Forefoot and hindfoot kinematics in subjects with medial tibial stress syndrome during walking and running

Authors

Takumi Okunuki[1,2], Yuta Koshino[1,3], Masanori Yamanaka[1], Kaori Tsutsumi[1], Masato Igarashi[1], Mina Samukawa[1], Hiroshi Saitoh[1], Harukazu Tohyama[1]

Affiliation

[1] Faculty of Health Sciences, Hokkaido University, Sapporo, Hokkaido, Japan

[2] Department of Rehabilitation, Matsuda Orthopedic Memorial Hospital, Sapporo, Hokkaido, Japan

[3] Rehabilitation Center, NTT East Japan Sapporo Hospital, Sapporo, Hokkaido, Japan

Corresponding author:

Yuta Koshino, RPT, PhD

Faculty of Health Sciences, Hokkaido University, Sapporo, Hokkaido, 060-0812, Japan

E-mail: y-t-1-6@hs.hokudai.ac.jp

Running title: Medial tibial stress syndrome

Author contributions statement: T.O., Y.K., H.T., M.S., H.S., and M.Y designed the research; T.O., H.T., K.T., and M.I. conducted the research; T.O., Y.K., and M.I. analyzed the data; T.O., Y.K, H.T., and M.Y. drafted the manuscript. All authors interpreted the data and have read and approved the final submitted manuscript. Y.K. had primary responsibility for the final content.

Abstract

Excessive foot pronation during static standing, walking and running has been reported as a contributing factor for the development of medial tibial stress syndrome (MTSS). The motion of foot pronation consists of hindfoot and forefoot motion. However, no previous studies have investigated forefoot and hindfoot kinematics during walking and running in subjects with MTSS. The current study sought to compare hindfoot and forefoot kinematics between subjects with and without MTSS while walking and running. Eleven subjects with MTSS and 11 healthy controls (each group containing 10 males and one female) participated in the current study. Segment angles of the hindfoot and forefoot during walking and running barefoot on a treadmill were recorded using three-dimensional kinematic analysis. An independent t-test was used to compare kinematic data between groups. Subjects with MTSS exhibited significantly greater hindfoot eversion and abduction ($P < 0.05$) during walking and running than subjects without MTSS, significantly greater forefoot eversion and abduction ($P < 0.05$) during walking, and significantly greater forefoot abduction during running ($P < 0.05$). Hindfoot and forefoot kinematics during walking and running were significantly different between subjects with and without MTSS. For prevention and rehabilitation of MTSS, it may be important to focus on not only hindfoot but also forefoot kinematics during both running and walking.

Keywords: kinematics, medial tibial stress syndrome; forefoot kinematics; hindfoot kinematics; walking; running

1. INTRODUCTION

Medial tibial stress syndrome (MTSS) is one of the most common overuse injuries of the lower extremities.[1] The incidence of MTSS is reported to be 16%–44% in a number of sports, including track and field, cross country running, and tennis.[2-4] In addition, a previous history of MTSS is a risk factor for further MTSS,[1,2,5] which requires a long period of rehabilitation before returning to sports participation.[6,7] One study revealed that, although patients with MTSS in whom conservative treatment failed underwent surgical treatment, 59% of patients did not return to their previous competition levels more than 6 months postoperatively.[8] Therefore, it is important for clinicians to understand the etiology of MTSS to improve rehabilitation programs.

Previously reported risk factors for MTSS include an excessively pronated foot when standing and excessive hindfoot eversion when running.[1,5,9] Subjects with MTSS exhibit greater hindfoot eversion than those without MTSS during forward steps and running.[10,11] Greater hindfoot eversion may lead to increased activity of the soleus, flexor digitorum longus, and tibialis posterior muscles.[1,9-11] A cadaver study reported that tension of these muscles' tendons generated strain on the posteromedial border of the tibia.[12] The increased contractions of these muscles, in turn, may create a traction force on the posteromedial border of the tibia, causing inflammation. In addition, during walking and running, foot pronation couple with internal rotation of the tibia may generate bone torsional stress.[13,14] Because the tibias of healthy subjects were weak against torsional stress, the tibia of subjects with MTSS may be subjected to large torsional strain during excessive foot pronation.[15] Therefore, an excessively pronated foot in both static and dynamic alignments could be related to the development of MTSS.

