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Do Plantar-Flexor Muscle Structure and Function Contribute to Medial Tibial Stress Syndrome in Long-Distance Runners? A Case Report

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Two long-distance runners developed medial tibial stress syndrome (MTSS; male age = 26.3 years, female age = 47.5 years) after baseline assessment of plantar-flexor muscle structure and function and spatiotemporal running variables. B-mode ultrasound and lean leg girth characterized plantar-flexor muscle structure. Handheld dynamometry and a single-leg heel raise–to-failure protocol characterized plantar-flexor muscle function. Finally, spatiotemporal running variables were determined during a treadmill protocol. The 2 runners who developed MTSS demonstrated less plantar-flexor strength and endurance capacity than published comparative control data and marked variability in muscle structure. Reduced plantar-flexor strength and endurance capacity were thought to contribute to an impaired ability to resist tibial-bending moments during midstance due to earlier muscle fatigue. Earlier muscle fatigue could, in turn, contribute to increased tibial-bending moments and MTSS development. Therefore, assessing plantar-flexor muscle strength and endurance might help to identify athletes at risk of developing MTSS.

Key Words: shin splints, injury prevention

Key Points

- Less plantar-flexor muscle strength and endurance are possibly associated with developing medial tibial stress syndrome.
- Clinicians could assess plantar-flexor muscle strength and endurance to identify individuals at risk of developing medial tibial stress syndrome.

Medial tibial stress syndrome (MTSS) is a leg injury frequently experienced by running and jumping athletes.[1] Unfortunately, there is a lack of high-quality evidence for any MTSS treatment intervention being better than rest.[2] Two pathophysiologies of MTSS development predominate in the literature: (1) muscular traction and (2) tibial bending–induced MTSS.[1] The prevailing pathophysiology is a bone-overload injury caused by tibial bending.[1] Although leg musculature can modulate tibial loads, prospective studies investigating how leg muscle structure and function are associated with MTSS development are lacking.[1,3] Therefore, further research is required to assess the role of leg muscles in MTSS development.

Mattock et al found that runners with MTSS displayed differences in plantar-flexor muscle size, strength, and endurance capacity compared with matched controls.[4] The authors concluded that differences in leg muscle structure and function likely rendered MTSS-symptomatic individuals less able to withstand the tibial-bending moment generated during midstance, potentially contributing to MTSS development or the slow recovery time typically seen with MTSS patients. However, Mattock et al could not confirm whether the between-groups differences were a cause or effect of MTSS because the study was not prospective.[4] We therefore aimed to characterize the structure and function of the plantar-flexor muscles at baseline of long-distance runners who later developed MTSS and compare these data with published healthy comparative control data.

BASELINE ASSESSMENT

Fifty-two asymptomatic long-distance runners were assessed at baseline to characterize their plantar-flexor muscle structure, function, and gait as described below. After baseline assessment, 2 runners developed leg pain and attended a follow-up assessment with an experienced podiatrist who diagnosed MTSS based on published criteria.[5] Ethical clearance was obtained from the institution's human research ethics committee (2015/012), and before inclusion, participants provided written informed consent.

Plantar-Flexor Muscle Structure

B-mode ultrasound (FUJIFILM) was used to quantify the thickness (millimeters) of each runner's peroneal muscles, soleus, flexor hallucis longus, and medial and

Table 1. **Plantar-Flexor Muscle Strength Testing Procedures**[a]

Muscle	Participant Position	Action
Peroneal muscles	Side lying	Eversion of the foot with plantar flexion of the ankle joint while applying resistance against the lateral border and sole of the foot, in the direction of inversion of the foot and dorsiflexion of the ankle joint
Soleus	Prone with the knee flexed to 90°	Plantar flexion of the ankle joint, without inversion or eversion of the foot and resistance applied against the metatarsal heads
Triceps surae (gastrocnemius and soleus)	Prone with the knee extended	Plantar flexion of the foot, with resistance applied against the metatarsal heads
Flexor hallucis longus	Supine	Plantar flexion of the hallux without plantar flexion of the ankle joint or lesser digits, with resistance applied against the distal phalanx of the hallux

[a] From Kendall et al.[8]

lateral gastrocnemius muscles. It was only possible to measure the cross-sectional area (CSA; square millimeters) of the peroneal muscles and flexor hallucis longus due to the constraints of the ultrasound probe. Muscle thickness (millimeters) and CSA (square millimeters) were measured using Image J software (National Institute for Health). Lean leg girth was calculated by measuring the maximal leg girth while a participant stood, which was corrected for adipose tissue thickness and normalized to leg length.[4] Leg girth was normalized to each participant's leg length to account for differences in height being a confounding variable.

