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Stress Injuries to Bone in College Athletes

A Retrospective Review of Experience at a Single Institution*

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Background: No comprehensive studies have been published on stress injuries to bone in college athletes.
Purpose: To review, in a college athlete population, the epidemiologic aspects of stress injuries to bone, and to examine a subset of patients who were treated with a uniform protocol for return to activities, with magnetic resonance imaging as the primary tool for diagnosis.
Study Type: Retrospective review.
Methods: Ten years of medical records from a Division I college institution were reviewed. Location and grade of stress injury to bone and duration of disability were recorded. All injured athletes followed the same treatment program, with the exception of football players, who were excluded from the return to sport analyses.
Results: Seventy-four athletes had lower extremity symptoms consistent with stress injury to bone. Diagnosis was confirmed in 68 of these athletes, 61 via magnetic resonance imaging, 6 via positive radiographs only, and 1 via bone scan only. Distance runners accounted for the most stress injuries to bone for both men and women. The tibia (37%) was the most frequently involved bone; however, as an anatomic region, the foot (44%) was the site of the most stress injuries. There was a significant correlation between grade of injury and time to full return to activity.
Conclusions: The grading system used at this institution is a standardized tool that can be used to predict time to return to sport. A standardized rehabilitation protocol allowed for an appropriate plan to return the athletes to pain-free competition.

Stress injuries to bone are a common overuse injury in athletes. One study reports that stress injuries to bone may account for up to 15% of all athletic injuries.[7] Among runners, stress fractures may be responsible for 15.6% to 20% of all musculoskeletal running injuries.[7,10] Retrospective studies show incidence rates in athletes of between 1.9% to 37%.[4,18,20] Various prospective studies on track and field athletes report incidence rates of 3.7% to 21.1%.[7,20,28]

Previous research in athletes has suggested that stress injuries to bone vary in incidence and location depending on the sport.[5,7,9,16,19] Research has also shown that women have a higher incidence of stress injuries to bone than men.[5,27] Only one previous study recorded the time gap between the onset of symptoms and the length of time to diagnosis in addition to time to sport return.[3]

A major limiting factor of early studies was dependence on plain radiographs for confirmation of stress fracture. Plain radiographs are initially negative in up to two-thirds of patients.[19] Radiographically, a stress fracture is not identified until the lesion has progressed to an intracortical injury with extension to the periosteum, resulting in periosteal changes or gross cortical bone failure, or both.[2] Roub et al.[31] used scintigraphy to demonstrate increased isotope uptake in symptomatic sites of 20% to 40% of patients without plain radiographic correlation. Thus, stress fractures that were not detectable on plain radiographs could be confirmed by scintigraphy.

Current research has benefited by the increased recognition that stress fracture is the end result of a continuum of biologic response to stress placed on bone. The availability of diagnostic modalities such as scintigraphy and

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MRI has also been beneficial. Scintigraphy and MRI can be used to diagnose a stress injury to bone before it has progressed to an advanced state in which the healing response of bone can be seen on plain radiographs.

We review here a 10-year history of Division I college athletes from a single institution who were seen by the athletic training department staff with symptoms consistent with lower extremity stress injury to bone. For this study, stress injury to bone was defined as pain in the lower extremity with weightbearing, with imaging studies revealing positive injury to bone. To the best of our knowledge, there have been no studies of this population and injury type that have examined sex differences, trends in injury location, time to return to sport, or that have used MRI as the primary diagnostic tool. This descriptive retrospective review is divided into two parts. The first part reviews the epidemiologic aspects of stress injuries to bone by sex, sport, and location of stress injury to bone. The second part examines a subset of patients who were treated with a uniform protocol for return to activities, with MRI being the primary tool for diagnosing stress injury to bone.

MATERIALS AND METHODS

Medical records from the physicians' office and training room were retrospectively reviewed for the 10-year period from September 1990 through June 2000. Athletes eligible for inclusion in this study were identified by reviewing a radiographic log of all athletes who underwent an MRI protocol for stress fracture. To ensure that all appropriate athletes were identified, we performed a double check by reviewing 1) the Sports Injury Monitoring System (SIMS) injury surveillance recording system, which is a method of injury surveillance used by this institution's certified athletic trainers; and 2) the senior clinician's personal log, which identified patients with a diagnosis of stress injury to bone. Our study population represented athletes who came to the athletic trainer and team physician during their competitive season with lower extremity pain consistent with the diagnosis of stress injury to bone. The athletic training room guidelines for athletes with lower extremity overuse pain during the off-season instructed that the athlete rest in the initial stage; radiography to confirm the diagnosis was not performed unless the pain did not resolve.

Over this 10-year period, approximately 6000 athletes were involved in intercollegiate athletics at the University of Minnesota. Tables 1 and 2 identify the sports offered by sex and the years these sports were offered at this institution. There were approximately 3610 male athletes and 2248 female athletes in the overall study group. The removal of the football athletes (who were included in the epidemiology study but not in the return to activity) from this population leaves only 2510 male athletes, making the two groups somewhat equivalent.

Stress injuries to bone were categorized by sex, sport, location of injury, and training variables. For purposes of this review, the team sports of cross-country and track and field are divided into two groups based on their train-

TABLE 1
Number of Female Athletes in the Study Population by Sport and Incidence of Stress Injury to Bone

Sport	Athletes per year[a]	Years	Total athletes	% of athletes with stress injury to bone
Basketball	14	1990-1999	140	3.57
Golf	14	1990-1999	140	0
Gymnastics	14	1990-1999	140	4.29
Ice hockey	21	1997-1999	63	0
Softball	23	1990-1999	230	1.14
Tennis	12	1990-1999	120	0.83
Swimming	41	1990-1999	410	0
Cross-country	25	1990-1999	250	6.4
Track and field	58	1990-1999	580	1.55
Soccer	25	1993-1999	175	2.29

[a] Approximate number.