Previous studies reported that static pronated foot posture is characterized by hindfoot eversion, forefoot inversion/eversion, abduction, and dorsiflexion.[16,17] In addition, hindfoot eversion is related to forefoot inversion, abduction, and dorsiflexion during walking and running.[13,14] Although greater hindfoot eversion is reported in subjects with MTSS compared with those without MTSS during forward steps or running,[10,11] it is currently unclear where abnormalities in foot kinematics occur. Kinematic changes of the forefoot and/or hindfoot may contribute to increased foot pronation in people with MTSS. In the current study, we compared hindfoot and forefoot kinematics during walking and running between subjects with and without MTSS. We hypothesized that subjects with MTSS would exhibit significantly greater forefoot inversion/eversion, abduction, dorsiflexion as well as hindfoot eversion and abduction.

2. METHODS

The current study used a cross-sectional design, producing Level 3 evidence. The subject groups were separated by the current presence or absence of disease and examined for prior exposure of interest. This study was approved by the Ethical Review Committee at the Faculty of Health Sciences, Hokkaido University, and informed consent was obtained from all subjects.

2.1. Subjects

In total, 11 subjects with MTSS and 11 healthy controls (10 males and one female in each group) participated in this study. All subjects belonged to a university athletic club (Table 1). The diagnostic criteria for MTSS were: (1) tenderness at the posteromedial border of the tibia, (2) a site of tenderness that spread over a minimum of 5 cm, and (3) no evidence of tibial stress fracture on plain radiographic images.[1,4] An experienced orthopedic surgeon (H.T.) diagnosed each subject with MTSS who had experienced symptoms for at least 2 weeks. Exclusion criteria were: (1) any history of fracture or surgery in the lower extremity or trunk, and (2) other injuries during the prior 3 months. None of the subjects complained of any symptoms except those associated with MTSS, and all subjects reported that they were taking no medications for any symptoms.

Pain severity at the tender area was assessed using a numeric rating scale. The injured or more severely injured leg of the MTSS subject was used for analysis. The control subject's leg was selected for analysis based on the ratio of the dominant and non-dominant legs. The dominant leg was defined as the side used for kicking a stationary ball.

2.2. Data collection

The arch height index and leg-heel angle while standing on both feet were measured for static foot alignment.[11,18] The arch height index was the ratio of the dorsal height and truncated foot length.[18] The dorsal height was taken at 50% of the total foot length. The truncated foot length was the length from the posterior calcaneus to the first metatarsal head. The leg-heel angle was the angle between the calcaneus midline and the lower leg midline.[11] Each of these parameters was measured three times, then averaged. The intraclass correlation values for intra-rater reliability were 0.941 for the arch height index (95% confidence interval [CI] 0.512–0.988) and 0.804 for the leg-heel angle (95% CI 0.349–0.952).

Subjects performed a static standing trial and two movement tasks: walking and running barefoot on a treadmill. Subjects walked at a self-selected speed for 6 min and ran at 12 km/hour for 3 min to become familiar with the treadmill's conditions.[19,20] The self-selected speed of walking was determined using a 10-m walking test. Subjects took whatever rest time they needed between walking and running. Ratings of the perceived exertion and pain severity during walking and running were recorded using a modified Borg scale and the numeric rating scale, respectively.

2.3. Data analysis

Following familiar walking or running patterns, five consecutive strides were recorded using EvaRT software (Motion Analysis Corporation, Santa Rosa, CA, USA) with six digital cameras (Hawk cameras; Motion Analysis Corporation, Santa Rosa, CA, USA) sampled at 200 Hz. Reflective markers were placed on the bony landmarks of the thigh (greater trochanter and lateral epicondyle of the femur), shank, and foot based on Leardini's foot model.[21] Segment angles of the hindfoot relative to the shank and the forefoot relative to the hindfoot were calculated using Visual 3D (C-Motion Inc., Germantown, MD, USA). All segment angles in the static standing position were set at

0° for each subject. These kinematic variables were normalized to 101 points of the stance phase while walking and running.

