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Medial Tibial Stress Syndrome: Who's at risk? A Systematic Review

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Abstract

Background and Purpose

The purpose of this review is to identify risk factors in the athletic population for the development of Medial Tibial Stress Syndrome (MTSS). MTSS is a lower extremity pathology that frequently impacts athletes and disrupts their ability to participate. Identifying risk factors and other direct causes of this condition can provide insight regarding treatment techniques and methods of prevention.

Methods

An extensive search of the literature was conducted. Databases used included PubMed, ProQuest Nursing, Cinahl and Allied Health, Proquest Health and Medicine, and Google Scholar. 11 articles were found meet inclusion and exclusion criteria. Critically Appraised Topic (CAT) analyses were completed for each include article. Quality assessment via Physiotherapy Evidence Database scale (PEDro) was also completed, average quality score being 6.

Results

Significant risk factors for MTSS development include high body mass index, female gender, navicular drop, foot pronation, limited hip internal rotation range of motion, increased plantarflexion range of motion, limited straight leg raise, cortical thickness of the tibia, bilateral ankle strength, impaired standing heel-rise test, decreased foot balance, increased miles run per week, less significant exercise history, higher pain level, and longer duration of symptoms.

Discussion

Overall it can be inferred that there is lack of agreement in the current literature regarding the cause of MTSS, the associated risk factors, and the best way to treat it. Based on the results provided by this systematic review, different healthcare providers may be able to better develop appropriate plans of care. Future studies may want to focus on risk factors consistently contributing to MTSS, larger sample sizes, analyzation based on type of impact sport, or running mechanics in relation to MTSS development.

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Introduction

Lower extremity injuries are a very common problem in the athletic population, therefore they are frequently addressed by physical therapists and other medical professionals. These injuries can include stress fractures, chronic compartment syndrome and Medial Tibial Stress Syndrome (MTSS) [1]. The highest incidence is seen in MTSS [1]. It has been estimated that this condition has accounted for 4 to 35% of overuse leg injuries in the athletic and military populations [2]. Research has also shown that MTSS is responsible for 13.2% to 17.3% of all running injuries and approximately 22% of injuries in aerobic dancers [1]. According to these statistics and others, this injury has become a very prominent issue that remains difficult to not only diagnose and treat, but also to identify individuals who are susceptible to its development.

The formal definition of MTSS varies throughout the existent literature. It was first qualified as "a symptom complex seen in athletes who complain of exercise induced pain along the posteromedial border of the tibia" [1]. The exact pathophysiology of MTSS remains unknown, however until recent research emerged, inflammation of the periosteum as a result of increased traction was viewed as the most viable explanation. Studies have now shown that it is more likely that MTSS is a bone stress reaction that progresses to a painful state as opposed to an inflammatory process [1]. The metabolic changes in bone that occur when an individual begins an exercise program result in an increased porosity on the posteromedial border of the tibia. In a normal individual, new bone is laid down in order to resist compressive forces and to increase the strength of the bone. However, in an individual who has suffered from longstanding MTSS, the tibia will remain more porous by approximately 15% according to one study [1].

In order to diagnose MTSS, a thorough clinical history and physical examination must be conducted. It will often present as "diffuse, palpable pain, localized to the posteromedial tibial border". The pain can be located anywhere along this border, however it is commonly found from the middle to distal thirds. It is described as a dull ache after exercise. It may last for several hours up to days [1]. MTSS is often diagnosed as shin splints, shin pain, periostitis, and exercise related lower leg pain [3]. Imaging and diagnosis MTSS with radiograph is not appropriate however, Magnetic Resonance Imaging (MRI), has increasingly been used for studying MTSS.

Currently, there is no accepted successful treatment plan that consistently alleviates the symptoms of MTSS in all populations. Many studies describe conservative options for treatment including ice application, aspirin, heel cord stretching and walking casts. Other researchers suggest more exercise based interventions such as graded running programs, strengthening, and stretching exercises specifically targeting the calf muscles. Sports compression stockings are also frequently used in athletic populations [2]. However, despite the volume of research that has been conducted on interventions for MTSS, there is a lack of agreement upon the most effective method. One reason for such lack of consensus might be the multitude factors leading to development of MTSS. With the several different risk factors known, treatment for and prevention of MTSS as a single problem is difficult and may encompass a wide range of options. This has led to a focus on attempting to determine the most relevant risk factors that contribute to the development of this condition. It is the intention of many medical professionals to identify these risk factors in individuals most known for developing MTSS, such as athletes, in order to implement prevention strategies.

Thus far, what is known about risk factors is that there are both intrinsic and extrinsic aspects that can possibly play a role in the development of MTSS. Additionally, some of the known risk factors are preventable, while others are inherent and may increase susceptibility. What are still under debate however, are the most common biomechanical risk factors or other direct causes. Understanding the most prevalent risk factors for MTSS may lead to better understanding of the best intervention and prevention approaches. Therefore, it is the purpose of this review to identify the most common risk factors of MTSS, specifically in the athletic population.

