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Epidemiology of Stress Fractures

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Stress fractures are a frequent cause of injury in competitive and recreational athletes. The pathophysiology of stress fracture has been well described in the literature. Data regarding the epidemiology of stress fractures in athletes, including injury patterns and risk factors, are lacking. Clinical experience suggests that stress fractures occur more frequently in sports involving repetitive weight-bearing activity; however, little else is known. This article briefly discusses the intricacies of sports injury epidemiology and reviews the current literature regarding stress fracture incidence, characteristics, and morbidity. Because the focus is on competitive and recreational athletes, the discussion does not include a review of the large body of literature pertaining to stress fractures in military recruits.

METHODS

To ensure a comprehensive review of available studies, a literature search was conducted using the MEDLINE database. The terms "stress fracture," "athletes," "epidemiology," and "incidence" were searched from 1966 through May 2005. The references of all retrieved articles also were reviewed. Prospective studies were searched for initially, but the inclusion criteria were expanded after only three such studies were identified [1–3]. Retrospective medical record reviews were then included. Studies using patient surveys to determine stress fracture prevalence were excluded from the review because of the potential for recall bias. Overall, a total of 25 studies were identified and thoroughly reviewed.

EPIDEMIOLOGY OF SPORTS INJURIES

Injury Exposure

Epidemiology is the study of diseases in populations, including the relationship between exposures and outcomes. For the purpose of this discussion, the term "exposure" is defined as athletic activity, and the occurrence of a stress

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fracture is the outcome of interest. One of the major challenges in sports injury epidemiology is the process of defining and collecting meaningful exposure data [4]. A quantitative measure of injury exposure is often not accounted for in studies, and data are expressed as the number of injuries per athlete over a given time period (eg, a calendar year or a season). Although this calculation makes data collection easier, it does not always allow for the expression of injury risk because neither the number of at-risk athletes nor the quality and quantity of the exposure are expressed. Knowing the characteristics of the exposure in the at-risk population allows for a greater potential to generalize the findings of a particular study.

Properly quantifying exposure can be difficult, and the methods depend on the sport being studied. Incidence rates are often measured by athlete-years, athlete- seasons, or athlete exposures. An athlete-year or athlete-season allows the researcher to account for the total number of participants over a stated period of time. An athlete exposure may consist of a single player participating in a single game or practice, or, for example, in football, it may be defined as an individual athlete participating in a single drill per practice or a single play per game. For sports such as cross-country and track and field, injuries per hour of activity may be more appropriate to consider. However, even this measure of risk does not account for all characteristics of the exposure, such as the intensity of the exposure.

Assessing Injury Incidence and Risk

Identifying the population at risk is one of the most important tasks in properly designing a sports injury study [4]. The population at risk is defined in the denominator as the total number of active participants. The rate is often misused but is considered an instantaneous measure of how fast a disease is occurring in the population (eg, fractures per week). A proportion describes what fraction of the population is affected and is expressed as a percentage or probability. Incidence is equal to the total number of new injuries occurring during a specified period of time divided by the population at risk.

Injury incidence may be reported as a measure of cumulative incidence or as an incidence rate. Because cumulative incidence is a measure of events, it is also a measure of *risk* [5]. An incidence calculated over a specified time period during which all of the individuals are considered at risk for the outcome is called the "cumulative incidence" [5]. The cumulative incidence of a stress fracture, therefore, is estimated by dividing the number of stress fractures by the number of subjects in the study at the beginning of the observation period.

Cumulative incidence is time-dependent; therefore, longer observation periods will likely yield a greater measured incidence because the population has a longer total exposure time. In the case of an observation period of several years, this can be adjusted for by calculating a cumulative annual incidence, which gives a proportion expressed as injuries per year. An incidence rate may be calculated when everyone in the population does not have an equal exposure or everyone has been observed for varying lengths of time. It is estimated by dividing the number of events by the number of subjects per time period (athlete-seasons or athlete-year). Incidence rates allow for an easier comparison and contrast of multiple studies but do not account for differences in the population at risk or the variation in exposure.

