

Evidence-Based Treatment and Outcomes of Tibial Bone Stress Injuries

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Abstract:

Bone stress injury (BSI) of the tibia is relatively common in athletes and is a spectrum of impairments that include medial tibial stress syndrome (MTSS), tibial stress reaction, and tibial stress fracture. Identification of nutritional, hormonal, and biomechanical risk factors is crucial to prevent persistent or recurrent injury. A basic and important mechanical risk factor, especially in those with chronic or recurrent injury, may be subtle to severe abnormalities in gait and ankle flexibility. MRI injury grading can provide a framework for expected healing time; treatment must be individualized and evolution of a patient's symptoms should guide the progression to return to sport after a prescribed period of rest. The vast majority of tibial BSIs can be managed nonoperatively and surgery is largely reserved for those who have undergone exhaustive conservative management without success, those with multiple recurrences, or high-level competitive athletes with the most severe grades of injury. The current review aims to highlight current concepts in the treatment of tibial BSI, with a particular focus on the high-risk population of adolescent athletes.

Key Concepts:

- Management of tibial bone stress injuries (BSIs) centers around rest from the offending activity and the identification and correction of any contributing nutritional, metabolic, or biomechanical risk factors.
- Treatment must be individualized, and complete clinical resolution of symptoms should precede return to activity.
- Anterior cortex-based tibial stress fractures, with a radiographic finding often referred to as the “dreaded black line,” and other high-risk BSIs may require up to 4–6 months of relative rest or surgical treatment.
- Recurrent tibial BSI is common and gait/neuromuscular training may be especially helpful in preventing chronic and repeated injury.
- In athletes with high-grade tibial BSI refractory to conservative treatment, surgical fixation such as intramedullary nailing and tension band plating can be considered. However, complication and re-operation rates may be relatively high.

Introduction

Bone stress injuries (BSIs) are among the most common overuse injuries of young adult athletes. BSI of the tibia may occur with an incidence as high as 10–20% in susceptible populations, such as competitive runners.^{1–3} Notably, the frequency of pediatric overuse injuries has

been rising,⁴ potentially due to increased participation in competitive sports and increased intensity of training regimens for this younger population. The term BSI is used to describe a spectrum of injury including tibial periostitis, medial tibial stress syndrome (MTSS), ‘stress reaction,’ and stress fracture.

The pathophysiology in all cases is believed to involve an imbalance in bone remodeling in which microtrauma outpaces the capacity of bone to heal.⁵ In the setting of competitive athletics and military training, abnormal cyclic loading can induce these injuries in normal bone. For those whose bone formation may be impeded due to nutritional and/or hormonal factors, or for those whose tibial bone geometry may lead to higher stresses,⁶ the threshold of loading activity that may result in BSI can be lower.⁵

Although BSIs commonly occur at the posteromedial and anterior tibial cortices, these injuries are unique in both etiology and severity. BSIs in runners and military members are primarily located at the posteromedial side of tibia due to the nature of compressive loading in these activities. For athletes in sports involving jumping, anterior tibial (tension-side) cortical BSIs may be more common.⁷ There is also growing evidence that pediatric patients demonstrate BSIs in anatomic areas of the bone that are different from those in adults. For example, while the mid-diaphysis is the most affected region in adult tibial BSIs, children and adolescents have a higher rate of proximal tibial BSIs.⁸⁻¹⁰

Highly motivated athletes commonly forego rest for these injuries and continue activity despite pain. Others may limit practice time but continue to participate in competition. However, if not recognized and treated appropriately, tibial BSIs may fail to unite or even progress to acute, complete fractures.¹¹ Recurrence rates of bone stress injury are high,^{1,12-13} with prior BSI significantly increasing the risk of subsequent injury.¹⁴ For high-level athletes, loss of training time can be significant, and correcting any contributing risk factors during healing may be especially beneficial in preventing further injury.