For the walking task, the instant of initial contact (IC) and toe-off were determined based on the acceleration of the calcaneus-based marker and the first metatarsal head marker, respectively.[19] For the running task, the strike pattern was determined based on the time difference between the calcaneus and the fifth metatarsal peak acceleration time.[22] The rearfoot strike was defined as the point at which the peak acceleration of the calcaneus marker was 15.2 ms earlier than that of the fifth metatarsal marker, and the forefoot strike was defined as the point at which the peak acceleration of the calcaneus marker was 5.49 ms later than that of the fifth metatarsal marker. The midfoot strike was defined as a difference of 5.49–15.2 ms between the calcaneus and fifth metatarsal markers. The IC was determined based on the acceleration of the calcaneus marker for a rearfoot strike runner and that of the second metatarsal marker for a midfoot or forefoot runner.[23] Toe-off during running in all subjects was determined based on the maximum extension of the knee joint angle, which was calculated according to the markers of the greater trochanter, lateral epicondyle of the femur, head of the fibula, and lateral malleolus.[19]

2.4. Statistical analysis

The kinematic data were extracted at every five points from the normalized stance phase. An independent t-test was performed to detect group differences in the demographic data, static foot alignment, walking speed, modified Borg scale, and kinematic data. All significance levels were set at $P < 0.05$. Statistical analyses were performed using IBM SPSS Statistics version 17 (SPSS Inc., Chicago, IL, USA). In addition, effect sizes (ESs) were calculated to indicate the magnitude of the differences using G*Power 3.1 (Universität Kiel, Germany).

3. RESULTS

The MTSS group had significantly higher body mass index values ($P < 0.005$) than the control group. There were no differences in the other demographic data, static foot alignment, walking speed, or modified Borg scale (Tables 2, 3). No subject dropped out of this study because of pain. The MTSS group had seven forefoot strikers and four midfoot strikers. The control group had eight forefoot strikers and three midfoot strikers. There were no rearfoot strikers in either group.

Analysis of the walking kinematics (Figure 1) showed that the MTSS group exhibited significantly greater hindfoot eversion at IC ($P < 0.05$, ESs = 1.07) and significantly greater abduction at IC and during 40%–60% of the stance phase ($P < 0.05$, ESs = 0.73–1.10) compared with the control group. In addition, the MTSS group exhibited significantly greater forefoot eversion at 80% ($P < 0.05$, ESs = 1.01) and significantly greater abduction during 5%–85% ($P < 0.05$, ESs = 0.94–1.89) of the stance phase than the control group. There were no significant differences in hindfoot or forefoot dorsiflexion between the MTSS and control groups ($P > 0.05$).

Analysis of the running kinematics (Figure 2) showed that the MTSS group exhibited significantly greater hindfoot eversion during 0%–15% and 75%–90% ($P <$

0.05, ESs = 0.98–1.34) and significantly greater abduction during 0%–20% and 70%–100% (*P* < 0.05, ESs = 1.00–1.76) of the stance phase than the control group. In addition, the MTSS group exhibited significantly greater forefoot abduction during 15%–40% and 70%–85% (*P* < 0.05, ESs = 0.96–1.11) of the stance phase than the control group. There were no significant differences in hindfoot dorsiflexion or forefoot eversion and dorsiflexion between the MTSS and control groups (*P* > 0.05).

4. DISCUSSION

The current results revealed that the kinematics of the hindfoot and forefoot while walking and running were different between subjects with and without MTSS, supporting our hypothesis that not only hindfoot but also forefoot kinematics during walking and running were different between these two groups. The findings of our study were consistent with the findings of previous studies investigating foot kinematics in subjects with MTSS. [9-11]

A previous prospective study reported that increased hindfoot eversion and abduction during running were significant risk factors for MTSS.[9] Moreover, hindfoot eversion is correlated with forefoot abduction during walking and running.[14] Therefore, we propose that the changes in kinematics of the hindfoot and forefoot observed in our study were more likely to be the cause than the result of MTSS. In addition, several previous studies reported that a previous history of MTSS is a risk factor for further MTSS.[1,2,5] These findings indicate that MTSS involves factors that portend the further development of MTSS. In the present study, subjects with MTSS exhibited greater eversion and abduction in both the hindfoot and forefoot during walking and running, which are factors that can contribute to the development of MTSS.