Plantar-Flexor Muscle Function

Plantar-flexor muscle function was characterized by measuring each runner's maximal voluntary isometric contraction (MVIC) strength against a handheld dynamometer (Lafayette Inc) for the peroneal muscles, soleus, flexor hallucis longus, and triceps surae muscles (see Table 1). To isolate the soleus muscle, participants lay prone, and soleus muscle strength was assessed with the knee flexed to 90°. To assess the triceps surae (gastrocnemius and soleus) muscle strength together, participants lay prone with the knee fully extended (see Figure).[6] The strength measurements were normalized to each runner's body weight.[7] Plantar-flexor muscle endurance capacity was assessed using a single-leg heel raise–to-failure protocol, with the maximum number of repetitions recorded.[7]

After structural and functional muscle assessment, individuals ran at a self-selected speed equivalent to their most recent 10-km race time on a treadmill (SportsArt Fitness) for 5 minutes to analyze their running gait. We determined running speed, stride length, and cadence during the final 1 minute of the trial.

Measurement reliability was established before data collection, and intraclass correlation coefficients for leg-muscle thickness (all >0.671) and CSA (all >0.932), lean leg girth (0.992), and leg MVIC strength (all >0.776) confirmed the measurements were moderately to highly reliable. The plantar-flexor endurance protocol was previously established to have excellent test-retest reliability.[8]

CASE SERIES PRESENTATION

Case 1

A male long-distance runner (see Table 2) with no confounding medical condition developed bilateral MTSS 16 months after the baseline assessment. Exercise and eccentric loading of the plantar-flexor muscles induced pain that remained after training ceased. The pain eased after warm-up exercises and relative rest. No lower limb paresthesia was reported, and upon palpation, diffuse pain was reproduced bilaterally at the posterior middle third of the tibia. Compared with published control data, the long-distance runner displayed a 58% and 64% deficit in left and right plantar-flexor endurance.[4] Before developing MTSS, he had a 12-week break from running before recommencing a structured running program at his previous training load of 25 km/wk, 4 weeks before developing leg pain. This rest period could have contributed to musculoskeletal deconditioning, causing his tibial loading capacity to be exceeded when he resumed training.[1]

Case 2

A female long-distance runner (see Table 2) developed bilateral MTSS 3 months after the baseline assessment. Pain, which was worse on her left than her right limb, was induced by exercise but eased after a warm-up and returned after training ceased. She reported that pain decreased with relative rest, and there was no lower limb paresthesia. Palpation revealed diffuse pain bilaterally along the length of the posteromedial tibial border and gastrocnemius and soleus muscle tenderness. She had a history of MTSS 3 years earlier and was prescribed custom-made orthotics with bilateral medial longitudinal arch support but had not received podiatric treatment in the 12 months before baseline assessment. The long-distance runner displayed a 47% and 24% deficit in left and right plantar-flexor endurance compared with published control data,[4] and she also exhibited considerable between-limbs asymmetry in the endurance test, whereby her left limb was 35% weaker than her right limb (see Table 3). The markedly reduced plantar-flexor endurance capacity displayed by her left limb could have contributed to an impaired ability to resist tibial-bending moments and explained the more pronounced MTSS symptoms experienced on that limb.[8]

She also reported an 8-year history of hypothyroidism managed with 50 µg/d of Eutroxsig (levothyroxine). Incorrectly dosed thyroxine replacement hormone can affect musculoskeletal physiological function.[9] However, no association has been made between MTSS development and thyroid dysfunction. Female sex, a history of MTSS and orthotic use, and an increased body mass index are reported to raise an individual's risk of MTSS recurrence.[1] However,

