European Journal of Sport Science, 2015
Vol. 15, No. 2, 173–181, http://dx.doi.org/10.1080/17461391.2014.932848

Routledge
Taylor & Francis Group

ORIGINAL ARTICLE

Structural deformation of longitudinal arches during running in soccer players with medial tibial stress syndrome

BYUNGJOO NOH[1], AKIHIKO MASUNARI[1,2], KEI AKIYAMA[3], MAKO FUKANO[4], TORU FUKUBAYASHI[4], & SHUMPEI MIYAKAWA[1]

[1]*Department of Sports Medicine, Graduate School of Comprehensive Human Sciences, University of Tsukuba, Ibaraki, Japan,* [2]*Center for Medical Sciences, Ibaraki Prefectural University of Health Sciences, Ibaraki, Japan,* [3]*Graduate School of Sport Sciences, Waseda University, Saitama, Japan;* [4]*Faculty of Sport Science, Waseda University, Saitama, Japan*

Abstract

The purpose of this study was to compare angular change and translational motion from the medial longitudinal arch (MLA) and lateral longitudinal arch (LLA) during running between medial tibial stress syndrome (MTSS) and non-MTSS subjects. A total of 10 subjects volunteered, comprising 5 subjects with MTSS and 5 subjects without injury (non-MTSS) as the control group. All subjects performed the test movement that simulated running. Fluoroscopic imaging was used to investigate bone movement during landing in running. Sagittal motion was defined as the angular change and translational motion of the arch. A Mann-Whitney *U*-test was performed to determine the differences in the measured values between the MTSS and non-MTSS groups. The magnitude of angular change for the MLA and LLA was significantly greater for subjects with MTSS than for control subjects. Translational motion of the MLA and LLA of the MTSS group was also significantly greater than that of the non-MTSS group (all $p < 0.05$). Soccer players with MTSS have an abnormal structural deformation of foot during support (or stance) phase of running, with a large decrease in both the MLA and LLA. This abnormal motion could be a risk factor for the development of MTSS in these subjects.

Keywords: *Medial tibial stress syndrome, longitudinal arch, fluoroscopy, foot biomechanics*

Introduction

Mubarak, Gould, Lee, Schmidt, and Hargens (1982) defined medial tibial stress syndrome (MTSS) as 'as a symptom complex seen in athletes who complain of exercise induced pain along the distal posterior-medial aspect of the tibia'. Clanton and Solcher (1994) reported that MTSS is one of the most common causes of exercise-induced leg pain during sports activities. The incidence rate of this injury is 5–15%, and approximately 60% of reports of injuries to the lower extremity describe the development of MTSS in patients (Bates, 1985). In runners, MTSS accounts for an overall injury rate of 2.8 per 1000 athlete exposures (Plisky, Rauh, Heiderscheit, Underwood, & Tank, 2007).

Numerous theories for the development of MTSS have been founded on the functional anatomy of the lower limb and the onset of pathological biomechanics. The traction mechanism suggests that traction to the periosteum can be caused by any strong force exerted by the flexor digitorum longus, tibialis posterior and soleus (Devas, 1958; Reshef & Guelich, 2012). Because the flexor digitorum longus, tibialis posterior and soleus muscles originate from the medial left tibia, these muscles cross the medial aspect of the ankle and run along the plantar surface of the foot (Behnke, 2006; Stickley, Hetzler, Kimura, & Lozanoff, 2009). Therefore, these muscles become overloaded because of excessive movement of the foot, which, in turn, can lead to development of MTSS during sports activities.

A number of studies have addressed the intrinsic and extrinsic risk factors for the onset of MTSS. The extrinsic risk factors are thought to include activity type, intensity, terrain and the choice of footwear (Tweed, Campbell, & Avil, 2008), whereas the intrinsic factors include muscle tightness, weakness of the tibialis posterior, lower extremity malalignment, low levels of bone mineral density (Franklyn, Oakes, Field, Wells, & Morgan, 2008; Magnusson

Correspondence: Shumpei Miyakawa, Laboratory of Sports Medicine, Department of Sports Medicine, Graduate School of Comprehensive Human Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba 305-8577, Japan. Email: miyakawa@taiiku.tsukuba.ac.jp

© 2014 European College of Sport Science

et al., 2001), a high body mass index (Plisky et al., 2007), increased ankle plantar flexion and a previous history of MTSS (Hubbard, Carpenter, & Cordova, 2009). In particular, increased foot pronation during quiet standing (Yates & White, 2004) and malalignment of the lower extremity during weight bearing can result in excessive navicular drop (Moen et al., 2012).

The longitudinal arches support the body and play a critical role in human bipedal locomotion during landing in running, as they facilitate shock absorption against the ground (Fukano & Fukubayashi, 2009). However, the foot consists of two arches: the longitudinal arch and the transverse arch; the longitudinal arch comprises medial and lateral components. Indeed, Fukano and Fukubayashi (2009) recently showed that the lateral longitudinal arch (LLA) provides the same function as the medial longitudinal arch (MLA). In the past, many studies have classified the foot based predominantly on the shape of the arch, such that, to date, the MLA has been reported as the primary source of variability, and there is little information regarding the function of the LLA.

