

Risk factors for medial tibial stress syndrome in physically active individuals such as runners and military personnel: a systematic review and meta-analysis

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ABSTRACT

Medial tibial stress syndrome (MTSS) is a common injury in runners and military personnel. There is a lack of agreement on the aetiological factors contributing to MTSS, making treatment challenging and highlighting the importance of preventive efforts. Understanding the risk factors for MTSS is critical for developing preventive measures. The purpose of this systematic review and meta-analysis was to assess what factors put physically active individuals at risk to develop MTSS. Selected electronic databases were searched. Studies were included if they contained original research that investigated risk factors associated with MTSS, compared physically active individuals with MTSS and physically active individuals without MTSS, were in the English language and were full papers in peer-reviewed journals. Data on research design, study duration, participant selection, population, groups, MTSS diagnosis, investigated risk factors and risk factor definitions were extracted. The methodological quality of the studies was assessed. When the means and SDs of a particular risk factor were reported three or more times, that risk factor was included in the meta-analysis. There were 21 studies included in the systematic review and nine risk factors qualified for inclusion in the meta-analysis. Increased BMI (weighted mean difference (MD)=0.79, 95% CI 0.38 to 1.20, $p<0.001$), navicular drop (MD=1.19 mm, 95% CI 0.54 to 1.84, $p<0.001$), ankle plantarflexion range of motion (ROM; MD=5.94°, 95% CI 3.65 to 8.24, $p<0.001$) and hip external rotation ROM (MD=3.95°, 95% CI 1.78 to 6.13, $p<0.001$) were risk factors for MTSS. Dorsiflexion and quadriceps-angle were clearly not risk factors for MTSS. There is a need for high-quality, prospective studies using consistent methodology evaluating MTSS risk factors. Our findings suggest that interventions focused on addressing increased BMI, navicular drop, ankle plantarflexion ROM and hip external rotation ROM may be a good starting point for preventing and treating MTSS in physically active individuals such as runners and military personnel.

INTRODUCTION

Medial tibial stress syndrome (MTSS) is one of the most frequently reported injuries in physically active populations. A recent systematic review of three prospective studies reported an incidence rate ranging from 13.6% to 20% in runners.¹ MTSS is also common in military personnel with a reported incidence ranging from 7.2% to 35%.^{2–4} Although a frequently reported injury, the treatment of this

condition is challenging due to a lack of consensus on aetiological factors.⁵

Without a full understanding of aetiological factors, an emphasis on preventive efforts is particularly important. Understanding MTSS risk factors is critical for developing preventive measures.⁶ Risk factors for MTSS have been studied in numerous individual studies. Researchers have examined many variables as potential risk factors for MTSS such as body mass index (BMI),^{4 7–9} bone geometry,¹⁰ gait kinematics,^{11–14} leg length differences,¹² navicular drop,^{9 15–20} range of motion (ROM),^{4 8 9 11 12 14 16 18 21} training history^{4 18 19 22} and others. Although the results of these individual studies can inform clinical practice, the reported findings are often based on small sample sizes with conflicting results. Studying the potential risk factors in a systematic fashion can reduce bias and increase confidence through the analysis of pooled data. The purpose of this systematic review and meta-analysis was to assess what factors put physically active individuals at risk to develop MTSS.

METHODS

Inclusion and exclusion criteria

For inclusion in this systematic review, studies were original research that investigated risk factors associated with MTSS, compared physically active individuals with MTSS to physically active individuals without MTSS, were in the English language and were accessible full papers in peer-reviewed journals.

Search strategy and study selection

The Database of Abstracts of Reviews of Effects (DARE) and the Cochrane Database of Systematic Reviews (CDSR) were searched for systematic reviews about risk factors associated with MTSS. The Cochrane Central Register of Controlled Trials (CENTRAL), MEDLINE (OVID SP), EMBASE and CINAHL were searched to identify studies that met the inclusion criteria. Reference lists of included or other relevant articles (e.g., recent reviews) were scanned and/or hand searched for additional references. Reference lists of articles that were identified via a hand search were also searched for additional references.

The initial search was carried out from the earliest date to January 2012 using key words (MeSH and/or text words) within three groups: group 1 terms pertained to injury, group 2 terms pertained to risk



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factors and group 3 terms pertained to population. The key words for each group were: group 1—medial tibial stress syndrome, mtss, medial tibial stress, shin splint\$, shin pain; group 2—risk factor\$, risk, vulnerability factor\$, risk indicator\$, risk characteristic\$, predictor\$, disorder predictor\$; group 3—run\$, physically active, athlete\$, exercise, conditioning, military, militaries, military personnel, recruit, armed forces. The terms within each group were linked with ‘OR’ and the individual group searches were combined using ‘AND.’ Owing to the time that elapsed between the initial search and completion of our analysis, additional searches of CINAHL and MEDLINE (OVID SP) were performed in September 2012 and July 2013 to ensure that papers published from January 2012 to July 2013 were included in the systematic review.

The two reviewers (KCHB and KLH-W) independently screened titles and/or abstracts of studies identified using the search strategy noted above. If it was clear that the study did not meet the inclusion criteria, it was eliminated from the analysis. The reviewers documented a decision for each article and noted why citations were rejected: clearly not relevant or addressed the topic but failed to meet one or more inclusion criteria (recording what inclusion criteria it failed to meet). When no abstract was available or if it was unclear if the study should be a part of the systematic review, full-text articles were retrieved and independently reviewed to determine inclusion or exclusion. Any disagreement between the reviewers was discussed and resolved by consensus.

Data extraction

Data on research design, study duration, participant selection, population, groups, MTSS diagnosis, investigated risk factors, risk factor definitions, means, SDs, CIs, effect sizes, ORs and any other data the reviewers deemed relevant were extracted

and summarised in Excel from all included studies. If continuous data were not reported by the authors, the reviewers contacted the authors requesting the data. Authors were contacted a minimum of two times via email and/or phone requesting data. If the authors did not respond, their manuscript was not included in the meta-analysis. Each reviewer independently extracted the data, checked their extraction for accuracy and completeness and then compared their findings with one another. When authors reported SEs, the reviewers converted them to SDs. For goniometry measurements that were reported from 180°, reviewers converted the measure so that all goniometry measures began at 0°. Any disagreements between the reviewers were discussed and resolved by consensus.

Quality assessment

The methodological quality of included studies was assessed to determine bias using an adapted^{23 24} checklist by van der Worp *et al*²⁵ (table 1). This checklist was selected because it contains items for multiple study designs (cross-sectional, case-control and prospective cohort studies) and assessed risk factors for an injury similar to that reported in the current study. The checklist contains five categories: study objective, study population, outcome measurements, assessment of the outcome, and analysis and data presentation. Every item was scored as positive (+), indicating that the criterion was met, or negative (–) when the criterion was not met. Two reviewers (KCHB and KLH-W) independently evaluated the included studies using this checklist and compared the findings. Any disagreements between the reviewers were discussed and resolved by consensus. The total quality score of each study was calculated by counting the number of positive scores on items 3–16, which addressed validity/precision.

