significantly higher than those of the control group (2.2 ± 1.0% vs. 1.2 ± 0.4%, $P = 0.01$; 3.2 ± 1.5% vs. 2.5 ± 0.9%, $P = 0.04$; 3.5 ± 1.4% vs. 2.5 ± 0.9%, $P = 0.04$, respectively; Fig. 6). In other areas, there were no significant differences between the two groups. (2) %Trans. In the control group, the COP path was generally located on the outside, at the central part, and moved toward the inside of the forefoot. However, in the MTSS group, the COP path was linear and shifted medially (Fig. 7). The %Trans in the MTSS group was significantly lower than that of the control group (6.9 ± 2.1% vs. 11.7 ± 2.3%, $P < 0.001$, Fig. 8).

LHA during walking. The maximal LHA during walking was significantly higher in the MTSS group than in the control group

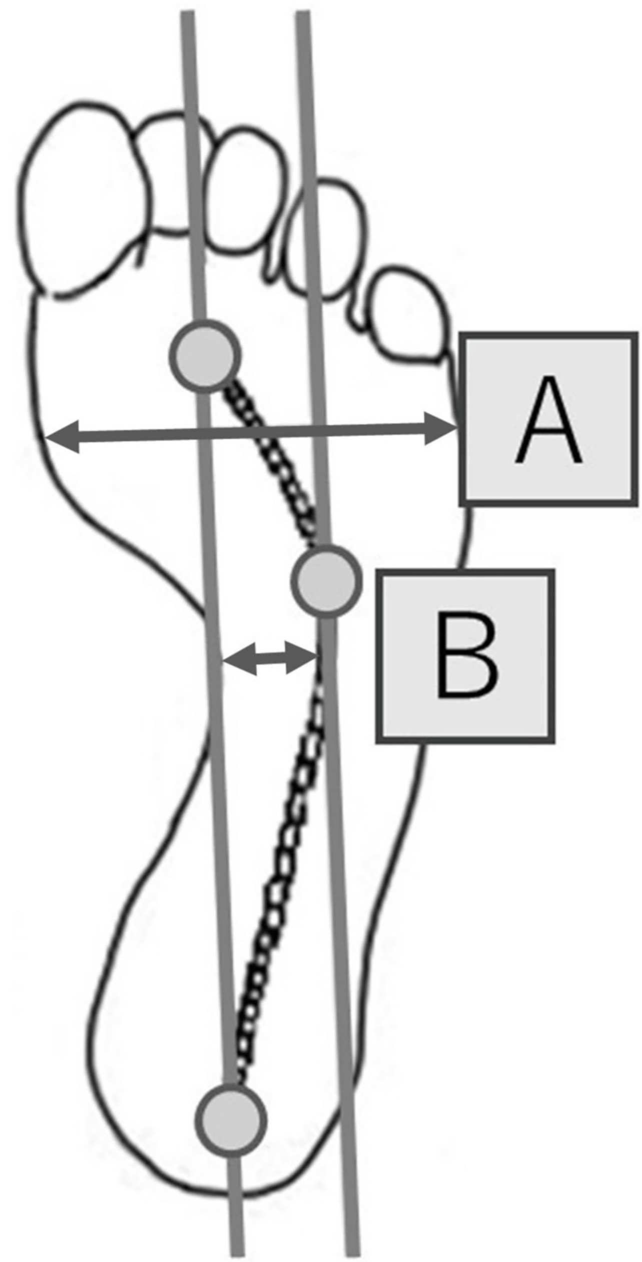

Fig. 4. Transverse width of the center of pressure (COP) path (%Trans) expressed as the percentage of the maximum foot width (A). The transverse width of the COP path is measured from the most medial to the most lateral point of the COP path (B).

(15.7 ± 3.5° vs. 11.2 ± 1.3°, $P = 0.02$). Although the angle on heel contact was not significantly different between the 2 groups (−3.5 ± 1.5° vs. −4.1 ± 2.1°, $P = 0.76$), the angle on heel off was significantly higher in the MTSS group than in the control group (−0.3 ± 1.8° vs. −3.6 ± 2.7°, $P = 0.04$).

