

Current Concept Review

Evaluation and Diagnosis of Tibial Bone Stress Injuries in Adolescents: Imaging and Nomenclature

Eric D. Nussbaum, MD, LAT, ATC¹; Bryan Holtzman, BA^{2,3}; Katherine H. Rizzone, MD, MPH⁴; Adam S. Tenforde, MD^{2,5,6}; Mark E. Halstead, MD⁷; Corinna C. Franklin MD⁸; Kathryn E. Ackerman, MD, MPH^{2,6,9}

¹Department of Orthopaedic Surgery, Rutgers, Robert Wood Johnson Medical School, New Brunswick, NJ; ²Division of Sports Medicine, Boston Children's Hospital, Boston, MA; ³Perelman School of Medicine at the University of Pennsylvania, Philadelphia, PA; ⁴Department of Orthopaedics, University of Rochester Medical Center, Rochester, NY; ⁵Spaulding Rehabilitation Hospital, Charlestown, MA; ⁶Harvard Medical School, Boston, MA; ⁷Washington University School of Medicine and St. Louis Children's Hospital, St. Louis, MO; ⁸Shriners Hospital for Children—Philadelphia, Philadelphia, PA; ⁹Neuroendocrine Unit, Massachusetts General Hospital, Boston, MA

Correspondence to: Kathryn E. Ackerman, MD, MPH, Boston Children's Hospital, Division of Sports Medicine, 319 Longwood Avenue—6th Floor, Boston, MA 02115, U.S, E-mail: kathryn.ackerman@childrens.harvard.edu

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Abstract:

Tibial bone stress injuries (BSIs) are common injuries experienced by active adolescent athletes. The current literature lacks consensus of BSI nomenclature and appropriate use of imaging modalities. The purpose of this Current Concept Review is to identify existing classification of atraumatic tibial pain/BSI, propose unifying nomenclature, and review imaging tools available to clinicians caring for young athletes. Unified terminology and recommended imaging modalities for the adolescent athlete with these injuries would improve patient care and professional communication. We propose using “Bone Stress Injury” (BSI) to describe overuse injury of the tibia with associated physical examination findings. Radiography is recommended as the first imaging modality, and MRI should be considered to confirm diagnosis and determine grade of injury.

Key Concepts:

- Atraumatic tibial pain is a common injury experienced by pediatric and adolescent athletes, but no uniform diagnostic terminology currently exists for appropriate identification and management.
- “Bone stress injury” should be used as a unifying term for “stress fracture,” “stress reaction,” and other phrases that are inconsistently used to define overuse injuries of the bone.
- MRI is the gold-standard by which bone stress injuries of the tibia can be graded for severity.
- Physicians are encouraged to maintain a broad differential diagnosis when treating tibial pain to avoid missing a catastrophic diagnosis (e.g., sarcoma) in a young athlete.

Introduction

Bone stress injuries (BSIs) are estimated to affect up to 20% of adolescent athletes, with variability based on primary sport.¹ The tibia is the most common location for injury, accounting for 19–54% of total injuries by anatomical distribution,¹⁻⁴ and the incidence of these injuries is rising: in 2005, the incidence in children 6–18 was 1.37 per 100,000 outpatient visits, and in 2015, the incidence was 5.32 per 100,000.⁵ BSI may occur most frequently in athletes between the ages of 15 and 24, corresponding with stage in development for reaching peak bone mass.^{3,6,7} The proposed mechanism for injury is repetitive load exceeding bone strength, resulting in micro damage that accumulates and may progress to complete fracture.⁸ BSIs occur when bone resorption exceeds ossification during normal remodeling.⁹

Specifically, the posterior medial cortex (compression side) of the tibial diaphysis is the most common anatomic region of injury. Anteromedial tibial diaphysis injury (tension side) is less common, though such an injury is considered high risk to progress to complete fracture.¹⁰ The injury may isolate to one tibia or occur bilaterally.¹¹ Athletes participating in land-based sports involving running, jumping, and repetitive stress are at higher risk for BSI, and the incidence is higher in female athletes.^{7,12}

Current literature lacks consensus of BSI classification and appropriate use of imaging. Consequently, the actual incidence of tibial BSI may be higher than currently noted. Clinical presentation and outcomes based on imaging of BSI may vary among adolescents. Injury classification, severity, or grade may differ substantially according to imaging modalities used and location of the injury. Appropriate diagnosis and management of tibial BSIs is made more difficult by the lack of common nomenclature and imaging consensus. With the frequency of various grades of BSI in adolescent athletes, the effects of such injuries on return to play, and the potential consequences radiation dosing can have on the growing skeleton, it is important to discuss unifying nomenclature for BSI and to review imaging modalities available to clinicians caring for young athletes.