Table 1 Checklist for the assessment of methodological quality of cross-sectional studies, case-control studies and prospective cohort studies

	Study type
Study objective	
1. Positive, if the study had a clearly defined objective	CS/CC/PC
Study population	
2. Positive, if the main features of the study population are described (sampling frame and distribution of the population according to age and sex)	CS/CC/PC
3. Positive, if cases and controls are drawn from the same population and a clear definition of cases and controls is given and if participants with the disease/symptom in the past 3 months are excluded from the control group	CC
4. Positive, if the participation rate is at least 80% or if the participation rate is 60–80% and the non-response is not selective (data shown)	CS/CC/PC
5. Positive, if the participation rate at the main moment of follow-up is at least 80% or if the non-response is not selective (data shown)	PC
Outcome measurements	
6. Positive, if data on history of the disease/symptom are collected and included in the statistical analysis	CS/CC/PC
7. Positive, if the outcome is measured in an identical manner among cases and controls	CC
8. Positive, if the outcome assessment is blinded with respect to disease status	CS/CC
9. Positive, if the outcome is assessed at a time before the occurrence of the disease/symptom	CC
Assessment of the outcome	
10. Positive, if the time period in which the assessment of disease/symptom was based was at least 1 year	PC
11. Method for assessing injury status: physical examination blinded to exposure status (+); self-reported: specific questions relating to symptoms/disease/ use of manikin (+), single question (–)	CS/CC/PC
12. Positive, if incident cases were included (prospective enrolment)	CC
Analysis and data presentation	
13. Positive, if the measures of association estimated were presented (OR/RR), including CI and numbers in the analysis	CS/PC/CC
14. Positive, if the analysis is controlled for confounding or effect modification: individual factors	CS/PC/CC
15. Positive, if the analysis is controlled for confounding or effect modification: other factors	CS/PC/CC
16. Positive, if the number of cases in the final multivariate model was at least 10 times the number of independent variables in the analysis	CS/PC/CC

Reproduced from: van der Worp *et al*,²⁵ with permission from BMJ Publishing Group Ltd. CC, case-control study; CS, cross-sectional study; PC, prospective cohort study.

Data analysis

After data extraction, the reviewers categorised common variables into the following risk factor categories: arch height or angle, BMI, bone parameters, calcaneus and rearfoot position and displacement, calf girth, demographics, flexibility/ROM, foot posture index,²⁶ forefoot position, gait variables, leg angle and tibia angle,^{18 19} medical history and symptoms, Ober's test,²⁷ strength, structure/alignment, and training variables/fitness level. When the means and SDs of a particular risk factor were reported three or more times, that risk factor was included in the meta-analysis. While meta-analytic statistical indices can be calculated with as few as two studies, the stability and interpretability of estimates based on so few data points are problematic. A cut-off of three studies was chosen so that the review could be as comprehensive as possible, and the results still reasonably reliable. For the meta-analysis, weighted mean differences (MDs) and 95% CI were calculated. MD is a measure of the difference between individuals with MTSS and those without MTSS for the specific risk factor being analysed. The weighted MD pools results of studies that used the same outcome measure in a manner that weights the results of each study using the inverse variance method, i.e., the variance reported for a study is assumed to be inversely proportional to its importance.²⁸ Heterogeneity was assessed using I^2 , which measures the degree of inconsistency across studies in a meta-analysis.²⁹ A value of 25%, 50% and 75% indicates low, moderate and high levels, respectively, of heterogeneity in a sample.²⁹ Fixed effects models were used for analyses in which I^2 was less than 20% (low); random effects models for I^2 greater than or equal to 20%. MIX V2.0 (Bax L: MIX V2.0. Professional software for meta-analysis in Excel. V2.0.1.4. BiostatXL, 2011; <http://www.meta-analysis-made-easy.com>) was used to calculate MDs and I^2 .

RESULTS

Search results

No systematic reviews were found on risk factors for MTSS. A total of 165 papers were found. After removing duplicates,

eliminating papers that did not fit the PICOS (patient, intervention, comparison, outcome, study design) question, and hand searching reference lists, a total of 21 original research papers were included in the systematic review (figure 1).

Study characteristics

The 21 included studies consisted of three cross-sectional,^{10 21 30} nine case-control^{7 8 11-15 20 31} and nine prospective cohort studies.^{2-4 9 16-19 22} In seven of the 21 studies, the participants were recreational athletes/physically active.^{7 10 11 14 15 20 30} In five of the studies, the participants were runners.^{9 12 13 16 22} In five of the studies, the participants were in the military.^{2-4 8 31} In two of the studies, the participants were high school or college athletes.^{18 21} Also, in two of the studies, the participants were college students enrolled in a physically active course.^{17 19} Online supplementary appendix 1 lists the 21 studies and the risk factors measured within the studies. Online supplementary appendix 2 provides the characteristics of the 13 studies included in the meta-analysis.^{4 7-12 14-20}

Quality assessment

The scores of the individual studies on the methodological quality assessment list are presented in table 2. The average score was $48.95 \pm 16.48\%$. Quality assessment scores for the cross-sectional studies ranged between 3 and 7 out of a possible 12 points (25–58%); case-control studies ranged between 2 and 4 out of a possible 8 points (25–50%); and prospective cohort studies ranged between 3 and 7 out of a possible 9 points (25–78%).

Risk factors for MTSS

Continuous data for the following risk factors were reported three or more times and included in the meta-analysis: BMI, navicular drop, ankle plantarflexion ROM, hip external rotation ROM, ankle dorsiflexion ROM, quadriceps-angle (Q-angle), hip internal ROM, ankle inversion ROM and ankle eversion ROM. Over 100 other risk factors were reported within the 21 studies; however, none were measured consistently in more than two studies with the majority of the risk factors reported by one

Figure 1 Search process flow chart.

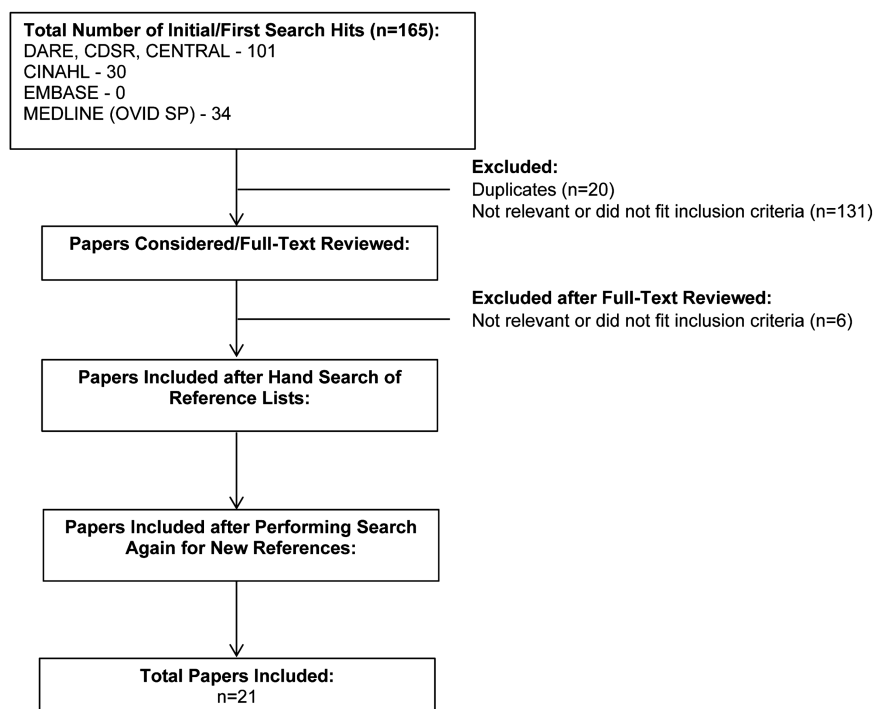


Table 2 Scores on the items of the quality assessment list (see table 1), with the total quality score for all positive (+) items (#3–16) and the percentage of the maximum attainable score (%)

