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Part I: Background and Clinical Considerations for Stress Fractures in Female Military Recruits

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ABSTRACT
Introduction:
Stress fractures (SFx) represent a significant proportion of musculoskeletal injuries in military recruits internationally. Incidence rates as high as 40% have been reported, varying by country and branch of military cohorts. Tibial SFx are the most common, followed by other lower extremity sites, and are related to the emphasis on running during training. SFx disproportionately affect female recruits, similarly to a disparity demonstrated in female athletes.

Methods:
A literature review of articles relevant to our review was conducted using PubMed, utilizing keywords stress fracture, military, recruits, diagnosis, management, treatment, prevention, epidemiology, background, and/or female. Articles older than 10 years old (prior to 2010) were not considered. Review articles were considered, but if a research article was cited by a review, the research was included directly. Articles with primary military data, members of the military as subjects, especially when female recruits were included, were strongly considered for inclusion in this review.

Results:
SFx can cause medical morbidity and financial burden and can require discharge from military service. SFx management in the military has cost the United States approximately $100 million annually, which may be underestimated due to lost duty hours or medical discharge with resulting compensation. However, SFx incidence rates have been demonstrated to be reducible with concerted efforts in military cohorts.

Conclusion:
This review, **Part I of a two-part series**, provides updated information for multidisciplinary management of SFx in female military recruits. There are many similarities to management in athletes, but unique nuances of the military recruit require specific knowledge to reduce the high incidence rates of injury.

BACKGROUND

Pathophysiology and Mechanism

Stress fractures (SFx) result from repetitive and excessive bone stress, with microfracture rates exceeding rates of bone remodeling.[1–12] Without adequate rest, osteoblasts cannot adequately produce new bone to compensate for osteocyte remodeling of stressed bone.[4,13,14] This is the simplified mechanism of fatigue SFx, which are commonly described in military recruits internationally.[4,6,7,10,12,15–19] Depending on the service branch, recruits complete 6–32 weeks of training; American branches' training is typically 6–12 weeks, with Israeli and British militaries training for relatively longer durations of 16 and 32 weeks, respectively.[1,5,9,12,13,15,17,20–22] Recruits who are less active prior to training are particularly at risk for SFx due to a relative lack of history of bone stress and consequent lack of bone strength needed for the new training demands.[1,17,22]

SFx are most commonly sustained during the first few weeks of training by recruits who are not accustomed to high intensity, high volume activity with limited recovery.[6,8] Activities involving jumping, walking, running, acceleration/deceleration movements, and marching can precipitate the development of SFx. All of these activities are incorporated as part of daily military training exercises.[1,18,20,22,23] Army recruits run for an average of 36 minutes and march for 129 minutes per day.[18] Running can triple forces across the femoral neck when compared to walking, and the cumulative stress of all training activities can be substantial.[23] Additional weightbearing during activities due to intentional loading and any equipment carriage also increases injury risk and is a unique factor contributing to the risk of SFx in military recruits.[1,9,18]

Epidemiology

SFx rates for military recruits are significant. Depending on the branch, incidence rates have been reported to be as high as 40% during training.[1] The incidence of SFx is significantly higher for recruits than for non-recruit members of

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the military (those who have completed basic training), due to the increased risk imposed by initial training.[4,8,9,24,25] In 2011, 2014, and 2016, Waterman et al.,[8] Claassen et al.,[19] and Lee et al.[25] analyzed injury data from the Defense Medical Epidemiology Database and the Defense Medical Surveillance System (DMSS), which compile medical information for service member patients from the U.S. Army, Navy, Air Force, and Marines. From 2009 to 2012, the SFx incidence rate for all recruits was found to be 18 times higher than all non-recruit active-duty service members, and 77.5% of SFx occurred in junior enlisted service members.[8] The Army and Marine Corps were found to have the highest SFx rates in this study.[8] A similar study using DMSS data during a surveillance period from 2004 to 2010 corroborated the 18-fold discrepancy in SFx rates between recruits and nonrecruits.[25] It also found the Marine Corps to demonstrate the highest SFx rate (41%) and to account for 20% of all tibia and fibula SFx in U.S. Military recruits.[25] Finally, Claassen et al.'s study utilizing data from DMSS and other military databases from 2003 to 2012 found that the Marine Corps and Coast Guard had the highest SFx rates; the Air Force demonstrated the lowest rates in this study.[19]