Bone Stress Injury of the Tibia

Lower leg pain is common in athletes and has variable reported incidence, partially reflecting inconsistent terminology to describe injury.¹³ During our review, we identified 32 different diagnoses used to describe atraumatic, exercise-related shin pain. The terms stress fracture, fatigue fracture, stress reaction, shin splints, periostitis, bone marrow edema, and medial tibial stress syndrome (MTSS) are the most frequently—and often interchangeably—used terms in the literature.¹³⁻²¹ Inconsistency of terminology creates ambiguity among clinicians, patients, coaches, and parents who are trying to manage the problem. In the absence of advanced imaging, however, many clinicians rely on clinical examination and general characterizations of shin pain and may use outdated terminology.

The term “shin splints” is frequently used to describe non-descript shin pain related to physical activity. Shin splints are reportedly associated with a theoretical pulling away of muscular attachments, causing an inflammation of the periosteum. They have long been considered the cause of MTSS.²² However, while recent studies have suggested that shin splints cannot be imaged by MRI,²³ there is ample evidence to warrant exclusion of the traction-based injury caused by the tibialis posterior or flexor hallucis longus attachment to the tibia as a possible mechanism of MTSS.²² MTSS may not represent inflammation of the periosteum but a progression to symptomatic BSI.²⁴ Because of the routine occurrence and use of benign terminology like shin splints or MTSS, many athletes will overlook the significance of the bone injury and continue with their training; these injuries exist on the spectrum of BSI severity. Consequently, it is likely that tibial BSI are under-reported, as athletes may continue to train with ongoing pain and worsening injury.²⁵

Because BSI can occur as a spectrum of injury from periosteal irritation to complete fracture, often on a continuum known as a “stress reaction” prior to a visible fracture line, not all injuries to bone should be referred

to as “stress fractures.” Misclassification is common: most diagnosed “stress fractures” do not demonstrate the presence of fracture line on imaging.²¹ A fracture line is apparent in only 1–4% of injuries localized to the tibia that present with exercise-induced shin pain.²⁶ Using “stress fracture” terminology to denote any injury isolated to the bone may overestimate the incidence of true stress fractures.

Unified classification in terminology of BSI may contribute to earlier, more efficient diagnosis, less time lost to injury, decreased patient confusion, and improved patient care. Timely diagnosis can improve return to sport and reduce disruptions to an athletic career.²⁷ Based on advances in our understanding of overuse injuries to bone, BSI is the preferred terminology to use in the diagnosis and management of this injury in adolescent athletes and may help improve our understanding for treatment and prevention.²⁸

Imaging in the Diagnosis of Tibial BSI

Imaging is commonly used in the evaluation and treatment of tibial BSI.^{29,30} For example, identifying BSI at earlier stages may help facilitate an earlier return to play.⁷ The benefits—manifest as improved patient outcomes—of any study should outweigh the costs and risks levied on the patient. Given that pediatric tissue is significantly more sensitive to ionizing radiation (in part due to increased mitotic rate and longer remaining lifespans compared to adults), special considerations should be granted to limiting ionizing radiation when evaluating pediatric and adolescent athletes.³¹

Plain Radiographs

Radiographs (x-rays) are the most common form of diagnostic imaging for the lower leg.^{32,33} Despite poor sensitivity early in the disease process, the American College of Radiology recommends x-ray as the best initial imaging modality in the workup for tibial BSI due to low cost and widespread availability.^{32,34,35} In the pediatric patient, AP and lateral view radiographs of the tibia/fibula will emit approximately 0.002 mSv of radiation combined, a dose equivalent to 6 hours