Previous studies have shown that it is difficult to measure the movement of these longitudinal arches. However, in recent years, fluoroscopy has been used for motion analysis as well as to evaluate alterations to the connective tissue structures during gait changes (Gefen, 2003; Gefen, Megido-Ravid, Itzchak, & Arcan, 2000). Several studies have shown that the development of MTSS is related to structural deformation of the longitudinal arches during standing and sports activities (Moen et al., 2012; Raissi, Cherati, Mansoori, & Razi, 2009). Therefore, it is necessary to consider the function of the arch, including both the MLA and the LLA, under dynamic conditions and to investigate structural deformation to these longitudinal arches during running.

Fluoroscopy studies have shown gender-based differences in the functional deformation of the MLA and LLA during landing, and have evaluated the effects of step-up exercises in anterior cruciate ligament deficiency (Fukano & Fukubayashi, 2009, 2012; Kozanek et al., 2011). These studies demonstrated a method to evaluate movement of the bones in the sagittal plane. However, only a few published studies have included an assessment of the LLA, and have yet to establish its role in injury. Fluoroscopy could be used to analyse the relationship between lower extremity injuries and kinematics of bony movement during sport. Therefore, knowledge of the angular changes that occur in the longitudinal arches and the translational motion of the bones during running can be used to develop prevention and treatment strategies for patients with MTSS.

The purpose of this study was to compare the angular change and the translational motion of the MLA and LLA between MTSS and non-MTSS subjects during simulated running. This study considered the relevance of structural deformation that occurs during heel-strike, which is observed in 74.9% of all analysed runners (Hasegawa, Yamauchi, & Kraemer, 2007). We hypothesised that, during running, subjects with MTSS would show significantly different structural deformation of the foot from that of control subjects.

Materials and methods

Subjects and data acquisition

Ten university soccer players volunteered to participate in the study. The MTSS group consisted of five male soccer players with MTSS (age, 21.4 ± 2.3 years; height, 1.75 ± 0.06 m; body mass, 71.0 ± 5.3 kg). Subjects in the MTSS group had been diagnosed with MTSS within a period of 6 months by an experienced orthopedic surgeon. MTSS was defined as exercise-induced pain in the posteromedial aspect of the tibia, and pain in the posteromedial tibia on palpation of at least 5 cm. Patients had experienced symptoms for at least 2 weeks (Yates & White, 2004). The non-MTSS group (control group) consisted of five male soccer players without pain in the posteromedial aspect of the tibia (age, 19.0 ± 1.0 years; height, 1.77 ± 0.05 m; body mass, 68.8 ± 4.7 kg). All subjects were university soccer players recruited through advertising and gave their informed consent. Natural forefoot strikers were excluded from the study. This study was approved by the Ethics Committee of the Graduate School of Comprehensive Human Sciences, University of Tsukuba, Japan.

The testing apparatus was equipped with a C-arm fluoroscopic imaging system (Infinix Celeve-I INFX-8000C, Toshiba Medical Systems, Tochigi, Japan) with a 200-mm (8-in.) image intensifier. Fluoroscopy data was collected at a rate of 60 Hz sampling rate, using a radiation exposure equivalent to 200 mA (1 ms) with an intensity of 50 kV.

Each subject completed three trials of bare foot running on customised platform (size: length 200 × height 100 × width 70 cm) for which a single trial was collected by fluoroscopy for analysis. Prior to the trials, subjects were imaged during quiet standing with the right foot on the platform. For the dynamic measurements, the subjects performed running with a heel-strike. To minimise the effects of foot pronation, lines to guide the foot placement of the subjects were placed at a distance of 10 cm parallel to the image intensifier. The subjects were instructed to land with the centre of their foot, contacting lines to

guide the foot placement with their second toe and the centre of their heel along the running platform at a low speed of 150 beats per minute (bpm) with metronome. Verbal or visual instruction of the heel-strike technique during running was given prior to testing and subjects were required to practice the technique before the trials were captured for analysis.

Data management and analysis

All fluoroscopic images were imported into graphics software (CANVAS™X, ADC System, Miami, FL, USA) and open source software (Image-J, National Institutes of Health, NIH, Bethesda, MD, USA) and manually digitised to dotting points of bony landmarks along the longitudinal arches. The two-dimensional *x*- and *y*-coordinates within the image frame of reference were recorded using a rectilinear calibration grid, which consisted of 16 metal points placed 5 cm apart in a rectangular grid pattern on an acrylic board.

The complete imaging sequences of three trials were collected for analysis, selecting imaging sequences with the clearest osseous contour. We confirmed the interclass correlation coefficient (ICC) of the three trials in advance. The ICC of the kinematics data was $r > 0.85$.

We used a template method that consisted of the calcaneus, first metatarsal and fifth metatarsal bones. This template method, arch angular change and translational motion were defined with reference to the anatomical parameters reported by Fukano and Fukubayashi (2009). Movements of the longitudinal arches in the sagittal plane were established as the angular change and translational motion observed after the heel-strike phase (Figure 1). The section of footage analysed encompassed the angular change of the longitudinal arches from right heel-strike phase to right toe-off phase with 20 frames and the translational motion of the longitudinal arches, with 10 frames within the mid-support phase during running. Furthermore, to evaluate the extent of the activities of the first and fifth metatarsals for the control point, we evaluated the translational displacement of the MLA (d1) and LLA (d2) for the calcaneus using the same analysis section of the translational motion by an equation of distance between two points.

