Retrospective Review of Radiographic Imaging of Tibial Bony Stress Injuries in Adolescent Athletes With Positive MRI Findings: A Comparative Study

Eric D. Nussbaum, MEd, LAT, ATC,*† Catherine King, MD,‡ Robert Epstein, MD,‡
Jaynie Bjornaraa, PhD, MPH, PT, ATC,§ Patrick S. Buckley, MD,† and Charles J. Gatt, Jr, MD†

Background: It is difficult to diagnose and grade bony stress injury (BSI) in the athletic adolescent population without advanced imaging. Radiographs are recommended as a first imaging modality, but have limited sensitivity and, even when findings are present, advanced imaging is often recommended.

Hypothesis: It was hypothesized that the significance of radiographs is underestimated for BSI in the adolescent with positive clinical examination and history findings.

Study design: Case series

Level of evidence: Level 4

Methods: A total of 80 adolescent athletes with a history of shin pain underwent clinical examination by an orthopaedic surgeon. On the day of clinical examination, full-length bilateral tibial radiographs and magnetic resonance imaging (MRI) scans were obtained. MRI scans were reviewed using Fredericson grading for BSI. At the completion of the study, radiographic images were re-evaluated by 2 musculoskeletal (MSK) radiologists, blinded to MRI and clinical examination results, who reviewed the radiographs for evidence of BSI. Radiographic results were compared with clinical examination and MRI findings. Sensitivity, specificity, negative predictive value, and positive predictive value were calculated based on comparison with MRI.

Results: All radiographs were originally read as normal. Of the tibia studied, 80% (127 of 160) showed evidence of BSI on MRI. None of the original radiographs demonstrated a fracture line on initial review by the orthopaedic surgeons. Retrospective review by 2 MSK radiologists identified 27% of radiographs (34 of 127) with evidence of abnormality, which correlated with clinical examination and significant findings on MRI. Review of radiographs found evidence of new bone on 0 of 28 Fredericson grade 0, 0 of 19 Fredericson grade I, 11 of 80 (13.7%) Fredericson grade II, 18 of 28 (64%) Fredericson grade III, and 5 of 5 (100%) Fredericson grade IV. Sensitivity of radiographs showed evidence of new bone on 27% (34 of 127) of initial radiographs, with presence more common with greater degree of BSI, as 23 of 33 (70%) were higher-grade injuries (III of IV) of BSI. Specificity and positive predictive value were 100%, while negative predictive value was 17%.

Conclusion: These findings highlight the importance of initial radiographs in identifying high-grade BSI. As radiographs are readily available in most office settings of sports medicine physicians, this information can influence the management of adolescent athletic BSI without the need to delay treatment to obtain an MRI.

Clinical Relevance: Adolescent athletes with radiographic evidence of BSI should be treated in a timely and more conservative manner, given the likelihood of higher-grade BSI. In addition, clinicians knowledgeable of the radiographic findings of high-grade BSI should feel more confident that a negative initial radiograph is not likely to be a high-grade BSI and can modify their treatment plans accordingly.

Keywords: adolescent athlete; bony stress injury; MRI; new bone; radiograph; radiography

From †Department of Orthopaedic Surgery, Rutgers, Robert Wood Johnson Medical School, New Brunswick, New Jersey, ‡Department of Radiology, Rutgers, Robert Wood Johnson Medical School, New Brunswick, New Jersey, and §Saint Catherines University, Minneapolis, Minnesota

*Address correspondence to Eric Nussbaum, MEd, LAT, ATC, University Orthopaedic Associates, 2 Worlds Fair Drive, Somerset, NJ 08873 (email: ericn@uognj.com) (Twitter: @UOA_NJ).

The following author declared potential conflicts of interest: C.J.G.J. has received consulting fee or honorarium from Musculoskeletal Transplant Foundation and reports patents from Meniscofix.

