Curr Rev Musculoskelet Med (2013) 6:173–181
DOI 10.1007/s12178-013-9167-x

WOMEN'S ISSUES (MA GOOLSBY, SECTION EDITOR)

Update on stress fractures in female athletes: epidemiology, treatment, and prevention

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Published online: 28 March 2013

Abstract Stress fractures are a common type of overuse injury in athletes. Females have unique risk factors such as the female athlete triad that contribute to stress fracture injuries. We review the current literature on risk factors for stress fractures, including the role of sports participation and nutrition factors. Discussion of the management of stress fractures is focused on radiographic criteria and anatomic location and how these contribute to return to play guidelines. We outline the current recommendations for evaluating and treatment of female athlete triad. Technologies that may aid in recovery from a stress fracture including use of anti-gravity treadmills are discussed. Prevention strategies may include early screening of female athlete triad, promoting early participation in activities that improve bone health, nutritional strategies, gait modification, and orthotics.

Keywords Stress fracture · Bone mineral density · Return to play · Female athlete triad · Vitamin D

Introduction

Stress fractures, which account for up to 20 % of all injuries treated in sports medicine clinics [1], can lead to pain, reduced performance, lost training time, and medical expense [2]. Furthermore, the failure to identify and properly manage stress fractures can lead to complications such as progression to complete fracture, malunion or nonunion, chronic pain, prolonged recovery, and/or disability. The female athlete triad (referred to in this report as *the triad*), which is a significant risk factor for stress fractures in women, describes how prolonged periods of low energy availability and undernutrition due to mismatch of nutrition intake and exercise expenditure leads to amenorrheic state, estrogen deficiency, and the dysfunction of other hormones required for bone health (cortisol, leptin), and result in impaired bone health [3, 4]. The triad is common in female athletes at all levels of abilities and ages but is most commonly seen in endurance, aesthetic, and weight-class sports [3–6]. Individuals with 1 or more components of triad may have an increased risk for multiple adverse health outcomes, including stress fracture and other musculoskeletal injuries [3, 4, 7]. Hoch and colleagues [8] noted that endothelial dysfunction is also a major part of the adverse health outcome in female patients with triad and suggested that the term *female athlete tetrad* may more correctly describe the encompassing adverse physiologic changes that such patients experience.

In this review, we discuss the most recent literature pertaining to the incidence of and risk factors for stress fractures in female athletes, review treatment strategies, and emerging technologies in the management of such injuries in that population, and examine methods of preventing stress fractures.

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Epidemiology of stress fracture injuries in female athletes

Women are at increased risk for stress fractures. A systematic review by Wentz and colleagues [3] showed that the incidence of stress fractures was approximately 9.2 % in female military recruits, 3 % in male military recruits, 9.7 % in female athletes, and 6.5 % in male athletes. Recent studies have further delineated the risk factors for and incidence of stress fractures in females. Using the data from The Growing Up Today Study (GUTS) [9•, 10•], Field and colleagues [9•] reported that the risk factors for stress fracture reported by the authors included older age at menarche, a maternal family history of osteoporosis or low bone mineral density, and the hours per week of participation in sports. Stress fractures were nearly twice as common in girls who participated in sports for 8 or more hours per week than in girls who engaged in sports for 4 or fewer hours per week. Surprisingly, eating disorders or having a high or low body mass index were not independently associated risk factors for stress fractures. The authors attributed the study findings to the relative importance of other risk factors in the development of stress fractures or to the low incidence of those factors in the study subjects.

Diagnosis of stress fractures

History and physical examination

Athletes with stress fractures often complain of insidious onset of limb pain that occurs after or toward the end of the physical activity, often with a history of significant change in training regimen in the preceding weeks. As the stress reaction progresses to stress fracture, the symptom may progress to persistent pain even during ambulation. Physical examination usually reveals local tenderness over the involved bone and there may also be local swelling. Special tests such as the hop test, fulcrum test, and hyperextension test should be performed as indicated by the site of suspected stress fractures [1].