The majority of studies reviewed report a proportion of individuals who developed a stress fracture of the total number of individuals who were evaluated at some point during the observation period. Because the studies did not use the number of subjects per time period in the denominator, the measurements cannot be considered incidence rates. Proportions were typically reported as either a participant proportion or case proportion, depending on the numerator. A participant proportion uses the number of athletes with stress fractures as the numerator, whereas a case proportion assesses the total number of stress fractures, accounting for athletes with multiple stress fractures during the study period. The denominator for both equations is the total number of athletes at risk at some point over the study population.

Of the studies evaluated for the present review, most report the participant proportion or both the participant proportion and the case proportion. Also, several of the studies do not clarify whether they are providing the number of athletes with stress fractures or the number of stress fractures. In these situations, a conservative assumption was made that the authors were providing the number of athletes with stress fractures and, thus, considered the measure to be a "participant proportion."

Study Design

Three separate study designs predominate in the stress fracture literature: case series, prospective cohorts, and retrospective cohorts. A case series consists of a population of individuals who have experienced the exposure and have developed the outcome of interest. Risk factors cannot be determined, nor can anything of interest be learned regarding the population at risk. Injury data reported without a denominator can describe only injury frequency [6]. Few conclusions can be drawn about the outcome because a variety of factors may result in an unrepresentative sample of injuries presenting to a given clinic.

A cohort design can be conducted prospectively or retrospectively. Each design allows for comparing athletes with and those without the outcome. Because the entire population at risk is defined at the beginning of the study, potential risk factors can be evaluated more easily. There are many differences between prospective and retrospective study designs. Most important, the retrospective cohort has already experienced the exposure; thus, data collection is subject to selection factors, inaccurate or incomplete record keeping, and, in the case of survey studies, to recall bias. The prospective cohort is the preferred design because it permits the ongoing collection of predetermined data sets over a specific period of time.

Method of Diagnosis

The validity of sports injury data depends on the definition of injury in the study population. Although all of the studies in this review used stress fracture

Table 1
Proportion of athletes with stress fractures

Study	Country	Study design	Sport	Number (M/F)	Data collection	Observation period (y)	Diagnosis	Participant proportion (T/M/F)	Case proportion (T/M/F)
Arendt et al [8] 2003	USA	Retrospective	NCAA	3610/2248	Review of medical records	10	MRI/BS/XR	1.0/0.8/1.9	NR
Bennell et al [1] 1996	Australia	Prospective	T-F	49/46	Monitoring	1	BS/CT	21.1/20.4/21.7	27.4/24.5/30.4
Brubaker and James [15] 1974	USA	Retrospective	T-F	109	Review of medical records	17	NR	15.6/NR/NR	NR
Clement et al [11] 1981	Canada	Retrospective	All	987/663	Review of medical records	2	NR	5.3/4.9/5.9	NR
Dixon and Fricker [26] 1993	Australia	Retrospective	Gymnasts	42/74	Review of medical records	10	XR/BS	26.7/21.4/29.7	NR
Goldberg and Pecora [9] 1994	USA	Retrospective	NCAA	3000	Review of medical records	3	XR/BS	1.9/NR/NR	NR

Hame et al [10] 2004	USA	Retrospective	NCAA	5900	Review of medical records	14	NR	1.4/NR/NR	NR
Hickey et al [32] 1997	Australia	Retrospective	Basketball	0/49	Review of medical records	5	NR	NR/NR/40.8	NR
Iwamoto and Takeda [12] 2003	Japan	Retrospective	All	6415/3861	Review of medical records	10	MRI/BS/XR	1.9/2.0/1.9	NR
Johnson et al [2] 1994	USA	Prospective	NCAA	593/321	Monitoring	2	XR/BS	2.6/NR/NR	3.7/2.0/6.9
Lloyd et al [7] 1986	USA	Retrospective	NCAA	0/199	Review of medical records	1	XR	NR/NR/6.5	NR
Matheson et al [13] 1989	Canada	Retrospective	All	867/540	Review of medical records	5	NR	7.8/5.5/ 11.5	NR
Nattiv et al [3] 2000	USA	Prospective	T-F	275	Monitoring	3	XR/MRI	8.7/NR/NR	NR
Witman et al [14] 1981	USA	Retrospective	All	680/309	Review of medical records	4.5	NR	0.5/NR/NR	NR