TABLE 2
Number of Male Athletes in the Study Population by Sport and Incidence of Stress Injury to Bone

Sport	Athletes per year[a]	Years	Total athletes	% of athletes with stress injury to bone
Baseball	36	1990-1999	360	0.28
Basketball	14	1990-1999	140	2.86
Golf	15	1990-1999	150	0
Gymnastics	10	1990-1999	100	3
Ice hockey	29	1990-1999	290	2.07
Tennis	11	1990-1999	110	0
Swimming	35	1990-1999	350	0
Cross-country	18	1990-1999	180	3.89
Track and field	53	1990-1999	530	0.75
Football	110	1990-1999	1100	0.27
Wrestling	30	1990-1999	300	0

[a] Approximate number.

TABLE 3
Radiographic Grading of Stress Injuries to Bone

Grade	Radiograph findings	MRI findings
Normal	Normal	Normal
1	Normal	Positive STIR image
2	Normal	Positive STIR, plus positive T2-weighted
3	Periosteal reaction	Positive T1- and T2-weighted, STIR without definite cortical break visualized
4	Injury or periosteal reaction	Positive injury line on T1- or T2-weighted scans

TABLE 4
Rehabilitation Protocol for Athletes With Stress Injury

Phase	Activity
I	Nonweightbearing or crutches
	Swimming
	Flotation-running
	Biking if pain-free
II	Nonpounding upright activities such as Stairmaster, NordicTrack
	Lower extremity weight training, including free weights
III	Sport-specific drills
	Sports play with limited minutes
IV	Full activities, no restrictions

ing. The category of distance runners includes the cross-country runners and the distance track runners (800 meters or greater). The track and field category includes the remaining runners (middle distance and sprinters) and all field event athletes. Location of stress injury to bone was obtained from plain radiographs, bone scan, or MRI, or a combination of these. For purposes of analysis, stress injuries to bone were grouped into one of the following categories: femur, tibia, fibula, navicular bone, calcaneus, and forefoot (metatarsal bones and phalanx). We were able to track two changes in training regimen. The first was whether the athlete sustained an injury during the freshman year or during the first year at our institution (transfer student); the second was whether the stress injury to bone occurred during the first year of a coaching change. Coaching change was defined as a change in the head coach or individual event coaches (distance coach, sprint coach) for the track and field athletes.

A confirmed diagnosis of stress injury to bone was made by a positive finding on radiographic films, bone scan, or MRI. Positive stress injuries to bone diagnosed by MRI were graded according to a rating system used at our institution since 1988. The early MRI sequences for viewing marrow edema have evolved from use of fat-suppression sequences to the use of the short T1 inversion recovery (STIR) sequence. Since 1990, the first image sequence of the MRI sequence has been the STIR sequence. Our MRI grading system, which has been published,[2,3] follows the four grades of scintigraphic imaging described by Roub et al.[31] (Table 3). Our grading system is similar to the only other published MRI grading system, that of Fredericson et al.,[17] with the exception that we define grade 1 as a positive signal change on STIR sequence, whereas Fredericson and coauthors described grade 1 as the presence of periosteal edema on T2-weighted images.

Treatment of Stress Injuries to Bone

All athletes, with the exception of football players, were treated according to the same four-phase treatment plan outlined in Table 4. Our treatment program involves reducing activity to a pain-free level but not advocating total rest. If the patient is symptomatic with weightbearing activities, he or she is placed on crutches. Rest or modified rest with elimination of the offending activity is paramount. Any activity that can be performed without pain is allowed. A typical program for patients with lower extremity stress injuries to bone involves cycling, swimming, and flotation-running in a pool. This was designated as phase I. A trial of walking took place every 2nd day. If the patient was pain-free, full ambulation without crutches was begun. If pain returned at any point in the program, we reinstituted the earlier phase of the program.

Phase II of the program began once there was pain-free walking for 3 to 5 days. Phase II consisted of weightbearing activities conducted in a nonpounding fashion. This included the use of Stairmaster (The Nautilus Group, Vancouver, Washington), NordicTrack (Logan, Utah), and other exercise equipment that allowed aerobic conditioning while weightbearing in a nonpounding fashion. Our phase II program also included sport-specific muscle rehabilitation, maintenance of aerobic endurance, and correction of any muscle imbalance or training error that was thought to have contributed to the initial injury.

When phase II could be completed in a pain-free manner for 3 to 5 days, phase III was begun. Phase III consisted of gradual reentry into sport-specific activity; this was initially done on alternate days. The patient performed the sport-specific activity by using onset of pain as a guide for activity cessation, with pain rigidly defined as any discomfort felt in the area of the original stress injury to bone. Phase III, at times, involved very brief episodes of sport activity. When a team activity was involved, sometimes as little as 2 or 3 minutes of basketball play was permitted before the athlete rested. Time of sport activity was incrementally increased. Phase IV was unrestricted sports activity without pain or time modification.

The certified athletic trainer and team physician managed each athlete's progression through these four phases. All progressions were documented in training room notes and were available for review.

Time to return to sport was obtained from the training room chart. Both full return and return with activity modification was charted. Full return was defined as the ability of an athlete to practice and compete without time restrictions and without relapse. Return with activity modification was defined as a return to varsity sport but with participation on a limited basis. The restrictions included reduction in practice time in addition to participation only in selected drills. The endpoint for each athlete was a return to full activity or the end of their competitive season. Athletes whose injuries prevented them from returning to their competitive season because of the timing of their injury were still followed up by the medical team until they were pain-free; injured athletes were typically prescribed rest postseason. All graduating seniors completed an exit evaluation with the university medical staff, as dictated by university policy. Time to diagnosis was defined as time between athlete's first report of pain to the certified athletic trainer and diagnosis by radiographic testing. Compliance with our program was mandatory for continued team participation. Because athletes are monitored on a daily or near-daily basis during the sport season, compliance was very high.