Classification and grading of stress fractures

The classification of stress fractures as high risk or low risk [11] is important in the management of such injuries. High risk fractures include those likely to progress to complete fracture, delayed union, or nonunion; those that require surgical repair; those that require assisted weight bearing or non-weightbearing; and those occurring on the tension side of the natural biomechanical axis. The sites for high risk fractures include the fifth metatarsal, the anterior tibia, the tarsal navicular, the femoral neck (tension side), the patella, the medial malleolus, the talar neck, and the first metatarsal sesamoids. Fractures with a favorable natural history, those that respond well to nonsurgical management, those that allow for unassisted weightbearing, and those that occur on the compression side of the natural biomechanical axis are considered low risk. Sites for low risk fractures include the femoral shaft, the medial tibia, fibula, the ribs, the ulnar shaft, the calcaneus, and the first through the fourth metatarsals.

In a systematic review, Miller et al. [12] analyzed the 27 different grading systems for stress fractures; however, none of those systems were validated due to the lack of reported inter-rater or intra-rater reliability. Among the most frequently used system is the Fredericson grading system [13] for tibial stress fractures using magnetic resonance imaging (MRI). The Fredericson grading system defines a grade 1 injury as periosteal edema only, a grade 2 injury as bone marrow edema visible on T2-weighted images only, a grade 3 injury as bone marrow edema visible on both T1-weighted and T2-weighted images, and a grade 4 injury as intracortical signal abnormalities.

Despite the recent advances in diagnostic musculoskeletal ultrasound, its use for stress fracture diagnosis is limited [14]. A stress fracture grading system using therapeutic ultrasound (TUS) by detecting pain over the site of stress fracture was proposed by Romani and colleagues [15] and Papalada and colleagues [16] recently reported positive results in their cohort study involving 113 elite track and field athletes. However, recent systematic review and meta-analysis by Schneiders and colleagues [17] showed a pooled sensitivity of 64 %, a specificity of 63 %, and a positive likelihood of 2.1. The authors concluded that the current evidence does not support the use of TUS as a standalone diagnostic tool for stress fractures; additional imaging studies are required to confirm the diagnosis stress fractures of the lower limbs.

Treatment for stress fractures

General treatment principles

A 2-phase protocol described by Andrish [18] can be safely implemented for the treatment of most low-risk stress fractures. Phase 1 of that protocol begins with pain control provided via ice massage, physical therapy modalities, and oral analgesic medications. The use of non-steroidal anti-inflammatory drug (NSAIDs) should be avoided due to its potential adverse effect on bone healing [19]. Weight bearing as tolerated is allowed for daily activities, but participation in sports should be discontinued. Walking boots can be provided for athletes who are unable to ambulate without pain. Minimal-impact aerobic activities (using elliptical machine, cycling, pool running, etc.) can help maintain cardiovascular fitness. Phase 2 begins when the injured athlete has been pain free for 10–14 days. One week after the resolution of focal bony tenderness, running may be resumed at half the usual pace and distance. Initially, athletes with a healing fracture should run only every other day for the first 2 weeks after pain resolution and should gradually increase running to the preinjury level over 3 to 6 weeks under proper supervision. The progression of that type of exercise should be dictated by the patient's pain level. The use of pneumatic braces may speed the healing of tibial stress fractures [20]. High risk stress fractures require different management. Grades 1 and 2 usually heal with nonoperative management, including weight bearing restriction and immobilization that is based on the location of the fracture [21]. To prevent progression to full fracture and associated complications, complete healing must be confirmed before the athlete returns to play [11]. Factors such as the site of the fracture, a higher grade of fracture, and competitive participation requirements determine whether surgery is the treatment of choice.

Return to sports participation

Return-to-sport time (RTST) is one of the most important issues for an athlete with a stress fracture. A timeline of 12 (±7) weeks has been suggested as a sufficient period of healing for a tibial stress fractures [22], but this large variance of timeline renders it impractical for clinical management. The correlation of MRI grading of stress fractures and RTST was first reported by Arendt and colleagues [23]. The authors found that the RTST was 3.3 weeks for grade 1, 5.5 weeks for grade 2, 11.4 weeks for grade 3, and 14.3 weeks for grade 4, with the comparison of grade 1 and 2 vs grade 3 and 4 reaching statistic significance. The authors concluded that (1) MRI grading system was prognostic for RTST, and (2) lower limb stress fractures may be considered as either low-grade (grade 1 and 2) or high-grade (grade 3 and 4) for clinical management.