This review will evaluate the existing literature regarding management of tibial BSIs, with a primary focus on the treatment of adolescent athletes, with an aim of providing evidence-based guidelines for the management of this spectrum of injury, including identification and correction of risk factors, expectations of duration of rest, and consideration of surgical treatment options.

Treatment/Management

General Principles

The mainstay of treatment of tibial BSI is cessation of high-impact lower extremity loading activity to allow for bony healing. Thus, athletes must avoid all running, jumping, cutting, and pivoting activity all together, whether in training or competition. Duration of rest is partially dependent on clinical improvement, but expectations can be established through empiric, time-based minimum periods during which the bone is allowed to heal. These periods are also somewhat based on the location of injury and the severity of injury as determined by MRI-based grading systems.¹⁵⁻¹⁶ As time to return to play is especially crucial to those participating in competitive athletics, it may be important to provide realistic expectations for healing time and projected return to activity. Due to high recurrence rates of tibial BSI, patients should be counseled that while the duration of these relative rest periods seem overly conservative, onerous, or detrimental to one's training process or competitive standing, proper duration-based management of these injuries, including correction of any contributing risk factors, may ultimately *reduce* the overall time spent out of sporting activity.

Posteromedial tibial BSIs are considered lower risk injuries and are more likely to heal with conservative treatment. For these injuries, MRI grading of severity has been shown to correlate with eventual time to healing,¹⁶⁻¹⁷ with higher graded injuries taking longer to heal. Anterior tibial BSIs, however, are considered high-risk stress injuries due to a higher likelihood of delayed union, nonunion, and progression to displaced fracture. This increased risk is, in part, attributed to the higher tensile forces at the anterior tibia and the relative avascularity of the region.⁷

Identification of contributing, patient-based, modifiable risk factors is essential in the primary management of tibial BSI as well as in the prevention of recurrence. Low bone mineral density, poor nutritional status, and menstrual dysfunction have all been shown to increase the risk of developing a BSI.¹⁸⁻¹⁹ Identifying and

correcting these risk factors is an important treatment consideration for all patients presenting with a tibial BSI. For those patients with biomechanical risk factors such as smaller bone cross sectional area^{6,20} and greater anterior-posterior tibial diameter,²¹ activity modification and gait retraining may provide additional benefit.

While tibial BSIs have classically been separated into categories of medial tibial stress syndrome (MTSS), stress reaction, and stress fracture, these related conditions require similar treatment approaches. While treatment duration and specific methods may vary depending on the severity and location of tibial BSI, fundamental strategies including relative rest, activity modification, and treatment of underlying risk factors remain crucial components of therapy for all BSIs.

Nutritional Factors/RED-S

Athletes who sustain a BSI, particularly those involved in sports emphasizing leanness (e.g., running, gymnastics, dance, diving), should be screened for low energy availability due to its direct effects on bone metabolism²² and fracture²³ risk. If low energy availability is suspected, a registered dietitian should conduct a detailed nutrition assessment to estimate energy intake, estimated energy expenditure, and overall nutrient intake. The Female Athlete Triad (low energy availability, menstrual dysfunction, and low bone mineral density) has been expanded to the concept of Relative Energy Deficiency in Sport (RED-S), which encompasses the multisystem health and performance consequences of low energy availability in male and female athletes.²⁴ Both “Triad” and RED-S revolve around the concept of energy expenditure exceeding caloric intake resulting in low energy availability. Disordered eating and inadequate nutrition disrupt hormonal balance and leads to impaired menstruation in women, impaired bone formation, and enhanced bone resorption, and can ultimately result in poor health outcomes and impaired sports performance.²⁵⁻²⁶ Athletes with one component of the triad increase their risk of BSI by 2.5 times, and those with at least two components have an increased risk of 4.7.¹⁹ If

low energy availability is suspected, the [RED-S Clinical Assessment Tool \(RED-S CAT\)](#) may assist clinicians with screening, management, and determining readiness of an athlete to return to play.²⁷