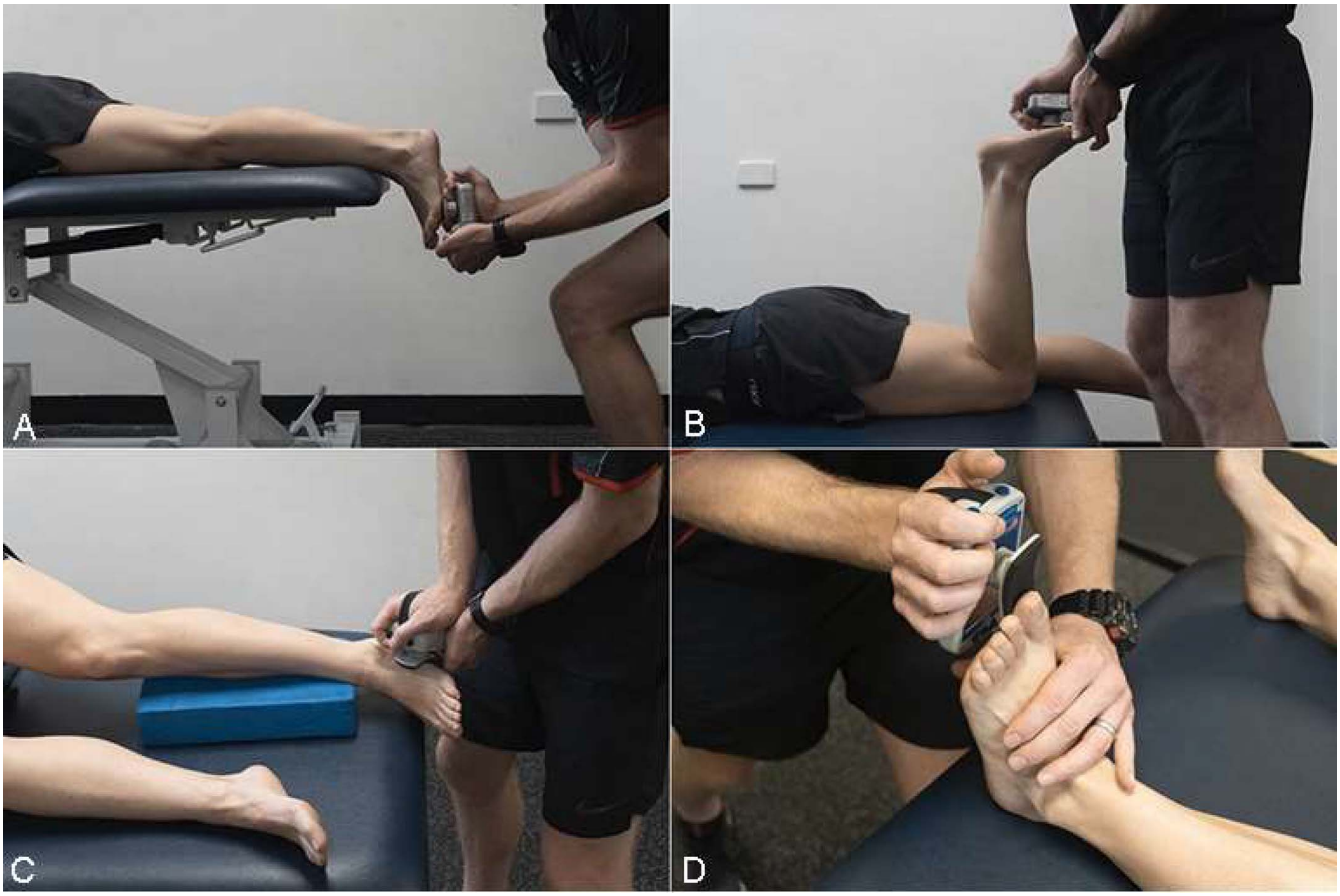

Figure. Plantar-flexor muscle strength testing procedures for the A, triceps surae; B, soleus; C, peroneal muscles; and D, flexor hallucis longus.

as the long-distance runner cannot modify her sex and medical history, we needed to identify modifiable risk factors that can be targeted to keep runners free of MTSS injury.