DOI: 10.1177/19417381221109537

Bony stress injury (BSI) occurs when the bone does not adapt normally to repetitive stress,[1,2] which may result in periosteal, marrow, or cortical edema, and, in rare cases, overt fracture. Stress fractures, with an actual visible fracture line on radiographs through a cortex, are rare and account for only 1% to 2% of all atraumatic tibial BSIs among adolescent athletes.

The most common site for adolescent BSI is the tibia,[4,5] which accounts for 26% to 54% of all reported stress fractures.[3,7] In the absence of radiographic findings, many atraumatic injuries have historically been classified as "shin splints," medial tibial stress syndrome, growing pains, or tendinitis. However, with the development of magnetic resonance imaging (MRI), shin pain has become better understood as a spectrum of injury to the bone that may account for up to 75% to 85% of exertional leg pain.[6] Most exercise-related tibial stress injuries (TSI) represent a stress reaction, not fracture, and show no evidence of a break in the cortex on histologic analysis.[8,22] Consequently, it is more appropriate to call these injuries BSIs, which includes the spectrum of bone injury including stress reactions exhibiting edema and actual stress fracture. BSI is synonymous with the fatigue injuries that result in any form of bony injury.

Tibial BSI is more prominent in certain demographics (female athletes, long-distance runners, and military recruits), as well as nonrunning athletes.[18,24,36] Tibial BSI can lead to significant time away from sports for adolescent athletes; up to 12 to 18 weeks or longer for a full return to unrestricted activity is common.[25] Among conditions associated with tibial overuse injuries, BSI is often the most difficult to treat because of prolonged healing times.[26] Delayed diagnosis and continued activity can prolong recovery, advance the severity of injury to complete fracture, and, for this reason, early identification and intervention of BSI is important.[30] Physicians frequently find it difficult to make a formal diagnosis based on the clinical examination alone, as clinical tests are not both highly sensitive and specific.[32,33,37]

Appropriate imaging can play an important role in confirming a diagnosis of tibial BSI, determining prognosis, and developing an individualized patient management strategy. X-rays are the most common type of examination in diagnostic imaging. It is usually the initial imaging modality of choice due to its low cost, low radiation risk, and relative availability. Currently, the American College of Radiology Appropriateness Criteria recommends conventional radiographs as the initial imaging study of nonvertebral stress fractures followed by noncontrast MRI of the area of interest when indicated.[9] However, the reported initial sensitivity of the radiograph is low (10%-29%),[14,23] with 85% of BSIs not detected on the initial radiograph.[25] The initial response of bone to stress can be subtle or occult on radiographs and is often overlooked on the interpretation of the radiograph. The literature notes that signs of injury are frequently not apparent for >2 weeks after onset of symptoms.[15] Initial findings may include osseous sclerosis,[35] gray cortex sign,[28] periosteal new bone (PNB), and endosteal new bone (ENB).[17,19,28] Fracture lines are reportedly rarely apparent on the initial radiograph.[6,14,19] The sensitivity of radiography can increase to 40% to 50% with a second radiograph in a delayed fashion,[39] but less than 50% of cases will ever be positive despite evidence of BSI on alternate imaging.[27] Consequently, some clinicians may downplay its value in the acute setting.

Existing literature has illustrated that evidence of PNB or ENB can be seen on the radiographs of a small percentage of BSI.[19,28] The size of PNB or ENB may influence the significance of the finding.[5] New bone formation may also be found unrelated to the site of bony symptoms and, therefore, it is necessary to correlate radiographic findings with a thorough clinical examination. While BSI may be radiographically occult, radiographs are also important to assess for bone tumor, infection, osteomyelitis, or cortical fracture, which could be other sources of tibial pain.[10]