While vitamin D and calcium are the more commonly recommended nutrients to evaluate in patients presenting with BSI, other nutrients such as carbohydrates, protein, iron, and magnesium support overall bone health and should be included in the nutritional evaluation.²⁸ Nieves et al. prospectively studied young female competitive distance runners and found that higher intakes of low-fat dairy products and dietary calcium were associated with a statistically significant decrease in BSI incidence. Calcium intake less than 800 mg per day was linked to a sixfold increase in BSI rate when compared to women who consumed at least 1500 mg.²⁹ Although dosing guidelines are variable, runners may aim to meet a daily recommended dose of 1,000 mg of calcium and 600 IU of vitamin D.³⁰ This may be particularly important in adolescents, as 90% of peak bone mass is accrued by the age of 18 years.³¹

Workup should also include other potential causes of impaired bone strength. Exposure to medications including glucocorticoids, antacids, antidepressants, and endocrine agents are important to consider, as these medications can impact bone health and add to overall BSI risk.³² Celiac disease,³³ osteogenesis imperfecta, irritable bowel syndrome, and other metabolic bone diseases³⁴ may contribute to poor bone health, while abnormal overall protein intake and carbohydrate availability may result in low bone mineral density (BMD).^{28,35} Specific interventions should be taken to address any of these underlying conditions if present.

Activity Modification and Modalities

Activity modification is one of the cornerstones of BSI management. Complete cessation of aggravating activity for 2–6 weeks may be required,³⁶ with higher MRI grade injuries correlated with a longer expected duration of rest.^{15-17,37}

Musculoskeletal testing is crucial in the early evaluation of tibial BSI, as biomechanical abnormalities or imbalance of the lower leg, upper leg, and core musculature may contribute to the development of injury.^{36,38} Therefore, physical therapy is a critical complement to the recommended rest and may be helpful in addressing these underlying risk factors, with a particular focus on neuromuscular training,³⁹⁻⁴⁰ including stretching and strengthening of the calf and other upper and lower leg muscles.⁴¹⁻⁴²

In the early management of low-risk BSIs, the treatment goal is to be pain-free during and after activities of daily living (ADLs). In athletes who are unable to achieve a normal gait pattern due to pain, crutches or a walking boot may be used to reduce weight-bearing load.³⁰ During this period of rest and recovery, cardiovascular fitness may be maintained through low-impact activities including cycling, swimming, and deep-water running. Adjunctive modalities, including low-intensity pulsed ultrasound (LIPUS) and extracorporeal shock wave therapy (ESWT), may help hasten recovery; however, current research supporting such measures remains limited by systematic errors and bias.⁴³

Running Progression

An athlete's return to sport progression should be a joint effort involving the athlete, physician, athletic trainer, coach, and parents. After an initial period of empiric rest, a graduated running progression may be initiated. Graduated running programs typically begin with dedicated walking on level surfaces that can be cautiously supplemented by increasing increments of jogging, defined as 50% of an athlete's normal pace.³⁰ Running frequency, duration, and intensity, with a balance of non-impact cross training, can be gradually increased by about 10% per week, with 1–2 dedicated days of rest per week. If there is recurrence of pain during or after training, the progression should be halted, and the athlete should return to the prior pain-free level.

Although time to return to sports participation varies widely, studies have indicated that the expected time to

MRI Grade	Fredericson et al. ¹⁵
Grade 1	Mild to moderate periosteal edema on T2 Normal marrow on T1 & T2
Grade 2	Moderate to severe periosteal edema on T2 Marrow edema on T2 but not T1
Grade 3	Moderate to severe periosteal edema on T2 Marrow edema on T1 and T2
Grade 4	Moderate to severe periosteal edema on T2 Marrow edema on T1 and T2 Fracture line apparent

Table 1. MRI grading system for tibial BSI proposed by Fredericson et al.¹⁵

return to sport following a tibial stress fracture is approximately 14 weeks, with female athletes requiring more time to return to sports.⁴⁴⁻⁴⁵ However, recent literature has suggested that BMD is lower at the 12-week time point following BSI in both the injured and uninjured leg and may not return to baseline for up to 24 weeks after initial diagnosis.⁴⁶ With the high recurrence rates of tibial BSI and the known consequence of low BMD, it may be that a more conservative, longer duration, and slower progression treatment pathway is favorable.

