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Medial tibial stress fracture diagnosis and treatment guidelines

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ABSTRACT

Objectives: To validate and make evidence based changes to the Israel Defense Forces medial tibial stress fracture diagnosis and treatment protocol.

Design: Prospective cohort study.

Methods: 429 Elite infantry recruits were reviewed for signs and symptoms of medial tibial stress fracture during 14 weeks of basic training. Suspicion of medial tibial stress fracture was based on the presence of pain, tenderness <1/3 the length of the tibia and a positive fulcrum and/or hop test. Recruits with suspected medial tibial stress fractures were initially treated with 10–14 days of rest. Bone scan was performed only when recruits failed to respond to the rest regimen or required immediate diagnosis.

Results: 31 Out of 49 recruits with a suspicion of medial tibial stress fracture underwent bone scan, including 8/26 recruits whose symptoms did not resolve after being treated clinically as stress fractures. There was a significantly greater incidence of medial tibial stress fractures when a positive hop test was present in addition to tibial pain and tenderness ($p=0.0001$), odds ratio 52.04 (95% CL, 2.80–967.74). Medial tibial stress fracture was found to occur when the band of tibial tenderness was ≤ 10 cm in length. Tibial pain scores were not predictive of stress fracture.

Conclusions: This validation study provides the clinician with evidence based guidelines for the clinical diagnosis and treatment of medial stress fractures and their differentiation from shin splints. An initial treatment protocol without the use of imaging was found to be effective in more than two-thirds of the cases.

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Practical implications

- The sensitivity of the hop test for diagnosing medial tibial stress fracture when pain and tenderness were present was 100%, the specificity 45%, the positive predictive value 74%, and the negative predictive value 100%, with an odds ratio of 57.52 (95% CL, 3.11–1062.58).
- The fulcrum test was not found to have a statistically significant relationship with the incidence of medial tibial stress fracture.
- Medial tibial stress fractures were found to occur when the length of tibial tenderness was ≤ 10 cm in length, but not when the length of tenderness was >10 cm.
- Self reported tibial pain scores according to activity were not predictive of medial tibial stress fracture.

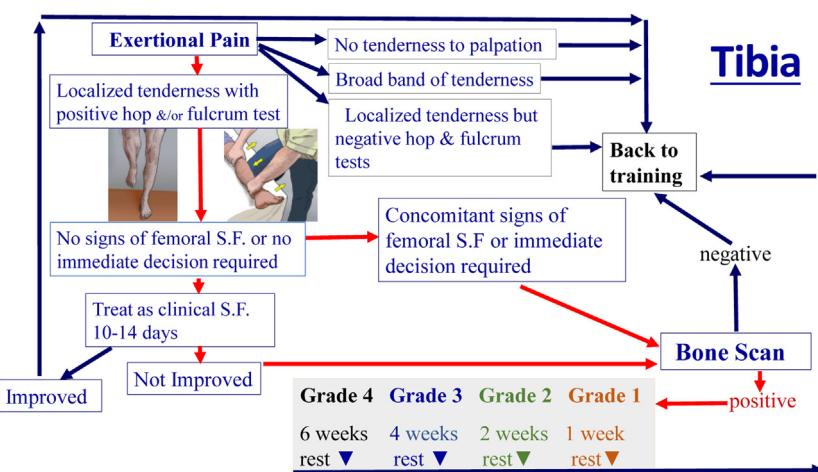
- The approach of initially treating suspected medial tibial stress fractures with a brief rest period without imaging, resulted in resolution of the symptoms in more than 2/3 of the cases.

1. Introduction

Medial tibial pain is one of the most common symptoms experienced by both athletic and military trainees.^{1–3} Historically the terms shin soreness and shin splints have been used to describe exertional medial tibial pain.⁴ The presence of pain along the posteromedial border of the tibia is now considered to be indicative of either medial tibial stress syndrome or medial tibial stress fracture.³ The two are considered to be distinct clinical entities. It is widely accepted that tenderness to palpation along the posteromedial tibial border in a span ≥ 5 cm is consistent with a diagnosis of medial tibial stress syndrome while tenderness in a span <5 cm is consistent with medial tibial stress fracture.⁵