Dobrindt and colleagues [24•] reached similar conclusions in their retrospective study evaluating the RTST in 52 athletes with stress fractures. The authors categorized the stress fracture sites as *high risk* or *low risk*, and the stress fractures as either *high grade* (a visible fracture line or bone marrow edema in T1-weighted, T2-weighted, or short T1 inversion recovery (STIR) sequences) or *low grade* (no fracture line, bone marrow edema only in STIR and/or T2-weighted sequences). In the matrix based on those 4 variations of RTST (Table 1), the authors showed that while the mean RTST for low-risk stress fractures differed significantly between the grades, the mean RTST of high-risk site did not differ significantly between low grade and high grade fractures. Only the mean RTST of the low risk/low grade group differed significantly from all other groups ($P=0.002$ to 0.005). Their finding illustrates several important points. (1) Identifying high grade stress fractures even at low-risk sites is important. (2) Stress fractures at high risk sites need to be managed diligently, regardless of the fracture grade. (3) Low risk/low grade stress fractures have the most favorable outcome and result in the shortest RTST. (4) The early diagnosis of stress fractures is important and may help prevent low-grade stress fractures from progressing to a high grade, thereby increasing the RTST and potentially complicating the outcome. Pending further validation, that work by Dobrindt and colleagues [24•] may serve as a general guideline for sports physicians, coaches, and athletic trainers.

Table 1 Statistical distribution of return-to-sports time for stress fracture, grouped according to severity and risk level of anatomic site

Risk/grade of stress fracture	Mean (days)	Median (d)	Q=25 (d)	Q=75 (d)
Low risk, low grade	61	50	35	78
Low risk, high grade	153	86	64	164
High risk, low grade	135	70	63	132
High risk, high grade	131	89	72	124

Q Quartile

Adapted from Dobrindt et al. [24•]

Screening and treatment of female athlete triad

Female athletes with a stress fracture should always be evaluated for female athlete triad. A detailed medical history (dietary practices, weight fluctuations, energy intake, menstrual history, and current menstrual status) should be obtained. Their height and weight should be used to calculate their body mass index. Vital signs should be evaluated for evidence of bradiacardia and orthostatic hypotension. Physical exam findings to include cold extremities, hypercarotenemia, lanugo hair, Russell's sign (calluses at back of fingers), poor oral hygiene, and parotid gland hypertrophy are the stigmata of eating disorder and should be noted. To evaluate for underlying metabolic disorders, a complete blood count and a complete metabolic panel blood test should be performed, thyroid function should be assessed, and the erythrocyte sedimentation rate should be tested. Urinalysis, a stool guaiac test, and an electrocardiologic evaluation should be performed. The levels of salivary amylase and urine electrolytes maybe to determine the presence of eating disorders. In amenorrheic athletes, a urine pregnancy test, prolactin, estradiol, follicle-stimulating hormone, luteinizing hormone should be obtained to rule out other causes of amenorrhea. A dual-energy X-ray absorptiometry (DXA) scan should be performed to assess bone mineral density (BMD). Referral for nutritional or psychological evaluations should be considered when appropriate [3, 4, 25].

The use of oral contraceptive pills (OCPs) for women with triad has become a controversial subject [26]. OCPs have been commonly used in amenorrheic athletes to normalize menses [27]. However, current evidence of the effects of OCPs on BMD is contradictory [28–33], and the use of OCPs may lead to complications such as premature physes closure [34] and lower femoral neck and spine BMD in female endurance athletes [35]. Such concerns have led some physicians to recommend the reexamination of the role of OCPs in triad treatment [34]. The resumption of adequate caloric intake via healthy eating habits continues to be the goal in management of the triad [3, 4].

The importance of early triad management was highlighted in the recent work by Barrack and colleagues [36]. Those authors performed baseline and 3-year follow-up assessments of bone density measurements in adolescent female runners who had either low bone mass for their age (agematched Z-scores, cutoff of −1 or −2) or normal bone health. At the 3-year follow-up assessment, 90 % of the athletes who had a low bone density value at baseline continued to meet the criteria for low bone mass for their age. Those findings suggest that catch-up growth should not be expected to occur in that population and further highlight the importance of identifying triad and optimizing bone health in early adolescence [36].