Gait Retraining

By reducing ground reaction forces and overall bone loading, gait retraining addresses underlying, faulty running kinematics as a potential strategy to reduce recurrence of low-risk BSI.³⁰ In a recent prospective observational study of collegiate cross country runners, Kliethermes et al. demonstrated an inverse relationship between BSI risk and step rate. An increase in step rate by one step per minute decreased risk of BSI by 5%.⁴⁷ Another prospective randomized controlled trial by Sharma et al. looked at the utility of gait retraining and incidence of MTSS/low grade BSI in military trainees.⁴⁸ The intervention included three times weekly supervised neuromuscular control and flexibility training combined with weekly biofeedback sessions enabling visualization and correction of pressure imbalances. Participants assigned to the intervention had a beneficial reduction in relative risk of MTSS when com-

pared to the control group. As runners adapt to preexistent faulty running mechanics over time, gait retraining should be incorporated slowly to prevent musculoskeletal injury at other sites.³⁰

Treatment of High-Grade Injury

Nonoperative treatment measures are usually successful even for high Fredericson grade (III, IV [Table 1]) or high-risk (anterior cortex) BSI, but treatment of these injuries requires especially vigilant multimodal management. Average return to running may be as high as 17 weeks in high-graded tibial BSIs with some authors suggesting avoidance of high-impact activity for 4–6 months.⁷

Immobilization with controlled ankle motion (CAM) walker boot or pneumatic leg brace has been explored in the treatment of high-grade BSIs in military recruits, with no clinically meaningful difference in time to return to activity for those patients who wore a pneumatic leg brace and those who did not.⁵⁰ For athletes with delayed union, such boots/braces have been proposed as an alternative to surgical intervention, although return to unrestricted activity may take up to 12 months.⁵¹

Surgery

In the rare instances of persistence or recurrence of BSI symptoms or diagnostic imaging findings despite compliance with a thoughtful and comprehensive conservative management plan along with the resolution of risk factors, surgery may be cautiously considered. There should be no role for surgery in MTSS/low grade BSI, despite prior reports of posterior fasciotomy and periosteal stripping to treat recalcitrant cases.^{36,52} While Yates et al. reported postoperative reduction of pain by 72% in patients who underwent posterior compartment fasciotomy and periosteal stripping, only 41% of athletes were able to return to pre-injury level of activity following surgical intervention.⁵²

The “dreaded black line” seen on a lateral radiograph at the anterior tibia can be seen in high-grade BSI and has historically been utilized as an indication for surgery, yet this does not histologically represent a fracture line.⁵³

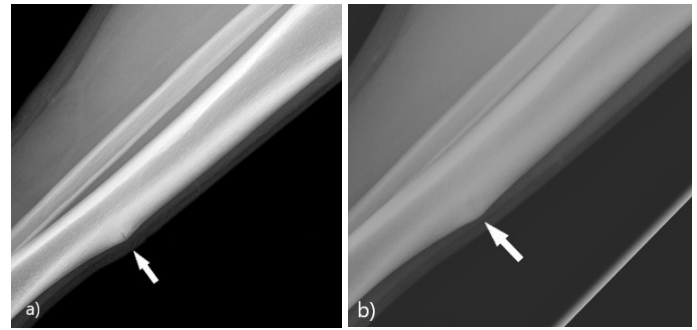


Figure 1. (a) Lateral tibial radiograph of a 15-year-old skeletally immature male football player demonstrating a stress reaction in the mid-diaphyseal region, representing a grade 4 bone stress injury. (b) Following 3 months of avoidance of impact activities, advanced bony healing and no symptoms allowed for progression to impact activities.