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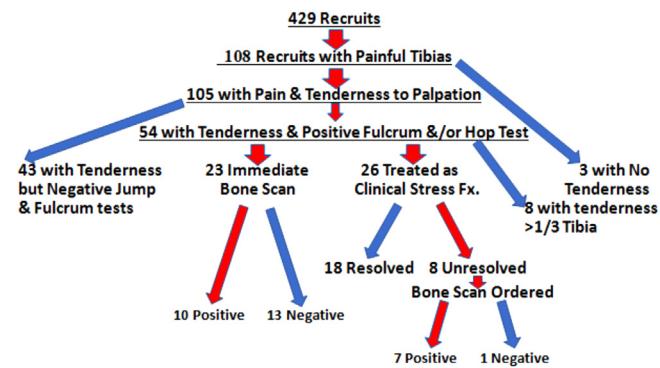
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**Fig. 1.** Painful medial tibial management protocol.

The etiology and pathophysiology of medial tibial stress syndrome have not been definitively established. One theory is that the pain is secondary to inflammation of the periosteum as a result of excessive traction of the tibialis posterior or soleus. This concept is supported by bone scintigraphy findings of a broad linear band of increased uptake along the medial tibial periosteum.⁶ However, a case-controlled ultrasound based study which compared periosteal and tendinous edema of athletes with and without medial tibial stress syndrome found no difference between the groups.⁷ A second theory is that medial tibial stress syndrome is a bony over-load injury with resultant microdamage and targeted remodeling. A study evaluating tibia biopsy specimens from the painful area of six athletes suffering from medial tibial stress syndrome gave only equivocal support for this theory.⁸ Linear microcracks were found in only three specimens and there was no associated repair reaction.

Of the two diagnoses of medial tibial pain, medial tibial stress syndrome and medial tibial stress fracture, the latter is by far of the most concern to the medical and training staff. In addition to the associated pain that can affect lower extremity physical performance, there is the risk that the stress fracture may evolve from a micro stage into a frank fracture of one cortex.⁴ It is important for the practitioner to have clear and validated physical examination, diagnostic imaging and treatment guidelines.

The Israel Defense Forces (IDF) has been using a standard protocol for diagnosing and treating medial tibial stress fractures since 2006. The protocol considers medial tibial pain and tenderness greater than one third of the length of the tibia to represent medial tibial stress syndrome and not to represent stress fracture or to be a precursor of stress fracture. Pain less than one third the length of the tibia is considered to be secondary to bone's physiological adaptation to stress, and may or may not represent progression of the physiological process to stress fracture. The protocol does not include other causes of lower extremity pain which do not occur along the medial tibial border, such as chronic exertional compartment syndrome, popliteal artery entrapment syndrome and muscle herniation.³ While the impression of IDF medical officers, is that the diagnosis and treatment protocol for suspected medial tibial stress fractures is both safe for the soldiers and allows them to rapidly return to service, the protocol has never been validated. We report the results of a prospective validation study of the IDF medial tibial stress fracture diagnosis and treatment protocol which was performed on five successive elite infantry induction companies. In the validation, the efficacy of specific physical diagnosis criteria and tests, pain evaluations and treatment protocols are all evaluated individually.

**Fig. 2.** Clinical distribution of recruits with medial tibial pain.

2. Materials and methods

The study protocol was approved by the ethics committee of the IDF (#1736.2016). All study participants signed informed consent. Before beginning their 14 week basic infantry training course, measurement of recruit height and weight were made and recruits filled out a sports participation and injury history questionnaire.

Recruits were reviewed every two to three weeks in the field by a dedicated team of three orthopedists. At each review, data for each recruit was recorded directly into a database developed for the study using AccessTM (Microsoft, Redmond, Washington, USA). All recruits underwent a mandatory tibial stress fracture exam performed by a dedicated orthopaedist. The medial border of each tibia was palpated from proximal to distal using firm thumb pressure. The proximal and distal boundaries of any tender area present were measured in centimeters using a measurement tape, with the distance from the tip of the medial malleolus as a reference point. A band of tenderness exceeding 1/3 of the tibial length was considered to be consistent with medial tibial stress syndrome and not tibial stress fracture. If tenderness was present then two additional tests were performed. The fulcrum test as originally described by Devas⁴ was performed with the patient in the supine position. The examiner places his or her knee against the lateral border of the lower limb at a point approximating the midshaft of the tibia and uses it as a fulcrum (Fig. 1). The examiner grips the inside of the lower leg at points just below the knee and just above the ankle and uses them to forcefully press the tibia against the fulcrum. This maneuver produces a tension force on the medial tibial cortex and if it causes pain the fulcrum test is said to be positive. The one-legged hop test⁹ was done with the subject barefoot. If the subject