Reference	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total	Per cent
Gehlsen and Seger ¹¹	+	+	–	+		–	+	–	–		–	–	–	–	–	+	3/12	25
Messier and Pittala ¹²	+	–	+	+		–	+	–	–		–	–	–	–	–	+	4/12	33
Tweed <i>et al</i> ¹³	+	+	–	–		–	+	–	–		+	–	+	–	–	+	4/12	33
Viitasalo and Kvist ¹⁴	+	+	–	+		–	+	–	–		+	–	–	–	–	+	4/12	33
Bandholm <i>et al</i> ¹⁵	+	+	+	+		–	+	–	–		+	–	–	–	–	+	5/12	42
Madeley <i>et al</i> ⁷	+	+	–	+		–	+	–	–		+	–	–	+	–	+	5/12	42
Rathleff <i>et al</i> ²⁰	+	+	–	+		+	+	–	–		+	–	–	–	–	+	5/12	42
Moen <i>et al</i> ⁸	+	+	–	+		+	+	–	–		+	+	–	–	–	+	6/12	50
Newman <i>et al</i> ³¹	+	–	–	+		–	+	+	+		–	+	+	–	–	+	7/12	58
Lilleveldt <i>et al</i> ²¹	+	+		+		–		–			–		–	–	–	+	2/8	25
Franklyn <i>et al</i> ¹⁰	+	+		+		–		–			+		–	+	–	+	4/8	50
Sommer <i>et al</i> ³⁰	+	+		+		–		+			+		–	–	–	+	4/8	50
Bennett <i>et al</i> ¹⁶	+	+		–	+	–				–	+		–	–	–	+	3/9	33
Delacerda ¹⁷	+	+		+	+	–				–	+		–	–	–	+	4/9	44
Sharma <i>et al</i> ³	+	+		–	+	–				–	+		+	–	–	+	4/9	44
Hubbard <i>et al</i> ¹⁸	+	+		+	+	+				–	+		+	–	–	+	6/9	67
Raissi <i>et al</i> ¹⁹	+	+		+	+	+				–	+		+	–	–	+	6/9	67
Rauh <i>et al</i> ²	+	+		+	+	–				–	+		+	+	–	+	6/9	67
Yates and White ⁴	+	+		+	+	+				–	+		+	–	–	+	6/9	67
Plisky <i>et al</i> ²²	+	+		+	+	+				–	+		+	+	–	+	7/9	78
Yagi <i>et al</i> ⁹	+	–		+	+	–				+	+		+	–	+	+	7/9	78

Case-control studies: 8 possible points, cross-sectional studies: 12 possible points, prospective cohort studies: 9 possible points.

author. Owing to the heterogeneity of the remaining risk factors, no moderate to strong evidence exists that the risk factors not included in the meta-analysis contribute to MTSS.

Body Mass Index

Individuals with MTSS had a significantly greater BMI compared with controls (MD=0.79, 95% CI 0.38 to 1.20, $p<0.001$, $I^2=0.00\%$; figure 2). The meta-analysis included a total of 451 participants (187 MTSS, 264 control). There were four studies that evaluated BMI as a risk factor for MTSS; on average, these studies reached 59% of the maximal attainable score on the quality assessment (table 2).^{4 7–9} Yagi *et al*⁹ reported BMI for males and females separately, so males and females were treated as discrete data sets for a total of five data sets in the meta-analysis. One study did not report control group SDs.⁴ After multiple attempts to reach the authors to obtain these data, the SD of the MTSS group was used for the control group. This approach was taken because Yates and White⁴ assessed group differences using t tests, which assume equal variances in groups. Owing to the low heterogeneity of the sample, sexes were pooled when conducting the

meta-analysis. In two of the five data sets, greater BMI increased the risk for MTSS; one study reported an effect in high school female runners (adjusted OR=0.51, 95% CI 0.31 to 0.86, $p=0.01$)⁹ and the other reported one in male soldiers (MTSS: 23.8 ± 2 , control: 22.5 ± 1.6 , $p=0.04$).⁸ In the other data sets, BMI was generally greater but not significantly different between the MTSS and control groups in adult patients,⁷ naval recruits⁴ and high school male runners.⁹

Navicular drop

Individuals with MTSS had a significantly greater navicular drop compared with controls (MD=1.19 mm, 95% CI 0.54 to 1.84, $p<0.001$, $I^2=40.19\%$; figure 3). The meta-analysis included a total of 564 participants (198 MTSS, 366 control). Six studies measured navicular drop as a risk factor for MTSS.^{9 15 16 18–20} Studies with male and female groups were treated as separate and unique data sets, while studies with both limbs¹⁹ and multiple measurement types (dynamic/static)²⁰ only included right limb and static measures, respectively. There was a total of seven data sets for the meta-analysis. In three of these data sets, the authors reported navicular drop to be the risk factor for MTSS in

Study or Subgroup	MTSS			Control			Weight	Mean difference, 95% CI
	Mean	SD	Total	Mean	SD	Total		
Madeley, 2007	23.5	2.66	30	22.8	2.25	30	10.68%	0.7 [-0.5, 1.9]
Yates, 2004	23.9	2.5	40	23.9	2.5	72	17.78%	0.05 [-0.9, 1.0]
Moen, 2012	23.8	2.0	15	22.5	1.6	20	10.95%	1.3 [0.07, 2.5]
Yagi, 2013 (males)	20.5	5.4	58	19.4	1.5	88	8.18%	1.1 [-0.3, 2.5]
Yagi, 2013 (females)	19.3	1.5	44	18.4	1.3	54	52.42%	0.9 [0.3, 1.5]
Total (95% CI)			187			264	100.00%	0.79 [0.4, 1.2]
Heterogeneity: $I^2 = 0.00\%$								
Test for overall effect: $Z = 5.1$ ($P < .001$)								

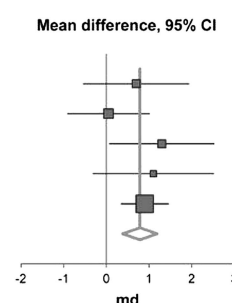
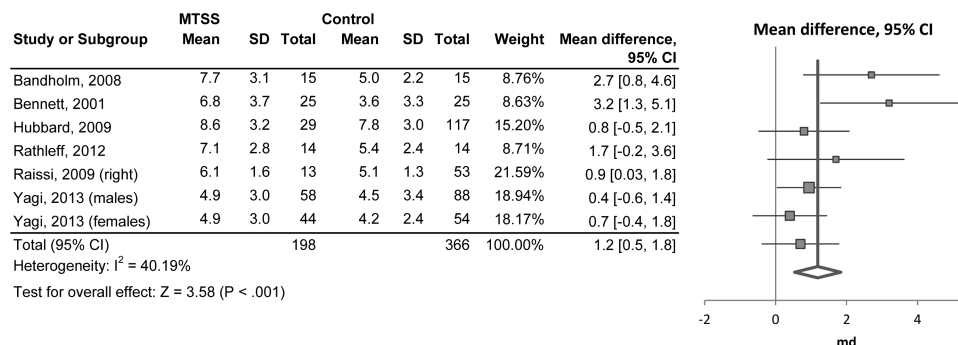
**Figure 2** Effects of body mass index on medial tibial stress syndrome (MTSS).

Figure 3 Effects of navicular drop on medial tibial stress syndrome (MTSS).



recreational athletes,^{15]} high school cross-country runners¹⁶ and recreational runners.¹⁹ In the other four data sets, navicular drop was generally greater but not significantly different in the MTSS versus control groups in high school runners,⁹ collegiate athletes¹⁸ and recreationally active individuals.²⁰

Ankle plantarflexion ROM

Individuals with MTSS had a significantly greater plantarflexion ROM compared with controls (MD=5.94°, 95% CI 3.65 to 8.24, $p < 0.001$, $I^2 = 0.00\%$; figure 4). The meta-analysis included a total of 237 participants (71 MTSS, 166 control). Four studies measured plantarflexion as a potential risk factor for MTSS.^{8 11 12 18} Gehlsen and Seger¹¹ reported right and left limbs separately; only right limb data were used, providing a total of four data sets for the meta-analysis.^{8 11 12 18} Sex, type of ROM (passive or active) and testing position of the participants (knees extended or flexed) were inconsistently reported in these studies, but owing to the low heterogeneity of the sample, sex, type of ROM and testing positions were pooled when conducting the meta-analysis. In a group of collegiate athletes from various division one and two teams, those with MTSS had significantly more plantarflexion compared with the healthy control group (MTSS: 46.0 ± 6.0 , 95% CI 43.5 to 48.4; control: 40.6 ± 9.3 , 95% CI 38.8 to 42.2).¹⁸ Increased plantarflexion was also significantly associated with MTSS in male soldiers (MTSS: 52 ± 8.6 , control: 43 ± 5.6 , $p = 0.001$; multivariate regression 95% with a 95% CI of 0.5–0.9).⁸ In recreational and competitive runners, plantarflexion ROM was greater but not significantly different between the MTSS and control groups (MTSS: 60.24 ± 2.63 , control: 56.58 ± 2.09).¹² Similarly, although not statistically significant, female athletes with MTSS had greater plantarflexion than female athletes without MTSS (MTSS—right limb: 54.6 ± 16.1 , left limb: 52.1 ± 18.5 ; control—right limb: 49.4 ± 14.6 , left limb: 46.8 ± 14.3).¹¹