Antigravity treadmills

The use of an antigravity treadmill is an emerging technology for the management of bone stress injuries. Antigravity treadmills provide adjustable body weight support and may promote fitness for individuals performing exercise in a hypogravity environment [37–39] and have potential applications in the recovery from injury or surgery [40, 41]. We recently reported [42] our experience with a 21-year-old female elite track athlete who had sustained an iliac stress injury. A return-to-run protocol designed to gradually increase her body weight allowed her to train safely during the healing phase. She was able to return to competition 10 weeks after the diagnosis of her injury and performed at a high level in the 10,000-meter track event without a recurrence of her injury for the remainder of the season. Further investigations are needed to determine the exact physiologic effect of hypogravity environment in healing stress fractures and its effect on clinical outcomes.

Pulsed ultrasound, extracorporeal shock wave therapy, and capacitive electric fields

Pulsed ultrasound, extracorporeal shock wave (ECSW) therapy, and capacitive electric fields (also known as bone stimulators) are noninvasive techniques applied to stress fractures to promote healing and hasten recovery. Pulsed ultrasound is thought to work by inducing aggrecan and proteoglycan synthesis in chondrocytes, thus leading to increased endochondral ossification [43]. ECSW is thought to work by inducing healing via causing periosteal detachment and microfractures of the trabeculae [44]. However, Griffin and colleagues [45] examined the effect of pulsed ultrasound and ECSW in a systematic review and concluded that although the potential benefits of those treatments cannot be ruled out, current evidence of such benefits is inconclusive, and the routine clinical use of either modality cannot be recommended.

An electric field is known to promote bone formation in vitro and in vivo [46–49]; that is the working theory behind capacitative electric field devices. In 2011, Griffin and colleagues [50] performed a Cochrane database systematic review in which they examined 4 studies involving 125 participants with either delayed union or nonunion of long bones. Those authors concluded that although there might have been some positive effects from treatment with capacitative electric field devices, the current evidence of that benefit is inconclusive and insufficient. They do not recommend the routine clinical use of that therapy in the treatment of stress fractures. Additional high-quality studies are needed to clarify the clinical effects of such emerging technologies.

Prevention of stress fractures in female athletes

Identifying and preventing female athlete triad

Identifying and correcting energy imbalance in female athletes while monitoring for the restoration of menstrual function may be the best method to ensure that proper bone health is maintained during adolescence. Education for athletes, health professionals, coaches, and parents is important to ensure appropriate screening for and early management of triad. In young female athletes, screening for triad should begin in high school or earlier [51]. Despite the recognition that triad is prevalent in female collegiate athletes, a recent study reported that National Collegiate Athletic Association Division I athletic programs may not optimally screen for that condition [52]. After reviewing the preparticipation examination forms and conducting surveys with team physicians or athletic trainers at each institution in National Collegiate Athletic Association Division I, Mencias and colleagues [52] concluded that collegiate athletic programs do not globally perform annual screening for female athlete triad. A screening questionnaire consisting of 12 questions about eating behavior, menstrual history, and prior fractures has been proposed by the Female Athlete Triad Coalition [53]. Positive responses may identify athletes at risk for triad and prompt a more comprehensive medical evaluation. We recommend using screening questions about nutrition, menstrual health, and prior fractures or musculoskeletal injuries to evaluate all female athletes annually.

Some medical professionals have suggested that all female elite endurance athletes be screened with DXA because of the increased risk for impaired bone health in that population [54]. DXA provides information about BMD and composition and serves as a proxy for bone health [55]. The ACSM Position Stand on the triad currently recommends DXA for athletes with stress or low impact fracture and after a total of 6 months of amenorrhea, oligomenorrhea, or eating disorder [3, 4].