Comparative Outcome

At baseline assessment, the participants in both cases displayed less plantar-flexor endurance capacity and less flexor hallucis longus, triceps surae, and peroneal muscle strength than seen in published data (see Table 3).[4,8] Furthermore, they displayed less MVIC plantar-flexion strength with the knee extended than with the knee flexed (flexed to extended MVIC strength ratios >1) than the controls (see Table 3).[4] In contrast, the controls displayed greater MVIC plantar-flexion strength with the knee extended than with the knee flexed (flexed to extended MVIC strength ratio of 0.9).[4] Compared with control data, they displayed marked variability in leg muscle structure, suggesting that plantar-flexor strength and endurance assessment is more useful than structural muscle assessment in identifying individuals at risk of developing MTSS.[4]

Table 2. Characteristics of Cases 1 and 2 at Baseline Assessment and Comparative Control Data

Variables	Case 1	Case 2	Comparative Controls[a]
Sex, female/male	Male	Female	8/3
Age, y	26.3	47.5	32.6 ± 8.9
Height, cm	191.5	159.0	171.0 ± 8.8
Mass, kg	78.8	71.8	67.1 ± 8.6
Body mass index, kg/m^2	21.5	28.4	23.1 ± 2.7
Running distance, km/wk	21.5	28.4	34.1 ± 9.4

[a] Comparative control data are expressed as mean ± SD except for sex, which is a count, and are from Mattock et al.[4]

DISCUSSION

A lack of evidence-based treatment options for MTSS necessitates further prospective research to understand what factors contribute to the syndrome. Although the 2 individuals who developed MTSS displayed variations in their leg-muscle structure, both showed less plantar-flexor muscle endurance and strength compared with a similar cohort of asymptomatic long-distance runners.[4]

This case series was the first to report prospective data on the plantar-flexor endurance capacity of long-distance runners who developed MTSS. The bilateral plantar-flexor endurance deficits displayed by both cases are consistent with previous case-control studies in which individuals with MTSS completed 30% and 56% fewer heel raises than matched controls.[4,8] Reduced plantar-flexor muscle endurance capacity could contribute to an impaired ability to resist tibial-bending moments during midstance due to the muscles fatiguing more quickly. An impaired ability to resist tibial-bending moments will, in turn, expose the tibia to greater forces, possibly contributing to tibial overload and MTSS development.[8]

Table 3. Plantar-Flexor Muscle Structure and Function of the Right and Left Limbs of Cases 1 and 2 and Comparative Control Data

Variables	Case 1		Case 2		Comparative Controls, Mean ± SD[a]
	Right	Left	Right	Left	
Plantar-flexor muscle structure					
FHL thickness, mm	18.7	21.3	13.7	16.5	20.6 ± 4.0
FHL CSA, mm^2	520.4	505.2	384.4	327.0	538.6 ± 126.0
GL thickness, mm	17.1	14.9	14.0	13.8	13.9 ± 1.9
GM thickness, mm	18.0	18.9	18.4	19.3	18.9 ± 2.1
PER thickness, mm	13.1	13.7	20.3	19.2	14.9 ± 2.0
PER CSA, mm^2	343.6	344.1	445.8	442.2	354.2 ± 57.7
SOL thickness, mm	20.9	18.9	18.1	16.7	18.4 ± 3.1
Normalized lean leg girth	0.8	0.8	1.2	1.2	0.95 ± 0.8
Plantar-flexor muscle function					
FHL, %BW	15.3	14.9	23.8	26.7	27.0 ± 11.2
Triceps surae, %BW	65.2	72.7	58.9	61.1	79.6 ± 14.1
PER, %BW	24.7	26.1	22.9	17.0	33.5 ± 7.5
SOL, %BW	79.8	76.4	65.5	70.2	72.7 ± 15.9
Knee flexed to knee extended muscle strength ratio	1.2	1.1	1.1	1.1	0.9
Plantar-flexor endurance, repetitions	27.0	31.0	57.0	40.0	75.4 ± 73.8
Running speed, m/s	3.9		1.8		Not reported
Cadence, bilateral steps/min	168.0		168.0		Not reported
Step length, m	1.4	1.4	0.6	0.7	Not reported

Abbreviations: BW, body weight; CSA, cross-sectional area; FHL, flexor hallucis longus; GL, lateral gastrocnemius; GM, medial gastrocnemius; PER, peroneal muscles; SOL, soleus.
[a] Comparative control data are from Mattock et al.[4]