had unilateral tibial pain he was requested to hop in place as high as possible on the uninvolving leg and then asked if he felt pain in the tibia during the maneuver. The subject then repeated the hop on the involved leg. If pain was felt in the tibia on the symptomatic side and not on the asymptomatic side, then the hop test was considered to be positive. If both tibias were symptomatic the subject hopped first on the less symptomatic side. A recruit with subjective tibial pain, combined with tenderness to palpation less than 1/3 the tibial length, a positive fulcrum test and/or a positive hop test was considered to have a suspected medial tibial stress fracture. Recruits who did not meet these criteria continued to train.

Recruits were questioned as to the onset of symptoms of their painful tibias and whether they experienced pain at rest, while walking, during exertion and post exertion. Recruits were asked to grade their pain on a scale of 1–10, for each activity.

Recruits with a suspicion of medial tibial stress fracture were not initially sent for imaging unless there was an immediate need for a definitive diagnosis such as before their parachuting course or the presence of a concomitant suspicion of a femoral stress fracture. They were treated clinically as if they had a tibial stress fracture, with 10–14 days of limited training. They were restricted from running, marching, carrying equipment more than 10% of their body weight, standing for more than six hours/day and guarding for more than 30 consecutive minutes standing. These restrictions were designed to limit the amount of tibial bone loading to less than 10% of that of their training program. At the end of this period they were re-evaluated. Those whose symptoms were not improved were sent for a bone scan. Recruits who were symptom free or markedly improved, were returned to duty. If their symptoms worsened on returning to training, they were evaluated by bone scan. Increased focal scintigraphic activity was graded according to the size and intensity of the focus.⁶ If an immediate definitive diagnosis was needed, recruits were not treated according to the above protocol but were sent for bone scan. Fig. 1 summarizes the management protocol for the painful medial tibia.

Statistical analysis was performed using the Statistical Analysis System (SAS Institute Inc., Cary, North Carolina, USA, version 9.4) reading directly from the AccessTM database. Nominal data were assessed with chi square. Normally distributed interval data were compared across the groups, using the Student's t-test. Skewed data and ordinal data were compared using Wilcoxon Rank Sums. ANOVA was used to assess whether there was a difference in the weight, height and age between the five induction companies. Odds ratios were calculated to evaluate possible predictors of medial tibial stress fracture.

3. Results

Overall, 429 elite infantry recruits, from 5 successive induction companies in the period of 2016–2018 participated in the study. Twelve recruits declined participation. The mean recruit age was 19.4 ± 0.9 years, weight 67.5 ± 8.5 kg and height 174.6 ± 6.6 cm. There was no statistically significant difference between the weight and height of the induction companies. The age of recruits was higher in the second induction company than in the third induction company (Diff, 0.4; 95% CL, 0.752–0.048; $p = 0.02$) and higher than in the fourth induction company (Diff, 0.7; 95% CL, 1.048–0.351; $p = 0.0001$) and higher than in the fifth induction company (Diff, 0.4; 95% CL, 0.752–0.048; $p = 0.02$). There was a statistically significant difference between the incidence of recruits with tibial bone pain (range 14.5–38%) between the induction groups ($p = 0.01$, chi-square).

Of the 429 recruits, 106 reported medial tibial pain. All but one had tenderness to palpation on physical exam. Forty-nine recruits had a suspicion of a medial tibial stress fracture based on the criteria

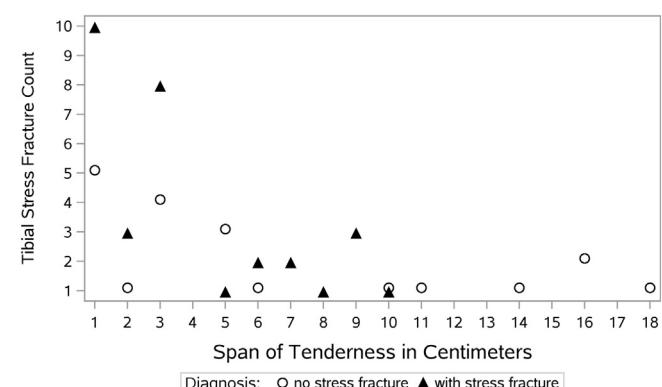


Fig. 3. Distribution of the length of medial tibial tenderness:versus the presence or absence of stress fracture.