of normal sun exposure.³² Most exercise-related tibial BSIs do not show evidence of a break in the bone cortex on initial radiographs.^{27,36} Typically, radiographs will show evidence of BSI once the healing response of bone has begun,³⁶ and the average/mean time interval between onset of symptoms and radiographic diagnosis ranges from 2 to 6 weeks.³⁷ Furthermore, up to 50% of BSIs may remain radiographically occult.³⁸ When BSI is detectable on radiograph, it is usually associated with increased clinical significance and higher BSI grade.^{18,39,40} In general, radiography has low initial sensitivity for detecting tibial BSI, ranging from 3 to 29%, and less than 50% of serial radiographs will demonstrate changes consistent with this diagnosis.^{34,41} Therefore, interpretation of radiographs should be in part based on clinical suspicion for BSI, as adolescent athletes tend to continue training and propagate their injury if they are reassured by a false negative radiograph. The pathognomonic radiographic diagnosis of anterior tibial cortex stress injury is the presence of a “dreaded black line” on lateral view,⁴² which is considered high risk for development of frank fracture, though only a minority of tibial BSIs will be in this category.

The first sign of BSI on radiograph may be reactive periosteal inflammation and inflammation of the overlying subcutaneous tissues. Both are difficult to appreciate without comparative views. These radiographic signs are not diagnostic of BSI; rather, they are suggestive of injury and indications for further imaging.⁴³ Initial signs of bony injury on radiography may include the appearance of “layers of eggs shell,”⁴⁴ periosteal or endosteal new bone,^{37,39,45} sclerosis,⁴⁶ or a “gray cortex sign” or “dreaded black line,” both of which represent a cortical fracture on radiograph.⁴⁶⁻⁴⁸ However, Schilcher and colleagues performed biopsies on tibiae that demonstrated “dreaded black line” and found that the radiographic fracture line is not a fracture on the microscopic level but instead represents resorption cavities lined with active osteoblasts and immature bone.⁴² This site is a weakened area of bone that is histologically different from a frank fracture.⁴² Other findings that can be visualized on radiography

include endosteal thickening, roughening, or “fluffiness” along the intramedullary canal.⁴⁹ Radiographic osseous changes that correspond with exam findings of pain are significantly more likely to have features on MRI that would confirm diagnosis of BSI.³⁹ Therefore, the clinical presentation of the patient remains a mainstay of assessment despite the radiographic findings.²¹

Bone lesions and infection are less common sources of leg pain in pediatric patients that can be visualized using plain radiographs. Primary bone tumors are the sixth most common neoplasm in pediatric patients,⁵⁰ although most in this age population are benign.⁵¹ Consequently, clinicians should not overlook the importance of imaging in the pediatric population who present with shin pain.

Magnetic Resonance Imaging

When initial radiographs are negative and clinical suspicion for BSI is high, MRI without contrast is recommended by the American College of Radiology.³² MRI may be the best imaging modality for visualizing BSI for the pediatric population because it uses non-ionizing radiation, provides excellent imaging resolution, and is both highly sensitive and specific.^{19,36,52} A 2016 systematic review found MRI to be the most sensitive and specific imaging modality for BSI; the authors also recommended MRI for patients with negative radiographs and a high clinical suspicion for a high-risk BSI.²⁷ MRI demonstrates stress abnormalities as early as bone scintigraphy⁵³ and is more sensitive and specific than radiography, bone scintigraphy, and computed tomography when used for BSI imaging. Furthermore, the severity of change in MRI corresponds with the clinical severity.¹⁵

When using MRI, fluid-sensitive sequences are typically recommended for detection of BSI.⁵⁴ A key feature of BSI is bone marrow edema, which is demonstrated by high signal on fat-saturated T2-weighted and short tau inversion recovery (STIR) images.³⁶ Fat-saturated T2 sequences and STIR improve sensitivity by suppressing fat signal, which can obscure edema on non-fat-saturated T2-weighted sequences.⁵⁵ A hypointense fracture line may be seen on T1 and T2 images.⁵⁶ Early tibial BSI

may be detected on fat-saturated T2 and STIR images with bone marrow or periosteal edema as well as cortical abnormalities.⁵⁷ Kijowski and colleagues defined several MRI features of tibial BSI: periosteal edema, linear high T2 signal immediately adjacent to the outer cortex; bone marrow edema, low T1 and high T2 within the canal; cortical abnormality (Table 1).³⁹