It has been well established in the radiographic literature that, for a variety of reasons, MRI outperforms both radiography and bone scintigraphy (the previous gold standard) for the diagnosis and prognosis of TSI.[3,11-13,19,21,29,31,38] The role of acute advanced imaging has been scrutinized due to cost, relative impact on treatment, and, in the case of bone scintigraphy, because of radiation dose.[29] MRI is advantageous for identifying bony and soft tissue injury, and the use of the Fredericson classification system can reliably grade the severity of BSI, accurately predict a return to sports,[34] and thereby assist in the clinical management of the patient.[20]

Despite the reported low initial sensitivity of radiography, digital radiograph units allow for the expansion and greater enhancement of subtle radiographic findings, including the identification of PNB or ENB formation. Notation of any new bone formation can improve radiographic sensitivity and may correlate with a higher grade of BSI when associated with the clinical site of pain.[11,13,16]

This study used digital tibial radiographs that were initially read as normal and lacking a fracture line by 1 of 4 fellowship-trained orthopaedic surgeons. These images were then compared retrospectively with same-day MRI findings and clinical examination results to document the acute occurrence of subtle radiography findings like PNB and ENB formation among an athletic adolescent population who presented for evaluation of tibial pain.

Methods

A total of 80 adolescent athletes aged 13 to 18 years, who participated in multiple sports, including track, crosscountry, soccer, lacrosse, football, and basketball, took part in the study. Participants had a history of >1 week of shin pain and enrolled voluntarily in an institutionally approved shin pain study at a single institution over 14 months. Participants underwent a clinical examination by 1 of 4 fellowship-trained orthopaedic surgeons, who documented the extent and location of tibial pain. Radiographic evaluation using anterior posterior (AP) and lateral full-length tibial views, and bilateral tibial MRI were also performed the same day as the clinical examination and reviewed by the treating orthopaedic surgeon for evidence of fracture. MRIs were reviewed by 1 experienced musculoskeletal

Table 1. Radiographic BSI corresponding to MRI TSI Fredericson grading on re-review[a]

Fredericson Grading	Total No. MRI	No Significant Finding	ENB, n (%)	PNB, n (%)	Both ENB/PNB, n (%)	Total + Radiograph
Grade 0	28	28 of 28	0 (0%)	0	0	28 of 28
Grade I	19	19 of 19	0 (0%)	0	0	19 of 19
Grade II	80	64 of 80	1 of 80 (1.3%)	9 of 80	1 of 80	11 of 80
Grade III	28	10 of 28	3 of 28 (10.7%)	13 of 28	2 of 28	18 of 28
Grade IV	5	0	0 (0%)	5 of 5	0	5 of 5
Total	160	112 of 160	4 of 160 (2.5%)	27 of 160	3 of 160	81 of 160

BSI, bony stress injury; ENB, endosteal new bone; MRI, magnetic resonance imaging; PNB, periosteal new bone; TSI, tibial stress injuries.
[a]Four discordant findings not included within data set.

(MSK) radiologist for evidence of BSI, and the MRI was graded using Fredericson grading scale.[11] The radiologist was blinded to the clinical examination, and grading was done before radiographic review.

At the conclusion of the study, digital radiographs associated with this study were re-reviewed by 2 MSK radiologists in tandem >1 month after initial review to identify subtle findings of PNB or ENB. The results of the radiograph review were then matched to the findings on clinical examination and MRI, and analyzed.

Radiographs were reviewed on a high-resolution dual monitor dedicated digital diagnostic radiology workstation using a singular picture archiving and communications (PAC) system for interpretation. Use of the magnification icon on the PAC system allowed for image enhancement. Measurements to evaluate for cortical thickening were made using calipers and compared with the contralateral side. MRIs of the bilateral tibia were acquired without administration of a contrast agent using a standard protocol of bilateral coronal short TI inversion recovery (STIR), bilateral coronal, bilateral axial STIR, bilateral axial T1, and unilateral fat-suppressed fast spin echo T2 of the affected side.

STATISTICAL ANALYSIS

Statistical analysis included calculations for sensitivity, specificity, likelihood ratios, as well as calculating for positive predictive value and negative predictive value.