To see if there was a relationship between the grade of stress injury to bone and the time to return to full activity, we performed a Pearson correlation analysis. To determine whether there was a significant relationship among the four different grades of stress injuries to bone and the mean time for return to full activity, we performed a one-way analysis of variance with post hoc Bonferroni and Scheffé corrections.

RESULTS

Our data represent an approximate denominator of 6000 athletes and shows a 10-year incidence of 1% stress injuries to bone. Among the female athletes, the rate of stress injury to bone was approximately 1.9%; among the male athletes, the rate was approximately 0.8% (1.1% when football is excluded). A total of 3.2% of track and distance runners sustained stress injuries to bone.

Seventy-four athletes with symptoms consistent with lower extremity stress injury to bone were seen by our medical staff during the sport season. Six of the 74 athletes had negative MRI scans and were excluded from this study. Of the 68 athletes who had a confirmed diagnosis of lower extremity stress injury to bone, 26 were male (38%) and 42 were female (62%). Three athletes (1 woman and 2 men) had two stress injuries to bone during the course of this review. Thus, there was a total of 71 lower extremity stress injuries to bone. All of the second stress injuries to bone in these three athletes were in different bones, with a range of 5 to 12 months separating the injuries and with a full return to activity between injuries. Table 5 shows the distribution of stress injuries to bone by sex, sport, and location.

For female athletes, stress injury to bone occurred most often in distance running. Distance running was followed in injury frequency by gymnastics, basketball, soccer, track and field, softball, and tennis. No female athletes reported stress injuries to bone in ice hockey, golf, volleyball, or swimming (see Table 1). For male athletes, stress injuries to bone occurred most often in distance running, which was followed in injury frequency by gymnastics, basketball, ice hockey, track and field, baseball, and football (see Table 2). No male athletes reported stress injuries to bone in golf, swimming and diving, tennis, or wrestling. All stress injuries to bone in ice hockey players were sustained after the institution of new and significant off-ice (land) workouts.

Certain trends in anatomic location of stress injuries to bone were identified. Five of the seven stress injuries to the femur occurred in distance runners. Six of the 13 stress injuries to the navicular bone occurred in the explosive sports of track and gymnastics, both of which involve a power take-off. The tibia was the single bone with the highest number of stress injuries (37%, 26 of 71); however, the foot, as an anatomic area, accounted for an even greater number of stress injuries. In this series, 44% of all stress injuries to bone in the lower extremity (31 of 71) occurred in the foot. The metatarsal (16) and the navicular (13) bones were the most commonly involved.

Of the 68 athletes with stress injuries to bone, 61 diagnoses were made and graded by MRI (6 by radiographs only and 1 by bone scan only). Of the 61 stress injuries diagnosed by MRI, 20 were grade 1 (33%), 9 were grade 2

TABLE 5
Crosstabulation of Sport, Stress Fracture Location, and Sex

Sport	Stress fracture location						Total
	Calcaneus	Femur	Fibula	Forefoot	Navicular	Tibia	
Men							
Baseball				1			1
Basketball				4			4
Distance runner		2		2	2	1	7
Football			1	1	1		3
Gymnastics			1		2		3
Ice hockey			1			5	6
Track				2		2	4
Total		2	3	10	5	8	28
Women							
Basketball						5	5
Distance runner		3		3	3	7	16
Gymnastics	1		2			3	6
Soccer			2	1		1	4
Softball		1			1		2
Tennis						1	1
Track		1		3	4	1	9
Total	1	5	4	7	8	18	43