of pain, tenderness less than 1/3 of the tibial length and a positive fulcrum and/or hop test. Twenty-three of the 49 had immediate bone scan evaluation because they either had a concomitant suspicion of a femoral stress fracture or needed medical clearance to do a mandatory parachuting course. Twenty-six recruits were treated as clinical medial tibial stress fractures. In eight of these recruits the treatment did not result in pain alleviation and a bone scan was done. Fig. 2 summarizes the clinical distribution of the 106 recruits with painful medial tibias.

Overall, 31 recruits in the study underwent bone scan because of suspicion of medial tibial stress fracture. Before their bone scans, the 31 recruits were found to have 51 areas of medial tibial tenderness. Four percent of the tender areas were in the proximal third, 49% in the middle third and 47% in the distal third of the tibia. In total, 31 symptomatic medial tibial stress fractures were diagnosed on the 31 bone scans. Seven were grade 1, sixteen grade 2 and eight grade 3. Fifty percent of the tender areas in the proximal tibia, 52% of the tender areas in the middle tibia and 71% of the tender areas in the distal tibia were diagnosed by bone scan as stress fractures.

The bone scan results of these 51 symptomatic areas were used to evaluate the diagnostic accuracy of the presence of medial tibia tenderness less than 1/3 the tibial length and the positive fulcrum and/or hop test in predicting medial tibia stress fracture. There was a statistically significant greater incidence of medial tibial stress fracture for participants who had tibial pain, tenderness and a positive hop test compared to participants who had only tibial pain and tenderness present ($p = 0.0001$), odds ratio 52.04 (95% CL, 2.80–967.74). The sensitivity of the hop test for diagnosing medial tibial stress fracture was 100%, the specificity 45%, the positive predictive value 74% and the negative predictive value 100%. There was no statistically significant difference between the incidence of medial tibial stress fractures of participants who had a positive fulcrum test and those who had a negative fulcrum test ($p = 0.13$), odds ratio 2.49 (95% CL, 0.76–8.16). The sensitivity of the fulcrum test for diagnosing medial tibial stress fracture was 52%, the specificity 70%, the positive predictive value 73% and the negative predictive value 48%.

When the bone scan results were analyzed according to the length of the tibial tenderness on the clinical exam, a statistically significant greater incidence of tibial stress fractures was found when the length of tenderness was ≤ 10 cm compared to tenderness > 10 cm ($p = 0.003$). No recruit with medial tibial tenderness > 10 cm in length was found to have a medial tibial stress fracture. Fig. 3 shows the distribution of the length of the medial tibial tenderness according to frequency and whether or not a tibial stress fracture was found at the site by bone scan. The odds ratio for tibial stress fracture if the length of tibial tenderness was ≤ 10 cm compared to > 10 cm was 22.35 (95% CL, 1.16–403.64).

All of the seven grade 1 bone scan lesions responded satisfactorily to the 7–10 days rest period and successfully returned to duty. The protocol's two-week rest regimen was inadequate for 7/16 grade 2 lesions and they required an additional week of rest. 4/8 of the grade 3 lesions were able to successfully return to duty after the four weeks rest designated by the protocol but the remainder required an additional 7–14 days rest. There were no grade 4 tibia lesions in the study. There was no statistically significant difference between the pain scores for any of the activity states and the presence or absence of medial tibial stress fracture.

4. Discussion

The IDF protocol's criteria for determining clinical suspicion of medial tibial stress fracture are a physical examination that includes medial tibial pain, tenderness less than 1/3 of the length of the tibia and a positive fulcrum⁴ and/or hop test⁹. In this study, the hop test was found to be a very sensitive test for predicting the presence of medial tibial stress fracture and to have a high negative predictive value, but its specificity was relatively low. The odds ratio for medial tibial stress fracture if pain, tenderness and a positive hop test were all present was 52.04 (95% CL, 2.80–967.74). No statistically significant relationship was found between a positive fulcrum test and medial tibial stress fracture. These findings illustrate the limitations of physical examination in diagnosing medial tibial stress fracture.