Preparticipation screening

In addition to female athlete triad, several behavioral, and activity patterns established as risk factors for stress fractures can be readily assessed by physicians, coaches, athletic trainers, and parents before participation in sports begins. Those patterns include consuming more than 10 alcoholic beverages per week, engaging in excessive physical activity with limited rest periods, running as recreation for more than 25 hours per week, smoking tobacco, suddenly increasing physical activity, participating in running sports, and running predominantly on hard surfaces [56, 57]. Other factors associated with an increased risk for stress fractures include female gender, current low dietary calcium intake, a history of irregular menstruation, a low total-body BMD, and multiple years of running [56, 57]. The step test is a simple validated test that can be quickly and reliably administered in an office setting to assess stress fracture risk in female military recruits [58]. Subjects are asked to perform 30 up-and-down step cycles per minute, and subjects who can complete 5 minutes of that activity pass the test. It was noted that women who failed the step test had a 76 % higher incidence of stress fractures and a 35 % higher incidence of musculoskeletal injuries during initial military induction training than those who passed the step test [58]. The results of the step test are superior to those of questionnaires in reducing recall bias. The step test is quick, simple, easy to administer, and can be administered to a large group in an office setting. The identification of athletes at risk for stress fractures enables both the timely modification of activity and injury prevention. Additional studies are needed to validate the use of the step test in female athletes.

Promotion of early sports participation

Encouraging pubescent and adolescent girls to participate in sports may enhance bone density and geometric properties and thus prevent stress fractures. Our literature review [59] on the effects of sports participation on bone health in young athletes showed that those who participated in sports involving high-impact or odd-impact loading (basketball, soccer, gymnastics, volleyball, jumping sports, racket sports, martial arts, step aerobics, speed skating) had higher bone density and more enhanced geometric properties than their peers who did not participate in similar activities. In contrast, endurance sports involving low-impact repetitive loading (distance running) or nonimpact sports (cycling, swimming, water polo) were not associated with improved bone health in that population. Our findings support those of Milgrom and colleagues [60], which suggest there are benefits of a pretraining program that simulates the loading forces encountered in basketball before athletes engage in activities that increase their risk for stress fractures. However, because increased hours per week of high-impact activities may increase the risk for stress fractures in female preadolescents and adolescents [9•], sports medicine physicians must encourage coaches and trainers to establish training programs that include varied impact activities to reduce those injuries in at-risk female athletes.

Running mechanics modification

Because stress fractures are among the top 10 injuries sustained by runners [61], recent efforts have examined stress fracture prevention via the modification of running mechanisms and training programs. Runners demonstrating relatively higher positive average and instantaneous vertical ground reaction forces, higher average peak positive acceleration, and higher vertical loading rate of the tibia sustain more stress fractures [62, 63]. Running mechanics including knee flexion stiffness during initial loading, greater hip adduction, and rear eversion angles during the stance phase, and rear-foot striking during initial landing are associated with a higher vertical load rate [64–67]. Therefore there has been much interest in reducing runners' tibial stress fracture risk by modifying the loading mechanics. Using real-time feedback from an accelerometer attached to the distal tibia of a subject who was running on a treadmill, Crowell and colleagues [68] showed that gait retraining can reduce the impact peak and the vertical ground reaction force in a single session. In that study, the effects of gait retraining had excellent carryover at the 1-month follow-up evaluation [69]. Hobara and colleagues [70] demonstrated that impact loading variables could be reduced by adopting a running step frequency greater than one's preferred cadence via improving running mechanics, primarily improved knee flexion, and foot striking patterns. That training strategy can be easily incorporated into an athlete's training routine without the need for specialized equipment (eg, instrumented treadmills) or accelerometer feedback. Although those results are promising, the biomechanical risk factors associated with various running gaits remain a subject of debate [64, 71] and additional studies are needed to assess the role of gait retraining in stress fracture prevention.

Calcium and vitamin D supplementation

Although some studies have demonstrated a significant benefit of calcium supplementation in stress fracture prevention [72, 73], current literature on the role of vitamin D supplementation in such prophylaxis (and the proper dosing of that vitamin) are conflicting [74–76]. Vitamin D deficiency is common in the US population, ranging from 30 % to 50 %, even in healthy young individuals [77–79]. Sonneville and colleagues [10•] compared calcium, vitamin D, and dairy intake and the risk for stress fractures, and found that high vitamin D intake (rather than a high calcium intake) was prophylactic against prospective development of fractures. After adjusting the data for calcium intake and other confounders, the authors found almost a 50 % reduction in the incidence of stress fractures in girls who participated in a high-impact activity and were in the highest quintile of vitamin D intake when compared with girls who were in the lowest quintile. However, girls of similar activity level and were in the highest (as opposed to lowest) quintile of calcium intake had an *increased risk* for fracture when accounting for vitamin D intake [10•]. This finding may represent reverse causality; girls in the studied population who knew that they are at increased risk for fracture may have altered their behavior by consuming more foods and supplements containing calcium.