Hip external rotation ROM

Individuals with MTSS had a significantly greater hip external rotation ROM compared with controls (MD=3.95°, 95% CI 1.78 to 6.13, $p < 0.001$, $I^2 = 0.00\%$; figure 5). The meta-analysis included a total of 279 participants (117 MTSS, 162 control). Three studies measured hip external rotation as a potential risk factor for MTSS.^{8 9 21} However, one study had incomplete data and was not included in the meta-analysis.²¹ Yagi *et al*⁹ reported male and female results separately; these results were treated as two data sets to provide a total of three data sets for the meta-analysis.^{8 9} Owing to the low heterogeneity of the sample, sexes and testing positions were pooled when conducting the meta-analysis. Moen *et al*⁸ measured passive hip external rotation in male soldiers with participants supine and the hip and knee flexed to 90°, while Yagi *et al*⁹ measured high school runners seated with the knee flexed to 90°. Yagi *et al*⁹ did not explicitly state if the passive or active ROM was measured, but their methodology suggests passive. Neither Moen *et al*⁸ nor Yagi *et al*⁹ reported significant differences between the MTSS and control groups in hip external rotation; however, mean values for hip external rotation were greater in the MTSS versus control groups for all three data sets.

Ankle dorsiflexion ROM

Dorsiflexion ROM was not significantly different between individuals with MTSS and controls (MD=−0.01°, 95% CI −0.96 to 0.93, $p = 0.98$, $I^2 = 17.89\%$). The meta-analysis included a total of 481 participants (173 MTSS, 308 control). Eight studies measured dorsiflexion as a potential risk factor for MTSS.^{4 8 9 11 12 16 18 21} Several data sets from these studies were not included in the meta-analysis for the following reasons: Lilletvedt *et al*²¹ had incomplete data, so they were not used; Gehlsen and Seger¹¹ reported right and left limbs separately, so only right limb data were used; Bennett *et al*¹⁶ and Yates and White⁴ reported limbs without identifying right and

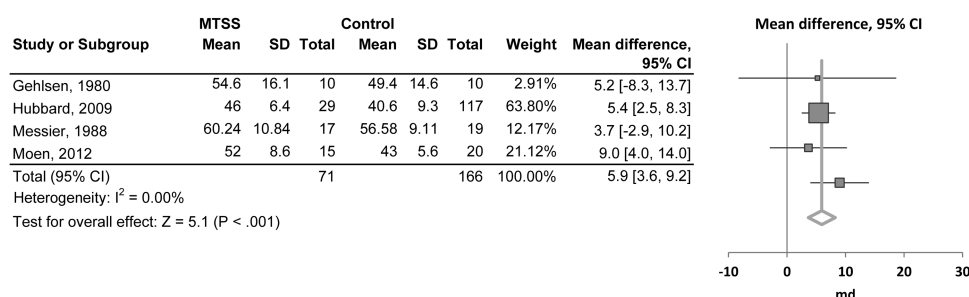


Figure 4 Effects of plantarflexion range of motion on medial tibial stress syndrome (MTSS).

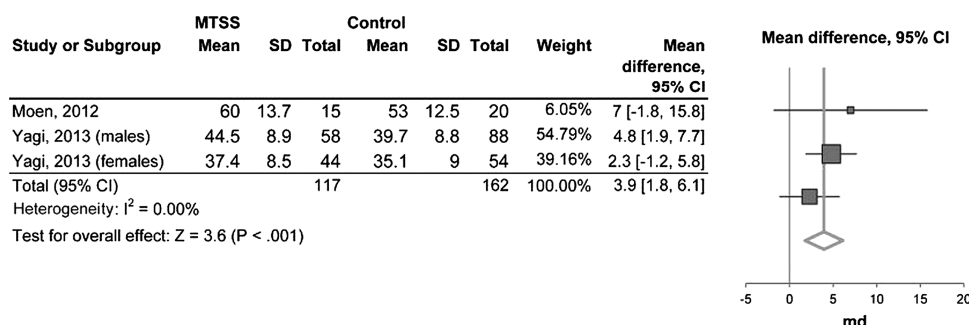


Figure 5 Effects of hip external rotation range of motion on medial tibial stress syndrome (MTSS).

left limbs, so no data were included; Yagi *et al*⁹ reported dorsiflexion in two different positions, so only dorsiflexion measures taken with the knee extended were used. A total of six full data sets were used for the meta-analysis. Owing to the low heterogeneity of the sample, sexes and type of ROM (passive and active) were pooled when conducting the meta-analysis. None of the results within the individual studies supported dorsiflexion ROM as a risk factor for MTSS.^{4 8 9 11 12 16 18 21}

Q-angle

Individuals with MTSS did not have significantly different Q-angles compared with controls (MD=-0.22°, 95% CI -0.95 to 0.50, $p=0.54$, $I^2=5.23\%$). The meta-analysis included a total of 346 participants (132 MTSS, 214 control). Three studies reported Q-angle as a potential risk factor for MTSS.^{9 12 19} Yagi *et al*⁹ reported male and female data separately and Raissi *et al*¹⁹ reported data from right and left limbs; only right limb data were included,⁹ providing four distinct data sets for the meta-analysis. None of the three individual studies reported Q-angle as a risk factor for MTSS.

Hip internal rotation ROM

Hip internal rotation ROM was not significantly different between individuals with MTSS and controls (MD=0.18°, 95% CI -5.37 to 5.73, $p=0.95$, $I^2=83.74\%$). The meta-analysis included a total of 279 participants (117 MTSS, 162 control). Three studies measured hip internal rotation as a potential risk factor for MTSS.^{8 9 21} One study had incomplete data and was not included in the meta-analysis.²¹ Yagi *et al*⁹ reported male and female results separately; these results were treated as two data sets to provide a total of three data sets for the meta-analysis.^{8 9} Moen *et al*⁸ measured passive hip internal rotation with participants supine and the hip and knee flexed to 90° and found that decreased hip internal rotation was significantly associated with MTSS in male soldiers (MTSS: 40±9.3, control: 47±8.7, $p=0.087$; multivariate regression 95% 1.2 (1.0 to 1.4)).⁸ Yagi *et al*⁹ measured participants seated with the knee flexed to 90° in high school runners. Yagi *et al*⁹ did not explicitly state if passive or active ROM was measured, but their methodology suggests passive. They state in their manuscript that decreased hip internal rotation increased the risk for MTSS in females.⁹ However, their data suggest that female high school runners with MTSS actually had an increased hip ROM compared with a control group (MTSS females: 31.1±9.9, control females: 25.5±9.5; $p<0.05$).⁹ More studies using similar methodology are needed to more accurately evaluate the role of hip internal rotation in MTSS.

Ankle eversion ROM

Ankle eversion ROM was not significantly different between individuals with MTSS and controls (MD=1.17°, 95% CI -0.02 to 2.36, $p=0.06$, $I^2=31.58\%$). The meta-analysis included a total of 281 participants (108 MTSS, 173 control). Five studies measured eversion as a potential risk factor for MTSS.^{8 11 14 18 21} One study had incomplete data and was not included in the meta-analysis.²¹ Gehlsen and Seger¹¹ analysed right and left limb ROM separately; only right limb data were used, providing a total of four data sets for the meta-analysis. Viitasalo and Kvist¹⁴ found an increased eversion ROM in the MTSS compared with the control group (MTSS: 10.7±4.4, control: 8.3±3.2; $p<0.05$). No other studies within the meta-analysis reported eversion as a risk factor for MTSS. More studies utilising a similar methodology and populations are needed to determine if ankle eversion is a risk factor for MTSS.