In the current study, subjects with MTSS exhibited greater hindfoot and forefoot eversion and abduction during walking and running than subjects without MTSS. The tibialis posterior originates from the posterior of the tibia and fibula and attaches to the navicular, cuneiform, and second through the fourth metatarsal base.[24] The flexor digitorum longus and soleus originate from the posteromedial border of the tibia, and attach to the distal phalanges of the foot and medial calcaneal tuberosity, respectively.[24] The soleus is an invertor of the calcaneus.[25,26] The increase in hindfoot and forefoot eversion may contribute to the stretching of these muscles and tendons. There may be more demand during contraction of these muscles in a more stretched position in subjects with MTSS than in those without MTSS. This may then generate greater traction force on the tibial fascia.[11,12,26]

Subjects with MTSS exhibited greater hindfoot abduction relative to the shank and greater forefoot abduction relative to the hindfoot, compared with subjects without MTSS. Therefore, the foot was at an abducted position relative to the shank in MTSS. This may indicate that the shank exhibits internal rotation relative to the foot, generating tibial torsional stress. In addition, increased foot pronation, consisting of foot eversion, abduction and dorsiflexion relative to the lower leg, would generate greater free moment during the stance phase of running.[27] Subjects with MTSS in the present study may exhibit increased shank internal rotation and greater free moment, which could generate torsional stress on the tibia. Moreover, subjects with MTSS exhibited higher

BMI values than those without MTSS. Several previous authors assumed that higher BMI values would increase loading on the tibia, causing stress when bending and/or bowing.[5,28] Thus, increased forefoot and hindfoot abduction and higher BMI values in subjects with MTSS would be expected to generate greater loading on the tibia.[5,27,28]

Subjects with MTSS had greater hindfoot and forefoot kinematics not only when running, but also when walking. Thus, the tibias of individuals with MTSS may be exposed to greater stress by traction force or free moment during activities of daily living than those without MTSS. Such walking may delay alleviation of MTSS symptoms and result in long rehabilitation periods before returning to sports participation.[6,7] Therefore, clinicians should correct the forefoot and hindfoot kinematics of subjects with MTSS during both running and walking during their rehabilitation. Several previous studies reported that augmented low-dye tape or induced contraction of intrinsic foot muscles could decrease forefoot abduction and hindfoot eversion during walking or sitting with a vertical load on the foot.[29,30] Taping the foot or promoting intrinsic foot muscle activity could be effective for modifying the forefoot and hindfoot kinematics of MTSS.

Although most runners are classified as rearfoot strikers, our subjects were classified as midfoot/forefoot strikers. It is unclear whether the results we observed during running in midfoot/forefoot strikers are applicable to rearfoot strikers, because the hindfoot kinematics during running were reported to be significantly different between rearfoot and midfoot/forefoot strikers.[31] Thus, further investigation will be needed to confirm whether our results apply to rearfoot strikers. However, our findings regarding hindfoot kinematics observed during running in midfoot/forefoot strikers with MTSS were consistent with the results of previous studies of rearfoot strikers with MTSS.[9,11] Thus, we assumed that patients with MTSS exhibited greater hindfoot motion during running, regardless of strike pattern. Furthermore, rearfoot strikers with MTSS might have exhibited similar forefoot kinematics to those observed in the current study during running because hindfoot motion is significantly correlated with forefoot motion during running.[14] Future studies should investigate multi-segmental foot kinematics in rearfoot strikers with MTSS.