Methods

Search strategy

Literature search was conducted over a period of approximately 7 days, throughout the time span of August 1, 2014-October 1, 2014, regarding risk factors and causes of medial tibial stress syndrome. The databases that were searched include PubMed, ProQuest Nursing and Allied Health, Proquest Health and Medicine, Cinahland Google Scholar. The key phrases that were included in all database searches included: shin splints and physical therapy, shoes and shin splints, shin splints and footwear, shin splints and treatment, medial tibial stress syndrome risk factors, medial tibial stress syndrome prevention, shin splints risk factors, athletes and medial tibial stress syndrome, prevention of shin splints in athletes, medial tibial stress syndrome and risk factors, medial tibial stress syndrome and athletes, and medial tibial stress syndrome and physical therapy. Table 1 displays the initial search results for such criteria without any filters, which are discussed in the next section of this review, study selection. The reference lists of the eligible articles were reviewed for any cited articles that fit the criteria of this review. Other potential sources were then subjected to the same evaluation process.

Study selection

In order to be included in this study, articles met the following eligibility criteria: Inclusion criteria: studies that had included 1) sample consisted of an athletic population 2) participants had symptoms of medial tibial stress syndrome 3) were peer-reviewed 4) outcome measures of (but were not limited to) navicular drop, foot length, and gastrocnemius and/or soleus length 5) demographic information such as BMI, gender, age, exercise amount and intensity, type of exercise, and past medical history. Exclusion criteria: 1) articles published in languages other than English 2) published before 2000 3) studies with case report designs 4) were not peer reviewed.

Search Engine	Key Works	Relevant Articles	Filters	Relevant articles
PubMed	Shin splints and physical therapy	31	Athletic population, symptoms of MTSS, non case study or systematic review, English	1
	Shoes and shin splints	12	Athletic population, symptoms of MTSS, non case study or systematic review, English	0
	Shin splints risk factors	43	Athletic population, symptoms of MTSS, non case study or systematic review, English	8
	Prevention of shin splints in athletes	7	Athletic population, symptoms of MTSS, non case study or systematic review, English	1
ProQuest Nursing and Allied Health	Shin splints and physical therapy	286	Full text, peer reviewed, not published prior to year 2000, athletic population, symptoms of MTSS	2
	Medial tibial stress syndrome risk factors	982	Full text, peer reviewed, not published prior to year 2000, athletic population, symptoms of MTSS	1
	Medial tibial stress syndrome and physical therapy	792	Full text, peer reviewed, not published prior to year 2000, athletic population, symptoms of MTSS	0
ProQuest Health and Medicine	Shin splints and footwear	289	Full text, peer reviewed, not published prior to year 2000, MTSS symptoms	0
	Medial tibial stress syndrome prevention	1782	Full text, peer reviewed, not published prior to year 2000, MTSS symptoms	1
	Athletes and medial tibial stress syndrome	1578	Full text, peer reviewed, not published prior to year 2000, MTSS symptoms	1
Google Scholar	Medial tibial stress syndrome and risk factors	30800	Not published prior to year 2000, athletic population, MTSS symptoms, non case-study or systematic review, within first 5 pages of search sorted by relevance	11
	Medial tibial stress syndrome and athletes	18000	Not published prior to year 2000, athletic population, MTSS symptoms, non case-study or systematic review, within first 5 pages of search sorted by relevance	7
	Shin splints risk factors	20700	Not published prior to year 2000, athletic population, MTSS symptoms, non case-study or systematic review, within first 5 pages of search sorted by relevance	3
Cinahl	Medial tibial stress syndrome and risk factors	31	Full text, peer reviewed, not published prior to year 2000, MTSS symptoms	0

Table 1: Search results *includes duplicate articles between search engines.

Data extraction and quality assessment

Data extraction was performed in a consistent manner across all eligible articles. Critically Appraised Topics (CAT's) were written for each article selected for this review. Each article was critically appraised and the pertinent data was gathered and implemented into an organized table for ease of accessibility for both authors and readers. The data of interest that was obtained from each article included: the study design, level of evidence, sample, outcome measures, and major results of the research conducted regarding risk factors for medial tibial stress syndrome, strengths and limitations of the study, and overall validity of the research. The results of the eligible articles were then compared in order to compile all possible risk factors as well as to determine if there were consistent findings across research, indicating an increased prevalence of certain risk factors. The samples were also evaluated to identify a possible at-risk population for this musculoskeletal condition. In order to ensure clinical applicability, the authors also examined the research for possible successful treatments and any prevention methods for medial tibial stress syndrome. These items were analyzed for effectiveness and practicality in the general population.

The methodological quality of each article was analyzed using the Physiotherapy Evidence Database (PEDro scale) [4]. Each paper was individually assessed for interval validity, external validity, and statistically sufficiency. A point was awarded for each question if there was sufficient evidence that the requested information was clearly stated. A maximum possible score for methodological quality was 11. A strong score was considered >6, fair 4-6, and poor <4. The quality score of the articles used ranged from 5-9. The score for each individual paper can be found in table 1.

Results

Eleven studies were analyzed as a part of this systematic review. All studies included human subjects, particularly athletes, with a range of number of participants from 15-468, mean of 118.5. The average PEDro quality score of the articles used in this review was approximately 6, which is considered fair quality. These articles were overall only at a fair quality because most articles lacked both blinding (for subjects, therapists, or assessors) and randomization (for subject recruitment, group allocation, or order of assessments completed). The details of the selected studies can be found in table 2.

Subject description

Four studies included only runners [5-8], two included military personnel [1,3], and five included athletes of different sports [2,9-12]. The disease severity of participants within the studies varied, as some were deemed "healthy" prior to study initiation while other were already diagnosed with MTSS. Two studies included only subjects with MTSS [1,9], two studies used subjects with and without MTSS for comparison reasons [12,13] and the remaining seven had subjects of overall "healthy" quality prior to study initiation.