Ankle inversion ROM

Ankle inversion ROM was not significantly different between individuals with MTSS and controls (MD=0.98°, 95% CI -3.11 to 5.07, $p=0.64$, $I^2=71.58\%$). The analysis included a total of 249 participants (89 MTSS, 160 control). Five studies measured inversion as a potential risk factor for MTSS.^{8 11 14 18 21} One study had incomplete data and was not included in the meta-analysis.²¹ Gehlsen and Seger¹¹ measured right and left limb ROM; only right limb data were used, providing a total of four data sets for the meta-analysis. Neither the type of ROM (passive or active) nor the position of the participants being measured was consistently reported in these studies. Additionally, within the individual studies, there were conflicting results. Inversion ROM was not a risk factor for MTSS in collegiate athletes (MTSS: 31.9±6.8, control: 30.6±8.1; $p=0.45$)¹⁸ or male army recruits (MTSS: 30±5.4, control: 30±5; $p=0.17$).⁸ However, Gehlsen and Seger¹¹ reported significantly increased right inversion in the control versus MTSS group (MTSS: 28.6±17.4, control: 45±16; $p<0.05$) while Viitasalo and Kvist *et al*¹⁴ found greater inversion ROM in the MTSS compared with the control group (MTSS: 19.5±8.6, control: 14±4.8; $p<0.01$). Owing to the heterogeneity of the sample and conflicting results, it is difficult to conclude the role of ankle inversion in MTSS risk.

DISCUSSION

The purpose of this systematic review and meta-analysis was to assess factors that place physically active individuals at risk to develop MTSS. There were 21 studies included in the systematic review. Over 100 risk factors were analysed in the 21 studies; however, only nine risk factors included the minimum data required for the meta-analysis. Of the nine risk factors analysed,

individuals with increased BMI, navicular drop, plantarflexion or hip external rotation compared with their non-injured counterparts were more likely to incur MTSS. Dorsiflexion and Q-angle were most clearly not risk factors for MTSS.

When considering BMI as a risk factor for MTSS, it is important to note that research suggests BMI is a poor indication of body fat in certain populations such as athletes and military personnel.^{32–33} Within the physically active populations studied in this systematic review, BMI is not a direct measure of body fat. Rather, it suggests that those with an increased mass relative to their squared height are at greater risk for MTSS, but the increased mass could be due to lean mass or fat mass. One explanation for BMI as a risk factor for MTSS is related to the response of bone to loading, specifically tibial bowing or bending, which produces hyperstimulated periosteal activation.^{34–35} Repeated bending/microdamage causes an adaptation to the bone, strengthening it to prevent bony overload; in fact, dynamic forces, such as those produced by muscles on bone, appear to provide the greatest stimuli for osteogenesis.³⁶ However, when loads exceed the bone's microdamage threshold, injury can occur. Males with MTSS have been found to have a smaller tibial cortical bone area and shape and females with MTSS to have a smaller tibial cortical bone shape compared with controls, but it is not known if this is a cause or an effect of the injury.¹⁰ Perhaps with an increased mass relative to height, the mechanical load on the tibia changes during physical activity. Since bone is an adaptable organism, it seems reasonable to believe that slow, steady and progressive increases in exercise would allow for the bone to adapt and those with a higher BMI may need a longer adaptation period than those with a lower BMI.

An increased navicular drop was found to be a risk factor for MTSS in our meta-analysis. Navicular drop is often used as a measure of arch height³⁷ and foot pronation.³⁸ An inverse relationship exists between navicular drop and arch height such that an increased navicular drop leads to lower arch height. If navicular drop is a measure of pronation, because rearfoot eversion is part of pronation,³⁹ it makes sense that there would be a relationship between navicular drop and rearfoot eversion. Although this has been found to be true during walking,⁴⁰ it does not appear to be true during running. During running, navicular drop and arch height have been found to be related to tibial internal rotation and not rearfoot eversion.^{41–42} Specifically, a less navicular drop (higher arch) was related to an increased tibial internal rotation during running.^{41–42} Pronation is thought to be a protective mechanism during running and allows for impact forces to be attenuated.⁴³ Perhaps individuals with an increased navicular drop (lower arch height) are at risk for MTSS because they do not then have as much tibial internal rotation, which may be an important factor in absorbing impact forces, placing greater load on the tibia itself. Since navicular drop has been shown to increase with fatigue of the foot intrinsic muscles,⁴⁴ foot and arch exercises to increase the rigidity of the arch may have an influence on navicular drop and tibial internal rotation and therefore be beneficial for the prevention and/or treatment of MTSS. This is an area in need of further exploration.

In addition to navicular drop, increased plantarflexion ROM was found to be a risk factor for MTSS. Of the four studies included in the meta-analysis, one measured active ROM,¹⁸ one measured passive ROM⁸ and the other two did not specify which makes it more challenging to understand why greater plantarflexion may be a risk factor for MTSS. Authors have postulated that increased plantarflexion leads to a greater likelihood

of individuals landing on their forefoot when running⁸; this may increase the strain on the posteromedial tibia compared with rearfoot landing.⁴⁵ Another speculation is that perhaps an increased navicular drop and increased plantarflexion ROM are related. During the first half of the stance phase of running, pronation occurs. Pronation is a combination of ankle dorsiflexion, rearfoot eversion and foot abduction.⁴³ If an individual has an increased navicular drop (lower arch height), symbolic of greater pronation, they may push through their first ray more heavily as their arch moves closer to the floor and foot abducts during the mid-stance of the gait when they are pronating to absorb impact forces. Greater push off could lead to greater active plantarflexion ROM and a potentially increased extensibility of the dorsiflexors. The anterior tibialis is a primary dorsiflexor of the ankle and attaches to the base of the first metatarsal and medial surface of the first cuneiform. In theory, increased extensibility of this muscle, associated with greater plantarflexion ROM, could influence navicular drop due to its pull on the bones adjacent to the navicular. Eccentric exercises for the tibialis anterior to control end range plantarflexion may be an important consideration for the prevention and treatment of MTSS.

It is not clear how an increased hip external rotation ROM may put an individual at risk for MTSS as indicated in our meta-analysis. Two of the three studies in our meta-analysis reported passive ROM measures^{8–9} and the other study did not specify if passive or active ROM was measured.²¹ Passive hip ROM and its relationship to lower leg pain has been studied primarily in the military population. In male soldiers, decreased passive hip internal rotation has been found as a risk factor for MTSS.⁸ In male recruits, greater passive internal and external rotation ranges of motion were related to exertional medial tibial pain.⁴⁶ Also, in male recruits, those with excessive external rotation of the hip (active or passive not specified) had higher incidences of tibia stress fractures.⁴⁷ As suggested by Moen *et al*⁸ perhaps both increased and decreased ranges of motion at the hip put an individual at risk for excessive medial tibia loading. The mechanisms behind why hip ROM may be related to tibia injury are unknown. It may be that the femoral neck angle sits in an anteverted or retroverted posture,⁴⁸ which changes the orientation of the femur on the tibia. Or perhaps balance between the amount of internal and external rotation and the amount of total hip ROM are key factors influencing lower leg loading. Hip ranges of motion should be a consideration of clinicians in the prevention and treatment of MTSS, but more research is needed to clarify the specific role it has as a risk factor for MTSS.

Dorsiflexion, Q-angle, hip internal rotation, ankle eversion and ankle inversion did not emerge as risk factors for MTSS in the meta-analysis. Of these, dorsiflexion and Q-angle most clearly do not appear to be risk factors for MTSS. Dorsiflexion and Q-angle were evaluated in many individuals (n=481 and 346, respectively) with very low heterogeneity in the data set. Additionally, in all of the individual studies included in the meta-analysis that measured dorsiflexion and Q-angle, none of them reported dorsiflexion or Q-angle as a risk factor for MTSS. Collectively, this strongly suggests that neither one contributes to the risk of obtaining MTSS. Hip internal rotation, ankle inversion and ankle eversion had sample sizes near 300, but had high heterogeneity and conflicting results when looking at the individual studies that measured these variables. More studies are needed using similar methodology to assess hip internal rotation, ankle inversion and ankle eversion ROM as risk factors for MTSS.