In the United States, SFx rates in different branches of the military have been reported at 1.9%–6% for male recruits and 8%–30% for female recruits[2,8,13,19,25] (Table I). Some studies report incidence in person-years, and the overall average U.S. rates for all branches have been reported as 44–66 per 1,000 person-years.[19,25] The incidence rates of SFx in U.S. Navy recruits have recently been reported as 3% for men and 10% for women.[2] The Army has demonstrated incidences of 1.9%–3% for male recruits and 8%–20% for female recruits.[13]

Studies from international militaries also provide the opportunity to compare injury rates. In 2015, Bhatnagar et al.[26] prospectively studied 2,000 male military recruits in India through the duration of training to determine the incidence and distribution of SFx. The authors found an overall incidence rate of 15% in this cohort. The authors compared this rate to the relatively lower U.S. Military rates. Kunte et al.[9] studied 3,220 Indian recruits in 2011–2012 to evaluate SFx incidence by gender and found an incidence rate of 6.9% for men and 15.8% for women. In the United Kingdom, SFx incidence for Royal Marine male recruits has recently been reported at 7.2%.[12] In the Israel Defense Forces, SFx rates have been reported to be between 2% and 21%, with rates up to 3-fold higher in female recruits than their male counterparts.[14,17,27,28]

In a 2019 study of over 4,000 Finnish male military recruits, the overall SFx incidence rate was only 1.1%.[15] The authors interpreted this low incidence rate to reflect that the level of physical activity is not excessive in the Finnish military cohort. In 1999, the Australian Army studied SFx incidence rates in training cohorts one year apart in order to interpret the effects of concerted preventive strategies.[29] The authors were interested in the first cohort's discrepancy between male and female recruits' rates of pelvic SFx; male recruits demonstrated an incidence of 0.1%, compared with an incidence of 11.2% in female recruits. Although not a relatively common SFx site, this disparity presented an opportunity to perhaps demonstrate the impact of preventive strategies. After implementations such as reduced march speed, changing the running surface, replacing distance runs with interval training, and retraining gait, the immediately subsequent cohort of female recruits demonstrated a pelvic SFx incidence of 0.6%. Importantly, changes did not worsen recruits' fitness.[29]

Tibial SFx are the most common SFx in military recruits based on studies from militaries internationally; lower extremity (LE) SFx rates are significantly higher than upper extremity SFx.[1,2,8,14,15,28] As high as 71% of SFx in the military involve the tibia, compared to 49.1% in athletic populations.[6,8] Similarly to what is demonstrated in athletes, after the tibia or fibula military recruits most commonly sustain SFx at the metatarsals, femur, tarsal bones, and pelvis.[2,14,20] Metatarsal SFx most frequently occur in the second and third metatarsal shaft and account for 20% of SFx in the lower extremity in military populations.[6,16] Femoral neck stress fractures (FNSF), which are rare but high risk and costly, represent 2% of stress fractures in military recruits.[4]

TABLE I. SFx Incidence Rates in Recruits During Basic Training, Separate Gender Analyses

Population	Female SFx IR (cases/1000 person-years)	Male SFx IR (cases/1000 person-years)	Female recruit SFx incidence (%)	Male recruit SFx incidence (%)
U.S. Military (combined branch data analyses)	IR 12.67–94.7[8,19,20]	IR 4.55–29.6[19,20]		
Army			8–20%[5,13]	1.9–5.7%[5,13]
Navy			10%[2]	3%[2]
Finnish Defence Forces	n/a		n/a	1.1%[15]
Indian Armed Forces			15.8%[9]	6.9%[9]
Royal Marines (UK)	n/a		n/a	7%[12]
Israel Defense Force			6.3–21%[17,27]	2.3%[17]
				37–40%[1] (elite Special Forces program)