MRI may be useful in evaluating other causes of leg pain in athletes, such as chronic exertional compartment syndrome and peripheral neuropathy.⁵⁵ Also, soft tissue injuries can be clearly differentiated using MRI. MRI has similar sensitivity to, but greater specificity than, bone scintigraphy to detect BSI.⁶⁰

Extrapolation of MRI findings in adults may not be completely applicable to the adolescent population, but these grading scales serve as the best reference in the absence of formal adolescent-focused guidelines. The adaptation of grading systems to help determine return to play are helpful, but none of the studies are large or diverse enough to make convincing arguments for change in nomenclature from Fredericson, et al.¹⁸ Ultimately, the scale proposed by Fredericson and colleagues was useful to bring some clarity to the 32 different terms used to describe BSI.¹⁸ See Figures 1 through 4 for examples of Fredericson, et al. grading of tibial BSI.

Changes on MRI consistent with BSI may not correspond to clinical symptoms.^{45,61} The findings of bone edema on MRI may represent osseous remodeling or localized changes in bone mineral density.^{62,63} A study of 55 asymptomatic Special Forces recruits found that endosteal edema >100mm in length had a high likelihood of progressing over time.⁶⁴ Those with edema measuring <100mm did not progress and often resolved over time.⁶⁴

Leg pain can be observed on clinical exam in adolescent athletes without corresponding changes on radiographs and MRI.^{18,26,65} Clinicians must remember that MRI is not 100% sensitive.⁶⁶ The less-common longitudinal tibial stress fracture may also be seen on MRI but is frequently missed. Finding a cleft in the bone on one or more images is essential for diagnosis and axial images

Table 1. Grading Scale for Categorizing BSI on MRI

MRI Grade	Fredericson, et al.^{18 *}	Arendt and Griffiths¹⁴	Kiuru, et al.⁵⁸	Kijowski, et al.³⁹	Nattiv, et al.⁵⁹	Kaeding and Miller¹⁰	Gmachowska, et al.¹¹
Grade 1	Mild to moderate periosteal edema on T2 Normal marrow on T1 & T2	Positive signal change on STIR	Endosteal edema	Periosteal edema	Mild marrow or periosteal edema on T2	Imaging evidence of stress fracture, no fracture line, no pain	Periosteal edema
Grade 2	Moderate to severe periosteal edema on T2 Marrow edema on T2 but not T1	Positive signal change on STIR and positive T2	Periosteal and endosteal edema	Periosteal and marrow edema	Moderate marrow or periosteal edema and positive T2	Imaging evidence of stress fracture, no fracture line, pain	Periosteal and marrow edema
Grade 3	Moderate to severe periosteal edema on T2 Marrow edema on T1 and T2	Positive STIR, T1, and T2	Muscle, periosteal, and endosteal edema	Liner intracortical fracture line	Severe marrow or periosteal edema on T1 or T2	Non-displaced fracture line	Grade 2 plus cortical abnormalities
Grade 4	Moderate to severe periosteal edema on T2 Marrow edema on T1 and T2 Fracture line apparent	Positive fracture line on T1 and T2	Fracture line		Severe marrow or periosteal edema on T1 or T2 plus fracture line on T1 or T2	Displaced fracture line >2 mm	Grade 3 plus fracture line
Grade 5			Callus at endosteal and/or periosteal surface of cortical bone			Non-union	

Multiple grading scales exist for categorizing bone stress injury (BSI) on Magnetic Resonance Imaging (MRI). All were established primarily with adult patients.

*Short tau inversion recovery (STIR) and fat-suppressed T2 sequences may have higher sensitivity than T2.⁵⁵

are the most useful.⁶⁷ All patients in this case series had either soft tissue edema or an eccentric periosteal reaction, and four of five had edema that began near the entrance of the nutrient vessel into the medullary cavity.⁶⁷ Identification of longitudinal injury may require more than one imaging modality.⁶⁸ In select cases of symptomatic patients with normal MRI, CT may depict osteopenia representing early cortical stress injury.⁶⁰

In cases where there is strong clinical suspicion but normal MRI and radiographs, clinicians must weigh the risk/benefit of additional imaging on the treatment recommendation for their patient. In some cases, additional imaging may be important for the patient, while in others, the additional imaging is not necessary. While MRI may be sufficient to detect most tibia BSI, inconsistencies in the literature on imaging findings to