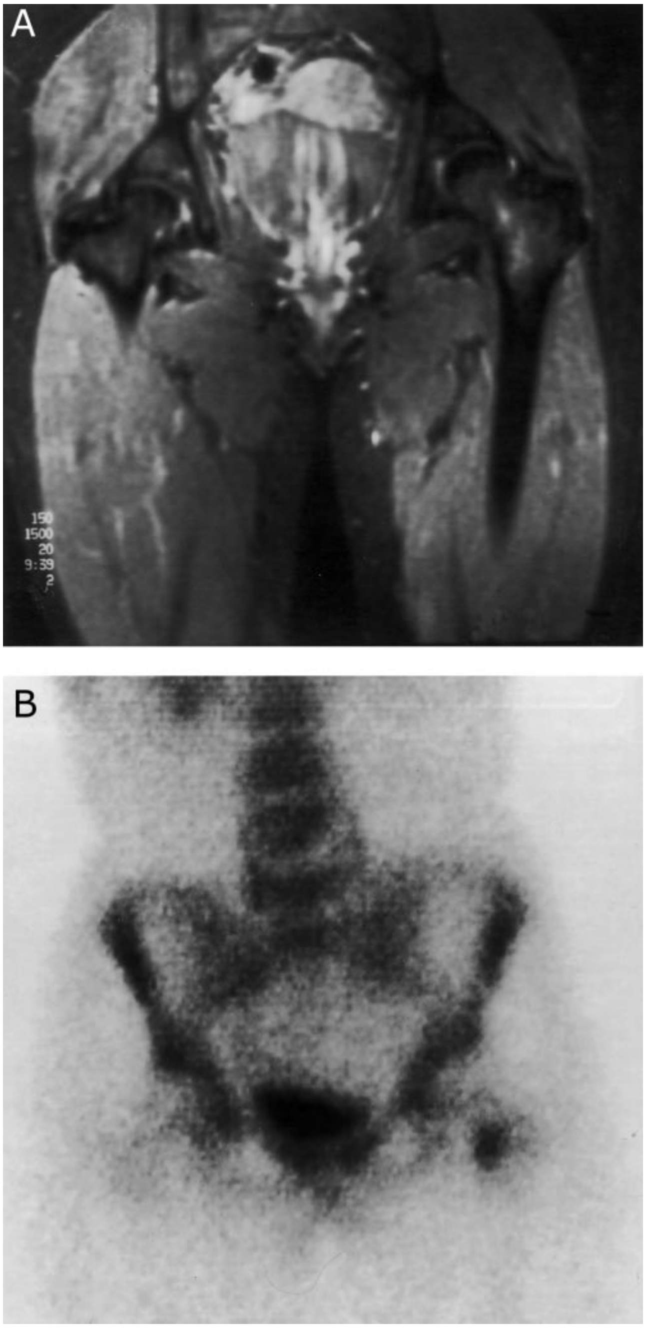

Figure 1. A, this coronal STIR image of the proximal femur demonstrates increased signal in the medial aspect of the left femoral neck and intertrochanteric regions. The T2- and T1-weighted images were negative. This represents a grade 1 signal change. B, anterior image of a whole-body bone scan demonstrating focal radiotracer uptake in the left proximal femur corresponding to the abnormal signal on the MRI scan.

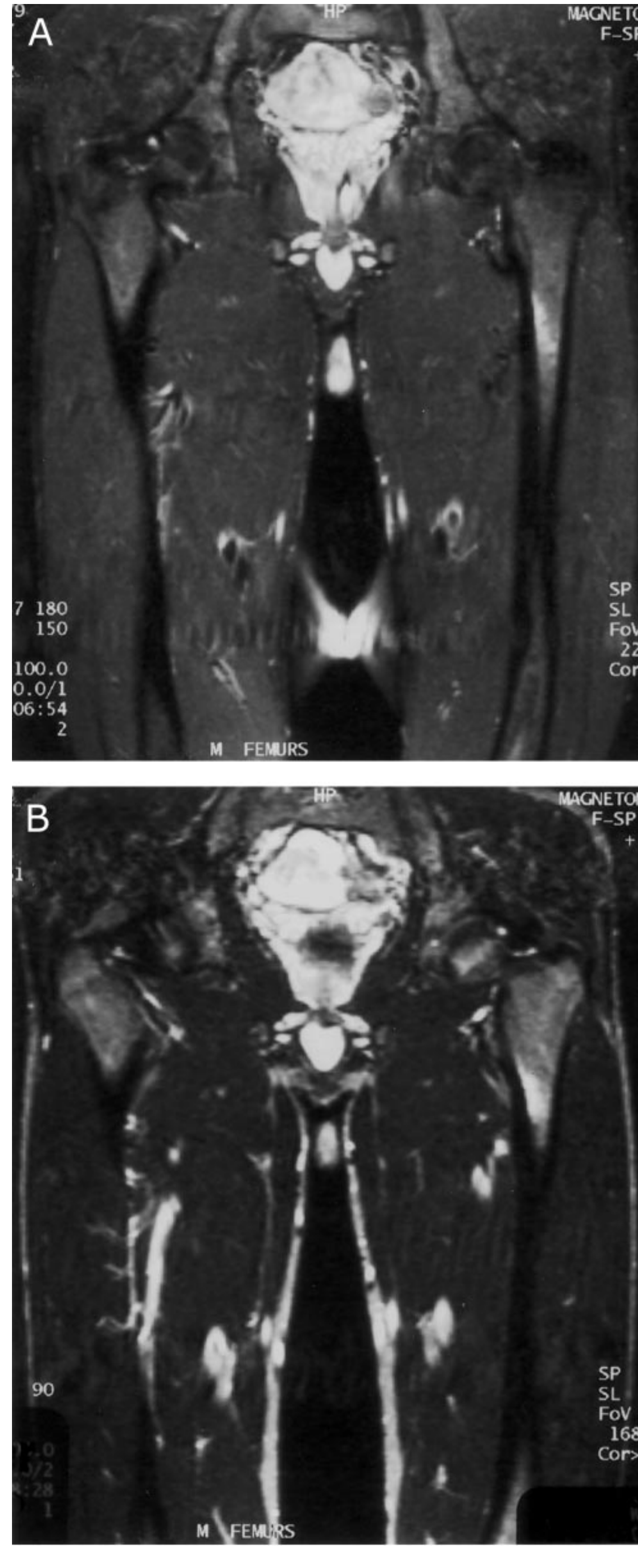

Figure 2. These coronal images of the proximal pelvic and hip region show increased signal in the proximal left femur. This is evident on both the STIR sequence (A) and on the T2-weighted sequence (B). The T1-weighted signal was negative. This was recorded as a grade 2 stress injury.

(15%), 18 were grade 3 (30%), and 14 were grade 4 (23%) (Figs. 1 through 4).

Time to return to sport varied according to the grade of stress injury. Of the 61 stress injuries diagnosed by MRI,

