[Primary Care]

Improving Diagnostic Accuracy and Efficiency of Suspected Bone Stress Injuries: Algorithm and Clinical Prediction Rule

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Context: Lower extremity stress fractures among athletes and military recruits cause significant morbidity, fiscal costs, and time lost from sport or training. During fiscal years (FY) 2012 to 2014, 1218 US Air Force trainees at Joint Base San Antonio–Lackland, Texas, were diagnosed with stress fracture(s). Diagnosis relied heavily on bone scans, often very early in clinical course and often in preference to magnetic resonance imaging (MRI), highlighting the need for an evidence-based algorithm for stress injury diagnosis and initial management.

Evidence Acquisition: To guide creation of an evidence-based algorithm, a literature review was conducted followed by analysis of local data. Relevant articles published between 1995 and 2015 were identified and reviewed on PubMed using search terms *stress fracture, stress injury, stress fracture imaging*, and *stress fracture treatment*. Subsequently, charts were reviewed for all Air Force trainees diagnosed with 1 or more stress injury in their outpatient medical record in FY 2014.

Study Design: Clinical review.

Level of Evidence: Level 4.

Results: In FY 2014, 414 trainees received a bone scan and an eventual diagnosis of stress fracture. Of these scans, 66.4% demonstrated a stress fracture in the symptomatic location only, 21.0% revealed stress fractures in both symptomatic and asymptomatic locations, and 5.8% were negative in the symptomatic location but did reveal stress fracture(s) in asymptomatic locations. Twenty-one percent (18/85) of MRIs performed a mean 6 days (range, 0- 21 days) after a positive bone scan did not demonstrate any stress fracture.

Conclusion: Bone stress injuries in military training environments are common, costly, and challenging to diagnose. MRI should be the imaging study of choice, after plain radiography, in those individuals meeting criteria for further workup.

Keywords: stress fracture; algorithm; clinical prediction rule; military; MRI

Stress fractures are extraordinarily common among trainees and present a fiscal and operational challenge in all branches of the US military.[10,11,22,24,30] At Joint Base San Antonio (JBSA), Lackland, Texas—the site of all US Air Force basic military training (BMT) and several technical skills training (TST) courses—the incidence of stress fractures increased 56% from fiscal year (FY) 2012 to 2014. This increased incidence, coupled with concern for missing a stress fracture, led to a high index of suspicion among healthcare providers in the Trainee Health Clinic, who frequently ordered nuclear scintigraphy (ie, bone scan) to evaluate suspected stress fractures. Many of these bone scans demonstrated positive findings in clinically asymptomatic regions remote from the presenting complaint, further increasing the incidence rate. The apparent surveillance

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bias and overdiagnosis rate associated with nuclear scintigraphy suggested the need for a standardized diagnostic algorithm to balance prevention of poor outcomes—most importantly, displaced stress fractures—with overly aggressive workups and overtreatment of clinically asymptomatic hot spots that result in substantial lost training time and treatment costs.[13]

The purpose of this study was to review recent stress injury epidemiology and, in light of this information, to evaluate various imaging modalities in a military training environment. The secondary purpose was to present a novel clinical prediction rule and algorithm for the diagnosis and initial management of bone stress injury.

STRESS FRACTURE EPIDEMIOLOGY IN MILITARY TRAINING

Literature Review

The cumulative incidence of lower extremity stress fractures during entry-level military training ranges from 0.8% to 6.9% for men and 3.4% to 21.0% for women,[10,15] with the tibia being the predominant site.[6,10,22] Stress fracture incidence among recruits in the uniformed services of the United States (43.8 per 1000 person-years) is 18 times higher than among active component service members (2.4 per 1000 person-years).[17]

In addition to the clinical symptoms suffered by individual trainees, lower extremity stress fractures significantly impair military readiness in terms of medical costs, lost training time, medical attrition during training, and early medical discharge prior to completing the term of enlistment.[29] Although it is difficult to pinpoint the average cost of a single stress fracture in basic military training, the total cost of all stress fractures in Air Force BMT in 2009 was reported at more than $4.8 million.[16] Femoral neck stress fractures are arguably the most devastating; while representing only 2% to 10% of bone stress injuries during initial military training, they often require surgical fixation and result in direct and indirect costs of approximately $100,000 per case,[16,24] not including ongoing disability benefits.