Stress Fracture Burden

Musculoskeletal injuries are the greatest contributor to lost duty time in the military[4] (Table II). SFx may be of more concern than other common overuse injuries such as soft tissue strains and sprains because of the potentially greater impact on lost time for service members, attrition rates, and significant potential morbidity for individual recruits.[15] For a recruit who sustains a SFx, the mean time required to return to preinjury activity can be as long as 21 weeks; some recruits are unable to return to training in the same year, and some must withdraw from the military.[10,15] SFx are the leading cause of injury to all U.S. Military recruits and typically require 10–18 weeks of physical therapy and rehabilitation, which often necessitates training repetition.[19] Many military recruits cannot continue training, and SFx are the most common training overuse injury which results in military discharge.[4] Recruits who sustain SFx have a fourfold higher likelihood of medical discharge during training.[4,11,15] Those who complete training despite this injury are at 6-fold greater risk for recurrent SFx within a year after graduation.[4,11,15] In a 2008 case series, Talbot et al.[30] studied British Army recruits who sustained FNSF in order to evaluate the impact on medical discharge. On average, rehabilitation for a recruit with FNSF required 3–7 months, with only 31% of recruits able to eventually complete training.[21,30] Military recruits who are able to return to training demonstrate diminished performance and military readiness, and those who require discharge often feel isolated or otherwise psychologically impacted.[2] FNSF can lead to lifelong consequences for young recruits.[21] FNSF can result in avascular necrosis of the femoral head, which may ultimately need surgical intervention.[14] FNSF account for 10% of lost training days, and two-thirds of FNSF cases are in female recruits.[4]

In addition to the consequences of SFx on individual recruits and company readiness, this injury poses an extreme financial burden. In 2009, LE SFx cost the United States over $4.8 million for rehabilitation, lost duty hours, and medical discharge payments.[4] Overuse injuries were responsible for the greatest number of outpatient appointments for recruits and a loss of greater than 25 million training days annually in an Israel Defense Force study.[31] In the Marine Corps, musculoskeletal injuries cost $111 million and 356,000 lost days of duty annually.[32] Overuse injuries cost the Department of Defense as much as $20 billion dollars per year, with SFx specifically costing $100 million dollars annually.[31] The estimate is roughly a $34,000 burden for each soldier affected by SFx.[5,33] Due in large part to their unique morbidity, FNSF cost an estimated $100,000 per recruit injured; this does not include the cost of surgical intervention, which is frequently required.[4]

TABLE II. Burdens/Losses Reported by Military Population

Military population	Burden or losses reported
U.S. military overall	• Overuse injuries: $20 billion annually[28] • SFx: $100 million annually, estimated $34,000 per SFx case[5,28,33] • SFx: 10–18 weeks of training postponement[19] • Lower extremity SFx: $4.8 million annually (rehabilitation, lost duty hours, medical discharge payments)[4]
U.S. Air Force	• FNSF: $100,000 per case (not including surgical costs)[4]
U.S. Marines	• Musculoskeletal injuries: $111 million and 356,000 duty days annually[32]
British Army	• FNSF: 3–7 months of rehabilitation on average[21,30]
Israel Defense Force	• Overuse injuries: 25 million training days annually[28]

Stress Fracture in Female Military Recruits

In recent studies internationally, female recruits demonstrate SFx incidence rates of up to 21%, 2–10 times greater than their male counterparts participating in the same activities.[19,20,25–28] Female recruits have up to a 12 times higher risk of FNSF compared to their male counterparts.[4,8,9,34]

A 2017 study analyzing SFx data in Indian military recruits also noted differences between SFx site distribution in addition to the incidence rates of 6.9% for men and 15.6% for women.[9] For female recruits, 51% of SFx were in the pelvis, 39% were in the tibia, and 9% were in the femur. For men, virtually all SFx were in the femur (92.6%). A disparity between timing of SFx diagnosis during training was also demonstrated. Female recruits were diagnosed with SFx as early as the fourth week of training, with peak incidence at weeks 8–9. SFx were diagnosed in male recruits as early as the first week of training, with peak incidence in the fourth week.[9]

The Israel Defense Force is just one of multiple military groups which has demonstrated a greater SFx risk for female recruits, up to three- or fourfold higher in recent studies.[14,28] Of note, military service is compulsory in Israel and there is a practice of gender-integrated programs having lower intensity training.[17] An Israel Defense Force study of female recruits, which demonstrated a 10% SFx incidence rate, noted that the combat training program specifically studied is not mandatory for women.[17] Women in this program may be more likely to delay presentation or to ignore symptoms due to their motivation to succeed in a higher intensity program. This may increase their risk for sustaining SFx.[17] Yanovich et al.[27] also studied Israel Defense Force recruits and demonstrated a 6.6% SFx prevalence in women in combat training; there were no SFx in male recruits or noncombatant female recruits.