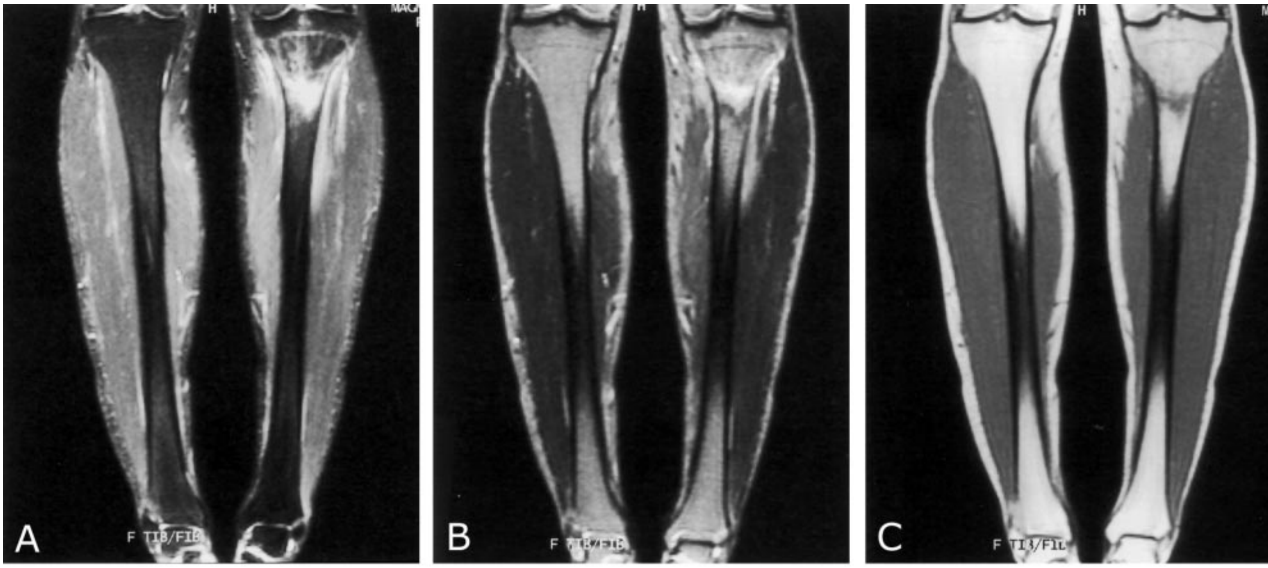

Figure 3. Coronal image of the tibias of a female runner with previous history of an eating disorder. A, coronal STIR sequence of the left tibia shows obvious increased signal in the proximal tibial metaphyseal region. B, a linear low-intensity signal on the T2-weighted image suggests an injury line. It does not violate the cortex, nor does it have the more characteristic straight-line nature of a true cortical stress injury to bone. C, on a coronal image, the left proximal tibia shows a decreased T1-weighted signal. These images represent a high grade stress injury to bone, consistent with a diagnosis of grade 3 stress injury.

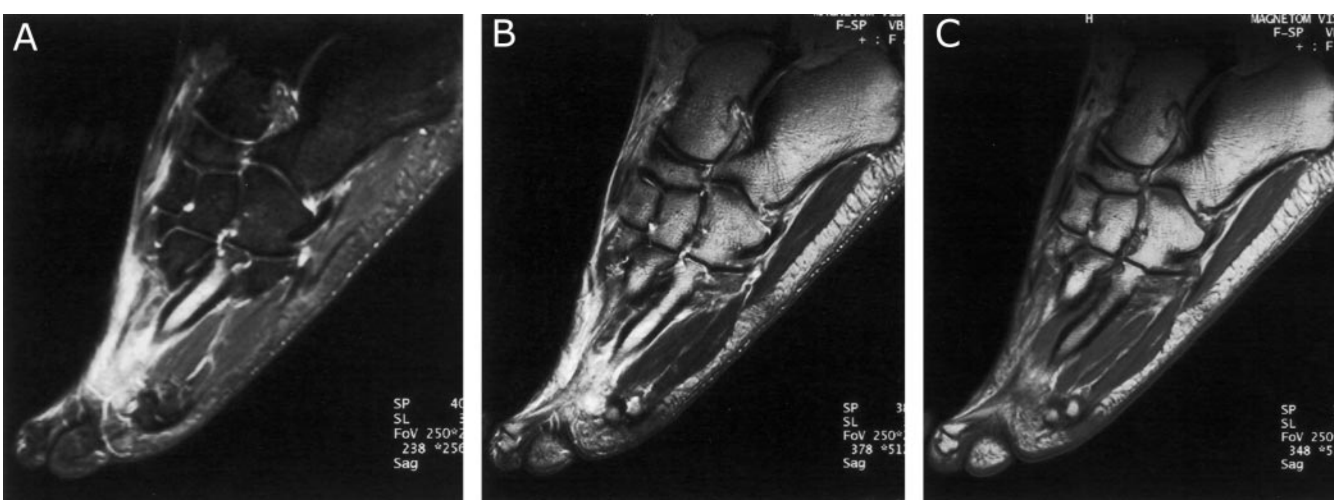

Figure 4. Sagittal STIR (A), T2-weighted (B), and T1-weighted (C) images of the foot with an MRI signal abnormality visible in the fourth metatarsal bone. There is a low signal intensity injury line on the T1-weighted image. This, combined with periosteal thickening seen on plain radiographs, resulted in the injury being designated a grade 4 stress injury of bone.

patients in 60 of these injuries had information available on return to activities. One athlete had incomplete training room records. In five athletes the stress injury was diagnosed at the end of the competitive season or the athlete had left the team, so that no return to full activity was recorded. Two athletes who were unable to return to their sport despite a prolonged period of reduced activities were ultimately medically disqualified from their sport. These two athletes were both female runners (one distance and one sprinter) and both had grade 4 stress injuries to the navicular bone (Fig. 5). Therefore, these eight athletes were excluded from the "return to sport" analysis. Of the 53 remaining cases of stress injury to bone, the mean time in weeks for full return to sport was 8.4 (SD, 7.72; range, 0 to 36). Grade of injury was correlated with time to full return to sport measured in weeks from the time of MRI diagnosis. The Pearson correlation was equal to 0.627 (P = 0.001). A one-way analysis of variance for differences among the mean times for full return to sport by grade of injury was performed. With F = 10.9 (P = 0.000), significant differences were found using post hoc analysis of Scheffé and Bonferroni between grade 1 and