Results

There were 52 women and 28 men who volunteered for the study. In total, 160 radiographs were available for review. Initially, all radiographs were read as normal with no evidence of cortical fracture line, by 1 of 4 orthopaedic surgeons. MRI review noted 127 of 160 (79.3%) of subjects demonstrated evidence of a BSI. Review of radiographs found evidence of new bone on 0 of 28 Fredericson grade 0, 0 of 19 Fredericson grade I, 11 of 75 (13.8%) Fredericson grade II, 18 of 28 (64.3%) Fredericson grade III, and 5 of 5 (100%) Fredericson grade IV (Table 1). Initial radiographs appropriately identified 100% of grade IV injuries, and 70% (23 of 33) of higher grades (III/IV) of BSI. Conversely, radiography did not show any radiographic evidence for grade 0/I, and only 13.8% of grade II injuries, suggesting that, when radiography was negative, a less significant (grade 0/I/II) BSI was most likely.

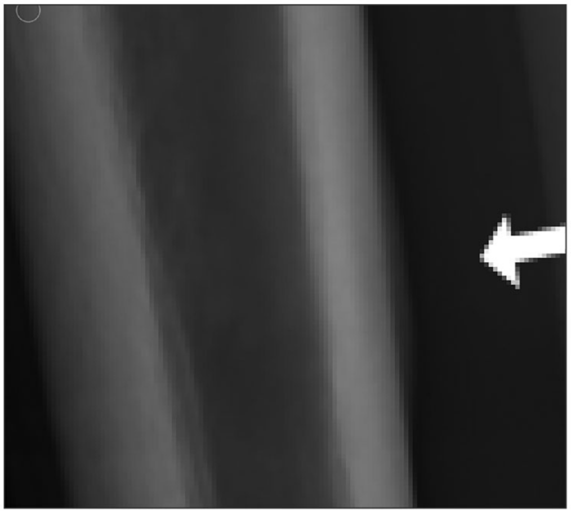

Figure 1. Enhanced view of subtle periosteal new bone with use of magnification enhancement.

Re-review using digital enhancement to allow the magnification of subtle new bone findings (Figure 1) and helped to identify 34 radiographs with evidence of PNB or ENB that coincided with the site of pain on clinical examination and MRI findings. New bone was seen on 16 male tibias, with 3 occurring bilaterally, and 18 female tibias, with 4 occurring bilaterally; 23 had PNB formation (Figure 2); and 11 had ENB formation (Figure3).

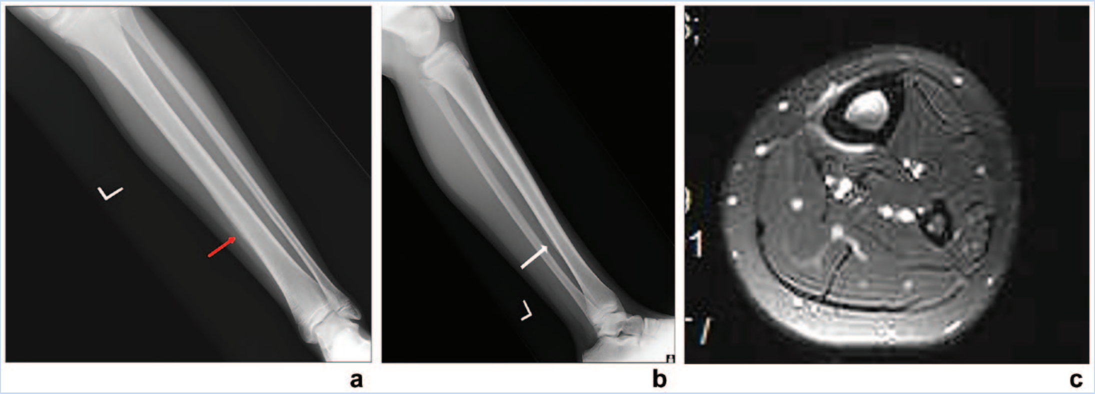

Figure 2. (a) Anterior posterior radiograph of the left tibula/fibula shows PNB pathology. (b) Arrow demarcating PNB formation at the left posterior mid to distal cortex seen on lateral radiograph of same patient. (c) Axial T2 shows corresponding moderate periosteal and endosteal bone marrow edema pattern. PNB, periosteal new bone.