Statistical analysis

A Mann-Whitney *U*-test (non-parametric) was performed to compare the values between the MLA and the LLA (including d1 and d2 displacements). A two tailed test was used to test the null hypotheses. The level of significance was set at $p < 0.05$.

Results

MLA and LLA angular changes

The magnitude of the MLA angular changes that appeared at early support phase of running occurred after about 80–145 ms (Figure 2A) and was significantly greater for subjects in the MTSS group compared with those in the non-MTSS group ($p < 0.05$). The LLA angular change, which appeared between 45 and 290 ms (Figure 2B), was also significantly greater for the MTSS group compared with the non-MTSS group ($p < 0.05$). The angular change of the MLA was 8.6 (1.9)° for subjects in the MTSS group and 6.2 (1.8)° for those in the non-MTSS group. The angular change of the LLA was 10.8 (2.0)° in the MTSS group and 7.0 (1.8)° in the non-MTSS group.

Translational motion

The maximal MLA (M1) translational motion occurred from 65 to 165 ms after heel-strike and was significantly anteriorly displaced in subjects in the MTSS group [1.38 (0.44) cm] compared with those in the non-MTSS group [0.89 (0.43) cm] ($p < 0.05$; Figure 3A). The maximal MLA (M1) was also significantly inferiorly displaced after about 80 ms for subjects in the MTSS group [1.79 (0.69) cm] as compared with those in the non-MTSS group [0.76 (0.49) cm] ($p < 0.05$; Figure 3B).

The LLA (M5) translational motion was also significantly anteriorly displaced for the MTSS group [0.88 (0.35) cm] compared with the non-MTSS group [0.41 (0.25) cm] at 8–165 ms ($p < 0.05$; Figure 3C) and was significantly inferiorly displaced for the MTSS group (1.14 ± 0.38 cm) compared with the non-MTSS group [0.35 (0.33) cm] after about 65 ms ($p < 0.05$; Figure 3D).

d1 and d2 displacements

A significantly different d1 displacement was measured for the MTSS group as compared with the non-MTSS group [0.58 (0.24) cm versus 0.41 (0.16) cm, respectively; $p < 0.05$] about 65 ms after heel-strike (Figure 4A). Similarly, a significantly different d2 displacement was observed between the two groups after about 50 ms [Figure 4B; 0.47 (0.41) cm versus 0.14 (0.03) cm, respectively; $p < 0.05$].

Discussion

This study investigated the structural deformation that occurs to the longitudinal arches during simulated running in subjects with MTSS using fluoroscopy and compared these findings with those of uninjured control subjects. The data confirmed the