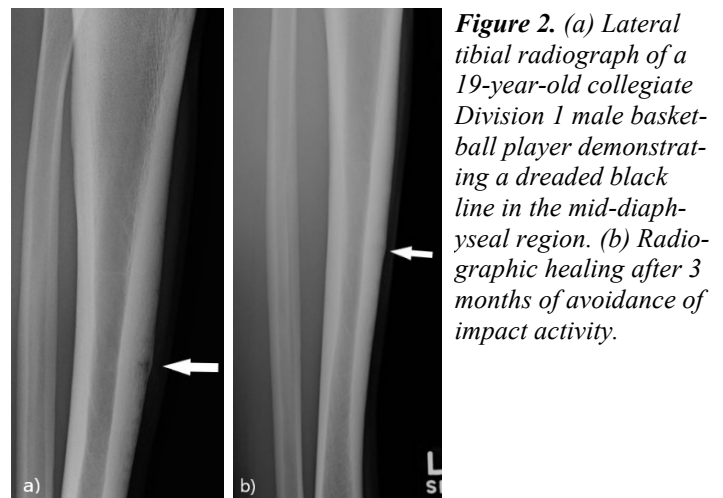


Figure 2. (a) Lateral tibial radiograph of a 19-year-old collegiate Division 1 male basketball player demonstrating a dreaded black line in the mid-diaphyseal region. (b) Radiographic healing after 3 months of avoidance of impact activity.

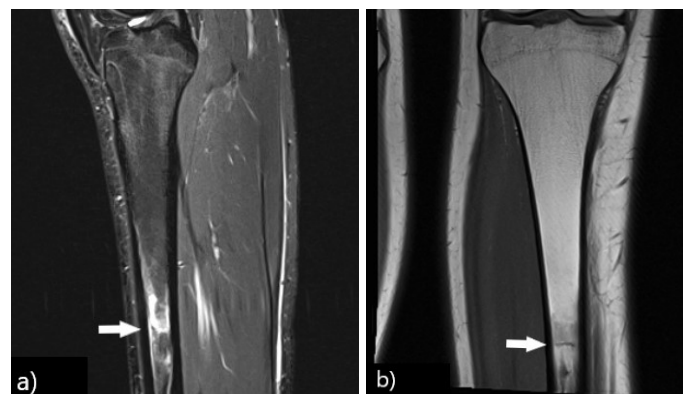


Figure 3. (a) Sagittal T2-weighted magnetic resonance imaging (MRI) image of the mid-diaphyseal region of a 15-year-old female soccer and lacrosse player demonstrating a high signal alteration in the cancellous bone. (b) T1-weighted coronal MRI image demonstrates a low-signal transverse linear alteration, allowing for diagnosis of a grade 4 BSI.

Nevertheless, historical reports suggest that this radiographic finding may be associated with nonunion or secondary fracture.¹¹ In either case, analysis of risk factors, patient demands, and failure of conservative treatment must be taken into consideration when deciding whether surgical intervention is ultimately justified. Such an indication for surgery may not be applicable to adolescents and younger adults whose improved biologic healing capacity may allow nonoperative treatment to be successful (Figures 1-3).

Intramedullary nailing of the tibia has been used to treat chronic tibial BSIs in athletes and military personnel, with patients reporting improvement in symptoms and return to activity at 4–6 months (Figure 4).⁵⁴⁻⁵⁶ Although complication rates have not been well reported in this population, the use of intramedullary nailing has frequently been associated with the development of chronic anterior knee pain.⁵⁷ Tension band plating of anterior tibial BSIs is an alternative surgical technique to intramedullary nailing, which may lead to quick recovery, with return to full activity around 10–12 weeks.⁵⁸⁻⁵⁹ However, up to 38% of patients treated with compression plating developed symptomatic hardware in prior series.⁶⁰⁻⁶¹ Although comparative literature is limited, biomechanical analysis of plate fixation vs. intramedullary nail fixation of anterior tibial stress fractures suggests that the anterior placement of a plate construct may provide an additional advantage in preventing microstrain⁶² at the fracture site compared to the use of an intramedullary nail.