DISCUSSION

This study was unique from existing published literature, but our overall sensitivity was consistent with existing literature (27% vs 15%-33% of their findings), but we did not identify any tibia with a "dreaded black line" or visible fracture lines.[11,14,19] Compared with previous studies, our subjects were younger (average age, 15.4 years), our clinical examination, radiography, and MRI were collected on the same day vs >2 weeks later, our duration of symptoms was >1 week (average, 2 weeks) and we did not have any subjects with findings in the anterior cortex.

The literature notes that there is a strong association between periosteal reaction on radiographs at the site of the clinical symptoms and a Fredericson grade IV stress injury on MRI.[22] We identified only 5 grade IV injuries on MRI, and none demonstrated a black line or formal fracture line on radiography, but we found all 5 had evidence of PNB on the radiograph. We did identify an additional 29 BSI with PNB/ENB with digital enhancement that may have progressed to grade IV if they continued activity and delayed the completion of MRI. Clinicians may look for a "dreaded black line" associated with anterior cortex injury, but this finding is rare in this age of population with less than 0% to 2% of injuries demonstrating an actual fracture line. These results illustrate that identifying subtle PNB or ENB is far more common and valuable for predicting more significant BSI. In the adolescent population as the severity of injury increased, so did the frequency of radiographic findings of PNB or ENB. Conversely, a radiograph without new bone formation was highly likely to be associated with an absence of, or a less significant, BSI. Injuries with MRI grade 0/I (0%) did not show any incidence of new bone formation, grade II only 11 of 80 (13.7%). In total, 11 of 127 (8.7%) tibia (grade 0-II) had a positive finding on radiograph, with 18 of 28 (64.3%) grade III, and 5 of 5 (100%) of grade IV injuries had evidence of new bone formation. Collectively, radiography appropriately identified 70% of grade III/IV injuries and 100% of grade 0/I injuries. The study illustrates that the use of an initial digital radiograph with magnification enhancement for the identification of PNB or ENB is valuable for determining the degree of BSI. A negative radiograph may be equally important for ruling out more significant BSI. Used in conjunction with a comprehensive clinical evaluation or scoring system,[32,33] clinicians should feel confident with their initial diagnosis. There is value in the initial radiograph, which can help clinicians appropriately manage their adolescent patients with tibial BSI.

In the future, increasing the identification of subtle radiographic changes of lower grade II TSI may aid in determining which patients with clinical symptoms would benefit from further workup with MRI and those whose radiographs are enough to warrant alteration or cessation of physical activities, potentially increasing the healthcare value of radiographs by decreasing MRI utilization.

LIMITATIONS

A limitation of this study is that we did not include histological findings to verify the nature of marrow edema or new bone formation. Gathering histological findings would have been invasive and is beyond the standard of care for adolescents with BSI. Statistical analysis identified a small value for radiograph+MRI. Increasing the number of tibias evaluated may help improve the statistical reliability of a positive radiograph.

Since the tibia is not uniform in shape, utilizing 2-dimensional images often makes subtle injury hard to identify. This is particularly true with endocortical findings and in comparison with cortex width. Findings of PNB are much easier to identify and subtle findings become more apparent with the image enhancement that is available with digital films. Clinicians should be cognizant of correlating radiographic findings with clinical findings as discordant findings are a possibility, especially with patients who have a previous history of BSI.