Overall, our results displayed varying risk factors for developing MTSS. The most common risk factors include general demographics and history, navicular drop, range of motion, pain level, miles ran per week, bilateral ankle strength, exercise history, cortical thickening of tibia shown with MRI, decreased repetition completion during standing heel rise test (decreased plantarflexion strength), presentation of symptoms, foot balance and duration of symptoms which were found significant in ten of the eleven studies analyzed.

Demographics and history

Seven of the eleven studies included in this review analyzed the effect of baseline characteristics on the development of MTSS. Characteristics evaluated by the various studies included age, gender, height, Body Mass Index (BMI), limb dominance, history of injury/pain, orthotic/tape use, dietary supplementation, menstrual cycle and smoking; however only increased BMI and female gender were correlated with the incidence of MTSS in six of the seven studies. Yates et al., found a significant relationship between the development of MTSS and female gender [1] where female naval recruits were twice as likely to develop the condition as male recruits. Females (n=40) demonstrated a 52.9% incidence rate as compared to the rate of 28.2% seen in males (n=84) [1]. Higher female injury rates among military recruits have been reported in past [14,15]. Injury rates are greater when women train in conjunction with men and are expected to achieve the same fitness levels [16]. This can be explained due to the fact that women have generally smaller stature and they have to "keep up" with male recruits while marching, resulting in overstrenous gait changes, thus increasing the risk of developing MTSS. Plisky et al., found that high school cross country runners with an increased BMI were at an increased risk of suffering from MTSS. However, individuals in higher BMI have overall higher incidence of lower extremity injury, not particular MTSS [5]. Both the female gender and those with increased BMI are at high risk for MTSS development because of the increased stresses that occur to the tibia during exercise.

Biomechanical characteristics

Multiple biomechanical characteristics were used as outcome measures throughout the studies analyzed in this review. The characteristics found to be significant include navicular drop, foot pronation, limited hip internal rotation range of motion, overall plantarflexion range of motion, limited straight leg raise, cortical thickness of tibia via MRI, bilateral ankle strength, standing heel-rise test, and foot balance. Overall deficiencies in lower extremity strength, proprioception, and available motion, as well as bony structure imposing postural deficits would be positive risk factors for developing MTSS. Yates et al., found that foot pronation was significantly associated with the development of MTSS in naval recruits [1]. Those recruits who demonstrated increased pronation were nearly twice as likely to develop MTSS as individuals with a normal or supinated foot posture [1]. Likewise, Hubbard, Carpenter, and Cordova demonstrated that athletes with MTSS had an average plantarflexion range of motion of 46.0° versus those in the healthy group had significantly less motion, averaging 40.6° [9].

Training characteristics

The incidence of MTSS is found to most prevalent in the athletic population; therefore studies that examine this topic often assess various qualities of participants' exercise and training regimes [1]. This systematic review included studies that analyzed type of shoes worn during physical activity, miles ran per week, running surface type and general exercise history. Those characteristics that were found to be significant include miles ran per week and exercise history. It can be inferred that a significant change in running history (increased weekly frequency, fewer years of training, etc.) places athletes at risk for the development of stress injuries, including MTSS. Such changes in characteristics place increased stress on the tibia, putting it at a higher risk for injury. For example, it was found that those with a history of fewer years running had a higher incidence of MTSS

Author, Year, n	PEDro Scale Score	Outcomes	Results	Strengths & Limitations
Yagi et al., 2013 (n=102)	6/10	Injury incidence, correlation between incidence and physical measurements determined as risk factors	123 cases of injury: 102 with medial tibial stress syndrome and 21 with tibial stress fracture. Body weight, BMI and limited hip internal roation determined to be risk factors for medial tibial stress syndrome in females. Limited straight leg raise determined to be risk factor for tibial stress fracture in males	Strengths: 1. Investigators operationally defined sample 2. Participants were representative of population from which they were drawn 3. All participants entered study at same stage of their condition 4. Study time frame was long enough to capture outcomes of interest 5. Outcomes were operationally defined 6. Sample included subgroups 7. Detailed description of physical measurements 8. Diagnosis was made by sports physician 9. Physical measurements taken by sports physical therapists 10. Sited other literature 11. Multiple radiographs taken to confirm diagnoses of SF 12. Included clinical application of results 13. Limited equipment needed to replicate 14. Large sample size 15. Detailed description of diagnoses being investigated 16. Utilized appropriate statistics 17. Post hoc tests performed Limitations: 1. Some participants had previous leg pain while others did not 2. Attrition occurred 3. No blinding 4. Investigators did not confirm their findings with a new set of participants 5. Ambiguous inclusion/exclusion criteria 6. Unequal numbers of males and females 7. Limited generalizability 8. Multiple physicians made diagnoses, possibly decreasing accuracy 9. Physical measurements only taken once 10. Participants' typical running distances varied (short-track, middle-distance, long-distance) 11. No detailed data regarding individual running distance 12. Assumptions for statistical tests not mentioned 13. No control group 14. Reliability and validity of outcome measures was not addressed 15. Power analysis was not completed
Sharma et al., 2011 (n=468)	5	Fitness level, foot balance, time to reach peek heel rotation, presence of smoking habit, incidence of MTSS	Dominant medial plantar presssures, low aerobic fitness, and smoking habit are all risk factors for developing MTSS. The logistic regression model predicted 96.9% of the non-MTSS group, 67.5% of the MTSS group, with an overall accuracy of 87.7%	Strengths: 1. Purpose of study clearly stated 2. Definition of MTSS provided 3. 1.5 mile timed-run known to be valid measure of aerobic fitness 4. Weight calibration completed for pressure plate 5. All participants underwent same training, therefore well-controlled study 6. Imaging used to confirm or reject clinical diagnosis 7. Good and bad definitions for balance data provided 8. Post hoc analysis completed 9. Smoking known risk factor based on other studies 10. Exclusion criteria used 11. Results of MTSS percentage comparable to other studies 12. First prospective study to look at biomechanical variables with lifestyle variables for MTSS risk factors 13. Large sample size Limitations: 1. Blinding unknown 2. Possibility of logistical regression model to be biased secondary to limited factors considered in analysis. 3. Logistical regression model unable to predict 32.5% of MTSS group members, meaning other important factors (such as nutrition and bone density) that were potential contributors to the development of MTSS were not considered in the analysis 4. No inclusion criteria 5. Extent (number of cigarettes per day) of smoking not documented in smokers 6. Few biomechanical outcome measures looked at other than plantar pressure 7. Which 6 right and left steps, pertaining to length of runway, included in analysis unknown 8. Number of days into the training period that the injury occurred was not analyzed 9. It is unknown if whom the subjects reported their injury to for further clinical diagnosis testing was an expert or not for such evaluation

