BONE STRESS INJURIES

STATE-OF-THE-ART APPROACH TO MANAGING STRESS FRACTURES IN TRACK AND FIELD ATHLETES

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INTRODUCTION

Bone stress injuries (BSI) represent overuse injuries to bone that develop in the context of repetitive loading resulting in cumulative damage[1]. These injuries are common musculoskeletal complaints among track and field athletes[2,3]. BSI encompass a spectrum of injuries ranging from early periosteal and endosteal bone tissue edema, to advanced injuries with the presence of a fracture line representing a stress fracture[1], Figure 1. The severity of injury can be graded using magnetic resonance imaging (MRI) which is considered the gold standard for diagnostic workup[4]. While athletes may present with a high-grade BSI or even a complete bone fracture[5,6], low-grade injuries are more common, evident by altered signal intensity within the marrow, endosteum, and/or periosteum on MRI[4,6-9]. Some BSI are recurrent, require prolonged recovery (>6 weeks), and can result in career-ending or season-ending injuries[10,11]. Therefore, evaluation and management require consideration for multiple risk factors that should be addressed to optimize healing, promote bone health, and reduce risk for future injury[1] (Figure 1).

Physical demands transmitted to bone during participation in track and field cause microdamage which results in repair through a process called targeted remodelling[1]. Bone is usually in a balance between damage formation and replacement[13]. BSI may occur when there is an imbalance between load-induced microdamage formation and its removal (bone remodelling), contributing to localized bone failure and resulting BSI[14]. Track and field athletes can sustain a BSI at any stage of preparation and competition, but may be particularly vulnerable at time of intense and/or rapid changes in training[1].

1. Epidemiology

In a retrospective 3-year injury surveillance in multiple sports, BSI represented 0.15% of all injuries[15]. In the 2016 Olympic Games overall burden of this injury amongst competitors was 2%[16]. However, BSI rates significantly differ between sports. Track and field athletics tend to be the sport with high annual injury rates[2,11,15]. BSI may contribute to up to 20% of all musculoskeletal injuries in track and field athletes[2,17]. It is suggested that between 30% to 60% of track and field athletes with a BSI may subsequently suffer from another BSI later in their athletic career[2,9,11,15,16,18]. The incidence and contribution of BSI may vary between the primary event in track and field and the level of competition.

Given the varying physical demands of track and field events, the anatomical location of the injury may involve all skeletal bone sites but mostly the lower extremity and spine. Sprints, jumps and hurdles were associated with a greater number of foot BSI, while middle- and long-distance running were associated with a greater number of long bone and pelvic BSI[2]. Furthermore, BSI occur 1.8-2.3 times more frequently in female compared to male athletes[19,20].

Overall, the tibia and metatarsal bones are the most common sites of injury in track and field athletes. However, a relatively high proportion of navicular, femur, and sacrum BSI are also sustained[2,9,18]. A portion of these

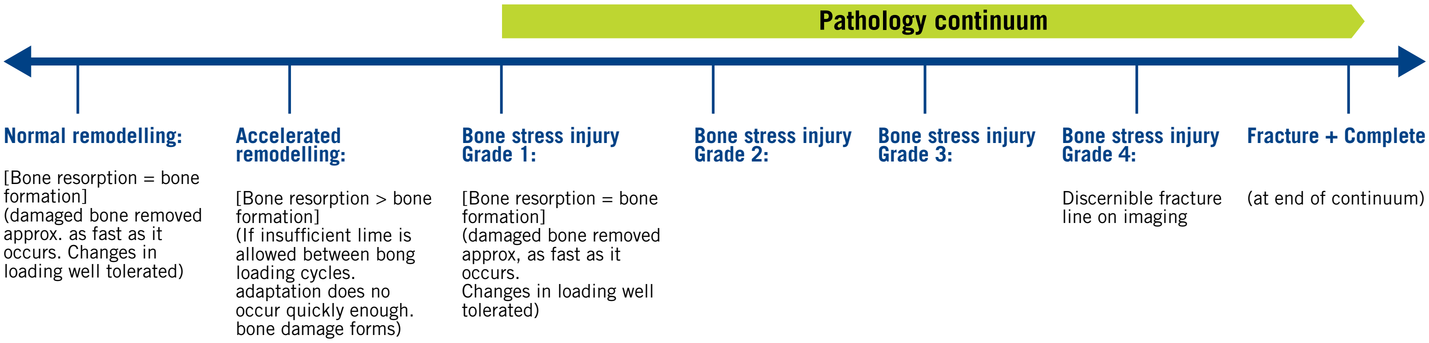

Figure 1: Bone stress injuries continuum. Modified from Beer[12].