Our study involved several limitations that should be considered. First, because we used a cross-sectional study design, we were unable to determine cause and effect. A prospective study in the future may be useful for elucidating this issue. Second, our study tasks comprised only walking and running. Athletes perform a wide range of other movements, including jumping, side-cutting, and turning. Hence, the results of the current study may not apply in the presence of other movements. Third, we did not measure muscle activation of the soleus, flexor digitorum, and tibialis posterior muscles. Activation of these muscles should be examined in future studies, to understand the relationship between kinematics and MTSS. Fourth, subjects with MTSS exhibited higher BMI values than those without MTSS. The higher BMI values may affect forefoot and hindfoot kinematics. Several studies, however, reported that subjects with MTSS exhibited increased foot pronation during walking, even though the BMI was not significantly different between subjects with and without MTSS.[32,33] These findings suggest that the changes in foot kinematics of the MTSS subjects may not depend on

BMI values. Finally, we did not record the ground reaction force or calculate free moment in our study. Future studies should investigate ground reaction force in subjects with MTSS during walking and running.

In conclusion, the current findings revealed that forefoot and hindfoot eversion and abduction differed between subjects with and without MTSS during walking. In addition, subjects with MTSS had greater forefoot abduction and hindfoot eversion and abduction during running than those without MTSS. For prevention and rehabilitation of MTSS, it may be important to focus on not only hindfoot but also forefoot kinematics during walking and running.

ACKNOWLEDGMENTS

We thank Edanz Group (www.edanzediting.com/ac) for proofreading a draft of this manuscript.

References

1. Yates B, White S. 2004. The incidence and risk factors in the development of medial tibial stress syndrome among naval recruits. Am J Sports Med, 32:772–780.
2. Hubbard TJ, Carpenter EM, Cordova ML. 2009. Contributing Factors to Medial Tibial Stress Syndrome: A Prospective Investigation. Med Sci Sports Exerc 41:490-496.
3. Plisky MS, Pauh MJ, Heiderscheit B, et al. 2007. Medial Tibial Stress Syndrome in High School Cross-Country Runners: Incidence and Risk Factors. J Orthop Sports

Phys Ther 37:10-47.

4. Yagi S, Muneta T, Sekiya I. 2013. Incidence and risk factors for medial tibial stress syndrome and tibial stress fracture in high school runners. Knee Surg Sports Traumatol Arthrosc 21:556-563.
5. Newman P, Witchalls J, Waddington G, Adams R. 2013. Risk factors associated with medial tibial stress syndrome in runners: a systematic review and meta-analysis. Open Access J Sports Med 4:229-241.
6. Moen MH, Holtslag L, Bakker E, et al. 2012. The treatment of medial tibial stress syndrome in athletes; a randomized clinical trial. Sports Med Arthrosc Rehabil Ther Technol 4:12.
7. Rompe JD, Cacchio A, Furia JP, Maffulli N. 2010. Low-Energy Extracorporeal Shock Wave Therapy as a Treatment for Medial Tibial Stress Syndrome. Am J Sports Med 38:125-132.
8. Yates B, Allen MJ, Barnes MR. 2003. Outcome of Surgical Treatment of Medial Tibial Stress Syndrome. J Bone Joint Surg Am 85:1974-1980.
9. Willems TM, De Clercq D, Delbaere K, et al. 2006. A prospective study of gait related risk factors for exercise-related lower leg pain. Gait Posture 23:91-98.
10. Akiyama K, Noh B, Fukano M, et al. 2015. Analysis of the talocrural and subtalar joint motions in patients with medial tibial stress syndrome. J Foot Ankle Res 8:25.
11. Viitasalo JT, Kvist M. 1983. Some biomechanical aspects of the foot and ankle in athletes with and without shin splints. Am J Sports Med 11:125-130.
12. Bouché RT, Johnson CH. 2007. Medial tibial stress syndrome (tibial fasciitis): a

proposed pathomechanical model involving fascial traction. J Am Podiatr Med Assoc 97:31-36.