Hubbard et al., 2009 (n=146)	7	Age, height, weight, previous injury (MTSS, stress fracture), current footwear (orthotic wear, how often shoes are changes, type of shoe), miles ran per week, current tibia pain or leg tightness (surface type of most running), dietary supplementation (including vitamins), info on menstrual cycle, bilateral ankle strength and range of motion (plantarflexion, dorsiflexion, inversion, and eversion), tibial-varum, and navicular drop	Significant differences between MTSS and healthy groups for plantarflexion ROM, length subjects had been running, previous history of MTSS, previous history of stress stracture, and orthotic use	Strengths: 1. Sample operationally defined 2. Long enough time frame to see outcomes 3. Outcome criteria operationally defined 4. Trial run of measurements with healthy subjects not in study completed for test measurement tool reliability and SE 5. All measurement tool ICC's >0.7, meaning all with good reliability 6. SEM values for all measurement tools relatively small, meaning good reliability 7. Statistical analysis completed in subgroups (MTSS and healthy) 8. Clear definition of MTSS provided 9. Extrinsic outcome measures looked at 10. Purpose of study clearly stated 11. Similar baseline demographics of subjects 12. Inclusion criteria provided 13. Specific criteria for presence of MTSS used 14. Certified athletic trainer completed initial measurements 15. Order that the measurements were completed in was counterbalanced to avoid any order effect 16. Copy of questionnaire provided 17. Results compared with similar studies previously completed Limitations: 1. Participants with varying past medical histories of MTSS and other diagnoses 2. No blinding completed 3. No exclusion criteria clearly provided 4. No interrater reliability for measurements, as all completed by the same athletic trainer 5. No training requirements mentioned for either athletic trainers or researchers defining participants with MTSS 6. Majority of athletes were cross-country runners (unequal balance of athletes from different sports) 7. Why orthotics were used was not examined 8. Other intrinsic factors identified to affect MTSS risk were not included as outcome measures in the study (rearfoot varus and valgus, forefoot varus and valgus, isokinetic ankle strength, and bone mineral density) 9. Only extrinsic factors included 10. Use of athletes from different sports may skew data as training intensity, surface, duration, etc. differs between sports. 11. Number of subjects that developed MTSS (n=29) much smaller than the healthy group compared to for statistical analysis (n=117)
Madeley et al., 2007 (n=30 MTSS athletes, 30 reference (control) athletes	6	Age, height, BMI, type of sport, level of competition, training frequency, training duration, competition duration, standing heel-rise test for muscle endurance - MTSS group additionally: presentation of symptoms, duration, pain over previous week, prior treatments in the past 4 weeks, effects of symptoms on sporting and everyday activities	No significant differences were found for age, height, BMI. Those in the MTSS group completed a significantly less number of heel-rise repetitions (p, 0.001). Additional questioning from the MTSS group revealed 29/30 had bilateral involvement, median duration of symptoms was 15 weeks, mean pain in the past week was 65mm, 23/30 said symptoms limited everday activity, 24/30 said it limited training and competition, and 23/30 had previous treatment. Previous treatments included change of running surface or sporting footwear, massage therapy, addition of foot orthoses, stretching and/or strengthening program, and general physical therapy treatments. Test-retest reliability for both groups was high, with ICCs >0.90 and low SEM values	Strengths: 1. MTSS diagnosis clearly defined 2. Data collected for all participants 3. Data analyzed separately for the two groups 4. First study to investigate endurance of ankle joint plantar flexors in patients with MTSS 5. Purpose clearly stated 6. Control group used 7. Reference participants used in control group matched to MTSS participants 8. Random limb selected for testing for reference group and those with equal, bilateral pain 9. Practice trial of heel raises completed so accurately completed during testing trial 10. Test-retest reliability of standing heel rise known to be excellent in healthy population, with deep vein thrombosis, and congestive heart failure 11. Test-retest reliability of standing heel rise calculated to be excellent (ICCs>0.90, low SEM values) with MTSS using 5 MTSS patients and 5 reference participants after study completion 12. Prospective sample size calculated prior to start of study 13. Power of study calculated 14. Statistical assumptions tested and corrected 15. Age and BMI matched for reference group Limitations: 1. No blinding 2. Practice trial of heel raises may have caused fatigue 3. Only ankle plantar flexor muscle endurance testing (no other muscle groups) 4. Retrospective design limits causal determination 5. 77% MTSS participants received prior treatment 6. Standing heel rise cannot isolate specific leg muscles 7. MTSS not confirmed with diagnostic imaging 8. Possibility of other pathologies in MTSS group members 9. Only one examiner completed standing heel-rise testing