Table 1

Key concepts for Team Physicians / Physiotherapists working in track and field athletics
Bone stress injury (BSI) is a common overuse injury in Athletics.
Assume up to 20% of athletes may develop a BSI in a single season.
Female athletes are more likely to develop BSI than males.
BSI may occur in any bone but are most common in the tibia and metatarsals.
Sprints, jumps, hurdles athletes more BSI in the foot (tarsal navicular, talus).
Middle- and long-distance runners more BSI in tibia, femur, and sacrum.
Counsel athletes with BSI of typical 2-4 months time-loss from sport (often longer for high-risk injuries to the spine and navicular).
Some BSI in Athletics will result in season ending injury.
Optimizing treatment is important as prior BSI is strongest risk factor for a future BSI.

Table 1: Epidemiology of BSI in track and field athletes.

injuries require prolonged time from sport, such as injuries to the navicular and spine[21] and a portion of all BSI may result in season-ending injuries[11] (Table 1).

2. Risk Factors

The aetiology of BSI is multifactorial and contributing factors may differ between individuals[1,14]. Sudden changes in training, low energy availability, previous BSI, low bone mineral density (BMD), genetics, ethnicity, female sex, biomechanics, early sport specialization, general psychological stress and poor sleep, hormone disruption, medications, and prior sports participation may be risk factors[22].

BSI are usually seen in the context of high physical demands and result from cumulative overload to bone [1,23]. The total training volume or intensity may be less important than a sudden increase in training volume or intensity[23,24]. In particular, the presence of a BSI must be considered when track and field athletes increase total training or return from recent cessation or reduced training resulting from injuries, illnesses, or planned off-season[1,23].

Nutrition factors (such as calcium and vitamin D intake) and low energy availability may influence risk for BSI. Low energy availability is the result of a mismatch between energy intake to meet the demands of energy exercise expenditure and is more common in endurance athletes[25]. The consequence of a low energy availability state may involve menstrual dysfunction, male hypogonadism, and decreased bone mass as described in the female and male athlete Triad[26,27], a component of health factors described in the Relative Energy Deficiency in Sports (REDs) syndrome defined by the International Olympic Committee[23,28,29]. Further considerations of nutrition include vitamin D and calcium intake which may contribute to low bone mass and mineral density and consequently increased risk of BSI[30-32].

Gender and ethnicity may influence risk for BSI, with women and Caucasian nonHispanics being at greater risk of low bone density and BSI[1]. While not specific to track and field athletes, certain foot types and anatomy may contribute to risk for BSI including pes planus (flat foot arch) or pes cavus (high foot arch), greater hip internal range of motion and Q-Angle (hip-knee alignment), and limb length discrepancies[22].

3. Diagnosis

The clinical presentation of BSI is variable[11] and requires a detailed history and physical exam with possible imaging to support diagnosis. Heightened concerns for BSI in track and field athletes include pain aggravating during exercise presenting in the leg and foot (e.g. tibia, fibula, tarsal or metatarsal bones in track and field athletes)[2,9,18]. However, BSI may occur in less common injury sites when sports activity contributes to intensified skeletal loading (e.g. olecranon injuries in throwing athletes)[1]. While pain is often the presenting feature, non-specific symptoms and the absence of a single traumatic event may contribute to a delay in the diagnosis[34].