13. Dubbeldam R, Nester C, Nene AV, et al. 2013. Kinematic coupling relationships exist between non-adjacent segments of the foot and ankle of healthy subjects. Gait Posture 37:159-164.
14. Pohl MB, Messenger N, Buckley JG. 2007. Forefoot, rearfoot and shank coupling: effect of variations in speed and mode of gait. Gait Posture 25:295-302.
15. Cristofolini L, Angeli E, Juszczyk JM, Juszczyk MM. 2013. Shape and function of the diaphysis of the human tibia. J Biomech 46:1882-1892.
16. Buchanan KR, Davis I. 2005. The Relationship Forefoot, Midfoot, and Rearfoot Static Alignment in Pain-Free Individuals. J Orthop Sports Phys Ther 35:559-566.
17. Kitaoka HB, Luo ZP, Kura H, An KN. 2002. Effect of foot orthoses on 3-dimensional kinematics of flatfoot: a cadaveric study. Arch Phys Med Rehabil 83:876-879.
18. Zifchock RA, Davis I, Hillstrom H, Song J. 2006. The effect of gender, age, and lateral dominance on arch height and arch stiffness. Foot Ankle Int 27:367-372.
19. Fellin RE, Rose WC, Royer TD, Davis IS. 2010. Comparison of methods for kinematic identification of footstrike and toe-off during overground and treadmill running. J Sci Med Sport 13:646-650.
20. Matsas A, Taylor N, McBurney H. 2000. Knee joint kinematics from familiarised treadmill walking can be generalised to overground walking in young unimpaired subjects. Gait Posture 11:46-53.

21. Leardini A, Benedetti MG, Berti L, et al. 2007. Rear-foot, mid-foot and fore-foot motion during the stance phase of gait. Gait Posture 25:453-462.
22. Giandolini M, Poupard T, Gimenez P, et al. 2014. A simple field method to identify foot strike pattern during running. J Biomech 47:1588-1593.
23. Leitch J, Stebbins J, Paolini G, Zavatsky AB. 2011. Identifying gait events without a force plate during running: A comparison of methods. Gait Posture 33:130-132.
24. Edama M, Onishi H, Kubo M, et al. 2017. Gender differences of muscle and crural fascia origins in relation to the occurrence of medial tibial stress syndrome. Scand J Med Sci Sports 27:203-208.
25. Edama M, Kubo M, Onishi H, et al. 2015. The twisted structure of the human Achilles tendon. Scand J Med Sci Sports 25:e497-e503.
26. Michael RH, Holder LE. 1985. The soleus syndrome. A cause of medial tibial stress (shin splints). Am J Sports Med 13:87-94.
27. Holden JP, Cavanagh PR. 1991. The free moment of ground reaction in distance running and its changes with pronation. J Biomech. 24:887-897.
28. Hamstra-Wright KL, Huxel Bliven KC, Bay C. 2014. Risk factors for medial tibial stress syndrome in physically active individuals such as runners and military personnel: a systematic review and meta-analysis. Br J Sports Med 49:362-369.
29. Franettovich M, Chapman AR, Blanch P, et al. 2010. Augmented low-Dye tape alters foot mobility and neuromotor control of gait in individuals with and without exercise related leg pain. J Foot Ankle Res 3:5. doi: 10.1186/1757-1146-3-5.
30. Kelly LA, Cresswell AG, Racinais S, et al. 2014. Intrinsic foot muscles have the

capacity to control deformation of the longitudinal arch. J R Soc Interface 11:20131188.

31. Almedia MO, Davis IS, Lopes AD. 2015. Biomechanical differences of foot strike patterns during running: a systematic review with meta-analysis. J Orthop Sports Phys Ther. 45:738-755.

32. Bandholm T, Boysen L, Haugaard S, et al. 2008. Foot medial longitudinal-arch deformation during quiet standing and gait in subjects with medial tibial stress syndrome. J Foot Ankle Surg 47:89-95.

33. Rathleff MS, Kelly LA, Christensen FB, et al. 2012. Dynamic midfoot kinematics in subjects with medial tibial stress syndrome. J Am Podiatr Med Assoc 102:205-212.

Figure legends

Figure 1. Kinematic waveforms during the stance phase of walking. Kinematic waveforms of the hindfoot relative to the shank (a)–(c), and the forefoot relative to the hindfoot (d)–(f). Dark gray boxes indicate the period of significant differences ($P < 0.05$) between the medial tibial stress syndrome group (MTSS) and matched control group (Control).

Figure 2. Kinematic waveforms during the stance phase of running. Kinematic waveforms of the hindfoot relative to the shank (a)–(c), and the forefoot relative to the hindfoot (d)–(f). Dark gray boxes indicate the period of significant differences ($P < 0.05$) between the medial tibial stress syndrome group (MTSS) and matched control group (Control).