Loudon et al., 2010 (n=23)	6	Sex, age, BMI, duration of symptoms, navicular drop test, talocrural dorsiflexion range of motion, pain level, quality of life	15/23 had successful treatment outcomes. Duration of symptoms, change in pain, and GRC questionnaire scores were statistically significant between successful and not successful groups, whereas age, ankle dorsiflexion, NDT, and BMI were not significant	Strengths: 1. Sample defined 2. Outcomes defined 3. Subgroup analysis 4. Bonferonni adjustment 5. Purpose clear 6. MTSS diagnosis explained 7. Participants with MTSS 8. Inclusion & exclusion criteria 9. NPRS reliable 10. Same investigator takes measurements 11. BFOs removable 12. Good time frame 13. HEP 14. No other treatments 15. GRC valid 16. Compared to other studies 17. First to document duration Limitations: 1. Two participants unable to complete 2. No blinding 3. Small sample size 4. Only runners/walkers 5. No inter-rater reliability 6. Possible inaccurate daily log 7. Participants unable to complete included in unsuccessful group results 8. Mostly students and medical center employees 9. Duration not compared to other studies 10. No post-intervention NDT & dorsiflexion 11. No strength testing
Newsham et al., 2013 (n=15)	5	MRI measures of tibia (tibial length, tibial width both antero-posterior and medio-lateral, and cortice thickness (anterior, posterior, lateral and medial) and palpation of middle third of medial border of tibia to determine presence of stress reaction in tibia	Symptomatic tibia had thicker medial cortices, thicker lateral cortices, and thinner anterior cortices than asymptomatic tibiae. MRI images of symptomatic tibia revealed either oedema within the cancellous bone and/or stress fracture. Participation in a ball sport in addition to tri-athlete training was associated with asymptomatic tibiae	Strengths: 1. Investigators operationally defined sample 2. Participants were representative from the population from which they were drawn 3. All participants entered the study at the same stage of their condition 4. No attrition 5. Conducted long-term follow up at 2 years post 6. Defined inclusion criteria 7. Qualified individuals conducted measurements on MRI images 8. Two individuals conducted measurements that were averaged increasing accuracy 9. Included detailed description of measurements taken from images 10. Included detailed method of taking images 11. Outcome measures were reproducible 12. Defined criterion for symptomatic tibiae 13. Included diagram of MRI positions and measurements 14. Participants had similar demographic characteristics 15. Included practical/clinical application of results 16. Utilized correct statistical measures 17. Sited other literature 18. Imaging is one of most reliable diagnostic tools Limitations: 1. No blinding 2. Sample did not include subgroups of people for whom the prognostic estimates will differ 3. Investigators did not confirm their findings with a new set of participants 4. Did not repeat measurements at long-term follow up 5. Did not define exclusion criteria 6. Utilized convenience sampling 7. No mention of reliability or validity of outcome measures 8. Six athletes were involved in other sports during training 9. Limited generalizability 10. Observational studies are low level of evidence 11. Small sample size 12. No mention of statistical assumptions 13. Unequal number of males and females