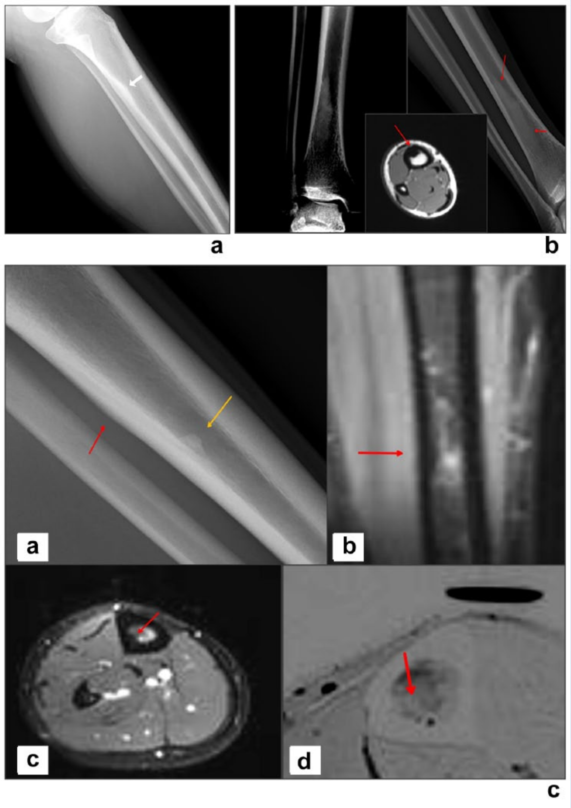

Figure 3. Examples of ENB (different patients). (a) Lateral radiograph with ENB. Arrow demarcates ENB formation at the left posteromedial proximal to midcortex. (b) STIR image. AP/lateral radiograph and axial MRI indicating endosteal sclerosis. (c, d) Axial views of lateral mid tibia with ENB; 3 had both evidence of PNB and ENB. A total of 27 tibia demonstrated that bony changes were seen on lateral radiographs, 17 were seen on AP; 7 tibias demonstrated findings on both AP and lateral views. Overall, 34 of 124 (27%) tibia showed evidence of PNB or ENB formation that coincided with evidence of BSI on MRI and noted location of pain on clinical examination. Four tibias demonstrated discordant PNB, which was not associated with a site of pain but was associated with patients who noted a previous BSI. The average thickness of PNB ranged from 1.5 mm to 5 mm (average, 2.5 mm) and all findings (27 of 146) on lateral view films were located on the posterior cortex. PNB was found in the proximal third of the tibia on 9 radiographs, in the middle third on 19, and in 6 on the distal tibia. Bone sclerosis was seen on 3 radiographs, of which 2 were seen in the distal third of the tibia. A nonossifying fibroma was found on 4 of 160 (2.5%) of tibias imaged. Using evidence of PNB or ENB on radiograph yielded a sensitivity of 27%, specificity of 100%, PPV of 100%, and NPV of 17%. AP, anterior posterior; BSI, bony stress injury; ENB, endosteal new bone; MRI, magnetic resonance imaging; NPV, negative predictive value; PNB, periosteal new bone; PPV, positive predictive value; STIR, short TI inversion recovery.

CONCLUSION

Radiography should be utilized acutely with adolescent athletes who report tibial pain from a suspected BSI. AP and lateral digital views play a valuable role in the diagnosis and management of adolescent tibial BSI. Though overall sensitivity is often low for evidence of a tibial BSI, digital images with enhancement and notation of subtle findings of PNB or ENB, when positive, may indicate a higher level of BSI that may benefit from more treatment that is conservative. Care should be taken to identify radiographic findings with clinical symptoms as discordant findings are possible, especially with athletes who have had previous BSI. Digital radiographs may help to reduce the need for MRI and help to reduce healthcare costs. However, advanced imaging may be helpful to confirm clinical suspicion, particularly with moderate grade II/III BSI and for athletes who wish to compete through their tibial pain.