It is important to identify ways to reduce the negative impact of this injury. The disparate SFx risk in female recruits presents a significant opportunity to address a high-risk population and make a substantial impact on overall burden and incidence rates. It is also imperative to prevent SFx in female recruits, as they demonstrate a 67% higher rate of discharge due to overuse injury than male recruits.[21,28]

There are a number of factors that may contribute to this discrepancy in SFx rates between men and women. These include lower body mass index and other anatomical differences such as reduced muscle mass, wider pelvis, and narrower tibiae, nutritional differences, biomechanical and gait differences, hormonal differences related to estrogen and menstruation, and comparatively lower fitness levels in women.[4,5,7,9,20,21,27] Women are also uniquely at risk for the female athlete triad, a phenomenon described as menstrual dysfunction, low energy availability with or without disordered eating, and decreased bone mineral density.[5] Risk factors for SFx in female recruits will be discussed in detail in **Part II of this series**.

CLINICAL CONSIDERATIONS

Diagnosis

Recent literature has strongly emphasized the impact of early SFx diagnosis in military recruits with screening, early magnetic resonance imaging (MRI), and higher clinical suspicion for this population. Early diagnosis reduces morbidity and complications, improving patient outcomes and decreasing military and healthcare burden significantly. As mentioned previously, female recruits, on average, are diagnosed 3 weeks later than their male counterparts,[9] a disparity with well-described consequences. Screening for SFx risk factors is of utmost importance in a patient population with large variability in fitness, anthropometrics, and past medical history. However, comprehensive screening can also result in valuable diagnoses of iron deficiency with or without anemia, the female athlete triad components, and even occult SFx prior to initiation of training, especially in recruits who have been pretraining.[6,24,27] Iron deficiency anemia can be addressed for recruits at the time of diagnosis and is associated with SFx.[24,27] The female athlete triad components can also be addressed early, especially with nutritional and psychological consultation.[6] Previous studies have demonstrated that 61% of Indian female cadets with SFx reported delayed periods or amenorrhea,[9] and women demonstrate higher prevalence of iron deficiency and anemia.[27]

Recruits typically present with SFx during training weeks 4–16[9,11,26,35] with a history of pain with exercise that can progress to pain at rest and sudden increases in pain with exercise.[6,9,11,26,36–38] In some cases, recruits delay presentation despite these symptoms and present only when symptoms are debilitating.[6,9,11] One female recruit presented after being unable to continue at the 5.5-mile mark while running downhill carrying 30 pounds, despite altered gait and pain for weeks prior.[11] Another recruit delayed presentation for 2 months because she was concerned about being able to graduate from training.[37]

Complications of late diagnosis of SFx are common and include lost training time, military separation, nonunion or delayed union requiring surgical intervention, and long-term need for rehabilitation and physical therapy.[9,11,24,35,37] Physical exam findings are nonspecific,[6,16,36,38] and the military recruit population is high risk with suddenly increased activity that should prompt a suspicion for SFx. It is imperative and a Best Practice Guideline that any recruit who presents with pain with exercise or with ambulation should receive an MRI, with cessation of activity until an MRI result is obtained.[6,11,16,24,34,38] MRI is 100% sensitive in occult fracture cases,[39] whereas x-rays are often negative or subtly positive initially[11,24,34,36] with an initial sensitivity of 10% and of 30%–70% after 3 weeks.[36] Many recent cases of delayed diagnoses were due to delayed MRI.[37] Late presentation by recruits should not be compounded by underuse of imaging to diagnose in a high-risk population.

Treatment

If SFx is confirmed with imaging, there should be cessation of any impact activities until the recruit is pain-free with ambulation[35] (Fig. 1). The indication for operative management depends on severity, grade, and location of the SFx. When conservative treatment is possible, patients may require several weeks or months until full return to activity.[6,16,19,26,37,39] The recruit should refrain from training and slowly initiate weightbearing guided by pain; physical therapy, activity modification, and pneumatic bracing are also recommended.[16,37,39] Minimal-impact activity to promote continued bone healing should be encouraged if tolerated. After 2 weeks with resolved pain, the recruit can progress to ambulation with physical therapy. This can be followed by a running progression over 3-6 weeks. Recruits should have medical follow up at least every 2 weeks, and activity should be reduced if there is pain with weightbearing.[39]

SFx on the anterior aspect of the tibial shaft demonstrate high risk for nonunion (4.6%).[6] Tibial SFx refractory to conservative management such as activity modification or physical therapy requires reamed intramedullary nailing as the gold standard operative treatment.[6] Similarly, patients with fifth metatarsal SFx who fail 6 weeks of nonoperative therapy should undergo intramedullary screw fixation.[6,38]