4. Discussion

The overuse of the long toe flexor supporting the longitudinal arch (Garth & Miller, 1989), tibialis posterior muscle (Saxena et al., 1990), soleus muscle (Detmer, 1980), stiffness of posterior lower leg (Saeki, Nakamura, Nakao, Fujita, Yanase, Chihashi, 2018), and shear elastic moduli of flexor digitorum longus and tibialis posterior (Ohya et al., 2017) could cause increased burden of the tibia and

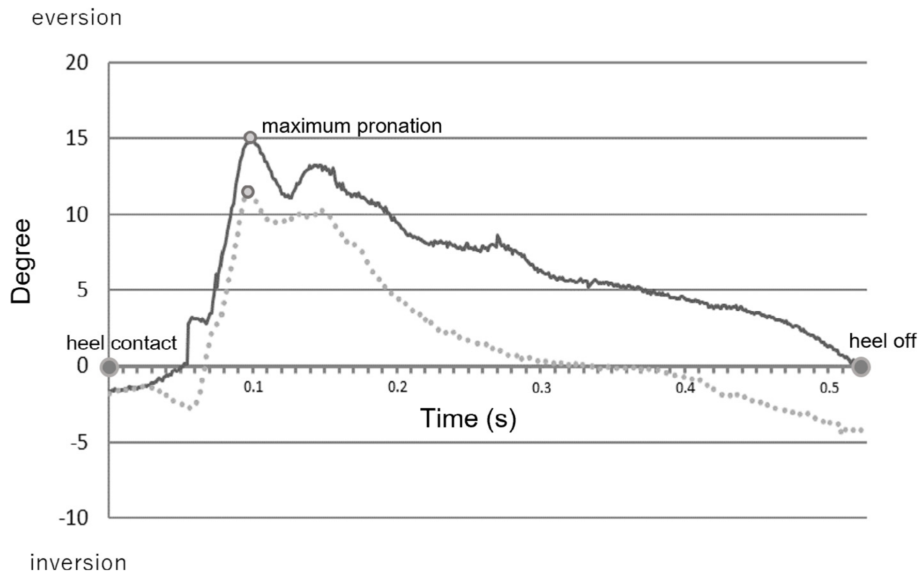

Fig. 5. Leg-heel angle (LHA) between the heel contact and heel-off phases. The maximal LHA during walking is significantly higher in the medial tibial stress syndrome (MTSS) group (solid line) than in the control group (dotted gray line). The LHA on heel off is significantly higher in the MTSS group than in the control group.

Table 2
Participant information.

	Male/Female (n)	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)	Sports (n)
MTSS (n = 18)	11/7	20.7 ± 1.3	169 ± 5.8	64.2 ± 6.8	20.8 ± 1.6	Track and field 14 Soccer 3 Hand ball 1
CON (n = 5)	9/6	19.0 ± 1.1	167 ± 5.8	62.8 ± 7.0	21.2 ± 1.3	Track and field 8 Soccer 7

Date are presented as the mean ± standard deviation.

induce periostitis and exercise-induced pain (Beck & Osternig, 1994; Viitasalo & Kvist, 1983), although their relationship to rearfoot alignment has still been obscure. For evaluation of the abnormal alignment of the rearfoot, the LHA, foot arch ratio, and navicular drop test in the standing position have been widely used (Moen et al., 2012; Viitasalo & Kvist, 1983; Yates & White, 2004). These previous studies reported that the values of the LHA and navicular drop test were significantly higher and that the arch ratio was significantly lower in MTSS patients than in healthy individuals. However, in the present study of mild MTSS, LHAs were normal during standing.

The foot is in a supinated position at the heel-contact phase during normal walking, and then, it gradually pronates and shows maximum pronated position until the mid-stance phase. After heel off, it gradually supinates and shows a supinated position at the toe-off phase. However, during walking with hyperpronation when foot pronation is excessive and prolonged, the foot may not resupinate at the terminal stance phase (Khamis & Yizhar, 2007). The present study also showed similar results. The maximal LHA during walking and the heel-off phase were significantly higher in the MTSS group, indicating a tendency for eversion of the foot. This tendency of foot eversion likely shifted the foot pressure of the metatarsal area medially. In fact, the participants with MTSS showed significantly higher %PFP of the first, second, and third metatarsal areas in this study. These higher foot pressures around the metatarsal area made the COP more medial with less lateral movement, resulting in the lower %Trans value observed in individuals with MTSS.

Several studies enrolling participants with Grade 3 or 4 MTSS have reported that MTSS feet significantly everted even in the standing position (Moen et al., 2012; Nagano et al., 1996). Accordingly, Bandholm, Boysen, Haugaard, Zebis, and Bencke (2008) mentioned that abnormal alignment during quiet standing did not correlate with the abnormal alignment during gait in both the MTSS and control groups, although there was a significant difference of the alignment during standing and walking between the 2 groups. Rathleff et al. (2012) mentioned that feet with MTSS had abnormal alignment during walking, despite the alignment being normal on standing upon evaluation by video camera. Herein, in individuals with MTSS, the maximal LHA during walking was high, whereas the LHA on one-leg standing position was not significantly different between the MTSS and control groups. Furthermore, in all individuals in the MTSS group, the symptoms were classified as Grade 1 or 2; these mild or moderate symptoms were thought to be associated with the normal alignment observed in the standing position. Although LHA in the present study could show only eversion angle on the coronal plane, it might be a sensitive measurement to detect a malalignment of individuals with Grade 1 or 2 MTSS.