Yuksel et al., 2011 (n=11 male and female athletes and 11 regularly exercising individuals)	6	Exercise questionnaire (age of beginning sports activities, weekly training schedule frequency and duration and how any months this program was followed, last training level, lifetime cumulative sports activity, total training level, and if an increase in training duration or intensity had been made in the time one month before MTSS symptom onset), Medial Longitudinal Arch (MLA) angle, both Weight Bearing (WB) and Non-Weight Bearing (NWB), MLA deformation, navicular drop, maximum isokinetic strength of inversion and eversion bilaterally	Baseline measurements were similar between groups (p>0.05). All MTSS group members complained of bilateral symptoms and 9 had increased training duration or intensity within the month before MTSS onset. No statistically significant differences were found between the groups for weekly training days, duration of single training sessions or total weekly trainings, monthly training period, last training level, WB and NWB MLA angles, MLA deformation, and navicular drop measurements. Statistically significant findings between groups included total training level difference (p>0.001), higher average eversion concentric strength in patient group for both 30°/sec and 120°/sec angular velocities (p<0.05), and higher Inversion/Eversion (I/E) strength ratio in the control group at the 30°/sec angular velocity	Strengths: 1. Sample in study operationally defined 2. Outcome data collected for all participants 3. Outcome measures operationally defined 4. Control group used for subgroup analysis 5. Definition of MTSS provided in introduction 6. Purpose of study clearly stated 7. First study at the time that looked at isokinetic invertor and evertor muscle strength in ankles of MTSS patients 8. Inclusion and exclusion criteria provided for both groups 9. Specific diagnosis criteria for MTSS provided 10. Bandholm method for MLA angles with high reliability 11. Standardized warm up completed by all participants 12. Submaximal testing completed prior to maximal to ensure accurate measurements 13. Dynamometer for strength testing calibrated before each test 14. Rest breaks given between strength testing trials 15. Parametric and non-parametric data with separate analysis Limitations: 1. Stage of MTSS syndrome unknown in MTSS group 2. Blinding not mentioned in study other than study type 3. Small sample size 4. Possible inaccurate reports from participants on exercise questionnaire 5. Possibility of technical error secondary to computer measurement of MLA angles 6. Submaximal testing prior to maximal possible source of fatigue making measurements inaccurate 7. Investigators of unknown qualifications
Plisky et al., 2007 (n=105 high-school cross-country runners)	6	Baseline history (age, gender, height, body mass, limb dominance, history of lower extremity injury or pain, number of years running experience, and orthotic or tape use), navicular drop, full and truncated foot lengths, DIR, post-season questionnaire	Female gender and higher BMI associated with higher risk of MTSS; when orthotic wear controlled for only higher BMI	Strengths: 1. Purpose clear 2. Power analysis 3. Approved by review board 4. Coaches and ATs trained to use DIR 5. Skilled investigators 6. MTSS definition 7. Well documented procedures 8. Pilot study 9. High intra-rater-reliable navicular drop & foot length measurements 10. Outliers & goodness of fit calculated 11. Limited bias based on study design 12. Data for all participants 13. First study on practices & events 14. Navicular drop and height normalized 15. Exclusion criteria Limitations: 1. Participant reported height & weight 2. Unknown inter-rater reliability of measurements 3. Small sample size 4. Small DIR sensitivity 5. Data collected monthly 6. No blinding 7. No follow-up 8. No cause and effect 9. Those with MTSS excluded 10. Validity of measurements unknown 11. Baseline varied 12. Self-reported shin pain 13. Training for DIR unknown 14. Reliability and validity of outcome measures (except navicular drop and foot length) unknown

Bennett et al., 2001 (n= high school cross-country runners: 15 with MTSS, 21 without injury)	6	Navicular drop, resting calcaneal position, tibiofibularvarum, gastrocnemius length	Navicular drop and sex two accurate predictors for incidence of MTSS	Strengths: 1. Operational definition of the sample included 2. Participant's representative of population 3. Outcome data collected from all participants that met criteria 4. Outcome criteria operationally defined (detailed description) 5. No attrition 6. All groups managed in same way (measurements conducted in same manner) 7. Reliability of measurements was tested (pilot study) 8. Relatively equal group sizes 9. Participants analyzed in assigned groups 10. Control group to provide comparison 11. Used appropriate statistics 12. Limited equipment necessary Limitations: 1. Participants entered study at different stages of their condition 2. Researchers were not blinded 3. Participants were not sub grouped based on difference in prognostic factors 4. Findings were not confirmed with new set of patients 5. Small sample size 6. Limited generalizability 7. Identification of symptomatic patients relied on self-report of medial shin pain 8. Measurements fail to account for dynamics of running 9. No randomization 10. No mention of training of researchers 11. No long term follow-up conducted 12. Assumptions for parametric tests not tested 13. No mention if participants were receiving treatment 14. No description of cross-country training 15. No description of symptoms experienced by patients 16. No pre and posttest measurements
Yates et al., 2004 (n=124 naval recruits (84 men and 40 women)	7	Foot Posture Index (FPI), ankle dorsiflexion, injury incidence, exit interview	Gender and foot pronation are significant risk factors for development of MTSS; past history of MTSS increased risk for development; BMI, age and ankle dorsiflexion had no effect	Strengths: 1. Large sample size 2. Investigators operationally defined sample 3. Participant's representative of population from which they were drawn 4. All participants entered the study at the same stage of the condition 5. Study time frame was long enough to capture outcomes of interest 6. All outcome criteria operationally defined 7. Investigator who took physical measurements was blinded 8. Included study specific definition of MTSS 9. Specific criteria for inclusion in either MTSS group or non-MTSS group 10. Specific exclusion criteria 11. Detailed description of physical assessment measures 12. Mentioned reliability of outcome measures 13. Utilized correct statistical measures 14. All participants wore the same types of shoes throughout training period 15. Explained reasons for participant drop-out 16. Sited other literature 17. Researchers included suggestions for prevention and treatment of MTSS Limitations: 1. Limited generalizability 2. Sample did not include subgroups of people for whom prognostic estimates will differ 3. Investigators did not confirm their findings with a new set of participants 4. Ambiguous inclusion criteria 5. No mention of statistical assumptions 6. Differences in amount of exercise completed by recruits prior to study 7. Attrition occurred 8. Unequal number of males and females 9. Possibility of decreased reported injury rate due to hiding of injury in military populations 10. No confirmation of diagnosis with imaging 11. FPI does not assess dynamic foot function 12. No mention of training of investigator taking physical measurements 13. Lower level of evidence (not as strong at determining cause and effect)