Excision and transverse drilling, with or without bone grafting, was used historically to treat tibial BSIs with mixed results. Although some more recent case series have demonstrated positive outcomes after drilling and bone grafting,⁵⁵ other authors have reported good to excellent results in only 50% of athletes who underwent drilling of the fracture site of the tibia.⁶¹ Despite the risk for symptomatic hardware with plate fixation or intramedullary nailing, drilling of tibial BSIs may be less effective in achieving return to high-level sporting activity and reduction in symptoms⁶¹ and should therefore be considered only of historical interest.

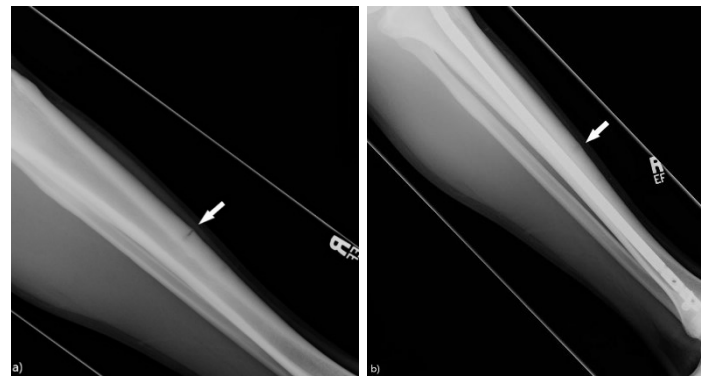


Figure 4. (a) Lateral tibial radiograph of a 20-year-old skeletally mature Division 1 male football player demonstrating a transverse lucency in the mid-diaphyseal region, representing a grade 4 bone stress injury. After failure of bony healing and continued symptoms, despite 3 months of avoidance of impact activities, the patient and parents elected to proceed with surgical treatment. (b) Three months following IMN treatment, advanced radiographic healing was associated with pain-free walking, biking, and lower extremity strengthening, and the patient was advanced to impact activities, such as running, jumping, and agility training.

Overall, although surgical treatment for anterior tibial BSIs is associated with a high rate of resolution of symptoms and return to sports, surgery may also be associated with high rates of complication and need for subsequent procedures.⁶³ Tension band plating and intramedullary nailing are preferred to tibial fracture drilling based on higher rates of return to sports and competition reported in the literature but should be limited to carefully selected, high-risk/recalcitrant injuries after failed nonoperative management.

Outcomes and Complications

The vast majority of tibial BSIs can be managed nonoperatively without complication. For those patients with higher risk injury or contributing risk factors, improper treatment can lead to failure of treatment, progression of injury, or injury recurrence.

Anterior Tibial Stress Injury

While anterior mid-tibial BSIs occur less frequently than posteromedial stress injuries (Figure 5), accounting for 5%–15% of all tibial BSIs,^{9,61} the overall risk for delayed union and nonunion may be higher.^{8,64-66} Multiple historical case series have suggested high rates of delayed

union or nonunion following treatment of anterior BSI with rest and immobilization.^{9,11} Conservative treatment of anterior BSIs may increase time to return to sport, and up to 45% of elite athletes may be unable to return to sport at a high level.⁶⁷ However, the quality of evidence remains low for most studies of conservative treatment of high-risk BSI,⁶⁸ and inadequate treatment of nutritional, hormonal, psychologic, and biomechanical factors may have influenced outcomes in these reports. Some authors have proposed that patients with anterior tibial BSIs should remain non-weight-bearing for at least 6–8 weeks,⁴⁹ but many will favor a less conservative protocol, utilizing crutch-based weight-bearing protection only for comfort, and allowing normal, but not excessive, walking patterns provided a patient remains pain-free. For grade 4 injuries in the anterior cortex of the mid-diaphyseal region, particularly with the presence of a “dreaded black line” radiographic finding, most favor a minimum of 3 months of avoidance of impact activities. Radiographic confirmation of advanced healing and resolution of the transverse lucency, as well as asymptomatic walking and lower extremity weight-bearing strengthening exercises, are requirements for consideration of return to running.