According to the literature the length of medial tibial tenderness present is an indicator of whether or not a stress fracture is present.^{5,10} Winters et al.¹⁰ in their study of medial tibial stress syndrome cite the Yates et al. criterion⁵ in which tibial tenderness ≥ 5 cm is not considered to be indicative of stress fracture. They consider tenderness of 2–3 cm in length to be characteristic of medial tibial stress fracture. Yates and White⁵ reference the article of Batt et al.¹¹ as the source data for this criterion, but that article does not state the scientific basis or source of the criterion. The current study was specifically designed to evaluate these criteria and used standard measurements. By bone scan criteria, medial tibial stress fracture was found to occur when the measured band of tibial tenderness was present up to 10 cm in length. No medial tibial stress fractures were found if the length of the measured medial tibial tenderness was >10 cm. This cut-off point for dividing cases between medial tibial stress syndrome and possible tibial stress fracture is an important finding because it differs from the previously stated values in the literature.

The IDF medial tibial stress fracture diagnosis and treatment protocol minimizes the role of imaging in the initial diagnosis and management of a suspected medial tibial stress fracture. The rationale for this limited role is that grades 1 and 2 tibial scintigraphic and MRI stress reactions can have equivocal meanings.^{12,13} They may either represent normal bone adaptation to physiological stress or early stress fracture. The protocol assumes that a trainee who has medial tibial tenderness less than 1/3 the length of the tibia and a positive fulcrum and/or hop test has a high probability of having a grade 1 or 2 lesion. It treats them initially without imaging, as if a positive bone scan lesion would be present, with 10–14 days of rest. Those whose physical exam is not according to these criteria continue to train. In this study, this approach of treating a suspected medial tibial stress fracture clinically, without initial imaging was successful in 69% of the cases.

Evaluating participant pain did not prove to increase the accuracy of the medial tibial stress fracture exam. The level of pain reported by recruits at rest, while walking, during exertion and post exertion was not found to be associated with the presence of stress fracture. Beck et al.¹⁴ reported similar findings. They found a negative association between the severity of pain during daily

activities and the imaging severity as assessed by bone scan, MRI, and plain radiographs. Nussbaum et al.¹⁵ have developed and validated a shin pain scoring system for predicting bone stress injuries but they reported that their criteria had only 26% specificity.

MRI has gained popularity as a tool for the diagnosis of stress fracture and it has clear advantages over bone scan. It does not expose patients to ionizing radiation and the imaging time is less than that of bone scan. The weakness of MRI in evaluating medial tibial cortical bone is because of cortical bone's short-lived proton nuclear magnetic resonance signals. This gives cortical bone a dark MRI image.¹⁶ Fredericson et al.¹⁷ reported an MRI 1–4 scoring system for grading the severity of medial tibial stress reactions based on a cohort of 14 runners. Their system or adaptations of it are widely used today as the basis for evaluating medial tibial pain and diagnosing medial tibial stress fracture. They note that the injury starts with MRI evidence of periosteal edema, progresses to marrow involvement and ultimately to "frank cortex stress fracture". As such they consider medial tibial stress fracture to be part of the continuum of medial tibial stress reaction. While the system grades the severity of the stress reaction it definitively defines the lesion as a stress fracture only for grade 4 lesions. Since grade 4 lesions involve complete fracture of one cortex they can also readily be seen on plain radiographs. Yao et al.¹⁸ examined the significance of periosteal versus marrow findings in MRI imaging of the tibia. They concluded that the MRI grading system of Fredericson et al.¹⁷ was not prognostic in evaluating cases of tibial stress injuries. Bone scan has similar limitations. There however are published correlations between plain X-ray evidence of cortical fracture and bone scan grades. In 4% of grade 1 lesions, 21% of grade 2 lesion, 76% of grade 3 lesions and 100% of grade 4 lesions plain radiographs were positive for stress fracture.⁶

The present study was done on military recruits and not sportspeople. The concerns of the medical staff treating these two populations may be somewhat different. Those treating athletes are of course concerned about the possibility of medial tibial stress fracture. They are also concerned about medial tibial pain itself, because its presence can be a major deterrent in achieving maximum performance. The elite infantry recruit is trained to perform during sustained adverse conditions, while carrying heavy loads.^{19,20} Performance under these conditions requires the ability to tolerate and even ignore pain. The elite infantry medical staff is inclined to be less concerned about the presence of medial tibial pain itself, if it does not represent the danger of medial tibial stress fracture.