Limitations of this systematic review and meta-analysis include not all risk factors being analysed due to the lack of consistency in the >100 risk factors reported in the 21 studies. Additionally, only 10 of the 21 studies had quality assessment scores >50%. The studies used to analyse three of the four significant risk factors for MTSS (BMI, navicular drop and hip external rotation ROM), on average, scored >50% while the studies used to analyse plantarflexion ROM scored 44%. These things should be considered when reading and applying the information presented. Further research is needed on risk factors of greatest interest utilising consistent methodology and strong research designs to increase the depth of the existing literature and allow for expanded meta-analyses. Additionally, very little research has investigated the role of combined risk factors in MTSS, representing an open and valuable area for exploration.

CONCLUSION

In a physically active population, the primary factors that appear to put individuals at risk for MTSS are increased BMI, navicular drop, plantarflexion ROM and hip external rotation ROM. Interventions focused on addressing these risk factors may prove valuable in preventing and treating MTSS. There is a need for high-quality, prospective studies using consistent methodology evaluating MTSS risk factors that have already been explored but not in depth. This will allow for further meta-analyses and the exploration of how the presence of combined factors affects MTSS risk.

What is already known on this topic?

Medial tibial stress syndrome (MTSS) is a very common injury in the physically active population. Treatment of MTSS is challenging because the aetiology of the condition is unclear. Many risk factors have been studied and hypothesised to contribute to MTSS.

What this study adds?

This paper systematically reviews and analyses MTSS risk factors. Studying risk factors in this fashion provides a higher level of evidence than singular studies, allowing for greater confidence in understanding the primary contributors to MTSS. Knowing these primary risk factors can guide healthcare professionals in their prevention and rehabilitation efforts.

Contributors KLH-W and KCHB planned the systematic review, conducted the search and data extraction, and drafted the manuscript. CB conducted the statistical analysis and critically reviewed the manuscript prior to submission.

Competing interests None.

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Appendix 1 Studies included in the systematic review and the risk factors measured within the studies

Author(s)	Title	Journal	Risk Factors
Bandholm T, Boysen L, Haugaard S, Zebis MK, Bencke J	Foot medial longitudinal-arch deformation during quiet standing and gait in subjects with medial tibial stress syndrome	<i>J Foot Ankle Surg</i> 2008;47:89-95	Navicular drop difference (mm) Navicular height loaded (mm) Navicular height neutral (mm) Medial longitudinal arch deformation difference (deg) Medial longitudinal arch deformation difference during walking (deg) Medial longitudinal arch angle heel strike (deg) Medial longitudinal arch angle loaded (deg) Medial longitudinal arch angle neutral (deg) Medial longitudinal arch angle push-off (deg)
Bennett JE, Reinking MF, Pluemer B, Pentel A, Seaton M, Killian C	Factors contributing to the development of medial tibial stress syndrome in high school runners	<i>J Orthop Sports Phys Ther</i> 2001;31:504-10	Active DF (deg) Navicular drop (mm) Rearfoot angle (deg) Resting calcaneal position in stance (deg) Sex (m,f) Tibiofibular varum (deg)
Delacerda FG	A study of anatomical factors involved in shinsplints	<i>J Orthop Sports Phys Ther</i> 1980;2:55-9	Footprint angle (deg) Navicular bone position (navicular drop) (mm) Weight:height ratio (kg/cm)
Franklyn M, Oakes B, Field B, Wells P, Morgan D	Section modulus is the optimum geometric predictor for stress fractures and medial tibial stress syndrome in both male and female athletes	<i>Am J Sports Med</i> 2008;36:1179-89	Tibia Measures: Anteroposterior dimension of the medullary region (mm) Anteroposterior width (mm) Amount of elongation (mm ⁴) Cross-sectional area (mm ²) Distal width (mm) Lateral length (mm) Maximum second moment of area (mm ⁴) Medial length (mm) Minimum second moment of area (mm ⁴) Mediolateral width (mm) Mediolateral dimension of the medullary region (mm) Polar moment of area (mm ⁴) Proximal width (mm) Radius of gyration Section modulus
Gehlsen GM, Seger A	Selected measures of angular displacement,	<i>Res Q Exerc Sport</i> 1980;51:478-85	Angular displacement (calcaneus and midline of lower leg (LL) (deg) - slow speed, shoes, contact Angular displacement (deg) - slow speed, shoes, support

strength, and
flexibility in subjects
with and without shin
splints

Angular displacement (deg) - fast speed, no shoes, contact
Angular displacement (deg) - fast speed, no shoes, support
Angular displacement (deg) - fast speed, no shoes, takeoff
Angular displacement (deg) - slow speed, shoes, takeoff
Angular displacement (deg) - fast speed, shoes, contact
Angular displacement (deg) - fast speed, shoes, support
Angular displacement (deg) - fast speed, shoes, takeoff
Angular displacement (deg) - slow speed, no shoes, contact
Angular displacement (deg) - slow speed, no shoes, support
Angular displacement (deg) - slow speed, no shoes, takeoff
DF ROM (deg)
DF strength (lb)
EV ROM (deg)
EV strength (lb)
Height (cm)
INV ROM (deg)
INV strength (lb)
Leg length (cm)
PF ROM(deg)
PF strength (lb)
Weight (kg)

Hubbard TJ,
Carpenter EM,
Cordova ML

Contributing factors
to medial tibial stress
syndrome: a
prospective
investigation

Age (yrs)
DF ROM (deg)
EV ROM (deg)
Females only: age of menstruation (yrs)
Females only: have a regular menstrual cycle (yes/no)
Females only: take birth control (yes/no) Height (cm)
How long subject has been running (yrs)
How often change running shoes (per year)
INV ROM (deg)
Isometric PF ($\text{N} \cdot \text{kg}^{-1}$)
Isometric DF ($\text{N} \cdot \text{kg}^{-1}$)
Isometric INV ($\text{N} \cdot \text{kg}^{-1}$)
Isometric EV ($\text{N} \cdot \text{kg}^{-1}$)
Miles run / week (miles)
Navicular drop (mm)
PF ROM (deg)
Previous history of MTSS (yes/no)
Previous history of stress fracture (yes/no)
Take vitamins (yes/no)
Tibial varum (deg)
Wear orthotics (yes/no)
Weight (kg)

Lilletvedt J, Kreighbaum E, Phillips RL	Analysis of selected alignment of the lower extremity related to the shin splint syndrome	<i>J Am Podiatry Assoc</i> 1979;69:211-7	Calcaneus position in relationship to the floor - subtalar joint neutral (deg) Calcaneus position in relationship to the floor - subtalar joint static (deg) DF ROM - knee extended (deg) DF ROM - knee flexed (deg) ER hip ROM - hip flexed (deg) ER hip ROM - hip ext (deg) EV ROM (deg) Forefoot position in relationship to rearfoot (deg) Frontal plane position of tibia - subtalar joint neutral (deg) Frontal plane position of tibia - subtalar joint static (deg) Hamstring flexibility (deg) INV ROM (deg) IR hip ROM - hip ext (deg) IR hip ROM - hip flex (deg) Transverse plane position of malleoli (deg)
Madeley LT, Munteanu SE, Bonanno DR	Endurance of the ankle joint plantar flexor muscles in athletes with medial tibial stress syndrome: a case-control study	<i>J Sci Med Sport</i> 2007;10:356-62	BMI (kg/m ²) Height (m) Standing heel raise (#)
Messier SP, Pittala KA	Etiologic factors associated with selected running injuries	<i>Med Sci Sports Exerc</i> 1988;20:501-5	Apparent leg length difference (%>0.64 cm) DF ROM (deg) Foot print Hamstring flexibility (% abnormal) Lowerleg flexibility (% abnormal) Max pronation (deg) Max pronation velocity (deg/s) PF ROM (deg) Q-angle (deg) Running terrain (% hills, crowned roads, trails) Sit and reach (cm) Time to max pronation (ms) Total rearfoot movement (deg) True leg length difference (not reported)
Moen MH, Bongers T, Bakker EW, Zimmermann AW, Tol JL, Backs FJG	Risk factors and prognostic indicators for medial tibial stress syndrome	<i>Scand J Med Sci Sports</i> 2012;22:34-9	Ankle DF (deg) Ankle PF (deg) BMI (kg/m ²) Duration of complaints (days) Hallux flex (deg) Hallux ext (deg)