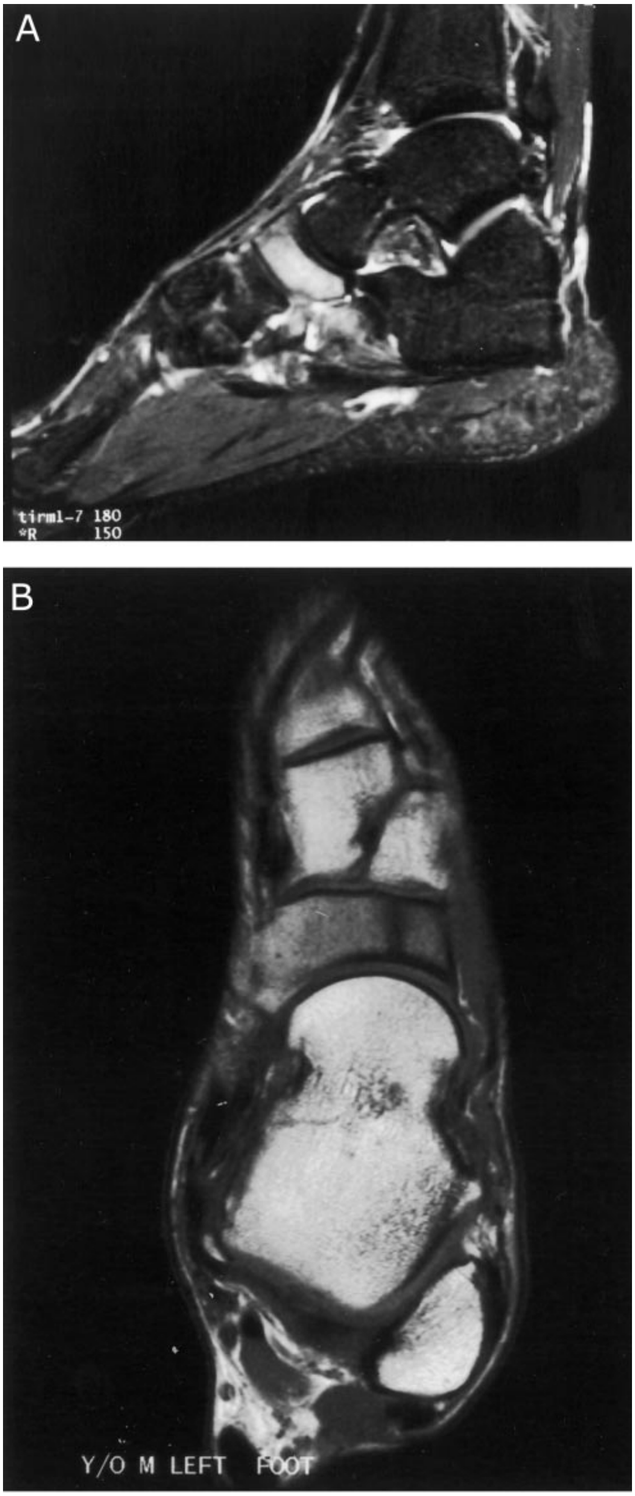

Figure 5. A, sagittal STIR image of the foot reveals edema (at site of increased signal) in the tarsal navicular bone. Near the dorsal aspect of the tarsal navicular bone there is suggestion of a injury line. B, axial T1-weighted image of the tarsal navicular demonstrates the injury line with some ill-defined adjacent decreased T1-weighted signal compatible with edema. The injury line on the T1-weighted image identifies this as a grade 4 stress injury of bone.

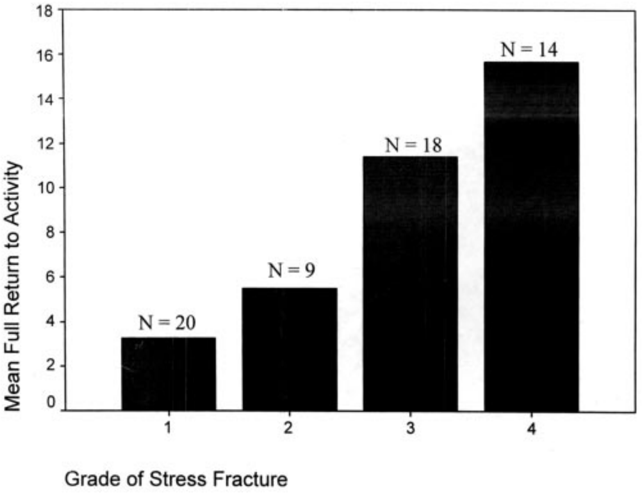

Figure 6. Grade of stress injury to bone correlated with average time to full return to sports activity in weeks.

grade 3, between grade 1 and grade 4, and between grade 2 and grade 4. Comparison with grades 1 and 2 versus grades 3 and 4 also demonstrated significant differences. Figure 6 is a graph of the time to return to full activity by weeks compared with the grade of stress injury to bone. Higher grade stress injuries to bone (grades 3 and 4) required a significantly longer time until return to full activities than lesser grade stress injuries to bone (grades 1 and 2). The average time to return to full activity was 3.3 weeks for a grade 1 stress injury, 5.5 weeks for grade 2 stress injury, 11.4 weeks for a grade 3 stress injury, and 14.3 weeks for a grade 4 stress injury (Fig. 6). When MRI-diagnosed stress injuries to the foot bones (calcaneus, metatarsal, and navicular bones) were grouped together, 20 of 22 (91%) were noted to be grades 3 or 4.

We defined change in training regimen for the purpose of this study as entry as a new athlete or as a change in coaching staff. Our data show that 31% of stress injuries to bone (9 of 61) occurred as a result of "new coach phenomena," and 23% (14 of 16) occurred in freshmen or transfer students. Thus, 48% of stress injuries to bone (30 of 61) could be correlated with a change in training regimen. Unfortunately, we do not know the percentage of all athletes who were freshmen or otherwise exposed to a new coach during this period of time. We are therefore unable to say whether exposure to a new coach was associated with an increased risk of stress injury to bone.