Moen et al., 2012 (n=74 athletes with MTSS)	9	Number of days from inclusion to completion of graded running program and participant satisfaction	No significant differences between three treatment groups in either running program completion time or participant satisfaction with treatment	Strengths: 1. Participants were randomly assigned 2. Data analyst was blinded 3. Groups had similar sociodemographic, clinical and prognostic characteristics at start of study 4. All groups managed in same way except for intervention 5. Researchers collected follow-up data over a long enough time frame 6. Participants analyzed in groups that they were assigned 7. Power analysis conducted 8. Investigators were trained by sports physician to increase consistency 9. Pretest measurements completed 10. Inclusion/Exclusion criteria included 11. Detailed description of intervention 12. Multiple follow-ups conducted 13. Measured compliance 14. Corrected for attrition in statistical analysis 15. Used appropriate statistics 16. Sited previous literature regarding topic 17. Detailed description of outcome measures 18. Equal group sizes 19. RCT is strongest design to show cause and effect Limitations: 1. Attrition occurred 2. Athletes and investigators were not blinded 3. No control group 4. Outcome measures were not validated 5. Power analysis may have been inaccurate 6. Athletes were involved in different sports 7. Limited generalizability 8. Potential bias in compliance measurements 9. Participants began in different phases of running program 10. Expensive equipment need for some phases (treadmill) 11. Artificiality (running on treadmill may not be applicable to athlete) 12. Running surface varied based on phase of running program

Table 2: CAT summaries of each article.

development, averaging 5.3 years of running, compared to 8.8 years history of those that didn't develop MTSS. With less years of running history, bones have not been able to adequately adapt to the high impact activity, which places them under greater stress [9]. Sharma et al., examined the contribution of poor fitness to the development of this condition in army recruits. The results of this study demonstrated that those recruits with a decreased level of fitness were 3.6 times more likely to develop MTSS during the training period [3]. Although not shown to be significant in the studies analyzed in this review, shoes and running surface may have an impact in MTSS development as well; abnormal forces may be placed on the tibia from improper foot position in the shoe, unsuitable cushioning, and/or surfaces that do not allow for the absorption of forces.

Symptom presentation

Pain level and duration of symptoms were both found to be positively correlated with increased incidence of MTSS. Many of the athletes studied who had previous symptoms were also found to have a higher rate of repeated occurrence. Hubbard et al., demonstrated the trend of a significant relationship between MTSS and a previous history of the condition in college athletes. The results included that 87% of the MTSS group had a previous history as opposed to only 16% of the healthy group [9]. Another study including 26 recruits with a previous history demonstrated the same relationship. Of these 26 recruits, 11 developed symptoms during the study period: an incidence rate of 42%. Therefore, it was concluded that recruits with a previous history of the condition were at a statistically increased risk of developing MTSS than those who did not [1].

Discussion

The purpose of this systematic review was to identify risk factors in the athletic population for the development of MTSS. As can be inferred through multiple research articles, there is a lack of agreement in the current literature regarding the cause of this condition, the risk factors for its incidence, as well as the most effective way to treat it [9]. To our knowledge this is the first systematic review to determine a group of risk factors in the susceptible population. Establishing such a group would provide evidence to develop prevention techniques and improve upon current treatment strategies. Although outcome measures and general demographic characteristics found to be significant throughout the examined studies were not consistent, the wealth of information collected through this review provides practitioners with potential factors to be aware of when providing care to athletes. Being aware of the impact that gender, BMI, previous history of condition, navicular drop, plantarflexion range of motion, poor fitness, and significant change in exercise frequency can have on the athletic population will make different health care providers able to better develop appropriate plans of care.

Higher BMI and female gender were shown to be associated with an increased incidence of MTSS symptoms. With a higher BMI, increased stress is automatically placed on the lower extremities. Adding in high-impact activity too significantly increases the chance of stress-related injuries because the bones cannot handle the additional stress and will not adapt to it quickly, if at all. The relationship between female gender and the development of MTSS has been examined primarily in studies with military populations. Results have shown that the incidence of injury is increased when women train with men and are therefore expected to demonstrate equivalent fitness levels. This is due partly to the fact that women are often smaller in stature than men. Therefore, when attempting to train at the same level as men, women are susceptible to overstrenuous gait changes, such as long stride lengths. This can increase the risk for development of MTSS. Current studies are investigating the separation of men and women during naval-training programs and its effect on incidence of MTSS [1].

Altered biomechanics, such as navicular drop and increased plantarflexion range of motion may also contribute to the development of MTSS symptoms. These factors have a detrimental effect on an individual's overall lower extremity posture, leading to improper forces placed on anatomical structures during activity. The forces can impact structures that are typically loaded during physical activity, however in a manner that will place an increased stress upon them. When examining these altered mechanics in the ankle/foot complex, in particular the talocrural and tarsal bones, it is evident that increased levels of stress on the structures and cyclic loading produce symptoms [9]. Specifically, navicular drop, measured by the amount of pronation occurring at the subtalar joint, contributes to the altered biomechanics of running, and changes the normal stresses placed on the tibia [6]. This tendency of altered biomechanics to predispose structures to anatomical damage is characteristic of stress injuries, including MTSS.

The results of this review suggest that exercise history and a sudden increase in running distance may place the individual at increased risk for development of MTSS as they are at an increased risk for incurring a stress injury. It has been past suggested that with more experience in athletic activity the tibia has been able to adapt and adjust according to the forces applied a concept that is based on Wolff's law. However, when increases in athletic participation are sudden, this law is not able to be applied because the body does not have adequate adjustment time. With a longer history of athletic participation, individuals are also in better overall physical fitness. Consequently, muscles and bones will both be able to act accordingly to normal impact forces placed on them during athletic activities [9]. Additionally, it should be taken into account that when a sudden change occurs in the type of exercise, biomechanics of the actions completed are altered and muscle imbalance may play a role in MTSS development secondary to their pull on bone [10].