Abbreviations: BS, bone scan; F, female; M, male; NCAA, National Collegiate Athletic Association; NR, not recorded; T, total; T-F, track and field; XR, radiography.

as the outcome, the methods of diagnosis varied. When comparing injury data among studies, the diagnostic tool must be considered because it may greatly affect the number of stress fractures reported. For example, Lloyd and colleagues [7] defined cases using only plain radiographs, although there may be a 2- to 4-week delay in stress fracture diagnosis using this method. Thus, stress fracture incidence may be under-reported in studies using only plain radiographs to diagnose stress fracture. Also, tarsal stress fractures are notoriously difficult to diagnose by radiography, potentially resulting in a delayed or missed diagnosis.

Conversely, both MRI and bone scans are sensitive and will detect stress fractures at an early stage. MRI scanning, particularly, is quite sensitive and detects bone "stress injury," a precursor to an actual stress fracture. Studies using MRI scans will likely detect a higher incidence of stress fractures and stress reactions compared with other diagnostic tests. Unfortunately, many of the studies did not identify the method of diagnosis. These studies must be interpreted with caution because the validity of the results cannot be determined.

RESULTS

Fourteen cohort studies were identified that provided a measure of either the proportion or cumulative incidence of stress fractures among athletic populations (Table 1). Each study that was reviewed observed different athlete populations, including recreational and competitive athletes, collegiate athletes, track and field athletes, gymnasts, and basketball players. Because of the variety in sport, frequency, and intensity of activity, caution should be exercised in comparing results across studies. Furthermore, because the study observation periods varied from 1 to 17 years and the subject population was often variable during the duration of the study, it is difficult to compare the proportions of athletes with stress fractures across groups.

Subject populations in the 14 studies consisted of either all of the athletes participating in a sport at an institution or all of the athletes who presented to a sports medicine or orthopedic clinic. It is important to make several important distinctions between these two study designs. First, the medical records reviewed from a sports medicine or orthopedic clinic include records from only those patients who were referred to the clinic. Therefore, because some participants who develop stress fractures may not seek treatment or may see only their primary care physician, the potential for referral bias was introduced into these studies. Second, studies that include all athletes participating in a sport in the denominator are more accurate than studies limited to the "injured athletes" (individuals who present to a clinic) or in the denominator.

Three of the 14 studies were prospective studies [1–3]. Bennell and colleagues [1] and Nattiv and colleagues [3] evaluated stress fractures in track and field athletes in Australia and the United States, respectively. Johnson and colleagues [2] prospectively studied collegiate athletes. In addition to these three prospective studies, 11 retrospective studies were identified that evaluated the occurrence of stress fracture in an athletic population by a review of medical records. Of the five studies that evaluated collegiate athletes, the proportion of athletes with stress fractures range from 1.0% to 2.6% [2,7–10]. Four studies assessed what proportion of recreational or competitive athletes who visit a sports medicine or orthopedic clinic present with stress fractures, and their findings range from 0.5% to 7.8% [11–14]. Of the studies that focus on track and field athletes, Nattiv and colleagues and Bennell and colleagues report cumulative annual incidences of 8.7% and 21.1%, respectively [1,3]. Brubaker and colleagues [15] have reported that 15.6% of individuals who visited an orthopedics clinic with a running-related injury presented with stress fractures.

A great deal of variation exists among studies reporting stress fractures as a proportion of total athletic injuries, likely because of differences in the populations studied and variations in the definition of all injuries reported (Table 2). In track and field athletes, James and colleagues [16] have reported that stress fractures accounted for 6.0% of all reported injuries, whereas Bennell and colleagues [1] have reported a proportion of 20%. Other studies assessing athletes from multiple sports have found that stress fractures account for 0.5% to 4.8% of all injuries [11,14]. Although methodologies differ, these contrasting results provide evidence of the increased occurrence of stress fractures in track and field athletes.