Height (cm)
 Hip ER ROM (deg)
 Hip IR ROM (deg)
 Knee extension (deg)
 Knee flexion (deg)
 Lean calf girth (cm)
 Max calf girth (cm)
 Navicular drop >0.5cm (yes/no)
 Pre-rehab symptom free running distance (m)
 Sports Rated Activity Scale at baseline (0-100)
 Standing foot angle <140deg (yes/no)
 Subtalar EV (deg)
 Subtalar INV (deg)

Newman P, Adams R, Wassington G

Two simple clinical tests for predicting onset of MTSS: shin palpation test and shin oedema test

Br J Sports Med 2012;46:861-4

Area under the curve - shin palpation test
 Area under the curve - shin palpation test + shin oedema test
 Area under the curve - shin palpation test + shin oedema test + female
 Shin oedema test (yes,no)
 Shin pain and oedema test (yes,no)
 Shin palpation test (yes,no)

Plisky MS, Rauh MJ, Heiderscheit B, Underwood FB, Tank RT

Medial tibial stress syndrome in high school cross-country runners: incidence and risk factors

J Orthop Sports Phys Ther 2007;37:40-7

BMI (Q1 - low $\leq 18.7 \text{ kg/m}^2$, Q2 - $18.8\text{-}20.1 \text{ kg/m}^2$, Q3 - $20.2\text{-}21.6 \text{ kg/m}^2$, Q4 - high $>21.7 \text{ kg/m}^2$)
 Grade (9th, 10th, 11th, 12th)
 Left to right difference in navicular drop (0-3 mm, > 3mm)
 Navicular drop ($\leq 10\text{mm}$, $>10\text{mm}$)
 Orthotic use (yes/no)
 Previous injury (0, 1+)
 Running experience (0-3 y, 4+ y)
 Sex (m,f)

Raissi GR, Cherati AD, Mansoori KD, Razi MD

The relationship between lower extremity alignment and medial tibial stress syndrome among non-professional athletes

Sports Med Arthrosc Rehabil Ther Technol 2009;1:11

Achilles angle (deg)
 Anterior location of previous pain (%)
 BMI (kg/m^2)
 Duration of MTSS (hours)
 Duration of professional activity (unit not reported)
 Height (m)
 Intercondylar distance of femur (mm)
 Intermaleolar distance (mm)
 Length of weekly physical activity (%)
 Navicular drop (mm)
 Positive history of professional activity (%)
 Past history of pain (%)
 Q-angle (deg)
 Tibia angle (deg)

Rathleff MS, Kelly LA, Christensen FB, Simonsen OH, Kaalund S, Laessoe U	Dynamic midfoot kinematics in subjects with medial tibial stress syndrome	<i>J Am Podiatr Med Assoc</i> 2012;102:205-12	Dynamic navicular drop (mm) FPI-6 Preferred walking speed (km/h) Static navicular drop (mm) Velocity of dynamic navicular drop (mm/sec) Visual analog scale (VAS) – during activity (cm) Visual analog scale – pain at rest (cm)
Rauh MJ, Macera CA, Trone DW, Reis JP, Shaffer RA	Selected static anatomic measures predict overuse injuries in female recruits	<i>Milit Med</i> 2010;175:329-35	Ankle DF ROM (≤ 10 , 11-20, ≥ 21 deg) Ankle EV ROM (0-1, 2-10 ≥ 11 deg) Arch index (low: (≤ 0.149 , normal: 0.150-0.216, ≥ 0.217) Hip IR ROM (≤ 25 , 26-45, ≥ 46) Knee alignment (varus, valgus, valgus/varus) Knee hyperextension (≤ 5 , ≥ 6 deg) Leg length difference (≤ 0.5 , >0.5 -1.0, >1.0 -1.5, >1.5 cm) Ober's Test (positive, negative) Pelvic Width/Femur Length Ratio (narrow: ≤ 0.26 , normal: 0.27-0.30, wide: ≥ 0.31) Q-angle (< 20 , ≥ 20 deg)
Sharma J, Golby J, Greeves J, Spears IR	Biomechanical and lifestyle risk factors for medial tibia stress syndrome in army recruits: a prospective study	<i>Gait Posture</i> 2011;33:361-5	Biomechanics (good, poor) Fitness (good, poor) Smoking (yes, no)
Sommer HM, Vallentyne SW	Effect of foot posture on the incidence of medial tibial stress syndrome	<i>Med Sci Sports Exerc</i> 1995;27:800-4	Standing foot angle (deg) Varus position (forefoot and hindfoot varus, forefoot or hindfoot varus, no varus)
Tweed JL, Campbell JA, Avil SJ	Biomechanical risk factors in the development of medial tibial stress syndrome in distance runners	<i>J AM Podiatr Med Assoc</i> 2008;98:436-44	1st metatarsophalangeal DF (unit not reported) Abductory twist (yes/no) Ankle DF ROM – knee ext (unit not reported) Ankle DF ROM – knee flex (unit not reported) Apropulsive gait (yes/no) Early heel lift (yes/no) FPI (unit not reported) Pronation (PRO) at early stance (yes/no) PRO at heel strike (yes/no) PRO late stance (yes/no) PRO at mid-stance (yes/no) PRO at propulsion (yes/no) Relaxed calcaneal stance (unit not reported)

Relaxed to neutral calcaneal stance position difference (unit not reported)

Viitasalo JT, Kvist M	Some biomechanical aspects of the foot and ankle in athletes with and without shin splints	<i>Am J Sports Med</i> 1983;11:125-30	<p>Achilles angle, treadmill running – before touch down, during full support during full support – minimum, during full support –maximum, after heel takeoff, at the ball of the foot takeoff</p> <p>Angular displacement, treadmill running – before touch down-during full support, during full support min-during full support max, during full support-after heel takeoff, after heel takeoff-at the ball of the foot takeoff</p> <p>Passive subtalar EV (deg)</p> <p>Passive subtalar INV (deg)</p> <p>Passive subtalar sum (deg)</p> <p>Standing feet diagonal – leg angle, calcaneus angle, achilles angle (deg)</p> <p>Standing normal – leg angle, calcaneus angle, achilles angle (deg)</p> <p>Standing heels together – leg angle, calcaneus angle, achilles angle (deg)</p>
Yagi S, Muneta T, Sekiya I	Incidence and risk factors for medial tibial stress syndrome and tibial stress fracture in HS runners	<i>Knee Surg Sports Traumatol Arthrosc</i> 2013;21:556-63	<p>BMI (kg/m²)</p> <p>Height (cm)</p> <p>Hip ABD strength (N)</p> <p>Hip ER ROM (deg)</p> <p>Hip IR ROM (deg)</p> <p>Intercondylar and intermalleolar interval (mm)</p> <p>Navicular drop (mm)</p> <p>Passive ankle DF – knee ext (deg)</p> <p>Passive ankle DF – knee flex (deg)</p> <p>Q-angle (deg)</p> <p>Straight leg raise (deg)</p> <p>Weight (kg)</p>
Yates B , White S	The incidence and risk factors in the development of medial tibial stress syndrome among naval recruits	<i>Am J Sports Med</i> 2004;32:772-80	<p>Ankle DF - knee ext (deg)</p> <p>Ankle DF - knee flex (deg)</p> <p>BMI (kg/m²)</p> <p>FPI (-16-16)</p> <p>FPI (supinated, normal, pronated, highly pronated)</p> <p>Previous Hx of MTSS (yes, no)</p> <p>Sex (m,f)</p> <p>Weekly exercise (hrs)</p> <p>Weekly weightbearing exs (hrs)</p> <p>Weekly weightbearing exs excluding walking (hrs)</p>

BMI: body mass index, DF: dorsiflexion, ER: external rotation, EV: eversion, f: female, FPI: foot posture index, INV: inversion, IR: internal rotation, m: male, Q-angle: quadriceps angle, ROM: range of motion