Finally, higher pain levels and longer duration of symptoms were found to be associated with both the initial onset of the syndrome as well as recurrence in the future. This may be due to the fact that MTSS causes chronic inflammation of the tibia. If athletic participation is not discontinued with symptom onset, the injury site is prevented from healing adequately. Without adequate rest and rehabilitation of the underlying issues that predisposed each athlete to developing MTSS, such risk factors will continue to be present and these individuals will have a continued chance of MTSS symptoms and possible stress fractures. In fact, it has past been concluded that an inverse relationship is present between stress fractures and bone mineral density [12]. The inflammation present with MTSS not only causes pain but inhibits osteoblast cell activity, weakening the bone. If activity is not significantly decreased when such pain occurs, the bone becomes gradually weaker and microfractures occur from the increased stress that the demineralized bone cannot handle. If stress fractures develop and activity is still continued, the athlete might even develop a full fracture. On the other hand, if activity is discontinued at the onset of pain, osteoblastic activity is allowed to resume and bone density is capable of increasing [9].

This systematic review has provided preliminary evidence regarding the prevalence of certain risk factors in the incidence of MTSS. As stated these are primarily related to baseline characteristics (age, gender and BMI), biomechanical factors (range of motion, strength, navicular drop, foot balance, and tibial measures), exercise regimes and history (miles run per week) and presentation of symptoms (such as pain level and duration of symptoms). Although these factors were identified in peer reviewed literature, there was a lack of consistency and agreement amongst the research. Despite the examination of a fairly representative sample of the athletic population, a significant variety of factors were found to play a role in the development of MTSS.

Previous research on MTSS has concluded many of the same things as our review has found. Many relate the limitation of this realm to the small number of studies completed on the subject matter and the wide range of methods used. Both of these create issues with coming to sound conclusions secondary to the insufficiencies. In particular, the impact of foot structure on the possibility of developing MTSS has been reviewed, and adds only that very high and very low foot arches are at increased risk for developing stress injuries on the tibia [9]. When significant findings were found by other reviews, those risk factors were of great similarity to those outlined above. Such significant risk factors include female gender, high BMI, navicular drop, and hip external rotation in males, previous history of MTSS, use of orthotics, and less experienced runners. Based on these findings, it was also suggested that males and females be evaluated separately when evaluating the risks for MTSS as the different body compositions, bony structure, and resulting kinematics may play significant roles in potentiating factors [7]. Overall, all studies that have looked at MTSS and the associated risk factors have not been able to definitively state reasons for development or propose prevention strategies based on gathered information.

Several limitations were encountered throughout this systematic review. One such limitation is that of low PEDro scales of a majority of the studies. It would have benefited this systematic review more to include studies all of which had strong scores based on the PEDro scale. Thus, the results of this study should be interpreted with caution. A second limitation of this systematic review is the variability of subjects, as not all athletes were participants of the same sport and were of different levels of competition. Such differences may impact the interpretation of the results and how they can be applied to different populations. Additionally, several of the studies used within this review had small sample sizes, which limit the generalizability of the results, as does the overall small number of studies used in this review. Of the studies included, many limitations were common between them, including limited blinding (subjects, therapists, or assessors), lack of randomization (for subject recruitment, group allocation, or order of assessments completed), self-reporting of symptoms, subjects entering studies at different stages of MTSS development, attrition, and lack of control groups.

Despite all of the limitations to this review, several aspects were conducted appropriately and led to some basic conclusions about the subject area. The review can serve as a comprehensive summary of the current and available research that exists regarding this topic. Although the resulting list of studies included was less than optimal, it provides a decent overview of the risk factors for MTSS. This was accomplished in part due to the strengths that were evident in many of the individual studies. One of the key aspects of the research that has been conducted thus far in this area is the inclusion of a definition of MTSS for the purpose of the research. This improves the accuracy and consistency of the results that are obtained. In addition, many of the studies operationally defined their samples as well as their outcome measures. These samples were typically representative of the population that of interest. Furthermore, many of the studies included time frames that were adequate in order to capture the outcomes of interest, populations with similar demographic and baseline characteristics, and reliable statistics. Finally, the current research being conducted on this topic generally requires limited to no equipment, improving the opportunity for clinical application.

Although this review successfully revealed a multitude of factors that are associated with the development of MTSS, instead of identifying a definitive list of those that can be addressed through treatment and prevention, it highlighted gaps in the information regarding this topic. Future research should focus on narrowing the group of potential risk factors to a more precise collection that have been consistently correlated with the development of MTSS and can be used in clinical practice for prognostic purposes. It may be beneficial to continue studies addressing the athletic population initially as this is the population that is most affected by MTSS. Future studies should also attempt to use larger sample sizes, from more diverse populations of athletes. Subjects could also be analyzed within groups based on the type of impact sport, such as ballistic movement versus cyclic high-impact activity. Running mechanics could also be analyzed using advanced technological resources, such as a gait mat or other computer software to analyze specific areas of the lower extremities receiving increased force or abnormal loading. Once conclusive evidence is achieved regarding the consistent risk factors that contribute to the incidence of MTSS, they can be applied to the clinical treatment and prevention of this condition to ultimately achieve a decreased impact on the quality of life of those impacted.

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