As the US population has become progressively sedentary, the average physical fitness level of incoming military recruits has declined.[9] Graduation requirements have not changed, however, so training commanders and instructors must surmount a greater fitness deficit in the same limited amount of time, 8 weeks, in the Air Force. It is challenging to accomplish this safely, as both poor baseline fitness and rapid increases in running mileage are known risk factors for stress fracture.

Lackland Basic and Technical Training

Stress fracture cases during Air Force BMT and TST at JBSA-Lackland were ascertained from the disease and nonbattle injury database. This database, managed by the local trainee health surveillance unit, includes all trainee medical encounters that are recorded in the Armed Forces Health Longitudinal Technology Application, the electronic health record of the Military Health System (MHS). The database was queried for International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) diagnostic codes of 733.10, 733.19, and 733.93-733.98 from October 1, 2011 through September 30, 2014 (FYs 2012-2014). Trainees were considered an incident case only once during the surveillance period. To avoid duplicative counting, which might falsely inflate the data, if an individual trainee had stress fractures in multiple locations, they were still considered as a single incident case. Therefore, our data represent the number of individuals affected, not the number of bones affected.

A total of 1218 Air Force trainees were diagnosed with 1 or more stress fracture during the 3-year surveillance period, for a cumulative incidence of 0.95%, lower than concurrent rates at other training locations such as Fort Jackson, South Carolina (Table 1).[15,30] The rate among basic military trainees (1.0%) exceeded that among technical skills trainees (0.75%), and the rate among women (1.65%) was more than double that among men (0.76%), consistent with other published data.[30] The rate increased over time, from 0.75% (FY 2012) to 0.98% (FY 2013) to 1.17% (FY 2014) (Table 1).

IMAGING-SUSPECTED BONE STRESS INJURIES

Literature Review

Plain radiographs are highly specific (88%-96%) but are not sensitive (12%-56%) for initial diagnosis of bone stress injury.[3,32] Radiographs may be initially negative in 60% to 82% of cases and remain negative in 46% to 60%. Nonetheless, plain radiographs are the initial imaging modality of choice as they are inexpensive, exclude other diagnoses, may obviate the need for further imaging if the findings are conclusive, and may aid in the interpretation of advanced imaging.[3,10] Plain radiographs most often become positive late in the course of a stress injury (weeks to months after symptom onset), often showing callus formation and bony remodeling during stress fracture healing.[2]

Nuclear scintigraphy (bone scan) is a highly sensitive tool for detecting nascent stress injuries.[7,26] In this imaging modality, a camera detects particles emitted by the radiotracer, typically technetium-99m-methylene diphosphonate (^{99m}Tc-MDP), thus indicating "hot" areas of increased bone cellular metabolic activity.[28] Since many conditions may cause focally increased radiotracer uptake (such as tumor, infection, inflammation, or trauma), bone scan has limited specificity for stress fractures. Consequently, supplemental imaging with MRI or noncontrast computed tomography (CT) may be necessary to rule out false positives and arrive at a conclusive diagnosis.[3] In addition to the low specificity, bone scan is time consuming. A 3-phase bone scan takes approximately 3 to 4 hours to complete. When accounting for transit and wait times, a full day of training time may be lost for the trainee and his or her wingman (ie, a fellow trainee who must accompany the injured trainee for accountability purposes). Furthermore, with an effective dose of 6.3 mSv (compare with 0.005 mSv for a knee radiograph or 7.9 mSv for a standard abdomen CT),[18,21] a ^{99m}Tc-MDP bone scan imparts significant radiation exposure to the patient. Given these limitations, bone scans should be ordered prudently and

Table 1. Counts and cumulative incidence rates of stress fracture by fiscal year, training type, and sex, Joint Base San Antonio–Lackland, 2012-2014