ACKNOWLEDGMENT

The authors would like to thank Kenneth G. Swan, MD; Jeffrey R. Bechler, MD; and Timothy M. Hosea for their assistance with this study.

REFERENCES

1. Baleani M. Compressive behavior of cortical bone in young humans. *J Biomechanics.* 2008;16:41.
2. Beck BR. Tibial stress injury: relationship of radiographic, nuclear medicine bone scanning, MR imaging, and CT severity grades to clinical severity and time to healing. *Radiology.* 2012;263:311-318.
3. Behrens SB, Deren ME, Matson A, Fadale PD, Monchik KO. Stress fractures of the pelvis and legs in athletes: a review. *Sports Health.* 2013;5:165-174.
4. Bennell KL, Brukner PD. Epidemiology and site specificity of stress fractures. *Clin Sports Med.* 1997;16:179-196.
5. Berger FH, de Jonge MC, Maas M. Stress fractures in the lower extremity. The importance of increasing awareness amongst radiologists. *Eur J Radiol.* 2007;62:16-26.
6. Bergman AG, Fredericson M, Ho C, Matheson GO. Asymptomatic tibial stress reactions: MRI detection and clinical follow-up in distance runners. *AJR Am J Roentgenol.* 2004;183:635-638.
7. Changstrom BG, Epidemiology of stress fracture injury among US high school athletes 2005-2006 through 2012-2013. *Am J Sports Med.* 2015; 43:26-33.
8. Courtenay BG. Stress fractures: clinical features and investigation. *Med J Australia.* 1990;153:155-156.
9. Expert Panel on Musculoskeletal Imaging:, Bencardino JT, Stone TJ, et al. ACR appropriateness criteria® stress (fatigue/insufficiency) fracture, including sacrum, excluding other vertebrae. *J Am Coll Radiol.* 2017;14:S293-S306.
10. Fottner A. Stress fractures presenting as tumours: a retrospective analysis of 22 cases. *Int Orthop.* 2009;33:489-492.
11. Fredericson M, Bergman AG, Hoffman KL, Dillingham MS. Tibial stress reaction in runners. Correlation of clinical symptoms and scintigraphy with a new magnetic resonance imaging grading system. *Am J Sports Med.* 1995;23:472-481.
12. Gaeta M, Mileto A, Ascenti G, Bernava G, Murabito A, Minutoli F. Bone stress injuries of the leg in athletes. *Radiol Med.* 2013;118:1034-1044.
13. Gaeta M, Minutoli F, Scribano E, et al. CT and MR imaging findings in athletes with early tibial stress injuries: comparison with bone scintigraphy findings and emphasis on cortical abnormalities. *Radiology.* 2005;235:553-561.
14. Giladi M, Nili E, Ziv Y, Danon YL, Aharonson Z. Comparison between radiography, bone scan, and ultrasound in the diagnosis of stress fractures. *Mil Med.* 1984;149:459-461.
15. Giladi M, Milgrom C, Kashtan H, et al, Recurrent stress fractures in military recruits. One-year-follow-up of 66 recruits. *J Bone Joint Surg Br.* 1986;68:439-441.
16. Hadid A, Moran DS, Evans RK, Fuks Y, Schweitzer ME, Shabshin N. Tibial stress changes in new combat recruits for special forces: patterns and timing at MR imaging. *Radiology.* 2014;273:483-490.