DISCUSSION

Stress injuries to bone result from a temporary disturbance in the balance of bone resorption and remodeling. Repetitive mechanical stress on bone causes microtrauma that stimulates the remodeling process. If the microtraumatic damage to bone is greater than the capacity of bone to repair it, a stress fracture may occur at the site of repetitive loading.[6,15]

The results of this study show that, in this study group, female distance runners suffered the most stress injuries to bone (6.4%). In addition, across all sports, female athletes incurred more stress injuries to bone (1.9%) than did male athletes (1.1%). Although studies on military populations have reported female recruits to be at a higher risk of stress fracture than male recruits,[22,30] sex differences in stress fractures among athletes have not been as evident.[5,7,20,28] However, several studies have shown that female athletes have higher injury rates than male athletes.[18,24,32] Recent reviews that have primarily focused on bone health in female athletes suggest that the observed differences in stress injury rates between men and women may not be explained by inherent differences in sex alone, but rather by sex-related factors, including bone mineral density, menstrual history, and diet.[1,7,8,13] The correlation of these factors with the rate of bone stress injury in the female athletes in this study was beyond the capability of this retrospective review.

Much of the literature on stress injuries to bone in an active population comes from either physicians' office visits or review of injuries sustained during formal running events. There is a paucity of epidemiologic data on the demographic aspects of stress injuries to bone in the college-aged population. Goldberg and Pecora[18] evaluated the distribution of stress fractures for 3 years in a college student population. Their review represented a population of active college students who sought treatment at a student health service. They found an annual incidence of 1.9%. Johnson et al.,[20] in a 2-year study of college Division IIA athletes, found an annual stress injury incidence of 3.7%. They found that 7% of female athletes sustained a stress injury to bone, compared with 2% of male athletes. Track and field was the sport associated with the largest number of stress injuries to bone. They did not distinguish distance runners separately from track and field. In our population, distance runners sustained the most stress injuries to bone.

In a recent 3-year prospective review of running injuries at a single Division I school, Nattiv et al.[28] reported an annual incidence of 8.7% stress injuries to bone. The injuries were equally distributed between male and female runners.

In studying injury rates in track and field athletes, it is prudent to separate distance runners from sprinters because of the differences in training programs. Sprinters run fewer miles per week and perform more speed work and plyometric drills. In one study on track and field athletes, Bennell et al.[7] found that there was no difference in bone stress injury rates among athletes competing in the different track and field events. However, they did find a difference in injury locations. The greatest number of foot fractures occurred in athletes who participated in sprinting, hurdling, and jumping events; middle and long-distance runners sustained a significantly greater number of long-bone injuries. This is consistent with the results of other studies.[11,20] Brukner et al.,[11] in a study on runners, found navicular bone injuries were more frequent in sprinters and hurdlers than in other types of runners. In the college athletes in our study, more than half of the navicular bone injuries were sustained by athletes whose sport involved a power take-off, such as gymnastics and sprinting; the majority of femur injuries occurred in distance runners.

In regard to training issues, it is interesting to note that the overwhelming majority of foot injuries to bone were high grade at the time of the initial visit to the training room. The reason for this is unknown. It might be explained by the fact that athletes may tolerate more pain in the foot than in other areas before alerting the athletic staff, or that long bones can sustain a greater amount (longer duration) of repetitive stress between grades of stress injury to bone.

Other studies have shown a correlation between college freshman activity and stress injury to bone.[18] We are not aware, however, of what we term the "change in training regimen" as being a particular risk for sustaining stress injuries to bone. At our institution, the new coach phenomenon was always coupled with a significant change in training regimen over the previous year or years. This has led the sports medicine staff at our institution to pay particular attention to counseling new coaches on making changes. Unfortunately, because we do not know the percentage of athletes who were exposed to a new coach during the period of this study, we are unable to verify our impression that such an exposure is associated with an increased risk of stress injury to bone.

Most studies, including this one, have shown the tibia (from the proximal/middle third junction to the middle/distal third junction) to be the most common site of athletic stress injury to bone.[6,20,24,25,29] Infrequently, the tibial plateau or proximal tibia are involved.[19] We found that stress injuries to the tibia were common in all sports.

In a prospective 3-year study of 70 college runners, Nattiv et al.[28] found the tibia to be the most frequent site of injury (45%), followed by the metatarsal bones (24%). No navicular bone fractures were identified. Our study also found a high incidence of foot injuries, the majority being metatarsal (24%) and navicular bone injuries (18%). This is consistent with the study of Johnson et al.,[20] which also found a high percentage of foot injuries, with both the metatarsal (21%, 7 of 34) and navicular (12%, 4 of 34) bones being the most common sites of injury. Although Nattiv et al. studied only runners, Johnson et al.[20] studied athletes in a variety of sports. By examining only the track and field athletes and distance runners in our study, we find a high percentage of midfoot injuries represented. This may be accounted for by the fact that our institution is located in a Northern climate and our subjects frequently run on harder surfaces or indoor surfaces.

Stress injuries to the navicular bone warrant special consideration because of diagnostic and treatment challenges. These injuries are difficult to visualize radiographically, although the recent increased use of bone scintigraphy and MRI has lessened the diagnostic challenge. The treatment of stress injury to this bone is complicated by the relative avascularity of its central third. The risks of navicular bone stress injury include complete fracture or displacement, delayed union, or nonunion. Indeed, two athletes in this study who were unable to return to their sport both had grade 4 navicular bone injuries.