Clinical history may include pain that worsens with continued training or competition in track and field[35]. Special attention needs to be given to risk factors including recent changes in training volume or intensity, previous BSI, and eating disorders[1,35,36]. In clinical examination, bone

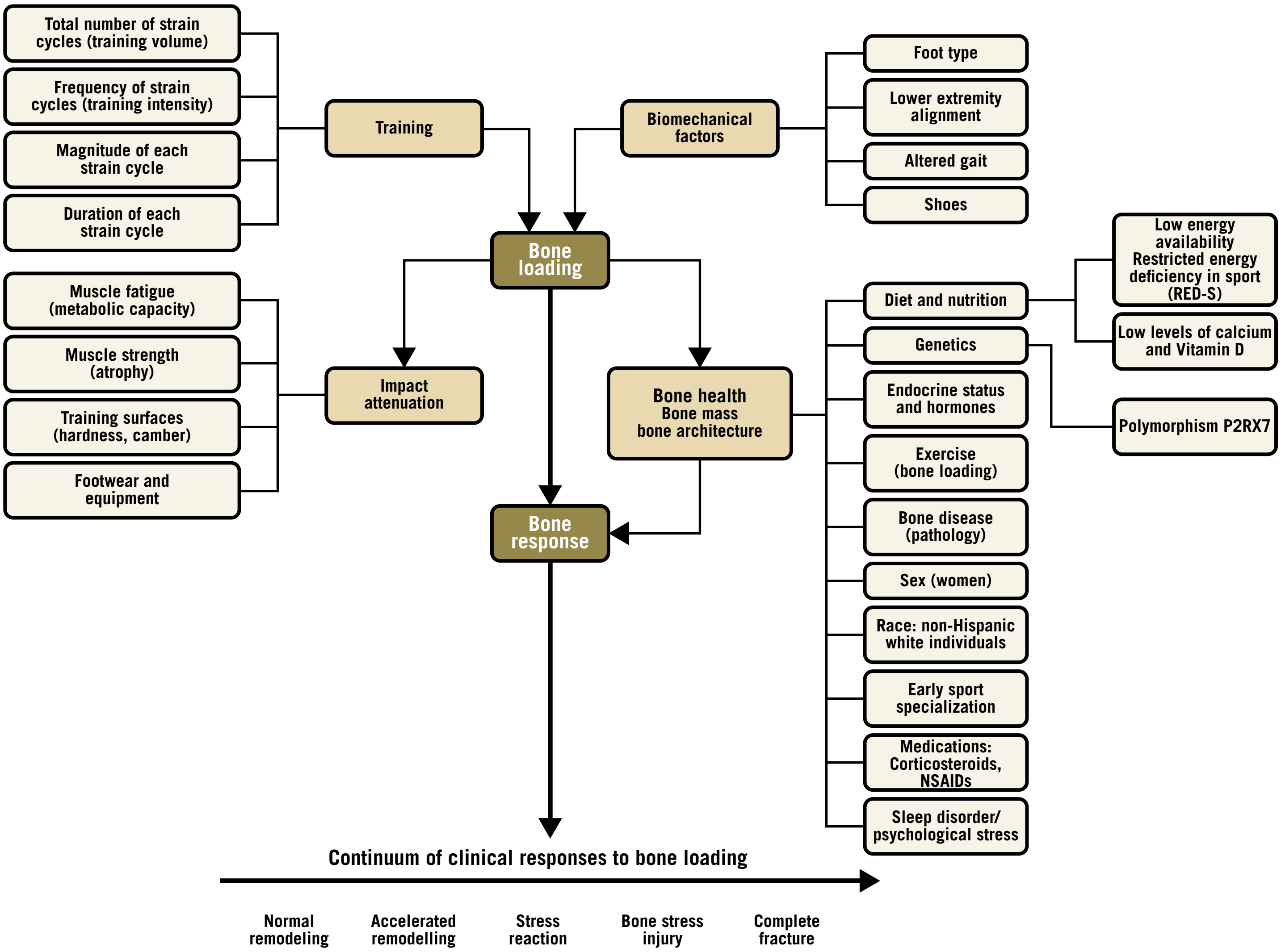

Figure 2: The contribution of risk factors to Bone Stress Injuries Pathogenesis. Modified from Bennell et al[33].

tenderness on palpation may be present. In addition, physical exam findings such as the single-leg hop test may transmit stress to bone and provoke pain.