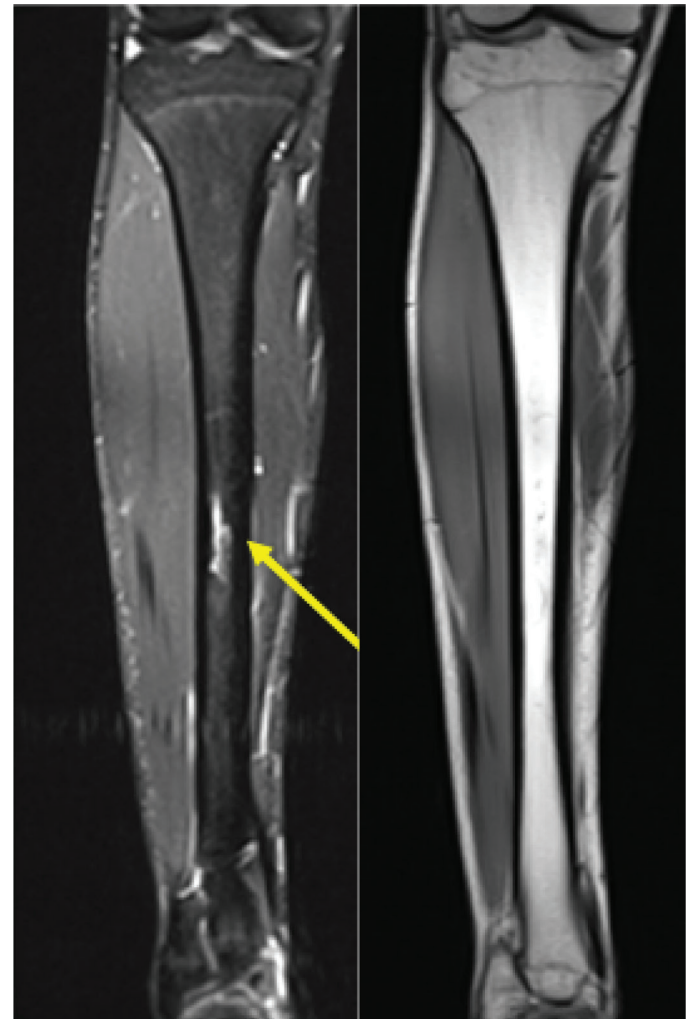
Fat-suppressed T2-weighted image

T1-weighted image

Figure 1. MRI of Fredericson Grade 1 bone stress injury of tibia. Arrow demonstrates mild to moderate periosteal edema on fat-suppressed T2-weighted image (normal appearance on T1-weighted image).

clinical features highlight the value in future research to understand chronic leg pain.¹³

The use of MRI has greatly improved the ability of physicians to diagnose radiographically occult BSI as a source of tibial pain in adolescents. The benefits of the use of MRI are its high sensitivity and specificity without exposing the patient to radiation. The drawbacks of MRI include its expense, scan time in a confined space, and justification for its use when the results may not change the course of conservative



Fat-suppressed T2-weighted image

T1-weighted image

Figure 2. MRI of Fredericson Grade 2 bone stress injury of tibia. Arrow demonstrates marrow edema on fat-suppressed T2-weighted image (normal appearance on T1-weighted image).

treatment. As such, MRI is not always approved by insurance for acute use or before a course conservative treatment and rest.

Bone Scintigraphy

Bone scintigraphy (also known as bone scan) has long been used in the evaluation of BSIs. Bone scans will be positive before radiographic changes are demonstrated,⁶⁹ with osteoblastic new bone formation represented by localized increased isotope uptake. Early studies



Fat-suppressed T2-weighted image

T1-weighted image

Figure 3. MRI of Fredericson Grade 3 bone stress injury of tibia. Arrows demonstrate marrow edema on fat-suppressed T2- and T1-weighted images.