Table 1 Distributions of sport-specific athletes in each group, number of training days per week, and main training sites

		MTSS (n=11)	Control (n=11)	Training days per week (days)	Main training site
Track and field	Short track	5	3	5	Ground
	Middle and long distance	1	4	5-6	Ground and Concrete
	Field	2	0	5	Ground
Tennis		2	4	3-4	Clay or grass court
Basketball		1	0	3-4	Gymnasium

MTSS: Medial tibial stress syndrome

Table 2 Demographic data

	MTSS group		Control group		P value
	Mean (SD)	95% CI	Mean (SD)	95% CI	
Age (years)	20.5 (1.5)	[19.5, 21.6]	20.5 (1.4)	[19.6, 21.5]	1.00
Height (cm)	170.7 (5.4)	[167.1, 174.4]	172.0 (5.6)	[168.0, 175.6]	0.66
Weight (kg)	64.3 (7.8)	[59.0, 69.5]	58.4 (7.2)	[53.5, 63.2]	0.08
BMI (kg/m^2) †	22.0 (2.0)	[20.7, 23.4]	19.7 (1.3)	[18.8, 20.6]	0.005
Arch height index	0.32 (0.02)	[0.30, 0.34]	0.31 (0.02)	[0.30, 0.33]	0.49
Leg heel angle (degree)	4.1 (1.8)	[2.9, 5.4]	3.7 (4.1)	[0.9, 6.4]	0.75

MTSS: Medial tibial stress syndrome, BMI: body mass index, 95% CI: 95% confidence intervals, †: $P < 0.05$

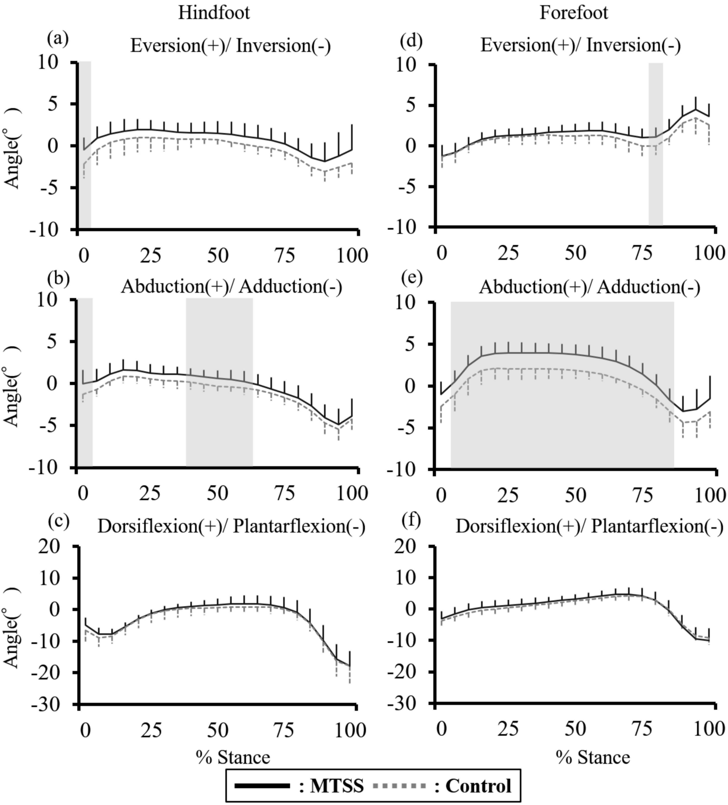
Table 3 Walking speed, pain severity and modified Borg scale

		MTSS group		Control group		*P* value
		Mean (SD)	95% CI	Mean (SD)	95% CI	
Walking speed (km/hour)		5.0 (0.8)	[4.4, 5.5]	4.9 (0.8)	[4.4, 5.4]	0.83
Pain severity	Tenderness	4.2 (1.3)	[3.3, 5.0]	N.A	N.A	N.A
	Walking	0.0 (0.2)	[-0.1, 0.1]	N.A	N.A	N.A
	Running	0.7 (1.3)	[-0.1, 1.6]	N.A	N.A	N.A
Modified Borg scale	Walking	0.3 (0.5)	[0.0, 0.6]	0.3 (0.4)	[0.0, 0.5]	0.81
	Running	2.1 (1.6)	[1.1, 3.2]	1.3 (1.5)	[0.3, 2.3]	0.22