Plain radiographs are commonly obtained for imaging confirmation[9]. However, the absence of findings on plain radiographs does not exclude BSI due to its low sensitivity especially early in the course of treatment[1,9]. MRI is considered the 'gold standard' and should be ordered in track and field athletes, including elite athletes who have a need for a definitive diagnosis to determine a safe return to sport[5,37]. Typically, fluid-sensitive sequences reveal a bone marrow edema and help detect early injury. MRI has the advantage that it can be used to grade the injury and guide return to sports but the disadvantage of high costs and non-ubiquitous availability[37]. Repeated MRI can be used to monitor bone healing, but clinicians should be aware that clinical healing may not match radiologic healing (e.g., persistence of radiological findings despite being pain-free). Other imaging modalities play a minor role in the diagnosis of BSI[38]. Scintigraphy may be used if MRI is contraindicated. Ultrasound is an important point-of-care diagnostic tool but is limited in the assessment of BSI[1]. Computed tomography can provide important additional diagnostic value in certain circumstances such as navicular bones[39,40] but is not routinely recommended[38]. We are conscious of the potential limitations and reduced ability to access MRI as well the limited availability of expert musculoskeletal radiologists in certain areas of the World. Therefore, we encourage clinicians to:

1. improve their clinical skills to flag potential BSI cases;
2. utilise the available imaging technology as best they can; and
3. improve their local and regional network to facilitate access to MRI and expert radiologists.

Common classification systems of BSI, (Figure 3)

Fredericson et al[7] were among the first authors to classify bone stress injuries according to MRI findings. Grades 1-3 represent MRI signal changes of the periosteum and bone marrow. In grade 4, a fracture line or cortical defect is visible. While initially described for tibial bone stress injuries, this classification has been clinically used for other bones, e.g., metatarsals. *Arendt et al.*[8] described a more universal classification system. Similarly, grades 1-3 represent signal changes on STIR, T2, or T1 sequences while a fracture line refers to the presence of a grade 4 injury.

Figure 3: Common classification systems of BSI. Fredericson et al[8] were among the first authors to classify bone stress injuries according to MRI findings. Grades 1-3 represent MRI signal changes of the periosteum and bone marrow. In grade 4, a fracture line or cortical defect is visible. While initially described for tibial bone stress injuries, this classification has been clinically used for other bones, e.g., metatarsals. Arendt et al[9]. described a more universal classification system. Similarly, grades 1-3 represent signal changes on STIR, T2, or T1 sequences while a fracture line refers to the presence of a grade 4 injury. The classification by Kaeding and Miller[33] is not limited to imaging findings but also accounts for clinical findings (pain), fracture displacement (grade 4) and non-union (grade 5). STIR, short tau inversion recovery. Modified from Hoenig et al[1].

Grade	Fredericson	Arendt	Kaeding-Miller
1	Mild to moderate periosteal edema on T2; normal marrow on T1 and T2	STIR Positive	Imaging evidence of stress fracture; no fracture line; no pain
2	Moderate to severe periosteal edema on T2; marrow edema on T2	STIR positive + T2 positive	Imaging evidence of stress fracture; no fracture line; pain
3	Moderate to severe periosteal edema on T2; marrow edema on T2 and T1	STIR positive + T1 and T2 positive	Non-displaced fracture line
4	Moderate to severe periosteal edema on T2; marrow edema on T1 and T2; visible fracture line	Visible fracture line on T1 or T2	Displaced fracture (≥ 2 mm)
5			Nonunion

The classification by Kaeding and Miller[41] is not limited to imaging findings but also accounts for clinical findings (pain), fracture displacement (grade 4) and non-union (grade 5). STIR, short tau inversion recovery. Modified from *Hoenig et al*[1].

4. Management

The three phases of treatment of BSI include initial modified weight bearing, gradual increase in physical activity, and graded return to sport progression[1]. The anatomical location of the BSI and grade of injury influence the time for return to sport[5,37]. High-risk anatomical locations for BSI include the femoral neck, anterior tibial cortex, medial malleolus, fifth metatarsal metaphyseal-diaphyseal junctions, base of the second metatarsal, hallux sesamoids, and tarsal navicular require strict non-weight bearing typically for six weeks and immobilization with a walking boot for

Table 2

Key concepts for Team Physicians / Physiotherapists working in track and field athletics

Suspect a BSI when skeletal pain develops after recent increases or changes in training load.

Palpate the painful area and consider other stress tests to bone such as hopping or fulcrum.

Request an MRI early to confirm presence and severity/grade of BSI.

MRI grading and anatomical location of BSI should guide treatment and time for return to sport.