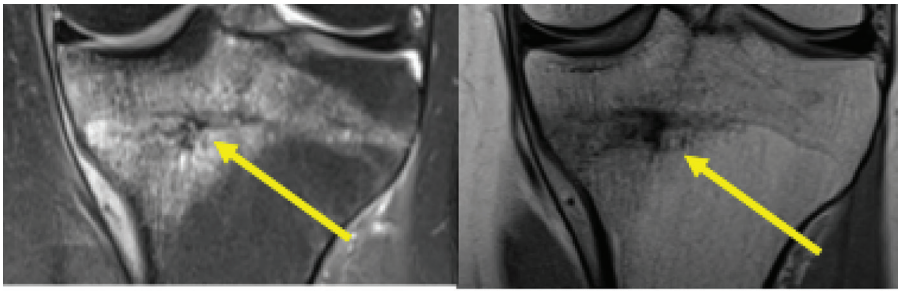
suggested a sensitivity of 100% by injecting a radiotracer of ^{99m}Tc-methylene diphosphonate intravenously.³⁸ Increased radiotracer activity often can be detected within 24 to 36 hours of the onset of fracture. The majority of the dose, however, is renally eliminated within six hours of injection.⁷⁰

There have been several attempts to grade BSI and project recovery time based on scintigraphy with mixed results. Greaney and colleagues subjectively graded the spectrum of scintigraphic uptake into four levels graded as normal (0) to 3+, in an attempt to quantify the degree of bone involvement, then reviewed their findings based

on trabecular and cortical findings and compared with radiography.⁷¹ The initial scintigraphic classification by Chisin and colleagues did not identify differences between classification and the clinical evolution of patients when separated into four grades.⁷² A modified version by Zwas and colleagues correlated recovery time across four grades of bone involvement.²⁵ Castropil and colleagues compared bone scan with MRI and developed a quantitative evaluation index (QEI) that compared injured and non-injured legs, identifying a positive correlation between QEI to time for recovery.⁷³

Because many early studies looking at BSI used bone scan as the gold standard, accurate representation of sensitivity and specificity of the test is lacking. A systematic review looking at the use of bone scan in lower extremity stress fractures in patients of all ages reported a sensitivity of 50–97%, with specificity ranging from 33–98%.²⁷ False positives are a concern with bone scan. Any condition that causes increased bone turnover may be positive on this imaging technique, including infections, tumors, aseptic necrosis, trauma, and complex regional pain syndrome/reflex sympathetic dystrophy.⁵⁸ Other disadvantages of bone scan include the length of time to perform the test, difficulty in determining the severity of BSI, and the high dose of radiation. It is estimated that the radiation from a single bone scan is equivalent to 60 two-view chest radiographs (effective radiation dose: 6.3 mSv).⁷⁴ There is also a fairly high radiation load to the entire body from the radioactive isotope. It has been calculated that a 10-year-old patient undergoing a bone scan will receive 3.9 mSv, theoretically inducing a 0.04% increased risk for cancer.⁷⁵

There are limited data on the use of bone scintigraphy for evaluating tibial BSI in pediatric and adolescent age groups. Pediatric data for sensitivity and specificity are lacking. Since MRI scanners are readily available in most areas, perform with excellent sensitivity and specificity, and do not provide any radiation load concerns, the use of bone scan in the pediatric population should be reserved for rare clinical scenarios.



Fat-suppressed T2-weighted image

T1-weighted image

Figure 4. MRI of Fredericson Grade 4 bone stress injury of proximal tibia. Arrows demonstrate edema on fat-suppressed T2 and T1-weighted images, and a horizontal fracture line is apparent.

Ultrasound

Musculoskeletal Ultrasound

Musculoskeletal ultrasound (MSK US) is an inexpensive imaging technique that many sports medicine physicians now use in their clinical diagnosis of pathology.

Periosteal reactions of BSI can sometimes be visualized on ultrasound before bony callus is observed on plain radiographs, aiding in earlier diagnosis.⁷⁶

MSK US can identify periosteal thickening, subcutaneous edema, calcified bone callus, hyper-vascular changes, and cortical irregularities that are associated with BSI.⁷⁷ It has the ability to identify presence of hypoechoic calluses and buckling in the bony cortex more than other imaging modalities.⁵⁷ Diagnostic ultrasound has a sensitivity of 43–99% and specificity of 13–79%.²⁷ The sensitivity of MSK US for identifying BSI on the posterior cortex of the tibia is low.⁵⁷