Metatarsal bones are frequent sites of stress injury to bone. One study reported that the metatarsal bones were the most common site of stress injury to bone.[18] Most often, the second and third metatarsals are the specific area of involvement.[25] In our study, the third metatarsal was the most frequently involved bone (7), followed by equal representation between the second (3), fourth (3), and fifth (4) metatarsal bones. Special consideration is needed in evaluating stress injury to the fifth metatarsal bone. In our study, all of the stress injuries to the fifth metatarsal bone were Jones injuries (injuries at the metaphyseal/diaphyseal junction). These injuries are often associated with delayed union or nonunion.[19] In all four Jones injuries in our study, the athletes were involved in jumping and pivoting sports (basketball, $N = 3$; track [discus], $N = 1$).

The amount of time needed before full return to sport is possible is an area of consideration that has not been well studied. Yao et al.[33] and Fredericson et al.,[17] using an MR grading system similar, although not identical to ours, have attempted to correlate clinical outcomes with MRI grade of injury. Fredericson et al. reported general recovery times for various grades of injury, but they did not perform statistical analysis. Their study evaluated only tibial injuries. Yao et al., using the same grading system as Fredericson et al., attempted to demonstrate statistical significance between various grades of stress injury to bone and return to activities. Their study suggested that the finding of a cortical signal intensity abnormality or injury line (grade 4 injury) did have prognostic value. However, the rating system of Fredericson et al. was not prognostic in their patient group. They were able to apply a grading system to only 24 of 35 patients because of the absence of periosteal abnormalities (which they defined as grade 1). Their MRI sequence did not include a STIR sequence or fat-suppression sequence. Follow-up was by clinical records and telephone interviews. Only 21 of 35 patients returned to regular sport activities, with 14 patients either not participating in sport activities or not returning to sport activities for other reasons. Their patients were graded on return to activities by placement in one of two large groups. Group 1 patients (those with less severe injury) returned to sport in 12 weeks or less. Patients who did not return to their sport were also placed in group 1 if duration of their symptoms was 16 weeks or less. All others were classified as group 2 (more severe injury).

Our study differed from that of Yao et al. and Fredericson et al. in that we used fat-suppressive MRI scans to define early marrow edema, which is believed to be the initial response of bone to stress phenomena. Additionally, although clinical information was gathered retrospectively, the retrospective data were obtained from training room records that were kept on a daily or near-daily basis. All athletes were treated in the same institution with a uniform treatment program.

The results of this study, with MRI data and return to activity data on 58 athletes and 61 stress injuries to bone, is consistent with our early work. It shows that low-grade injuries (grades 1 and 2) have a significantly shorter duration of time before return to full activity than high-grade injuries (grades 3 and 4).

Scintigraphic evidence has clearly supported the concept of a radiographic grading system to delineate increasing degrees of bony change in response to stress.[14,31,34] Chisin et al.[14] have shown not only the clinical usefulness of a scintigraphic rating system, but also that low-grade stress injuries to bone can heal with continued activity. Using bone scans, they followed 27 military recruits with tibial pain. Recruits with high-grade stress fractures (grade 3 and 4 lesions) were rested until they were asymptomatic on excursion. Grade 1 and 2 lesions were not considered to be true stress injuries to bone, and recruits with this level of lesion were returned to duty. Among this latter group, 6 of 14 recruits progressed to a higher scintigraphic grade, with the remaining 8 reverting to a negative bone scan. These results show that bone can heal in the face of continued stress, if the stress injury is in the lower scintigraphic grading stages (grades 1 and 2). This concept is supported by the work of Burr et al.[12] In their animal model, they showed that some healing occurred between week 6 and 9 of continuous cyclic loading, indicating that lesions may resolve even with continued loading. The MRI grading system that we used to classify level of lesion is in line with the scintigraphic grading system described Chisin et al.[14] as well as with the biologic classification of bone stress phenomena.[2,21,23]

Paramount to our treatment program is keeping the injured athlete's activity below the threshold of pain. Most authors agree that pain is a useful guide in assessing bone's injury progression toward healing, as well as being a useful guide in increasing work load in the recovery phase.[3,14] Chisin et al.[14] correlated pain with the scintigraphic picture and found that increased pain correlated with progression of the stress injury, whereas decreased pain correlated with scintigraphically observed healing. Although Milgrom et al.[26] reported in an earlier study that the absence of pain was a poor indicator of healing in stress injuries to bone, Milgrom later reversed that statement in a study that he coauthored with Chisin and others.[14]

We believe that an MRI grading system can be used to accurately define the clinical picture, which in turn enhances clinical management. The use of an MRI grading system increases a clinician's ability to define and predict the duration of injury as well as to tailor the rehabilitation of the injury for speedy return to full activities. Thus, it is a tool that is well suited for the clinician, the athlete, and the athletic setting.

The intent of our research was not to describe the etiologic factors involved in stress injuries to bone but rather to describe the epidemiologic factors involved in a college-aged athletic population. As such, this study did not include investigation of factors generally thought to be causative of stress injuries to bone, such as body composition, menstrual history, or specifics of training regimens.

CONCLUSIONS

To the best of our knowledge, this is the largest reported study on a series of college athletes who were treated for radiographically diagnosed stress injury to bone. Diagnosis included the use of a uniform MRI grading system, and all patients were treated with a standardized treatment protocol. Our study revealed that stress injuries to bone are an uncommon injury (1%) within this population, with most occurring in male and female distance runners. Trends in anatomic location reveal distance runners to be at risk for long-bone stress injuries, and power take-off athletes to be at risk for navicular bone injuries. The tibia was found to be the most frequent site of stress injury. In combination with a standardized treatment program, the MRI grading system used at this institution has been shown to be of value in predicting return to activities. This system of MRI grading and standardized treatment offers a safe yet aggressive approach to return to activities; monitoring of MRI grade increase permits rehabilitation and return to the sport without any adverse progression of the stress injury.

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