Establish a multidisciplinary team early (e.g., athletic trainer, sports & exercise physician, orthopaedic, PM&R physician, endocrinologist) to agree on the rehabilitation and return to sport process.

Table 2: Key diagnostic tips for Sports Physicians / Physiotherapists working with track and field athletes with suspected bone stress injury (BSI).

foot injuries, Table 3. In contrast, BSI to other anatomical locations may require modified weight bearing and short use of crutches if there is initial pain with mobility.

Athletes with BSI should be screened for REDs factors and referred to a sports dietician to ensure optimal energy availability and nutrition status[29]. Calcium and vitamin D should meet dietary requirements, with foods rich in calcium preferable to supplements for bone healing and to prevent future injuries[30]. In contrast, vitamin D supplementation may be helpful to ensure serum vitamin D levels are in normal range. Further, iron supplementation may be considered in athletes with ferritin below 35 μg/L given the association of iron deficiency with female athlete Triad and goals to optimize iron status for endurance athletes[47,48]. Medications are not typically prescribed for the management of BSI as pain is helpful in monitoring healing response. Acetaminophen may be considered for pain interfering with function, but non-steroidal anti-inflammatory medications are not advised due to concern for delaying bone healing[49].

Athletes with a history of prior BSI, risk factors for REDs, or with injury in trabecular-rich sites of BSI (including the pelvis and femoral neck)[50,51] may require dual-energy x-ray absorptiometry to evaluate bone density. Low bone mineral density is defined as Z-score below -1.0 for exercising women[52] and men[31]. Athletes meeting criteria for low bone mass require further laboratory workup to evaluate for endocrine contributors for low bone mass and to meet with a sports dietician. While non-pharmacological strategies are primary management, female athletes with oligomenorrhea or amenorrhea and low bone mass may be candidates for use of transdermal oestradiol with progesterone to support bone healing and for bone gains[53].

Physical therapy should be prescribed to each athlete to address existing deficits in strength and mobility, to correct for any strength deficits that result from modified weight bearing, and to restore motion in joints following immobilization[1]. Cross-training to maintain aerobic fitness is advised during management of BSI. Deep water running can be incorporated early in treatment if the athlete does not need crutches to avoid stress to bone (femoral neck) or to maintain neutral position of the foot (navicular bone).

Return to run progression should follow principles of load management with a walk-run progression, alternating days of no running. Given the desire to maintain weight bearing activities, total loads applied to the musculoskeletal system are important to monitor to avoid acute overload and recurrence of injury. The full amount of time to restore full skeletal strength may require up to 6 months, so athletes should ensure overall progression in return to sport incorporates lower volumes of training as return to sport is achieved[54].

For chronic or non-healing BSI, other interventions can be considered. Extracorporeal shockwave therapy using focused shockwave has been studied for management of chronic stress fractures[55,56]. A larger cohort of runners with acute or chronic BSI demonstrated that shockwave can be successful for the treatment of most injuries in runners[57]. Non-union or delayed union, should it occur, may be treated by surgical open reduction and internal fixation[58]. While the use of orthobiologic treatments has enthusiasm, limited current evidence supports routine use[1].

5. Prevention

BSI may result in physical, psychological, and financial burden on the track and field athlete and his/her entourage, prevention is critical. Education of athletes, particularly those at elevated risk, along with their parents, coaches, and health professionals should include recognizing signs and symptoms of BSI to facilitate early diagnosis

TABLE 3

High Risk Bone Stress Injuries Anatomical Locations
Olecranon (ulna)
Pars Inter-articularis
Femur Neck tension (lateral) side
Patella, Medial Tibial Plateau
Tibia – Anterior border
Tibial (medial) malleolus
Talus
Tarsal navicular
2nd & 5th Metatarsal base; Hallux Sesamoids

Table 3: High-risk locations of Bone Stress Injuries[1,42-46].