Appendix 2 Characteristics of studies included in the meta-analysis

Author(s)	Study Design	Population	N	Groups	Risk Factors
Bandholm et al[15]	CC	Recreational athletes/physically active	30	MTSS: 9F, 6M Control: 9F, 6M	Navicular drop difference (mm) Navicular height loaded (mm) Navicular height neutral (mm) Medial longitudinal arch deformation difference (deg) Medial longitudinal arch deformation difference during walking (deg) Medial longitudinal arch angle heel strike (deg) Medial longitudinal arch angle loaded (deg) Medial longitudinal arch angle neutral (deg) Medial longitudinal arch angle push-off (deg)
Bennett et al[16]	PC	Runners	36	MTSS: 13F, 2M Control: 8F, 13M	Active DF (deg) Navicular drop (mm) Rearfoot angle (deg) Resting calcaneal position in stance (deg) Sex (m,f) Tibiofibular varum (deg)
Franklyn et al[10]	CS	Recreational athletes/physically active	57	MTSS: 11F, 12M Control: 16F, 18M	Tibia Measures: Anteroposterior dimension of the medullary region (mm) Anteroposterior width (mm) Amount of elongation (mm ⁴) Cross-sectional area (mm ²) Distal width (mm) Lateral length (mm) Maximum second moment of area (mm ⁴) Medial length (mm) Minimum second moment of area (mm ⁴) Mediolateral width (mm) Mediolateral dimension of the medullary region (mm) Polar moment of area (mm ⁴) Proximal width (mm) Radius of gyration Section modulus
Gehlsen & Seger[11]	CC	Recreational athletes/physically active	20	MTSS: 10F Control: 10F	Angular displacement (calcaneus and midline of lower leg (LL) (deg) - slow speed, shoes, contact Angular displacement (deg) - slow speed, shoes, support

					Angular displacement (deg) - fast speed, no shoes, contact
					Angular displacement (deg) - fast speed, no shoes, support
					Angular displacement (deg) - fast speed, no shoes, takeoff
					Angular displacement (deg) - slow speed, shoes, takeoff
					Angular displacement (deg) - fast speed, shoes, contact
					Angular displacement (deg) - fast speed, shoes, support
					Angular displacement (deg) - fast speed, shoes, takeoff
					Angular displacement (deg) - slow speed, no shoes, contact
					Angular displacement (deg) - slow speed, no shoes, support
					Angular displacement (deg) - slow speed, no shoes, takeoff
					DF ROM (deg)
					DF strength (lb)
					EV ROM (deg)
					EV strength (lb)
					Height (cm)
					Inversion (INV) ROM (deg)
					INV strength (lb)
					Leg length (cm)
					PF range of motion (PF ROM) (deg)
					PF strength (lb)
					Weight (kg)
Hubbard et al[18]	PC	College athletes	146	MTSS: 9F, 20M Control: 30F, 87M	Age (yrs)
					DF ROM (deg)
					EV ROM (deg)
					Females only: age of menstruation (yrs)
					Females only: have a regular menstrual cycle (yes/no)
					Females only: take birth control (yes/no)
					Height (cm)
					How long subject has been running (yrs)
					How often change running shoes (per year)
					INV ROM (deg)
					Isometric PF ($\text{N}\cdot\text{kg}^{-1}$)
					Isometric DF ($\text{N}\cdot\text{kg}^{-1}$)
					Isometric INV ($\text{N}\cdot\text{kg}^{-1}$)
					Isometric EV ($\text{N}\cdot\text{kg}^{-1}$)
					Miles run/week (miles)
					Navicular drop (mm)
					PF ROM (deg)
					Previous history of MTSS (yes/no)
					Previous history of stress fracture (yes/no)

					Take vitamins (yes/no) Tibial varum (deg) Wear orthotics (yes/no) Weight (kg)
Madeley et al[7]	CC	Recreational athletes/physically active	60	MTSS: 14F, 16M Control: 14F, 16M	BMI (kg/m ²) Height (m) Standing heel raise (#)
Messier & Pittala[12]	CC	Runners	36	MTSS: 17 Control: 19 (sex not reported)	Apparent leg length difference (%>0.64 cm) DF ROM (deg) Foot print Hamstring flexibility (% abnormal) Lower leg flexibility (% abnormal) Max pronation (deg) Max pronation velocity (deg/s) PF ROM (deg) Q angle (deg) Running terrain (% hills, crowned roads, trails) Sit and reach (cm) Time to max pronation (ms) Total rearfoot movement (deg) True leg length difference (not reported)
Moen et al[8]	CC	Military	35	MTSS: 15M Control: 15M	Ankle DF (deg) Ankle PF (deg) BMI (kg/m ²) Duration of complaints (days) Hallux flexion (deg) Hallux extion (deg) Height (cm) Hip ER ROM (deg) Hip IR ROM (deg) Knee ext (deg) Knee flex (deg) Lean calf girth (cm) Max calf girth (cm) Navicular drop >0.5cm (yes/no) Pre-rehab symptom free running distance (m) Sports Rated Activity Scale at baseline (0-100) Standing foot angle <140deg (yes/no) Subtalar EV (deg) Subtalar INV (deg)
Raissi et al[19]	PC	College students in a	66	MTSS: 10F, 3M	Achilles angle (deg)

		physically active course		Control: 53 (sex not reported)	Anterior location of previous pain (%) BMI (kg/m ²) Duration of MTSS (hours) Duration of professional activity (unit not reported) Height (m) Intercondylar distance of femur (mm) Intermaleolar distance (mm) Length of weekly physical activity (%) Navicular drop (mm) Positive history of professional activity (%) Past history of pain (%) Q-angle (deg) Tibia angle (deg)
Rathleff et al[20]	CC	Recreational athletes/physically active	28	MTSS: 10F, 4M Control: 10F, 4M	Dynamic navicular drop (mm) FPI-6 Preferred walking speed (km/h) Static navicular drop (mm) Velocity of dynamic navicular drop (mm/sec) Visual analog scale – during activity (cm) Visual analog scale – pain at rest (cm)
Viitasalo & Kvist[14]	CC	Recreational athletes/physically active	48	MTSS: 13M ("bad" MTSS), 22M ("slight" MTSS) ("bad" and "slight" groups were combined for data analysis) Controls: 13M	Achilles angle, treadmill running – before touch down, during full support during full support – minimum, during full support –maximum, after heel takeoff, at the ball of the foot takeoff Angular displacement, treadmill running – before touch down-during full support, during full support min-during full support max, during full support-after heel takeoff, after heel takeoff-at the ball of the foot takeoff Passive subtalar EV (deg) Passive subtalar INV (deg) Passive subtalar sum (deg) Standing feet diagonal – leg angle, calcaneus angle, Achilles angle (deg) Standing normal – leg angle, calcaneus angle, Achilles angle (deg) Standing heels together – leg angle, calcaneus angle, Achilles angle (deg)
Yagi et al[9]	PC	Runners	244	MTSS: 44F, 58M Control: 54F, 88M	BMI (kg/m ²) Height (cm) Hip abduction strength (N) Hip ER ROM (deg) Hip IR ROM (deg) Intercondylar and intermalleolar interval (mm)

					Navicular drop (mm)
					Passive ankle DF – knee ext (deg)
					Passive ankle DF – knee flex (deg)
					Q-angle (deg)
					Straight leg raise (deg)
					Weight (kg)
Yates & White[4]	PC	Military	112	MTSS: 18F, 22M Control: 16F, 56M	Ankle DF - knee extension (deg)
					Ankle DF - knee flexion (deg)
					BMI (kg/m ²)
					FPI (-16-16)
					FPI (supinated, normal, pronated, highly pronated)
					Previous history of MTSS (yes, no)
					Sex (m,f)
					Weekly exercise (hrs)
					Weekly weightbearing exs (hrs)
					Weekly weightbearing exs excluding walking (hrs)

BMI: body mass index, CC: case-control, CS: cross-sectional, DF: dorsiflexion, ER: external rotation, EV: eversion, f: female, FPI: foot posture index, INV: inversion, IR: internal rotation, m: male, PC: prospective cohort, Q-angle: quadriceps angle, ROM: range of motion