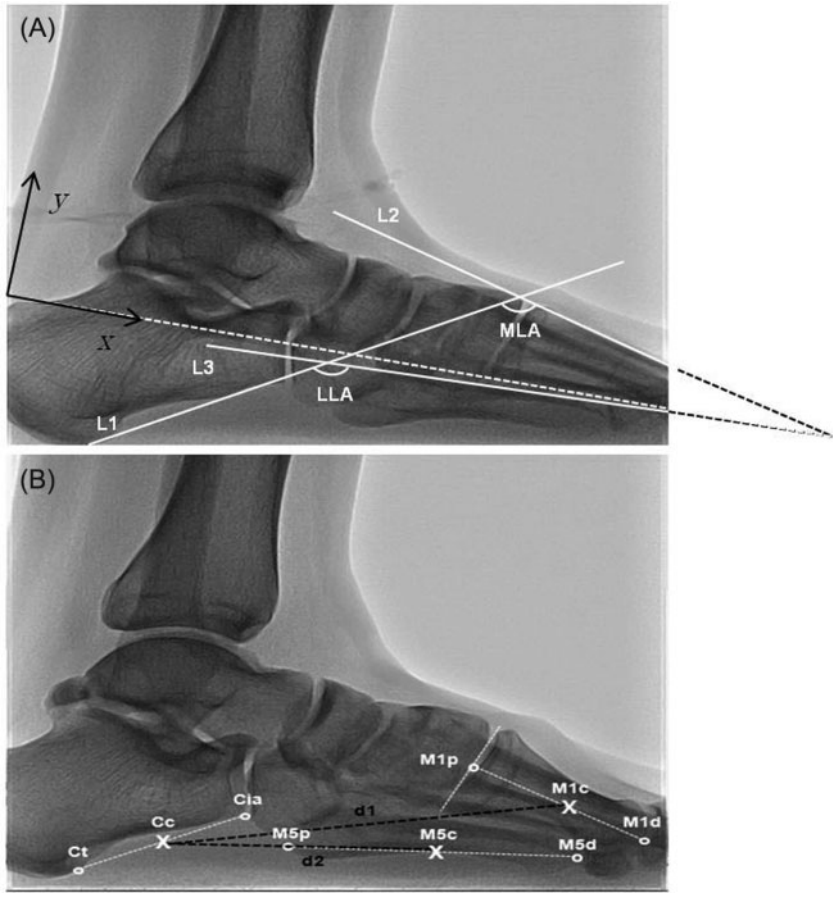


Figure 1. (A) Definitions of the MLA and LLA angular coordinates. L1 describes the line that connects the calcaneal anterior tubercle and the medial process of the calcaneal tuberosity. L2 describes the dorsal aspect of the first metatarsal bone shaft. L3 describes the dorsal aspect of the fifth metatarsal bone shaft. The MLA angle is defined as the obtuse angle created by the intersection of L1 and L2. The LLA angle is defined as the obtuse angle created by the intersection of L1 and L3. (B) Definitions of the MLA and LLA translational motion coordinates. The coordinates of the *x*–*y* axis marking the anterior epiphyseal portion of the first metatarsal (M1d), fifth metatarsal (M5d) and calcaneus (Cia), and the posterior epiphyseal portion of the first metatarsal (M1p), fifth metatarsal (M5p) and calcaneus (Ct) are shown. The bony coordinates of the centres of the calcaneus (M1c, M5c and Cc) are calculated using coordinate averages of the M1p and M1d, M5p and M5d, Ct and Cia. The d1 describes the line that connects the Cc and M1c. The d2 describes the line that connects the Cc and M5c. Each frame recorded the bony coordinates of the M1c, M5c, Cc, d1 and d2.

initial hypothesis that subjects with MTSS would show significantly different structural deformation of the foot from that of control subjects during running as compared with non-MTSS control subjects.

There is still much debate about the etiology of MTSS. MTSS has been broadly investigated with studies showing that increased minor movements between the foot bones brought on by repetitive and, at times, malaligned weight bearing during landing in running could be the cause of the pathological changes in the connective tissues (Bates, 1985; Moen et al., 2012).

Increased angular changes of the arches in subjects with MTSS

In this study, we showed that angular changes in the MLA and LLA were increased during running in subjects with MTSS as compared with control subjects. Moreover, we found that the angular change in the LLA was greater than that in the MLA after the heel-strike phase. The amount of time to maximum angular change in the MTSS group (at about 235–250 ms) was faster than that in the non-MTSS group (at about 265 ms). Excessive pronation, such as that observed with increased angular change of the MLA and LLA, exerts stress to the musculoskeletal structures of the foot and ankle, and transfers abnormal stresses on the lower leg (McKeag & Dolan, 1989; Yates & White, 2004). Furthermore, because of the likely role of the MLA and LLA in resisting depression of the longitudinal arch during landing in running, this increased angular change in the MLA and LLA in MTSS subjects probably causes a decrease in the foot supinator strength and an increase in the internal rotation torque of the lower extremity (Hintermann & Nigg, 1998). This leads to inflammation and

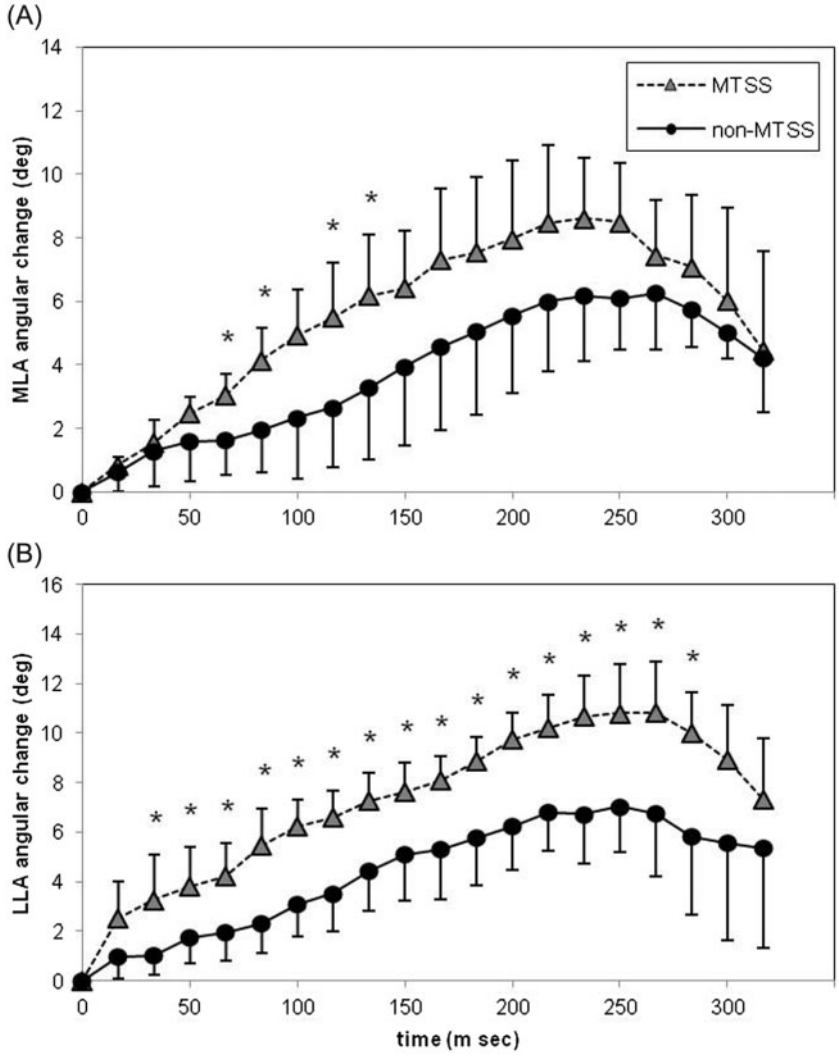


Figure 2. Medial and lateral longitudinal arch movements in the sagittal plane. Mean (SD) angular change of the medial (A) and lateral (B) longitudinal arches during running in the MTSS versus non-MTSS groups. Asterisks denote statistically significant differences at $p < 0.05$.