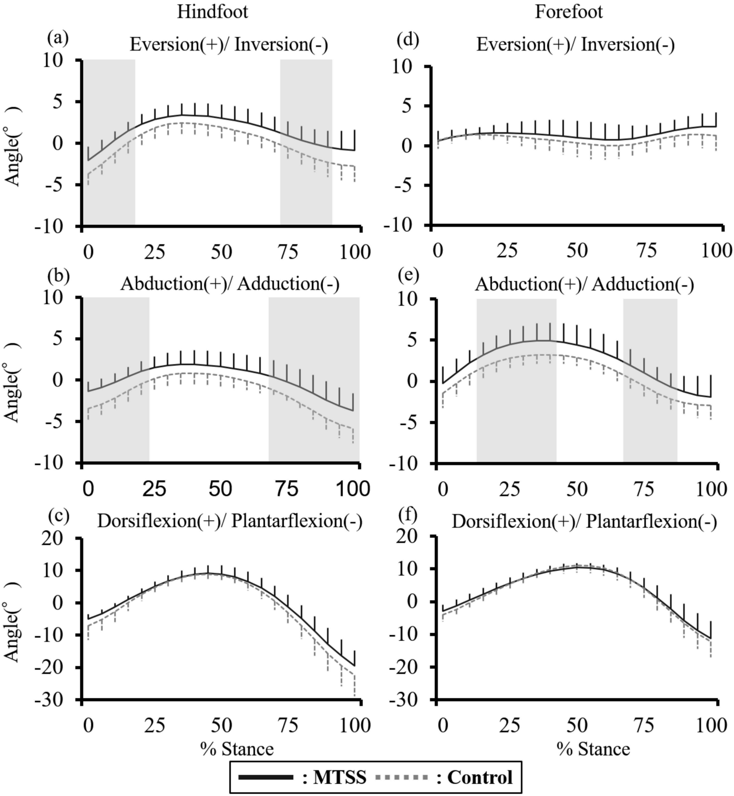
MTSS: Medial tibial stress syndrome, 95% CI: 95% confidence interval, N.A: not applicable

Figure 1. Kinematic waveforms during the stance phase of walking. Kinematic waveforms of the hindfoot relative to the shank (a)–(c), and the forefoot relative to the hindfoot (d)–(f). Dark gray boxes indicate the period of significant differences ($P < 0.05$) between the medial tibial stress syndrome group (MTSS) and matched control group (Control).

Figure 2. Kinematic waveforms during the stance phase of running. Kinematic waveforms of the hindfoot relative to the shank (a)–(c), and the forefoot relative to the hindfoot (d)–(f). Dark gray boxes indicate the period of significant differences ($P < 0.05$) between the medial tibial stress syndrome group (MTSS) and matched control group (Control).



Hindfoot
Forefoot
(a)
Eversion(+)/ Inversion(-)
(d)
Eversion(+)/ Inversion(-)
(b)
Abduction(+)/ Adduction(-)
(e)
Abduction(+)/ Adduction(-)
(c)
Dorsiflexion(+)/ Plantarflexion(-)
(f)
Dorsiflexion(+)/ Plantarflexion(-)
Angle(°)
10
5
0
-5
-10
20
-20
-30
25
50
75
100
% Stance
: MTSS
: Control



Hindfoot
Forefoot
(a)
Eversion(+)/ Inversion(-)
(d)
Eversion(+)/ Inversion(-)
(b)
Abduction(+)/ Adduction(-)
(e)
Abduction(+)/ Adduction(-)
(c)
Dorsiflexion(+)/ Plantarflexion(-)
(f)
Dorsiflexion(+)/ Plantarflexion(-)
Angle(°)
10
5
0
-5
-10
20
-20
-30
25
50
75
100
% Stance
: MTSS
: Control