Hubbard et al previously found no statistically significant difference in the MVIC strength of the leg plantar-flexor, dorsiflexor, invertor, or evertor muscle groups between those who developed MTSS and control individuals.[10] Additionally, Yüksel et al reported that MTSS symptomatic individuals had greater evertor than invertor leg muscle strength.[11] In contrast, cases 1 and 2 displayed less flexor hallucis longus, triceps surae, and peroneal muscle strength than comparative controls.[4] The inconsistency in our findings compared with those of Hubbard et al and Yüksel et al could be associated with individualized muscle recruitment strategies to produce plantar-flexion force.[10,11] Furthermore, greater evertor muscle strength could be an effect rather than a cause of MTSS.[11] To our knowledge, we are the first to investigate whether the MVIC strength of individual leg muscles is associated with MTSS development in long-distance runners. Cases 1 and 2 demonstrated a reduced MVIC strength of the flexor hallucis longus, triceps surae, and peroneal muscles, which could make them more reliant on using their soleus muscles to produce plantar-flexion force for forward propulsion. Greater reliance on the soleus would repeatedly increase traction on the posteromedial tibia during the propulsive phase of running, possibly contributing to MTSS development. In addition, cadaveric studies have revealed that the soleus attaches at the site of MTSS pain, and higher peak soleus electromyographic amplitude was associated with MTSS development.[1,12] Interestingly, despite displaying greater plantar-flexor MVIC strength with the knee flexed than extended, cases 1 and 2 displayed substantially less plantar-flexor endurance capacity than the controls.[4] Greater plantar-flexor MVIC strength with the knee flexed than extended, as identified in cases 1 and 2, is a novel finding, although it is consistent with previous research.[12] However, larger prospective studies must be performed to confirm or refute this notion. If it is proven true, assessing soleus and gastrocnemius muscle strength could easily be incorporated into clinical practice to identify individuals at risk of developing MTSS.

At self-selected running speeds, a lower cadence was reported to be significantly associated with shin injuries in high school runners ($<$172 compared with $>$173 steps/minute, $P =$ .02), potentially associated with increased stride length and tibial loading.[13] Despite substantial running speed and step length differences, cases 1 and 2 displayed the same relatively low cadence (168 steps/minute). At speeds below 7 m/s, increases in stride length are primarily achieved by greater soleus and gastrocnemius muscle contraction, subsequently increasing tibial loading.[14] Long-distance runners who display risk factors identified in this study as likely associated with MTSS development (see Table 4) could benefit from increasing their cadence and reducing their step length to reduce tibial loading and MTSS development risk. Although outside the scope of this study, reduced muscle strength may not be confined to the plantar-flexor muscles alone, and full 3-dimensional kinematics should be investigated. We acknowledge that the sex and individual risk factors of cases 1 and 2 likely contributed to their MTSS development and explain some observed differences in the outcome variables. Furthermore, due to this study's small number of cases, further research is required to substantiate our findings.

Clinical Bottom Line

Although runners who developed MTSS displayed individual risk factors, compared with comparative controls, both

Table 4. Risk Factors Likely Associated With Medial Tibial Stress Syndrome Development in Long-Distance Runners

Reduced plantar-flexor strength
Reduced plantar-flexor endurance
Less muscle strength with knee extended than flexed
Low cadence

runners demonstrated less plantar-flexor endurance and flexor hallucis longus, triceps surae, and peroneal muscle strength. Both runners also displayed less plantar-flexor MVIC strength with the knee extended compared with flexed and a relatively low cadence. These findings suggest that long-distance runners with reduced plantar-flexor muscle strength and endurance could have an impaired ability to resist tibial-bending moments, contributing to MTSS development, particularly when reduced strength and endurance are combined with a low cadence. Furthermore, long-distance runners with less flexor hallucis longus, gastrocnemius, and peroneal muscle strength could rely more heavily on the soleus muscle for propulsion during the stance phase of running, possibly contributing to greater soleus muscle traction on the tibia and MTSS development. We therefore conclude that assessing plantar-flexor endurance and strength could help identify individuals at risk of developing MTSS.

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