increased stress to the periosteum of the tibia in subjects with MTSS. While the maximal angular change of the MLA appeared during early support phase, the maximal angular change of the LLA appeared during mid-support phase of movement of the foot. Thus, the LLA was in contact with the ground during the entire mid-support phase. For this reason, the LLA was directly under the influence of a load. Terawaki, Kouno, Fujiya, Yatabe, and Suga (2009) showed that the centre of pressure in the foot was located on the outside in subjects with MTSS more than that seen in the control subjects after the mid-stance phase during gait. Although the subjects in this study were analysed while running, one might speculate that the centre of pressure was on the outer side of the foot after the mid-support phase. Thus, these results indicate that subjects with MTSS have an abnormal structural deformation of foot during support phase of running.

Increased translational motion changes in subjects with MTSS

The MLA and LLA were anteroinferiorly displaced in subjects with MTSS as compared with the non-MTSS subjects. Because the displacement of the metatarsals were increased, muscle activation of the plantarflexors (flexor digitorum longus, tibialis posterior and soleus), which insert onto these bones, was reduced. Accordingly, because stress to the tibial periosteum was increased, traction forces also increased in MTSS subjects (Beck & Osternig, 1994; Gath & Miller, 1989; Saxena, O'Brien, & Bunce, 1990). These plantarflexors then perform the functions of the primary foot supinators. In particular, the tibialis posterior generates the greatest supination torque. The extensive insertion of this muscle provides supination torque to the midfoot (Donald, 2004). When supination torque is reduced, muscle activation of the plantarflexors is

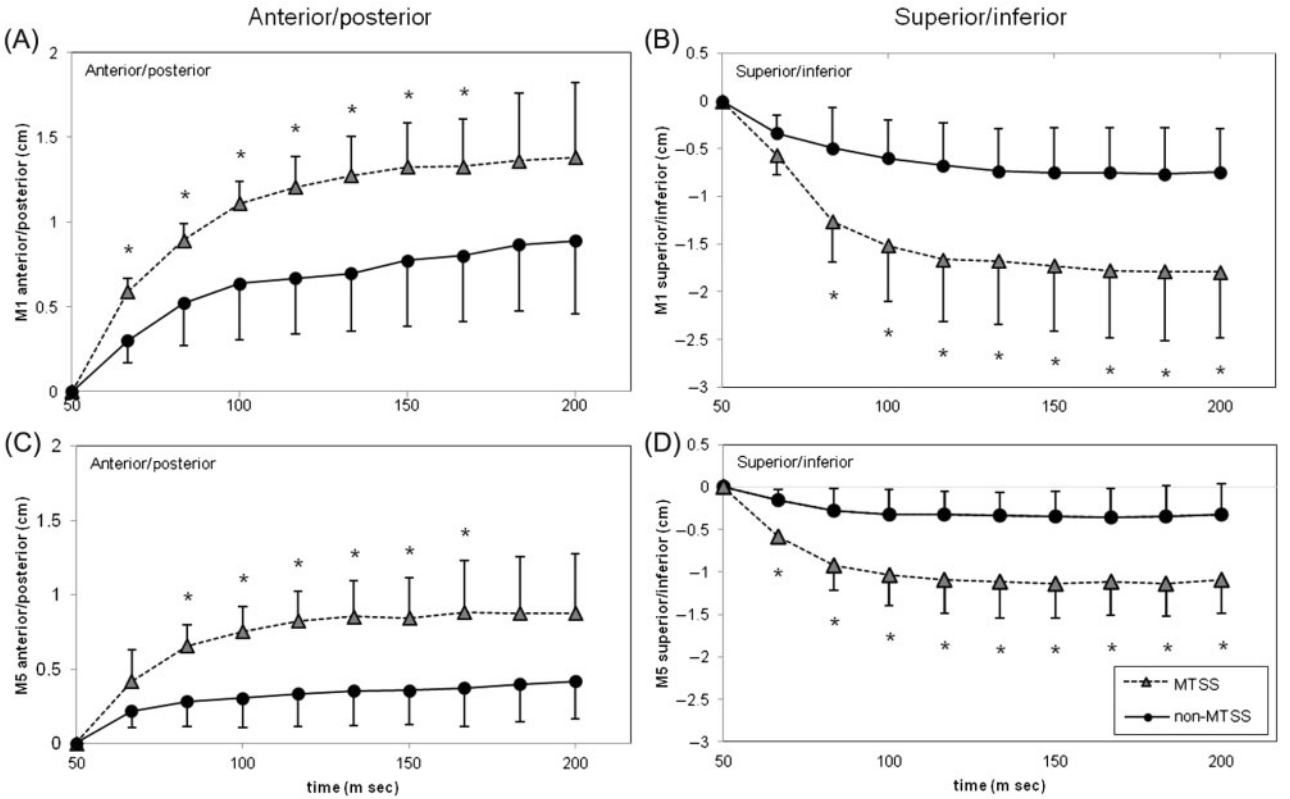


Figure 3. Medial and lateral longitudinal arch movements in the sagittal plane. Mean (SD) translational motion of the medial (A, B) and lateral (C, D) longitudinal arches during running in the MTSS versus non-MTSS groups. Asterisks denote statistically significant differences at $p < 0.05$.