	FY 2012		FY 2013		FY 2014		FY 2012-2014	
	n	%	n	%	n	%	n	%
Basic training								
Men	155	0.52	217	0.82	248	1.01	620	0.77
Women	122	1.61	120	1.66	168	2.38	410	1.87
Total	277	0.74	337	1.00	416	1.32	1030	1.00
Technical training								
Men	51	0.73	57	0.89	34	0.58	142	0.74
Women	20	0.99	17	0.90	9	0.50	46	0.81
Total	71	0.78	74	0.89	43	0.56	188	0.75
All training								
Men	206	0.56	274	0.83	282	0.93	762	0.76
Women	142	1.48	137	1.50	177	2.00	456	1.65
Total	348	0.75	411	0.98	459	1.17	1218	0.95

FY, fiscal year.

must be interpreted in close correlation with the patient's clinical history, examination, and plain radiographs.

MRI is considered the test of choice for early diagnosis of stress fracture.[3,32] It is more sensitive and specific than bone scan[19,32] and may identify bone stress injuries early in the pathologic spectrum. Periosteal edema, the earliest macroscopic change associated with stress injury, is visible on MRI within approximately 1 to 3 days of onset of pain.[18,26] Along with providing a relatively detailed evaluation of regional bone morphology and soft tissues, MRI allows for early detection, grading and precise localization of stress fractures.[5,12,13,26,27] Important management decisions with high-risk stress fractures, including surgical options, often rely on this information. In a study comparing MRI and bone scan for identifying early tibial stress injuries, using a reference standard of history and physical examination by experienced sports medicine physicians, the authors found sensitivities of 88% and 74%, respectively.[7]

In contrast to bone scan and MRI, CT is largely unable to demonstrate bone turnover or periosteal/bone marrow edema patterns, which limits its utility for early diagnosis of stress fractures. It is useful, however, in distinguishing between an osteoid osteoma and a stress fracture.[26]

Lackland Basic Military and Technical Skills Training

Chart review was performed on 459 individuals with stress fracture diagnoses that occurred during FY 2014. The imaging modalities used to diagnose these fractures varied: plain films only (n = 18); plain films and bone scan (n = 325); plain films and MRI (n = 25); plain films, bone scan, and MRI (n = 85); and plain films, bone scan, and CT scan (n = 4).

By querying the Military Health System Management Analysis and Reporting Tool (M2) database, it was determined that 1071 bone scans were performed on trainees in FY 2014. Among all trainees diagnosed with a stress fracture in FY 2014 and who had a bone scan (n = 414), 66.4% were positive for stress fracture only in the symptomatic location, 21.0% were positive for stress fractures in both symptomatic and asymptomatic locations, and 5.8% were negative for stress fracture in the symptomatic location but positive in 1 or more asymptomatic locations. Twenty-one percent of bone scans required further imaging—typically plain films to rule out additional pathology in unanticipated sites. Twenty-one percent of MRIs after a positive bone scan (18/85) did not demonstrate any stress fracture when performed a mean 6 days (range, 0-21 days) after the bone scan.

NEW DIAGNOSTIC ALGORITHM

Rationale

The epidemiology and clinical challenges associated with bone stress injuries in military training indicated the need for an updated algorithm to improve the timeliness and accuracy of diagnosis and treatment. Many existing algorithms for