There is a natural safety factor in treating medial tibial pain. Devas⁴ long ago observed that when medial tibial pain does represent stress fracture and progresses, the fracture is incomplete involving only one cortex of the bone. To the best of our knowledge, complete medial tibial fractures have not occurred in the IDF as a result of medial tibial stress fracture.

The rest regimens in the IDF tibia stress fracture treatment protocol are based on the grade of bone scan foci. It is assumed that the possibility of cortical microdamage being present and/or the extent of the microdamage increases with each increase in scintigraphic grade. The recommended rest regimens are grade 1 = 1 week; grade 2 = 2 weeks, grade 3 = 4 weeks; grade 4 = 6 weeks. The rest regimens were based on an estimate of the time thought to be needed for the bone to halt development or progression of cumulative microdamage and allow for successful bone adaptation to medial tibial stress. The current study shows that the rest regimen guidelines may be inadequate for some recruits with grades 2 and 3 lesions to successfully return to duty. Therefore it is important that participants be re-evaluated at the end of the recommended rest period to determine if the protocol's rest guidelines are sufficient for the individual trainee. Fredericson et al.¹⁷ recommend longer rest regimens in their study population of runners based on their MRI grading system. Grade 1 medial tibial stress reactions receive 2–3 weeks of rest

before they return to running on grass or a soft dirt track. For grade 2 lesions, the rest is increased to 4–6 weeks and for grade 3 lesions 6–9 weeks of rest is given. In the Fredericson et al.¹⁷ study a grade 4 lesion was treated by casting for 6 weeks followed by 6 weeks of non-impact activity.

The incidence of medial tibial stress fracture found in this study was much lower than historically reported in the IDF.¹⁹ This reflects the training changes adopted by the IDF to reduce stress fracture risk.¹⁹ It should be emphasized that the protocol is not for anterior tibial stress fractures. The study is limited in that it is based solely on male subjects²¹ and on a military population.²² The IDF protocol, unlike the Fredericson et al.¹⁷ protocol treats medial tibial stress syndrome as a separate and clinically definable entity. The IDF protocol considers medial tibial stress syndrome to be a reaction to stress of training, but not to represent an entity that progresses to stress fracture. A weakness of the protocol is its reliance on bone scan for imaging evaluation. The IDF is currently studying the feasibility of replacing bone scan in the medial tibial stress fracture protocol with MRI because of concerns of the radiation hazard.²³ MRI criteria need to be further developed for identifying stress fracture before they become evident on plain X-rays.

5. Conclusions

Even for training programs that use MRI for the evaluation of medial tibial pain, this validation study of the IDF protocol offers important information to the clinician. In this study using bone scan criteria, medial tibial stress fracture was found to occur when a band of tibial tenderness was present even up to 10 cm in length. This value differs from the published cutoff value of 5 cm, above which medial tibial stress fractures are said not to occur. When searching the published literature, the authors could not find the basis for the 5 cm criterion.^{5,10,11} In this study the physical examination criteria of the presence of medial pain, tenderness and a positive hop test was found to be useful in determining suspicion of medial tibial stress fracture, but was not diagnostic. The fulcrum test was not found to be useful in predicting medial tibial stress fracture. The study indicates that obtaining participant self-reported tibial pain scores is not of value to the clinician in predicting the likelihood of medial tibial stress fracture. Clinicians may want to adapt the protocol's concept of initially treating suspected medial tibial fractures clinically without imaging. Only if subjects do not respond to the protocol is imaging then used. This is because of the inherent problems interpreting the significance of grades 1 and 2 MRI and bone scan findings in cases of medial tibial pain.