Additional extension of MSK US includes visualization of increased blood flow and vascularization related to fracture pathology using Doppler technology. Changes in vascularity using power Doppler imaging may be helpful for the early diagnosis of BSI.⁷⁸ Bodner and colleagues identified sonographic features of anatomy surrounding site of BSI, including presence of soft tissue edema, fluid collection, and increased vascularity.⁷⁹

Imaging findings on MSK US frequently coincide with findings on MRI.^{79,80} Banal and colleagues established

guidelines for MSK US diagnosis of metatarsal BSI defined as meeting two or more criteria: hypoechoic periosteal elevation above cortical bone, cortical disruption, or increased vascularity on power Doppler.⁸¹ These criteria had reported sensitivity of 83% and specificity of 76%.⁸¹ Bianchi and Luong modified this algorithm and described five hallmarks of BSI: (1) periosteal thickening, (2) a calcified bone callus, (3) cortical irregularities, (4) subcutaneous edema, (5) hyper-vascular changes seen on color Doppler US.⁷⁷ These studies, however, have not been reproduced with tibial BSI but highlight the potential utility of MSK US for diagnosing BSI.

Because of its relative diagnostic accuracy when compared with MRI, lack of exposure to ionizing radiation, portability, safety, point-of-care capability, and low cost, MSK US is recommended for clinical examination and should be considered an adjuvant imaging modality to utilize in addition to the traditional initial plain film evaluation.⁵⁷

Limitations of MSK US include the inability to assess structures deep to the bone cortex such as marrow edema. However, many of the surface findings MSK US identifies may correlate with findings of bone marrow edema.⁵⁷ As an in-office imaging modality, perhaps the greatest limitation is that there is inter-sonographer variability and a steep learning curve for clinicians. In general, the literature associated with

MSK US imaging of pediatric BSI is lacking, but considering the safety and relative capabilities of MSK US, it is an imaging modality that should be included in future BSI research.

Therapeutic Ultrasound

Many rehabilitation specialists (e.g., physical therapists, athletic trainers) also have access to therapeutic ultrasound (TUS). TUS employs a low frequency range of 1-3 mHz that is not used for visualization of anatomic structures.⁸² Application of 1.5–2.0 W/cm², 100% duty cycle for 1 minute over the suspected injury may create an increase in pain and heat in the damaged periosteum due to energy absorption; such increased pain and heat is considered a positive diagnostic test.^{83,84} TUS has been noted to provide positive findings 2–3 weeks prior to radiographic findings.⁸⁵ In a comparative study, TUS was less sensitive compared to bone scan, but more sensitive than radiography at detecting tibial BSI (75% TUS, 100% bone scan, 22% radiograph).³⁷ However, TUS was not as specific as bone scan or radiography (67%, 100%, 98%, respectively). TUS fails to reveal many low-grade BSIs that can be identified by MRI and therefore is not considered a definitive diagnostic tool for BSI.³⁰ There are no published BSI classification systems for TUS of the tibia.⁸⁶

Computed Tomography (CT)

CT scans are sometimes selected for imaging of a tibial BSI following radiographs. There are few reports of the sensitivity and specificity of CT for the assessment of tibial BSIs in pediatric—particularly athletic—populations. Like other imaging modalities, a grading system for assessment of BSI severity has been proposed. This grading system, however, was developed with a non-pediatric sample (age range: 19–37 years; mean age ± standard deviation: 27.8 years ± 5.4), though all participants completed regular competitive or recreational physical activity.⁶⁰ CT has shown superior imaging of the cortex over MRI and bone scan. However, MRI is more sensitive and specific than CT and bone scan on imaging soft tissue and marrow edema.⁶⁰

CT provides diagnostic value in select cases of BSI or in shin pain with a differential diagnosis expanding beyond BSI, particularly when bone neoplasm is a possibility. In cases with negative MRI findings, CT can demonstrate the earliest signs of cortical stress injury that are occult on other imaging techniques.⁶⁰ Furthermore, CT has been shown to be particularly sensitive at diagnosing longitudinal stress changes in the tibia. For example, one study⁸⁷ reported the sensitivity of CT for longitudinal BSI as 82% (versus 73% for MRI), and a recent review⁵⁶ rated CT as the modality of choice for longitudinal fracture lines. CT may also clarify lesion etiology including osteomyelitis with a Brodie abscess and various neoplasms such as osteoid osteoma.^{55,88} Malignant tumors in young adults present similarly to BSI and, in situations of adequate clinical suspicion, such a study can be useful.⁸⁹ While useful in the cases of a broad differential for shin pain, BSI severity as assessed by CT scan has not been correlated with clinical severity or time to recovery. When compared to other imaging, CT grades for the same injury were lower than bone scans and MRI and higher than x-ray.¹⁵ This poor clinical correlation suggests the need for a new severity scale for CT scans of tibial BSI.