Tension-sided femoral neck stress injuries (FNSI) (involving the superior-lateral aspect of the neck), and compression-sided FNSI (involving the inferior aspect of the femoral neck), which are >50% of the width of the femoral neck require percutaneous placement of cannulated screws.[6] Displaced femoral neck and femoral shaft SFx require open reduction internal fixation to prevent avascular necrosis and other complications.[6] In a retrospective review of British Royal Marines recruits from 2001 to 2011, surgically indicated FNSIs required 11 months on average for union.[40]

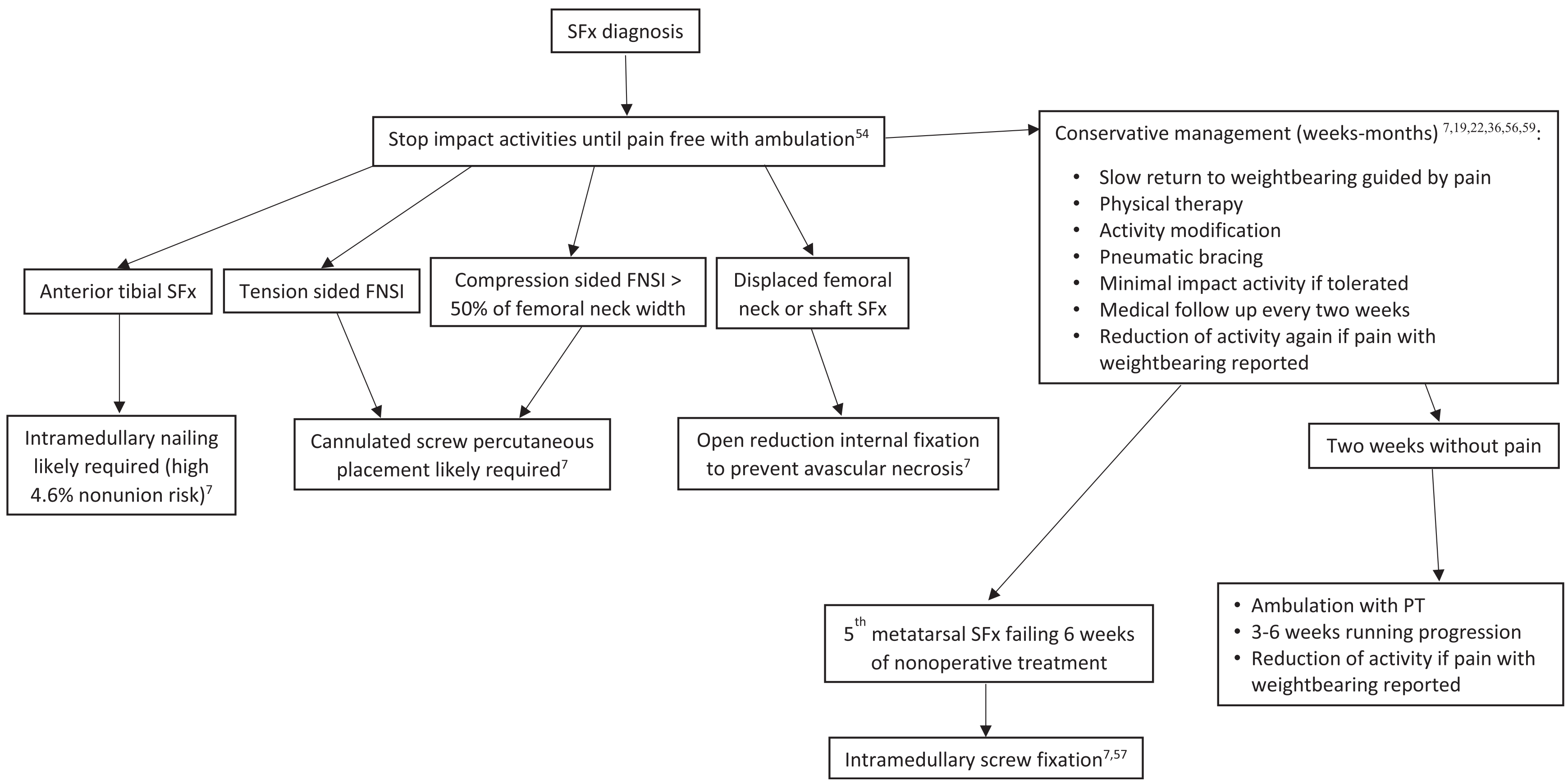

FIGURE 1. SFx treatment algorithm.