In this article, the %Trans was used as an evaluation of the COP path. Saito et al. (2013) first proposed using the %Trans in the evaluation of osteoarthritis of the knee. The authors reported that the %Trans of individuals with knee osteoarthritis was significantly lower than that of the control participants, owing to flat foot deformity under body weight load. Similarly, other studies have also concluded that flat foot might cause MTSS (Bennett, Reinking, & Rauh, 2012; Nagano et al., 1996) and significant decreases of the % Trans. However, no obvious deformity was observed in any of the

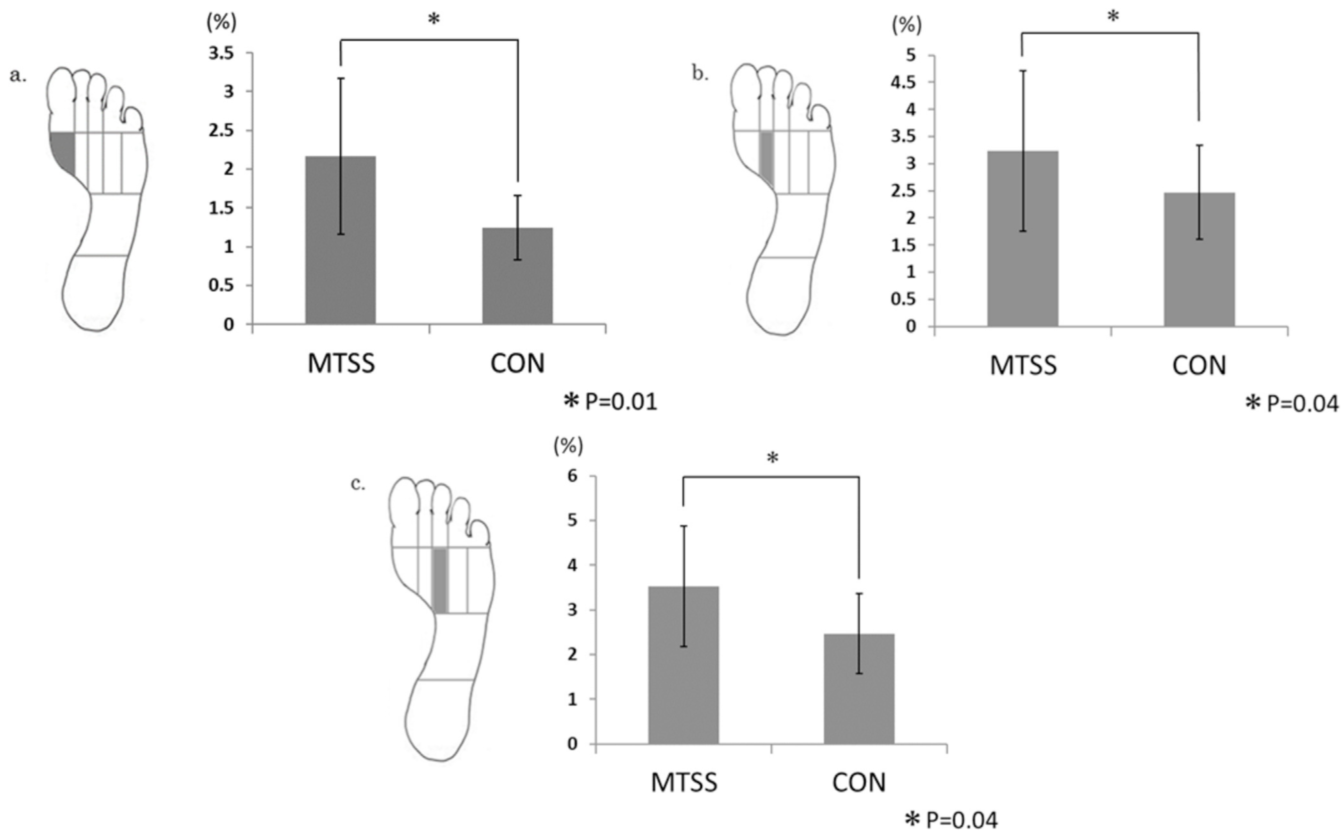

Fig. 6. Partial foot pressures (%PFPs) of the first (A), second (B), and third (C) metatarsal areas. In these areas, the %PFPs of the medial tibial stress syndrome (MTSS) group are significantly higher than those of the control (CON) group.