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References

- Burne SG, Khan KM, Boudville PR et al. Risk factors associated with exertional medial tibial pain: a 12 month prospective clinical study. *Br J Sports Med* 2004; 38(4):441–445.
- Milgrom C, Giladi M, Stein C et al. Medial tibial pain. A prospective study of its cause among military recruits. *Clin Orthop Relat Res* 1986; 213:167–171.
- Burrus MT, Werner BC, Starman JS et al. Chronic leg pain in athletes. *Am J Sports Med* 2014; 43(6):1538–1547.
- Devas MB. Stress fractures of the tibia in athletes or shin soreness. *J Bone Joint Surg* 1958; 40-B(2):227–239.
- Yates B, White S. The incidence and risk factors in the development of medial tibial stress syndrome among naval recruits. *Am J Sport Med* 2004; 32(2):772–780.
- Zwas ST, Elkannovitch R, Frank G. Interpretation and classification of bone scintigraphic findings in stress fractures. *J Nucl Med* 1987; 28(4):452–457.
- Winters M, Bon P, Bijvoet S et al. Are ultrasonographic findings like periosteal and tendinous edema associated with medial tibial stress syndrome? A case-control study. *J Sci Med Sport* 2017; 20(2):128–133.
- Winters M, Burr DB, van der Hoeven H et al. Microcrack-associated bone remodeling is rarely observed in biopsies from athletes with medial tibial stress syndrome. *J Bone Miner Metab* 2019; 17, 596–502.
- Matheson GO, Clement DB, McKenzie DC et al. Stress fractures in athletes. A study of 320 cases. *Am J Sports Med* 1987; 15(1):46–58.
- Winters M, Bakker EWP, Moen MH et al. Medial tibial stress syndrome can be diagnosed reliably using history and physical examination. *Br J Sport Med* 2018; 52(19):1267–1272.
- Batt ME, Ugalde V, Anderson MW et al. A prospective controlled study of diagnostic imaging for acute shin splints. *Med Sci Sports Exerc* 1998; 30(11):1564–1571.
- Bergman AG, Fredericson M, Ho C et al. Asymptomatic tibial stress reactions: MRI detection and clinical follow-up in distance runners. *Am J Roentgenol* 2004; 183(3):635–638.
- Drubach LA, Connolly LP, D'Hemecourt PA et al. Assessment of the clinical significance of asymptomatic lower extremity uptake abnormality in young athletes. *J Nucl Med* 2001; 42(2):209–212.
- Beck BR, Bergman AG, Miner A. Tibial stress injury: relationship of radiographic, nuclear medicine bone scanning, MR imaging, and CT severity grades to clinical severity and time to heal. *Radiology* 2012; 263(3):811–818.
- Nussbaum ED, Gatt Jr CJ, Epstein R et al. Validation of the shin pain scoring system: a novel approach for determining tibial bone stress injuries. *Orthop J Sports Med* 2019; 7(10). <http://dx.doi.org/10.1177/2325967119877803>, 2325967119877803.
- Zhang B, Lee J, Khitrin A et al. Long lived NMR signal in bone. *J Magn Reson* 2013; 231:1–4.
- Fredericson M, Bergman AG, Hoffman KL et al. Tibial stress reaction in runners. Correlation of clinical symptoms and scintigraphy with a new magnetic resonance imaging grading system. *Am J Sports Med* 1995; 23(4):472–481.
- Yao L, Johnson C, Gentili A et al. Stress injuries of bone: analysis of MR imaging staging criteria. *Acad Radiol* 1998; 5(1):34–40.
- Milgrom C, Finestone AS. The effect of stress fracture interventions in a single elite infantry training unit (1983–2015). *Bone* 2017; 103:125–130.
- Nunns M, House C, Rice H. Four biomechanical and anthropometric measures predict tibial stress fracture: a prospective study of 1065 Royal Marines. *Br J Sports Med* 2016; 50(9):1206–1210.
- Shaffer RA, Rauh MJ, Brodine SK et al. Predictors of stress fracture susceptibility in young female recruits. *Am J Sports Med* 2006; 34(1):108–115.
- Bennell KL, Malcolm SA, Thomas SA et al. The incidence and distribution of stress fractures in competitive track and field athletes. A twelve-month prospective study. *Am J Sports Med* 1996; 24(2):211–217.
- Finestone A, Schlesinger T, Amir H et al. Do physicians correctly estimate radiation risks from medical imaging? *Arch Environ Health* 2003; 58(1):59–61.