Table 2
Stress fractures as a proportion of total injuries

Study	Sport	Stress fractures/ total injuries (%)	Stress fractures/ total injuries (M) (%)	Stress fractures/ total injuries (F) (%)
Bennell et al [1] 1996[a]	T-F	20.0 (N = 26/130)	16.4 (N = 12/73)	24.6 (N = 14/57)
Clement et al [11] 1981	All	4.8 (N = 87/1819)	4.4 (N = 48/1081)	5.3 (N = 39/738)
Hickey et al [32] 1997	Basketball	NR	NR	9.0 (N = 20/223)
James et al [16] 1978	T-F	6.0 (14/232)	NR	NR
Witman et al [14] 1981	All	0.5 (N = 5/951)	NR	NR
Dixon and Fricker [26] 1993[b]	Gymnastics	51.7 (N = 31/60)	47.4 (N = 9/19)	53.7 (N = 22/41)
Hame et al [10] 2004[b]	NCAA	22.9 (N = 80/349)	NR	NR
Lloyd et al [7] 1986[b]	NCAA	NR	NR	52 (N = 13/25)

Abbreviations: F, female; M, male; NCAA, National Collegiate Athletic Association; NR, not recorded; T-F, track and field.

[a] Percentage of musculoskeletal injuries.

[b] Percentage of total fractures.

STRATIFIED DATA

Age

The role of age as an independent risk factor for developing a stress fracture cannot be determined from the available literature. No study has controlled for activity level; thus, the distribution of fractures among age groups is more likely to be associated with training volume and intensity rather than the ages of the participants. There are no studies in athletes that suggest an independent effect of age on the occurrence of stress fractures. Studies in military recruits have had conflicting results as to whether recruits in their late 20s and early 30s are at an increased risk for stress fractures compared with their younger counterparts [17–19].

Only a handful of studies report stress fracture frequency by age group. Courtenay and Bowers [20] have reported that a higher proportion of stress fractures occurred among younger subjects. Goldberg and Pecora [9] have found that college freshman suffer far more stress fractures than upperclassmen; however, it is likely that this increased injury frequency reflects the sudden increase in training volume and intensity on initiation to college athletics. Following a retrospective chart review at a large sports medicine clinic, Matheson and colleagues [13] have reported a stress fracture incidence of 4.2% among older subjects (≥50 years old) and 11.2% among younger subjects (≤50 years old). Over 50% of athletes with stress fractures were younger than 20 years of age in one series, with 8% of the stress fractures occurring in 10- to 14-year-old athletes [12]. Ohta-Fukushima and colleagues [21] have reported five stress fractures in children under the age of 10, including a tibial stress fracture in a 6-year-old boy.

Race

There are few comparative data regarding stress fractures among different racial groups. The majority of studies come from Europe and North America, and few report race or ethnicity of the participants. Two studies from the United States have attempted to examine differences in stress fracture rates between African Americans and whites [3,22]. Barrow and Saha [22] have found no differences, but their data were compiled from a questionnaire and included a sample of only 12 African American athletes. Nattiv and colleagues [3] also have reported no significant differences in stress fracture incidence between African American and white collegiate track athletes ($P \leq .35$). Studies from Japan and Korea show slight differences in fracture patterns compared with the more heavily studied white populations, but the differences are more likely related to the variation in activity rather than race [12,21,23].

Gender

The female athlete triad (menstrual irregularity, disordered eating, and osteopenia) emphasizes the susceptibility of young female athletes to stress fracture and contributes to the clinical impression that females are at an increased risk for such injuries compared with young men. Two authors have reported significant findings in subpopulations of female athletes. Lloyd and colleagues [7] have found a difference in cumulative stress fracture incidence of 4% in girls with a regular menstrual history versus 15% in girls with irregular or absent menses ($P \leq .025$). In a separate report, female athletes with a history of disordered eating suffered significantly more stress fractures ($P \leq .001$) [3]. Clearly, more research is needed in this population, which may be at particular risk.

Several descriptive studies have reported stress fracture rates in athletes stratified by gender, but few studies have been appropriately designed to assess true differences in risk. Hame and colleagues [10] have found that women experienced a higher proportion of stress fractures than men did ($P = .001$) in a population of college athletes, but the report did not provide specific details. Nattiv and colleagues [3] have reported no significant difference in stress fracture incidence between men and women ($P \leq .39$), and neither did Iwamoto and Takeda [12].