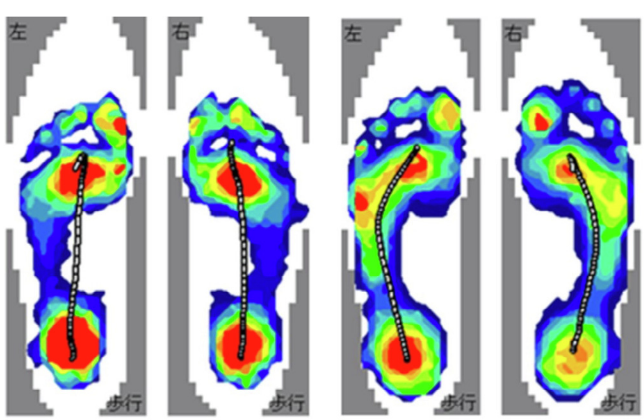

Fig. 7. Center of pressure path of the medial tibial stress syndrome (MTSS) (left) and control groups (right). Note that the center of the pressure path of the MTSS group is linear and shifts medially.

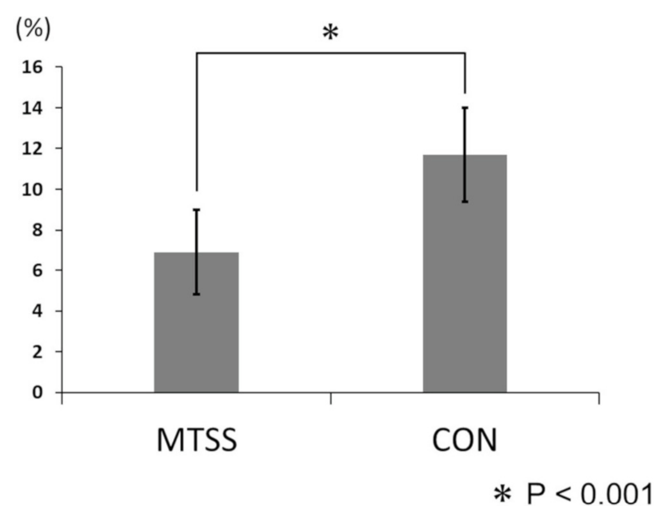

Fig. 8. Results of the transverse width of the center of pressure (%Trans) analysis. The %Trans in the medial tibial stress syndrome (MTSS) group is significantly lower than that of the control (CON) group.

participants in the current study. Instead, it is likely that the COP path showed a linear shape and shifted medially due to the excessive eversion of the rearfoot, resulting in the significant decrease of the %Trans.

There are two limitations of this study. First is the diagnosis of MTSS. It is important to distinguish MTSS from stress fractures and chronic compartment syndrome. In the current study, the diagnosis of MTSS was made clinically based on the criteria reported by Yates and White (2004). In these days, however, radiographs, magnetic resonance imaging (Moen, Tol, Weir, Steunebrink, & De Winter, 2009), bone scintigraphy (Chisin et al., 1987), and ultrasonography (Kijima et al., 2010) have been described as auxiliary diagnostic methods. Furthermore, similar studies employing these auxiliary tools should be performed in the future. Second is the dynamic plantar pressure collected during walking. Considering the pain during exercise and the precision of equipment required for measurement, the evaluation on walking is more practical and clinical than that running. However, it is not necessarily the case that pressure distribution patterns during walking would be the same as in running. In the future, a comparison between the evaluation on walking and that on running would be necessary.

In conclusion, the current study enrolling 18 athletes participating in daily sports exercise with Grade 1 or 2 MTSS showed increased rearfoot eversion during walking although the LHA during standing is normal compared to the control group. This eversion results in high foot pressure of the medial metatarsal areas and narrow and straight figure of COP path. We should notice that rearfoot malalignment in individuals with MTSS can be detected not only during running but also during walking, even if the alignment during standing is normal. Furthermore, it should be stressed that the foot pressure pattern analysis is an easy and useful tool for the evaluation for individuals with mild MTSS.

Conflicts of interest

The authors declare no conflicts of interest associated with this manuscript.

Ethical statement

The review board of our institution approved the study (Akita University Graduate School of Medicine and Faculty of Medicine: No.1158), and written informed consent for the collection and use of the information was obtained from all respondents in accordance with the Declaration of Helsinki.

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