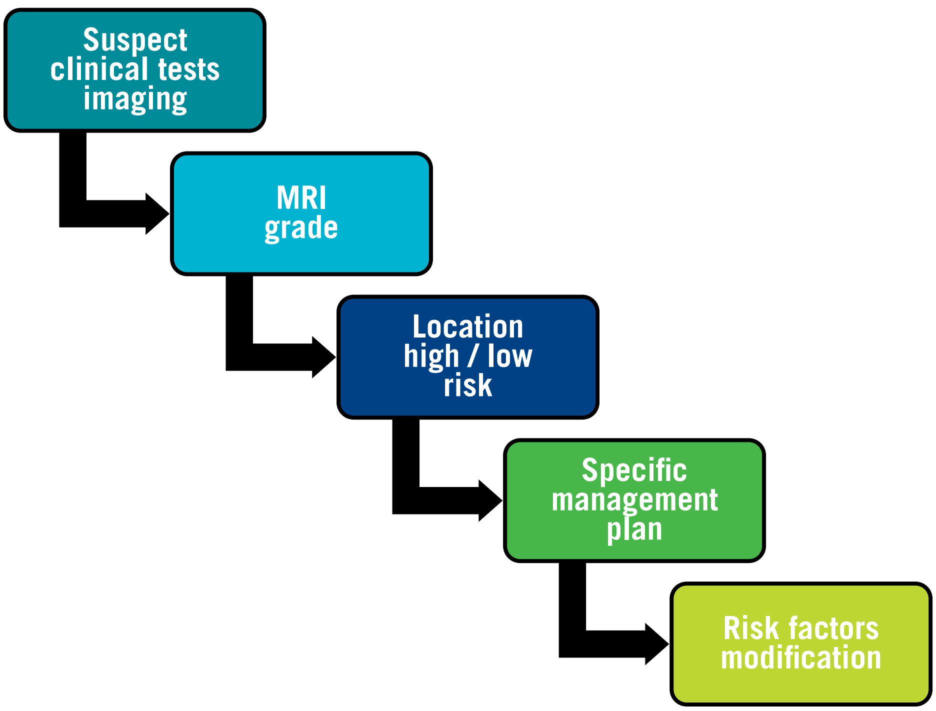

Figure 4: Management Algorithm for BSI in Track and Field Athletes.

CASE REPORT

Male 17 y/o High Jumper Black African from Sudan
2 m high 78 kg BMI 19.5;
Flat feet
Mid-foot diffuse ache
He stopped training workout **as he felt an unbearable pain while running**
Training session ended up with limping
Until up to two days ago, pain has been increasing
He recalls pain at night a couple of days and transient wakeup pain at some mornings in the last week
He stopped training for 35 days during summer break He resumed workouts 30 days ago and is training harder than usual, **increased his training load**

Tenderness on palpation on the "N" spot (navicular) Single leg hop test very painful
Strong suspicion of Tarsal Navicular BSI – MRI referral
MRI Showed **Grade 3-High Grade** in Arendt Classification
Anatomical Location: **Tarsal navicular High-Risk**

Initial Management:
Activity modification:
Six weeks cast non-weight bearing – cast + crutches

Rehab program:
Maintenance Physical condition (swimming, deep water running, anti-gravity treadmill, physical fitness at gym, no overground running, no jumping)
Addressing muscle disbalances / weaknesses Bone stimulator / LIPUS
Return to walking only after 6 weeks;
Then **return to initially light jogging, aprox. 9 weeks** later running-Consider Gait, running retraining
Return to light jumping about 12 weeks post diagnosis. Return to training 16 weeks postdiagnosis.

Risk Factors identification and modification:
Blood work – **Vit D deficiency, Calcium low, Ferritin level low are confirmed** – Immediate supplementation is prescribed
Nutritionist assessment – REDs screening: **Low Energy and low protein intake** is confirmed, DXA-scan Bone shows L1-L4 BMD Z-score being within normal range (-0.7)
Adequate diet is prescribed and followed up the whole treatment

Final Return to play – **Discharge 17 weeks after diagnosis**

and treatment[59], including recognition of the low energy availability state resulting in Triad and REDs[60]. Furthermore, prevention of BSI is best accomplished through identifying and modifying the multiple BSI risk factors. Among these, evading training errors with appropriate and gradual loading, optimizing nutrition to avoid low energy, and promoting recovery to enable bone repair damage worth to be emphasized. Sleep to facilitate recovery and prevention of bone loss is important[61]. Participation in youth ball sports (soccer and basketball) has been shown to reduce risk for BSI at older ages[62,63], highlighting that development in the sport of track and field should emphasize early sport sampling for long-term health.

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References
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