The limitation of these studies is that all failed to account for total injury exposure (training volume) when comparing injuries between men and women. For example, Bennell and colleagues [1] have found a stress fracture incidence of 20.4% in men and 21.7% in women in a prospective study of track and field athletes. However, when stress fractures rates were adjusted for total training hours, a difference emerged. Men experienced 0.54 stress fractures per 1000 training hours versus 0.86 stress fractures per 1000 training hours for women [1]. This difference was not statistically significant ($P = .82$), but the study was not sufficiently powered to detect a statistically significant difference in stress fracture incidence rates [1]. Hence, although this difference was not statistically significant, it may be of clinical significance. Only a large prospective study, accounting for differences in volume and intensity of training, will definitively answer the question of gender differences in stress fracture risk.

STRESS FRACTURE CHARACTERISTICS

Fifteen studies provided sufficient details to allow a review of anatomic fracture sites, but the studies are of limited value in assessing fracture occurrence by sport. Few inferences can be made regarding specific injury patterns because of the heterogeneity of the study populations and inconsistent methodology. Variations in exposure will affect fracture patterns. In addition to the volume of activity, other potentially confounding variables include sports or activities, climate, and male-to-female participation ratios. For example, athletes in colder climates may run on frozen ground or use indoor surfaces, resulting in higher impact. On the other hand, some athletes may discontinue running for the winter and, thus, have no injury exposure. Factors such as these deserve consideration when interpreting limited epidemiologic data.

Regional and national variations in sporting activities also may greatly affect the association between particular sports and stress fractures. A large study [12] of Japanese athletes found a majority of stress fractures occurring among basketball and baseball players, followed by track and field athletes and rowers. The injury exposure in these populations differed with the majority of reviewed studies from Europe and North America and resulted in a high proportion of rib (15.8%) and ulnar (8.2%) stress fractures [12]. Differences in injury exposure within a clinic population are highlighted by one study that details a large number of injuries in dancers, contrasting with few dancing injuries reported in the other studies [24].

A handful of authors have investigated the occurrence of stress fractures among intercollegiate athletes in the United States [2,7–10]. Compared with specialty clinic populations, these studies offer a more homogeneous population in regard to age and sporting activities. Unfortunately, few associations can be made between particular sports and fracture patterns in collegiate athletes (Table 3). The relatively small number of stress fractures sustained makes analysis difficult because even a slight variation in training practices may greatly influence stress fracture rates in a given population. Arendt and colleagues [8] detail an aggressive land training program initiated over one summer by the men's hockey team, which resulted in five athletes with tibial stress fractures. These were the only stress fractures of the tibia suffered by male athletes over the 10-year observation period and comprised 14% of all stress fractures sustained by men in the study [8].

Stress fractures of the tibia, metatarsals, and fibula are the most frequently reported anatomic sites in the majority of studies (Table 4). Stress fractures of the femur, first metatarsal sesamoid, and pelvis were encountered far less commonly but had relatively similar rates of occurrence among studies. The occurrence of tarsal navicular fractures was variable, but overall, such fractures were

Table 3
Sport-specific proportion of athletes with stress fractures

	Proportion of athletes with stress fracture		
Sport	Arendt et al [8] 2003	Goldberg and Pecora [9] 1994	Johnson et al [2] 1994
Basketball (T/M/F)	NR/2.9/3.6	2.9/NR/NR	NR/0/3.6
Baseball (M)	0.3	2.6	0
Crew (T/M/F)	NR	2.2/NR/NR	NR/2.4/8.2
Cross-country (M/F)	3.9/6.4	NR	NR
Fencing (T/M/F)	NR	1.9/NR/NR	NR/0/0
Field hockey (F)	NR	2.2	0
Football (M)	0.3	0.8	1.1
Golf (M/F)	0/0	NR	0/0
Gymnastics (T/M/F)	NR/3.0/4.3	2.8/NR/NR	NR
Ice hockey (M/F)	2.1/0	NR	NR
Lacrosse (T/M/F)	NR	2.7/NR/NR	NR/4.3/3.1
Soccer (T/M/F)	NR/NR/2.3	2.0/NR/NR	NR/0/2.6
Softball (F)	1.1	6.3	0
Swimming (T/M/F)	NR/0/0	1.3/NR/NR	NR/0/0
Tennis (T/M/F)	NR/0/0.8	2.8/NR/NR	NR/0/0
Track and field (T/M/F)	NR/0.8/1.6	3.7/NR/NR	NR/9.7/31.1
Volleyball (T/M/F)	NR	2.4/NR/NR	NR/NR/0
Wrestling (M)	0	NR	NR