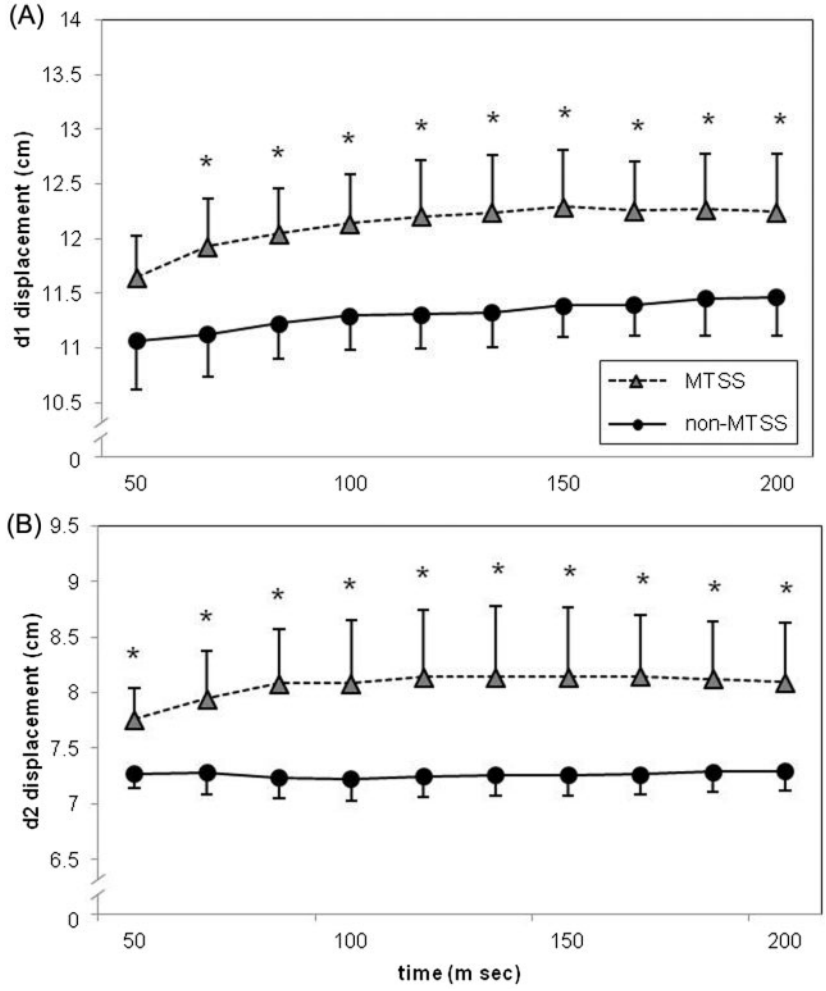


Figure 4. Medial and lateral longitudinal arch movements in the sagittal plane. Mean (SD) translational displacement of the d1 (A) and d2 (B) during running in the MTSS versus non-MTSS groups. The d1 (MLA) shows the distance from the calcaneus to the first metatarsal and the d2 shows the distance from the calcaneus to the fifth metatarsal. Asterisks denote statistically significant differences at $p < 0.05$.

also reduced. In line with this reasoning, it would seem that the plantarflexors could not provide proper arch support during landing in running because of reduced supinator activity. We therefore suggest that increased supination torque could improve the symptoms of MTSS; this could be achieved by strengthening the tibialis posterior with the use of balance training and elastic resistance band exercises.

One might speculate that the inferior displacement of the longitudinal arch components was likely caused by early muscle fatigue because of insufficient shock absorption on landing during the initial resistance to weight bearing in sports involving running. Thus, these results indicate that translational motion of the metatarsals is controlled primarily by flexor digitorum longus, tibialis posterior and soleus. Therefore, effective prevention and rehabilitation for subjects with MTSS could be achieved by improving the function and strength of these muscles.

Mann and Inman (1964) showed that the intrinsic muscles in the foot exert considerable flexion force on the forefoot and play a critical role in muscle stabilisation in the foot. Therefore, these muscles are likely to be the main contributors to the muscle support of the arch. Banks, Downey, Martin, and Miller (2001) also reported that ligaments in the foot provide enough passive support to maintain the integrity of the foot during quiet standing. Thus, the soft tissues of the foot determine foot shape and stabilisation. However, in the case where there is a soft tissue problem, such as increased activation in the intrinsic muscles or increased ligamentous laxity in the foot, intrinsic muscles strength of the foot would be decreased. This may explain the long-range d1 and d2 displacement for subjects in the MTSS group.

Studies by Yates and White (2004) and Bartosik et al. (2010) found that individuals with MTSS had less ankle dorsiflexion. This would shorten the eccentric contraction time of the dorsiflexors from

heel-strike phase to mid-support phase during running. Plantarflexion torque transmits its forces to the ankle joint while the dorsiflexors engage in proper eccentric contraction on landing in running. Therefore, a shortened dorsiflexion time would lead to increased plantarflexion strength (Gehlsen & Seger, 1980) and range of motion in MTSS individuals (Hubbard et al., 2009) during the heel-strike phase of running. This dysfunction would not provide proper arch support and the d1 and d2 would not be under the control of the dorsiflexors upon landing in running. To treat this dysfunction, we recommend that subjects with MTSS perform eccentric contraction exercises of the dorsiflexors to improve dorsiflexion torque. Furthermore, because decreased dorsiflexion suggests excessive tightness in the triceps surae muscle of calf, we also recommend that MTSS subjects perform triceps surae stretching to alleviate this tightness. It may also be beneficial for MTSS subjects to obtain neoprene insoles or custom-designed insoles for proper locomotion of the intrinsic muscles of the foot and to provide proper arch support during heel-strike while running. These treatment options would collectively help to reduce internal rotation torque of the lower extremity and provide proper arch support for subjects.