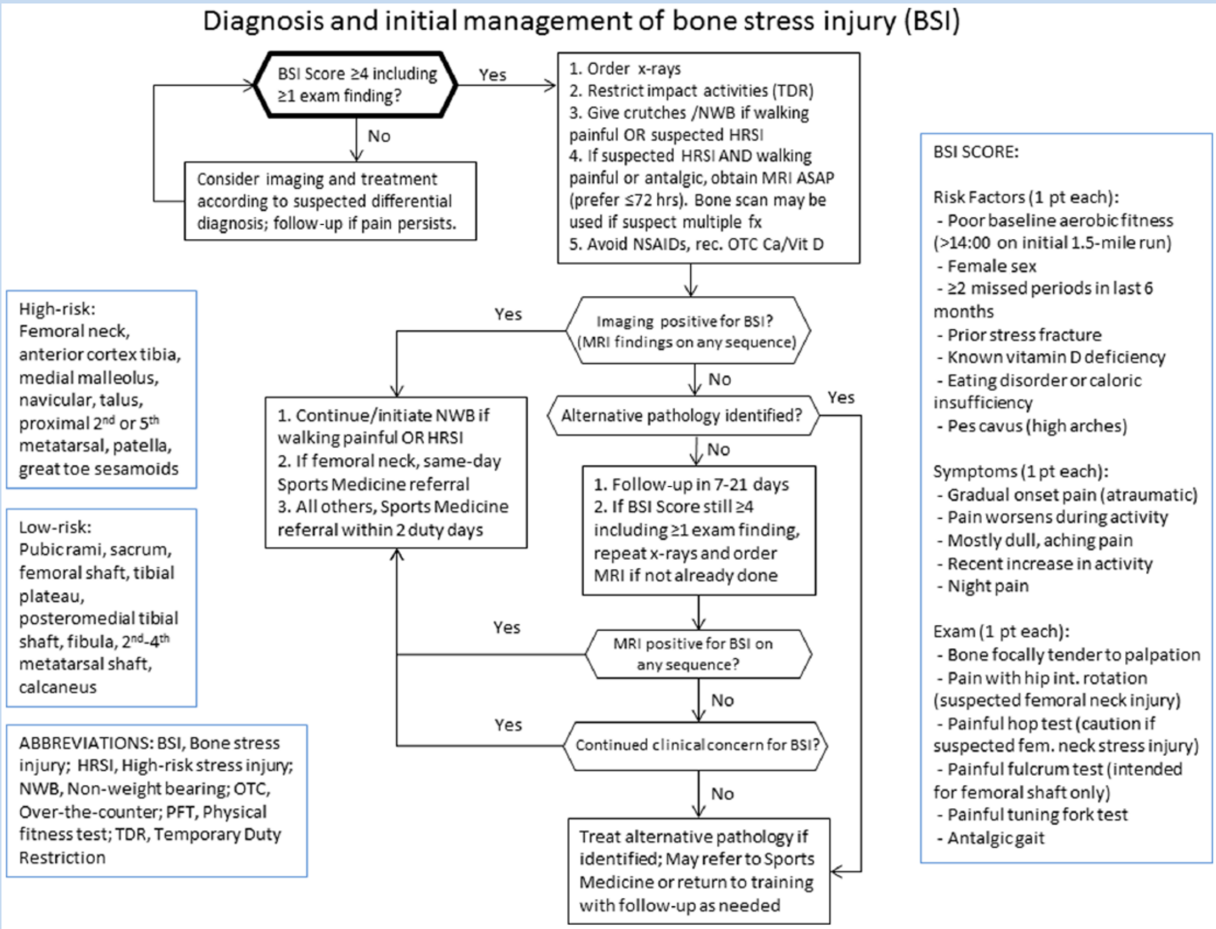

Figure 1. Stress injury algorithm.

evaluation[23,24,32] and treatment[13] of stress fractures do not contain clinical prediction rules and/or rely primarily on bone scan. Of note, a recently published algorithm by Wright et al[32] is useful for the selection of proper imaging modalities but neither does it offer guidance on a threshold for beginning a diagnostic workup nor does it guide initial treatment steps. Furthermore, new radiologic strategies involving MRI for grading injury severity and predicting return-to-sport time have become available.[4,14,19]

The importance of early diagnosis of a stress fracture is well established. Among young athletes who sustained a stress fracture, those who were diagnosed within 3 weeks of symptom onset returned to play in a mean of 10.4 weeks compared with 18.4 weeks for those diagnosed after 3 weeks.[20] Models for predicting rehabilitation time and return date, which have been described in the context of collegiate and professional sports,[4,19] would likely have a profound impact on military readiness if found to be applicable in military training environments.

Algorithm

Our algorithm (Figure 1) is based on 3 principles derived from the medical literature and from the epidemiology presented in this article.