CT scans of pediatric and adolescent patients carry significant concern for radiation load and have been noted to carry 200–300 times the radiation load of a single radiograph. The effective radiation dose from a CT scan varies by area of the body studied but generally ranges from 2–8 mSv for most body regions.⁷⁴ With concerns about radiation load, modified protocols should be implemented in the pediatric population. CT may be indicated for those who are unable to undergo an MRI due to claustrophobia, implanted metal hardware or pacemaker, or an inability to remain still.

Summary

Tibial bone stress injuries are common within the adolescent athletic population and can have a significant impact on athletic activity. Exercise-induced atraumatic injury of the tibia has been referred to in the literature by many different diagnostic terms, creating confusion for clinicians and patients who attempt to appropriately

Table 2. Grading Comparison of Imaging Modalities

	X-ray	MSK US	Bone Scan	MRI	CT Scan	Treatment
Grade 1	Normal	Periosteal swelling Hyperechoic periosteal elevation	Poorly defined area of increased activity	Positive STIR	Soft tissue mass Periosteal surface	Reduced activity for 1–3 weeks
Grade 2	Normal Periosteal reaction	Periosteal elevation Subcutaneous edema	More intense but still poorly defined activity	Positive STIR Positive T2	Yellow attenuation	4–6 weeks rest
Grade 3	PNB*, ENB† Periosteal reaction	Increased vascularity Periosteal elevation Cortical thickening	Areas of increased activity Fusiform or focal uptake	Positive T1 and T2 without cortical break	Osteopenia Hypoattenuation	8–12 weeks rest
Grade 4	Sclerosis “Black line” PNB, ENB	Callous Increased vascularity on doppler Crack or fracture line	Focal uptake	Positive T1 and T2 Fracture line	Fracture line	4–6 months rest vs. surgical fixation

*PNB – periosteal new bone; †ENB – endosteal new bone

manage the injury. Overuse injuries span a spectrum of severity ranging from periosteal irritation through frank fracture that go by many names both in the scientific discourse and clinic. Unification of terminology and grading allows for improved diagnosis, treatment, patient communication and return to play decision making. Consequently, we propose the use of the term “bone stress injury” (BSI) to describe various degrees of bone injury. Differences between imaging modalities exist. Based on review of available studies, we suggest using the Fredericson criteria for injury staging (Table 1),¹⁸ and fat-suppressed T2 sequences or STIR can be used in place of the T2-weighted sequences, with same descriptive findings applicable.⁵⁵ A comparison of grading systems by imaging modality is shown in Table 2.

When evaluating patients with atraumatic tibial pain, clinicians should maintain a high level of suspicion for BSI. Appropriate imaging can lead to earlier diagnosis, which may result in shorter disability. Radiography

should be used as the initial imaging modality. If the initial radiographs are within normal limits, but clinical suspicion is high for BSI, MRI is the preferred next imaging choice, offering high sensitivity and specificity without radiation exposure. Radiation load must be thoughtfully considered in the adolescent population, and physicians should be mindful of the potential cumulative effects when ordering additional imaging. Ultimately, physicians must weigh the costs, risks, and benefits of additional studies on patient outcomes.

We suggest the following directions for future study of tibial BSI in adolescents: (1) validation of MRI for diagnosis of and return to play timelines following tibial BSI, (2) further study of MRI vs. US for diagnosis and prediction of return to play timelines after tibial BSI, and (3) development of best-practice imaging guidelines and nomenclature for common overuse injuries of other bones.

Additional Links

- The AMSSM National Fellow Online Lecture Series: High-Grade Stress Fractures: <https://www.youtube.com/watch?v=F3IemapSJzk>
- The Image Gently Alliance: <https://www.imagegently.org/>

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