17. Hughes JM. The role of adaptive bone formation in the etiology of stress fracture. *Exp Biol Med (Maywood)*. 2017;242:897-906.
18. Kelly AKW, Hame SL. Managing stress fractures in athletes: the goal of diagnosis and treatment is a speedy return to play. *J Musculoskel Med*. 2010:27;480.
19. Kijowski R, Choi J, Mukharjee R, de Smet A. Significance of radiographic abnormalities in patients with tibial stress injuries: correlation with magnetic resonance imaging. *Skeletal Radiol*. 2007;36:633-640.
20. Kijowski R, Choi J, Shinki K, Del Rio AM, De Smet A. Validation of MRI classification system for tibial stress injuries. *AJR Am J Roentgenol*. 2012;198:878-884.
21. Kiuru MJ, Pihlajamaki HK, Hietanen HJ, Ahovuo JA. MR imaging, bone scintigraphy, and radiography in bone stress injuries of the pelvis and the lower extremity. *Acta Radiol*. 2002;43:207-212.
22. Li GP, Zhang SD, Chen G, Chen H, Wang AM. Radiographic and histologic analyses of a stress fracture in rabbit tibias. *Am J Sports Med*. 1985;13:285-294.
23. Matheson GO, Clement DB, McKenzie DC, Taunton JE, Lloyd-Smith DR, MacIntyre JG. Stress fractures in athletes. A study of 320 cases. *Am J Sports Med*. 1987;15:46-58.
24. Milgrom C. Youth is a risk factor for stress fracture. A study of 783 infantry recruits. *J Bone Jount Surg Br*. 1994;76:20-22.
25. Miller TL, Jamieson M, Everson S, Siegel C. Expected time to return to athletic participation after stress fracture in Division I collegiate athletes. *Sports Health*. 2018;10:340-344.
26. Miyamoto RG, Dhotar HS, Rose DJ, Egol K. Surgical treatment of refractory tibial stress fractures in elite dancers: a case series. *Am J Sports Med*. 2009;37:1150-1154.
27. Moran DS, Finestone AS, Arbel Y, et al. A simplified model to predict stress fracture in young elite combat recruits. *J Strength Cond Res*. 2012; 26:2585-2592.
28. Mulligan ME. The gray cortex: an early sign of stress fracture. *Skeletal Radiol*. 1995;24:201-203.
29. Nattiv A, Kennedy G, Barrack MT, et al. Correlation of MRI grading of bone stress injuries with clinical risk factors and return to play: a 5-year prospective study in collegiate track and field athletes. *Am J Sports Med*. 2013;41:1930-1941.
30. Niemeyer P, Weinberg A, Schmitt H. Stress fractures in the juvenile skeletal system. *Int J Sports Med*. 2006;27:242-249.
31. Niva MH, Sormaala MJ, Kiuru MJ, Haataja R, Ahovuo JA, Pihlajamaki HK. Bone stress injuries of the ankle and foot: an 86-month magnetic resonance imaging-based study of physically active young adults. *Am J Sports Med*. 2007;35:643-649.
32. Nussbaum ED, Gatt CJ Jr, Bjornaraa J, Yang C. Evaluating the clinical tests for adolescent tibial bone stress injuries. *Sports Health*. 2021;13:502-510.
33. Nussbaum ED, Gatt CJ Jr, 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;7:2325967119877803.
34. Reinking MF, Austin TM, Richter RR, Krieger MM. Medial tibial stress syndrome in active individuals: a systematic review and meta-analysis of risk factors. *Sports Health*. 2017;9:252-261.
35. Savoca CJ. Stress fractures a classification of earliest radiographic sign. *Radiology*. 1971;100:519-524.
36. Sharma J, Weston M, Batterham AM, Spears IR. Gait retraining and incidence of medial tibial stress syndrome in army recruits. *Med Sci Sports Exerc*. 2014;46:1684-1692.
37. Schneiders AG, Sullivan SJ, Hendrick PA, et al. The ability of clinical tests to diagnose stress fractures: a systematic review and meta-analysis. *J Orthop Sports Phys Ther*. 2012;42:760-771.
38. Sofka CM. Imaging of stress fractures. *Clin Sports Med*. 2006;25:53-62.
39. Wright AA, Hegedus EJ, Lenchik L, Kuhn KJ, Santiago L, Smoliga JM. Diagnostic accuracy of various imaging modalities for suspected lower extremity stress fractures: a systematic review with evidence-based recommendations for clinical practice. *Am J Sports Med*. 2016;44:255-263.