Methodological limitations

This study and its experimental design have some methodological limitations that should be considered when interpreting the results. First, in our study, only 10 subjects were included. This study included a relatively small sample size because of the risk of X-ray radiation exposure. Second, we investigated foot biomechanics during running in soccer players with MTSS that consisted of three-dimensional movements but only two-dimensional data interpretation. We endeavored to minimise potential misrepresentations by using an attached guideline with white sellotape for the landing point. Nonetheless, there is the possibility that error in the angular deformation calculations could occur due to pronation or out of plane movement of the foot. Third, this study was performed using a relatively low sampling frequency of 60 Hz compared with other motion analysis techniques. This sampling frequency was restricted to evaluate bony movements during running. However, to minimise these technical limitations of fluoroscopy, we used a single investigator to perform the measurements. Finally, subjects performed the running test at a relatively low velocity of 150 bpm. However, the subjects were asked to perform a single foot landing that simulated real running conditions and allowed us to compartmentalise the run and gait.

Perspectives

The research on motion characteristics of the longitudinal arches during sports activities provides important new insights into the etiology of MTSS. Numerous studies have investigated the risk factors associated with the development of MTSS, assessing the function of the flexor digitorum longus, tibialis posterior and soleus muscles. In this study, we show that movement of these muscles at their insertion on the plantar surface of the foot is higher in MTSS subjects. These results also implicate changes in LLA positioning as a risk factor for the development of MTSS. Further research is needed to investigate the relationship between the LLA and the development of MTSS. These results may help to establish preventive measures for and improve the management of MTSS in athletes.

Conclusions

This study investigated the kinematics of the longitudinal arches in subjects with MTSS during running. The data analysis confirmed the initial hypothesis, showing significant angular changes in the MLA and LLA of subjects with MTSS and an increased anteroinferiorly displaced translational motion of the first and fifth metatarsals during running. Excessive structural deformation to the MLA and LLA could be a risk factor for the development of MTSS.

References

Banks, A. S., Downey, M. S., Martin, D. E., & Miller, S. J. (2001). *McGlamry's comprehensive book of foot and ankle surgery* (3rd ed.). Philadelphia, PA: Lippincott Williams & Wilkins.

Bartosik, K. E., Sitler, M., Hillstrom, H. J., Palamarchuk, H., Huxel, K., & Kim, E. (2010). Anatomical and biomechanical assessments of medial tibial stress syndrome. *Journal of the American Podiatric Medical Association*, *100*(2), 121–132. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/20237364

Bates, P. (1985). Shin splints: A literature review. *British Journal of Sports Medicine*, *19*(3), 132–137. doi:10.1136/bjsm.19.3.132

Beck, B. R., & Osternig, L. R. (1994). Medial tibial stress syndrome: The location of muscles in the leg in relation to syndrome. *Journal of Bone and Joint Surgery. American Volume*, *76*, 1057–1061. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8027114

Behnke, R. S. (2006). *Kinetic anatomy* (2nd ed., p. 223). Champaign, IL: Human Kinetics.

Clanton, T. O., & Solcher, B. W. (1994). Chronic leg pain in the athlete. *Clinical Journal of Sport Medicine*, *13*, 743–759. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7805104

Devas, M. B. (1958). Stress fractures of the tibia in athlete or shin soreness. *Journal of Bone and Joint Surgery. British Volume*, *40-B*, 227–239. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/13539106

Donald, A. N. (2004). *Kinesiology of the musculoskeletal system* (p. 563). St. Louis: Mosby.

Franklyn, M., Oakes, B., Field, B., Wells, P., & Morgan, D. (2008). Section modulus is the optimum geometric predictor

for stress fractures and medial tibial stress syndrome in both male and female athletes. *American Journal of Sports Medicine*, *36*, 1179–1189. doi:10.1177/0363546508314408

Fukano, M., & Fukubayashi, T. (2009). Motion characteristics of the medial and lateral longitudinal arch during landing. *European Journal of Applied Physiology*, *105*, 387–392. doi:10.1007/s00421-008-0915-3

Fukano, M., & Fukubayashi, T. (2012). Gender-based differences in the functional deformation of the foot longitudinal arch. *Foot*, *22*(1), 6–9. doi:10.1016/j.foot.2011.08.002

Gath, W. P. Jr., & Miller, S. T. (1989). Evaluation of claw toe deformity, weakness of the foot intrinsic, and posteromedial shin pain. *American Journal of Sports Medicine*, *17*, 821–827. doi:10.1177/036354658901700617

Gefen, A. (2003). Plantar soft tissue loading under the medial metatarsals in the standing diabetic foot. *Medical Engineering & Physics*, *25*, 491–499. doi:10.1016/S1350-4533(03)00029-8