First, and most importantly, MRI is recommended over bone scan in almost all cases that require advanced imaging. This change reduces radiation exposure, false positives, overdiagnosis (ie, identifying stress changes in asymptomatic sites due to bone scans imaging the entire lower half of the body regardless of location of symptoms), and time lost from training. Not only is an MRI examination itself less time-consuming, but in our setting, it involves less transit time. Switching from bone scan to MRI as the default advanced imaging modality is expected to save approximately 11,000 person-hours per year of lost training time at JBSA-Lackland (2 hours per MRI vs 7 hours per bone scan for the patient and wingman). Furthermore, switching to MRI reduces the unnecessary treatment and activity restrictions from positive bone scan results in areas where the patient has no clinical symptoms or examination findings. In light of the high existing demand on the MRI scanner, it was critical to create an abbreviated scanning protocol specifically for stress fractures, as well as to educate trainee health providers on the appropriate use of MRI. To clarify, this limited MRI protocol was implemented in December 2014 in light of the aforementioned analysis; the data described above are retrospective and include only full-sequence MRI scans. The stress fracture MRI protocol involves only T1 and short tau inversion recovery (STIR) or proton density fat suppression (PDFS) sequences in only 2 planes (typically axial and coronal) and can be completed in 5 to 10 minutes of scan time. Previous studies utilizing limited MRI protocols in the evaluation of suspected stress injuries have shown this method to be successful and reliable.[25,31] In our institution, a full MRI protocol is recommended over a limited study if (1) the patient has already undergone another bone stress injury screening procedure such as bone scan, (2) the screening MRI suggests pathology (such as tumor) that requires more detailed evaluation, or (3) initial symptoms and examinations suggest pathology other than bone stress injury. Of note, bone scan is considered optional (versus multiple MRIs) when clinicians suspect stress injuries in multiple locations.

Second, in cases of suspected low-risk stress injury, any decision regarding advanced imaging is delayed at least a few days while relative rest is implemented.[32] This “triage by time” technique is designed to allow those with less significant injuries (eg, delayed-onset muscle soreness or foot pain from ill-fitting boots) to avoid unnecessary imaging. Instead, plain films are ordered at the first visit, and MRI is ordered at the 4- to 7-day follow-up visit if the presentation is still suggestive of stress fracture. A longer period (2-3 weeks) between follow-up for suspected low-risk stress injuries is clinically acceptable, but many scenarios such as competitive sports and military training environments often require an expeditious, definitive diagnosis. Those with suspected stress injuries in high-risk locations but who can ambulate without pain are also evaluated initially with plain radiographs, delaying decision for MRI until follow-up. In contrast, patients with suspected high-risk stress fractures whose gait is antalgic or painful are referred for MRI within 72 hours.[1]

Third, a clinical prediction rule was incorporated to codify and standardize an appropriate clinical threshold for pursuing an evaluation for bone stress injury. Our system requires a total score of ≥4, including at least 1 positive physical examination finding, as the minimum threshold for working up a possible stress fracture. This threshold was determined by consensus among sports medicine physicians, orthopaedic surgery and family medicine faculty, and a musculoskeletal radiologist—all of whom recognized the need to translate expert opinion into scientific evidence by validating the clinical prediction rule with prospective data.

Important treatment principles incorporated into the algorithm include the avoidance of nonsteroidal anti-inflammatory medications for pain control, as these may impair bone healing,[8] and the proper distribution of crutches (specifically by helping less-experienced clinicians avoid ordering crutches in low-risk stress injuries when walking is not painful or antalgic).

CONCLUSION

Bone stress injuries in military training environments are common, costly, and challenging to diagnose. The clinical prediction rule and algorithm described in this article incorporate current medical evidence and local epidemiologic data. MRI should be the modality of choice in the vast majority of patients meeting criteria for advanced imaging, with routine timing (4-7 days) when low-risk stress injury is suspected.

Clinical Recommendations

SORT: Strength of Recommendation Taxonomy
A: consistent, good-quality patient-oriented evidence
B: inconsistent or limited-quality patient-oriented evidence
C: consensus, disease-oriented evidence, usual practice, expert opinion, or case series

Clinical Recommendation	SORT Evidence Rating
Plain radiographs should be used as initial imaging in all cases of suspected bone stress injury.[3,32]	A
When advanced imaging is indicated for evaluation of a suspected bone stress injury, magnetic resonance imaging should be used (rather than bone scan) with rare exception.[3,4,19,32]	A
Though presumptive treatment begins at the first appointment, the decision to order advanced imaging is generally delayed until a follow-up visit for suspected low-risk stress injuries.[3,32]	C

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