Studies in female military recruits and female athletes suggest that daily intake of 1500 mg of calcium may reduce stress fracture incidence [80]. Several recommendations for vitamin D supplementation that are based on the serum 25(OH)D level have been put forth, despite the ongoing debate on the optimal normal reference range of serum 25(OH)D values in competitive athletes [81]. The current National Institutes of Health guideline [82] breaks down vitamin D levels as follows: "vitamin D deficiency associated with an increased risk for rickets in children and osteomalacia in adults" (<30 nmol/L or <12 ng/mL of vitamin D), "generally inadequate intake of vitamin D" (30–50 nmol/L or 12–20 ng/mL), "generally adequate for healthy individuals" (>50 nmol/L or >20 ng/mL), and "potentially harmful" (>150 nmol/L or >60 ng/mL; >125 nmol/L or >50 ng/mL). Although the Institute of Medicine guideline recommends 600–800 IU of vitamin D daily, McCabe and colleagues suggest that most patients should receive 800–1000 IU (or perhaps as much as 2000 IU daily) of vitamin D3 because it is relatively safe and has a high therapeutic index [81]. Screening for serum 25(OH)D levels should be performed on patients at risk for low BMD, and in those individuals, the therapeutic goal for vitamin D supplementation should range from at least 50 nmol/L (20 ng/mL) to as high as 90–100 nmol/L (36–40 ng/mL) [81]. Although higher dietary intake of vitamin D was found to protect against fractures in the study by Sonneville and colleagues [10•], the exact role of vitamin D in fracture prevention is still unclear and requires further research.

Orthotic devices

Orthotic devices are thought by many investigators to prevent lower-extremity stress fractures by absorbing shock and altering biomechanics, but that issue remains controversial. Most data on the effects of orthotics on stress fractures are derived from studies on the prevention of stress fractures and lower-extremity soft tissue injuries in military recruits undergoing military induction training. In a Cochrane database systematic review in 2000 by Gillespie and colleagues [83], they examined 12 studies of military recruits in 3 countries and concluded that the use of shock-absorbing insoles in military boots was effective in stress fracture prevention. However, when that topic was reevaluated in a 2005 update by Rome and colleagues [20], those devices were deemed "probably" effective in reducing the incidence of stress fractures in military personnel. In a recent 2-arm feasibility study, Baxter and colleagues [84] evaluated the effects of orthotics on lower-extremity soft tissue injuries in New Zealand army recruits by screening for subjects with a biomechanical abnormality. The results revealed a reduction in the incidence of stress fractures of the foot and tibia. In a randomized controlled trial, Mattila and colleagues [85], evaluated the incidence of lower-extremity injuries (including stress fractures) in Finland Army recruits. They compared the effects of wearing combat boots with orthotics over a 6-month period. The study results showed that orthotic devices were not effective in preventing lower extremity stress fractures. Further study of this topic is needed.

Conclusion

Stress fractures are a common form of injury in many athletes, particularly females. The causes of those injuries are multifactorial and involve biomechanics, activity mechanisms, training factors, environmental factors, nutritional factors, and the female athlete triad. The treatment of a stress fracture begins with using the fracture site and grade to categorize the injury as high risk or low risk. Conservative management is the treatment of choice for low-grade stress fractures, but high-grade fractures may require more aggressive management. Identifying the presence of triad, performing preparticipation screenings, and promoting early sports participation can help prevent stress fractures in female athletes. Running-mechanism modification may prevent stress fractures in runners. The roles of calcium, vitamin D, and orthotics in stress fracture prevention await further investigation.

Conflict of Interest Yin-Ting Chen declares that he has no conflict of interest. Adam S. Tenforde declares that he has no conflict of interest. Michael Fredericson declares that he has no conflict of interest.

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