Abbreviations: F, female; M, male; NR, not recorded; T, total.

Table 4
Stress fracture distribution by most frequent anatomic sites

Study	Country	Sport	Number (M/F)	Diagnosis	Gender	Anatomic site (%)							
						Tib	Fib	MT	Nav	Tars	Fem	Pelvis	Ses
Arendt et al [8]	USA	NCAA	28/43	MRI/BS/XR	M	28.6	10.7	35.7	17.9	0	7.8	NR	NR
					F	41.9	10.3	16.5	18.6	2.3	11.6	NR	NR
Benazzo et al [25]	Italy	T-F	22/23	CT/BS/XR	M	33.3	12.5	12.5	29.2	8.3	0	0	0
					F	28	12	16	28	12	0	0	4
Bennell et al [1]	Australia	T-F	12/14	BS/CT	M	41.7	25	0	25	8.3	0	0	0
					F	50	0	14.3	7.1	0	14.3	7.1	0
Brukner et al [24]	Australia	All	102/78	CT/BS/XR	—	20.6	16.7	23.3	14.4	5.6	3.3	1.7	1.1
Courtenay and Bowers [20]	Australia	All	108	XR/BS	—	38	29.6	18.5	4.6	0.9	2.8	0.9	0
Goldberg and Pecora [9]	USA	NCAA	26/32	BS/XR	—	19	12.1	25.9	NR	3.4[b]	10.3	3.4	3.4
Ha et al [23]	Korea	All	169	BS/XR	—	32	10.7	7.2	4.7	1.2	12.4	4.1	1.8
Hulkko et al [28]	Finland	All	217/97	XR/BS	M	64.1	18.4	20.7	2.8	0.9	8.3	0.9	3.7
					F	44.3	4.1	28.9	3.1	0	5.2	5.2	7.2
Iwamoto and Takeda [12]	Japan	All	125/71	XR/MR/BS	—	44.4	4.6	11.2	NR	NR	NR	6.6	3.6
Johnson et al [2]	USA	NCAA	12/22	XR/BS	M	33.3	0	25	0	0	33.3	0	0
					F	41	0	18.2	18.2	0	18.2	0	0
Matheson et al [13]	Canada	All	145/175	BS/XR	M	46.2	5.5	6.9	NR	32.4[b]	6.9	0	1.4
					F	51.4	7.4	10.3	NR	19.4[b]	7.4	1.7	1.7
Nattiv et al [3][a]	USA	T-F	33/37	XR/MRI	—	45	12.1	24.2	NR	NR	12.1	NR	NR
Ohta-Fukushima et al [21]	Japan	All	222	XR/BS	M	21.1	3.5	29.8	NR	1.8[b]	7	1.8	0.9
					F	47.2	7.4	26.9	NR	3.7[b]	0	2.8	0
Sullivan et al [27]	USA	Running	57	XR/BS	—	43.9	21.1	14	0	7	3.5	10.5	0
Taunton et al [30]	Canada	Running	62	XR/BS	—	54	11	16	3	8	6	NR	NR

Abbreviations: BS, bone scan; F, female; Fem, femur; Fib, fibula; M, male; MT, metatarsal; Nav, Navicular; NCAA, National Collegiate Athletic Association; NR, not recorded; Ses, sesamoid; Tars, tarsal; T-F, track and field; Tib, tibia; XR, radiography.

[a] Did not separately report tarsal navicular injuries.

[b] Published as abstract only.

encountered more commonly in track and field athletes. The overall frequency could not be ascertained because several studies did not differentiate navicular fractures from other tarsal bone fractures.