Gefen, A., Megido-Ravid, M., Itzchak, Y., & Arcan, M. (2000). Biomechanical analysis of the three-dimensional foot structure during gait: A basic tool for clinical applications. *Journal of Biomechanical Engineering*, *122*, 630–639. doi:10.1115/1.1318904

Gehlsen, G. M., & Seger, A. (1980). Selected measures of angular displacement, strength, and flexibility in subjects with and without shin splints. *Research Quarterly for Exercise and Sport*, *51*, 478–485. doi:10.1080/02701367.1980.10608070

Hasegawa, H., Yamauchi, T., & Kraemer, W. J. (2007). Foot strike patterns of runners at the 15-km point during an elite-level half marathon. *Journal of Strength and Conditioning Research*, *21*, 888–893.

Hintermann, B., & Nigg, B. M. (1998). Pronation in runners: Implications for injuries. *Sports Medicine*, *26*, 169–176. doi:10.2165/00007256-199826030-00003

Hubbard, T. J., Carpenter, E. M., & Cordova, M. L. (2009). Contributing factors to medial tibial stress syndrome: A prospective investigation. *Medicine and Science in Sports and Exercise*, *41*, 490–496. doi:10.1249/MSS.0b013e31818b98e6

Kozanek, M., Hosseini, A., de Velde, S. K., Moussa, M. E., Li, J. S., Gill, T. J., & Li, G. (2011). Kinematic evaluation of the step-up exercise in anterior cruciate ligament deficiency. *Clinical Biomechanics*, *26*, 950–954. doi:10.1016/j.clinbiomech.2011.05.003

Magnusson, H. I., Westlin, N. E., Nyqvist, F., Gärdsell, P., Seeman, E., & Karlsson, M. K. (2001). Abnormally decreased regional bone density in athletes with medial tibial stress syndrome. *American Journal of Sports Medicine*, *29*, 712–715.

Mann, R., & Inman, V. T. (1964). Phasic activity of intrinsic muscles of the foot. *Journal of Bone and Joint Surgery*, *46*, 469–481. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/14131426

McKeag, D. B., & Dolan, C. (1989). Overuse syndromes of the lower-extremity. *Physician and Sports Medicine*, *17*, 108–123. Retrieved from https://physsportsmed.org/

Moen, M. H., Bongers, T., Bakker, E. W., Zimmer-mann, W. O., Weir, A., Tol, J. L., & Backx, F. J. (2012). Risk factors and prognostic indicators for medial tibial stress syndrome. *Scandinavian Journal of Medicine and Science in Sports*, *22*(1), 34–39. doi:10.1111/j.1600-0838.2010.01144.x

Mubarak, S. J., Gould, R. N., Lee, Y. F., Schmidt, D. A., & Hargens, A. R. (1982). The medial tibial stress syndrome: A cause of shin splints. *American Journal of Sports Medicine*, *10*, 201–205. doi:10.1177/036354658201000402

Plisky, M. S., Rauh, M. J., Heiderscheit, B., Underwood, F. B., & Tank, R. T. (2007). Medial tibial stress syndrome in high school cross-country runners: Incidence and risk factors. *Journal of Orthopaedic and Sports Physical Therapy*, *37*(2), 40–47. doi:10.2519/jospt.2007.2343

Raissi, G. R., Cherati, A. D., Mansoori, K. D., & Razi, M. D. (2009). The relationship between lower extremity alignment and medial tibial stress syndrome among non-professional athletes. *Sports Medicine, Arthroscopy, Rehabilitation, Therapy and Technology*, *1*(1), 11–18. doi:10.1186/1758-2555-1-11

Reshef, N., & Guelich, D. R. (2012). Medial tibial stress syndrome. *Clinics in Sports Medicine*, *31*(2), 273–290. doi:10.1016/j.csm.2011.09.008

Saxena, A., O'Brien, T., & Bunce, D. (1990). Anatomic dissection of the tibialis posterior muscle and its correlation to medial tibial stress syndrome. *Journal of Foot Surgery*, *29*(2), 105–108. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2338467

Stickley, C. D., Hetzler, R. K., Kimura, I. F., & Lozanoff, S. (2009). Crural fascia and muscle origins related to medial tibial stress syndrome symptom location. *Medicine and Science in Sports and Exercise*, *41*(11), 1191–1196. doi:10.1249/MSS.0b013e3181a6519c

Terawaki, A., Kouno, T., Fujiya, H., Yatabe, K., & Suga, E. (2009). Foot pressure during standing and walking related to the onset of Shin splints. *Japanese Journal of Physical Fitness and Sports Medicine*, *58*, 767. (In Japanese). Retrieved from https://www.jstage.jst.go.jp/browse/jspfsm/58/6/_contents

Tweed, J. L., Campbell, J. A., & Avil, S. J. (2008). Biomechanical risk factors in the development of medial tibial stress syndrome in distance runners. *Journal of the American Podiatric Medical Association*, *98*, 436–444. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/19017851

Yates, B., & White, S. (2004). The incidence and risk factors in the development of medial tibial stress syndrome among naval recruits. *American Journal of Sports Medicine*, *32*, 772–780. doi:10.1177/0095399703258776

Copyright of European Journal of Sport Science is the property of Taylor & Francis Ltd and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.