Other Risk Factors

Athletes with lower BMD are at elevated risk of developing more advanced BSIs and experiencing a prolonged recovery time. Adolescent female athletes with low BMD may have a 4.5 times greater risk of developing BSI,⁶⁹ and lower total BMD may be an independent predictor of increased time to full return to sport.¹⁶

Nutritional and hormonal status significantly impact bone structure. Low energy availability has been shown to disrupt both reproductive and metabolic hormones, resulting in menstrual irregularities and altered bone microarchitecture and turnover.²² Collegiate athletes with BSI and a history of disordered eating have been reported to have longer recovery times.¹⁶ Oligomenorrheic athletes have a higher lifetime history of BSI compared to eumenorrheic athletes and nonathletes,⁷⁰ and numerous studies have linked amenorrhea and menstrual dis-



Figure 5. Lateral tibial radiograph of a 15-year-old skeletally immature female cross-country runner, demonstrating peri-cortical new bone formation in the mid-proximal diaphyseal region, representing a posterior cortical tibial BSI.

turbance with increased risk of future BSI,^{19,71-74} however, it remains unclear whether these factors may lead to higher grade BSI on presentation.¹⁶

Progression of Tibial BSIs and Displaced Fractures

While BSIs occur on a continuum of severity,⁷⁵ a delay in recognition and treatment can lead to injury progression from low-grade to high-grade BSI and even to displaced tibial fracture.^{8,64} Female athletes are at increased risk of BSI progression,⁷⁶⁻⁷⁷ which may be related to the increased incidence of low BMD among females.^{52,76-77} Patients with BSIs of the anterior mid-tibial shaft are also at increased risk of progression to frank fracture compared to counterparts with posteromedial tibial BSI. Of six adolescent patients (mean age: 16.7 years) with anterior mid-tibial BSIs described by Green et al., five progressed to complete fracture.¹¹ Of 17 cases of anterior mid-tibial BSIs described by Orava et al., (age range: 14–39 years), one progressed to a complete fracture.⁹ Early recognition and treatment of all grades of BSI, including addressing contributing risk factors, is crucial in preventing these injuries from becoming even more significant.

Conclusions

Management of tibial BSI is multifaceted, and clinicians must be familiar with patterns of injury and contributing risk factors when evaluating a patient who presents with this injury. Failure to adequately treat tibial BSI can lead

to chronic and recurring injury or even displaced tibial fracture. Recent literature has highlighted the crucial population of young female athletes who have increased risk for tibial BSI and may experience prolonged recovery time. The RED-S framework may be an important consideration when managing this injury in both male and female athletes. While nutritional and menstrual factors are vital to identify and correct if present, gait retraining and neuromuscular training may be among the more crucial aspects of treatment for the majority of athletes. Progression of tibial BSI and recurrence rates may be high, and consideration of all contributing factors is crucial in guiding treatment for each patient presenting with this injury.

Empiric rest intervals, followed by controlled activity progression based on patient symptoms, is more of a modern standard of care. Moreover, some high-risk tibial BSIs may need over 6 months of avoidance and/or reduction of sports participation. Return to play intervals, at times, reflect the enthusiasm of patients and providers to avoid long periods of sports inactivity, but overly ambitious protocols may lead to recurrent injury if the injured bone is not allowed to fully heal or if proper progression of impact activity is not followed. Although the vast majority of patients have good outcomes with non-operative management, surgical management with compression plating or intramedullary rod placement may be considered in certain high-risk cases, instances of recurrence, or considerations for professional and elite-level athletes but remains an important area of shared decision-making with patients and certainly an important area for continued research.

Additional Links

- *Female Athlete Triad Coalition Consensus Statement on Treatment and Return to Play of the Female Athlete Triad*—<https://bit.ly/3jxvo8B>
- *Female Athlete Triad or Relative Energy Deficiency in Sports (RED-S)*—<https://bit.ly/3Babir8>

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