PREVENTION AND RECOMMENDATIONS

Recent literature has provided recommendations to help military recruits avoid SFx (Table III). Leadership education for those designing, modifying, or enforcing recruits' training schedules has been strongly recommended and associated with injury prevention; nonadherence to training programming, especially by adding activity time, is a commonly discussed barrier.[3,14,19,22] Recruits' training schedules should be considered as variables that can be controlled by recruits' leadership. Schedules can be adjusted based on SFx rates by cohort and feedback from recruits, physical therapists, and other members of a multidisciplinary team. It is more difficult to objectively make changes when training schedules are not adhered to or are modified inconsistently amongst different cohorts by program leadership. In 2010, Scott et al.[22] studied injury outcomes in U.S. Army recruits after implementing injury prevention interventions, including leadership education, leadership enforcement of prevention guidelines, and injury surveillance with reporting. Compared to a 2008 cohort, their group demonstrated a 50%–58% reduction in FNSI, a 57%–64% reduction in Physical Training and Rehabilitation Program referrals, and up to $5.3 million saved from FNSI reduction alone. Although it was not possible to isolate the effects of individual interventions made for this cohort, the authors concluded that the most temporally associated change was enforcement of a specific predetermined exercise program.[22] Claassen et al.[19] studied recruit data from the Army, Navy, Air Force, Marine Corps, and Coast Guard from 2003 to 2012 and similarly concluded that efforts to reduce injury contributed to a decline in SFx incidence rates by 12% from 2008 to 2012. These efforts included leadership education, discouraging the use of physical activity as punishment, and adjusting training schedules to reduce injury risk.

TABLE III. Prevention Recommendations

Recommendations for prevention	Description
Leadership education[3,14,19,22]	• Leadership design, modify, and enforce training schedules • Barriers to objective and safer programming include nonadherence to program, especially to add activity
Periodize training schedules and designing schedules with injury prevention prioritized[3,9,19,25,28,31,38]	• Resting during high-risk weeks such as weeks 3–4, with repeated intervals of rest throughout long training periods
Pretraining, gait retraining, technique training[3,18,28,31,32,38]	• Load carriage and functional movement pretraining proposed for new recruits
Screening for risk factors[1,27,32,38]	• Nutrition (especially iron, vitamin D, and calcium), injury history, menstrual history, nutrition and disordered eating history, biomechanical movements, baseline fitness, identification of anthropometric risk factors

When designing training schedules, periodization of training (with subdivisions and rest periods) and scrutinizing running and marching distance and training volume to allow adequate recovery is recommended.[3,9,25,28,31,38] Some studies recommend a week of complete rest at high-risk weeks, such as weeks 3–4, which is repeated if training is months long.[3,9] Pretraining, gait retraining, and initiating specific training interventions for technique to reduce biomechanical risk factors have also been recommended.[3,18,28,31,38] Jensen et al.[32] suggested encouraging pretraining recruits to focus on skills specific to training when pretraining, especially load carriage and functional movements.

Finally, there are many screening opportunities for secondary injury prevention: laboratory screening for anemia and nutritional deficiencies such as iron, vitamin D, and calcium with supplementation when indicated; questionnaire screening for injury history, menstrual history, and nutritional and disordered eating; biomechanical movement screening; baseline fitness level assessment including currently implemented tests such as the step test or the Occupational Physical Assessment Test; and identification of anthropometric risk factors.[27,32,38] Further research for quantifying multifactorial risk would allow military leadership to objectively assess the need for modifications in programming. In 2012, Moran et al.[1] created a multifactorial risk identification and prediction model for SFx in Israel Defense Force recruits. Their final simplified model of 3 variables predicted SFx development in 76.5-85% of new recruits. The variables utilized as highly predictive yet simple to monitor were aerobic training frequency and duration during training and waist circumference. These can be assessed prior to training as well as throughout training and were significantly associated with SFx occurrence.[1] Models like this and risk factor identification can allow a higher index of suspicion and more conservatism with respect to nutritional supplementation, program intensity, individualization, and medical management.

CONCLUSIONS

SFx represent a significant overuse injury that is well-described in the literature for athletes. Military recruits are at high risk for this overuse injury given the need to significantly increase their activity levels to become fitter in a relatively short period of time. Female military recruits are even more vulnerable and demonstrate a disproportionately high-risk subpopulation. Reducing SFx rates for female recruits and for recruits can result in improvements in unit capabilities, militaries' financial burdens, and, most importantly, recruit outcomes.

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