Few conclusions can be drawn from analyzing specific fracture sites by sport, given the small number of reported injuries (Table 5). In a prospective study of elite Australian track and field athletes, Bennell and colleagues [1] did report a

Table 5
Stress fracture occurrence according to sport and bone (by percentage)

Sport	Number	Gender	Tib	Fib	MT	Nav	Tars	Fem	Pelvis	Ses
Basketball										
Arendt et al [8]	4	M	0	0	100[c]	0	0	0	NR	0
	5	F	100	0	0	0	0	0	NR	0
Brukner et al [24]	4	—	25	0	25	25	0	0	0	0
Hickey et al [32][a]	20	F	40	20	15	10	5	5	NR	NR
Iwamoto and Takeda [12]	44	—	63.6	NR	18.2	NR	NR	NR	0	9.1
Distance Running										
Arendt et al [8]	7	M	14.3	0	28.6[c]	28.6	0	28.6	NR	0
	16	F	43.8	0	18.8[c]	18.8	0	18.8	NR	0
Benazzo et al [25]	10	M	40	20	20	20	0	0	0	0
	6	F	33.3	33.3	16.7	0	16.7	0	0	0
Brukner et al [24]	35	—	42.9	22.9	14.3	2.9	5.7	5.7	2.9	0
Hulkko et al [28]	204	—	61.8[b]	NR	27[c]	0	1	6.9	2.5	NR
Sullivan et al [27]	57	—	43.9	21	29.6	0	7	3.5	10.5	0
Taunton et al [30]	62	—	54	11	16	3	8	6	NR	NR
Track										
Arendt et al [8]	4	M	50	0	50[c]	0	0	0	0	0
	9	F	11.1	0	33.3[c]	44.4	0	11.1	0	0
Benazzo et al [25]	14	M	28.6	7.1	17.1	35.7	14.3	0	0	0
	19	F	26.3	5.2	15.8	36.8	10.5	0	0	5.2
Brukner et al [24]	54	—	25.9	9.3	16.7	35.2	3.7	1.9	1.9	1.9
Hulkko et al [28]	39	—	71.8[b]	NR	25.6[c]	2.6	0	0	0	NR
Soccer										
Arendt et al [8]	4	F	25	50	25	0	0	0	0	0
Iwamoto and Takeda [12]	11	—	36.4	NR	9.1	NR	NR	NR	18.2	9.1

Abbreviations: F, female; Fem, femur; Fib, fibula; M, male; MT, metatarsal; Nav, Navicular; NR, not recorded; Ses, sesamoid; Tars, tarsal; Tib, tibia.

[a] Method of diagnosis not described.

[b] Listed only as "lower leg" and includes tibia and fibula.

[c] Listed as "forefoot" and includes sesamoids of great toe and phalanges.

statistically significant ($P \leq .01$) association between specific events and the fracture site. Distance runners were more likely to suffer a long bone (tibia, femur, and fibula) or pelvic stress fracture, whereas foot fractures occurred more frequently in jumpers, sprinters, hurdlers, and multi-event athletes [1]. Although the number of total participants was not given, the findings by Benazzo and colleagues [25] also suggest an association between the "power" running events (jumping and sprinting) in track and the occurrence of tarsal navicular stress fractures.

Overall, fractures of the upper extremities were found to be relatively rare, although most studies focused only on lower-extremity injuries. The ulna was the upper-extremity bone injured most frequently. Because many of the reviewed studies focused on track and field athletes in general and runners in particular, the overall frequency of upper extremity stress fractures could not be discerned. Stress fractures of the axial skeleton also were relatively infrequent, consisting mainly of injuries to the ribs, pars interarticularis, and pelvis. Rib stress fractures were associated with rowing, whereas the majority of athletes with ulnar stress fractures played baseball [12,21]. Dixon and Fricker [26] have found that 45% of all stress fractures in the female gymnasts involved the pars.

MORBIDITY AND OUTCOMES

The available literature offers few data in regard to outcomes and recurrence rates following a stress fracture. Sullivan and colleagues [27] have reported that seven of 51 athletes who had a stress fracture had suffered a radiologically proven fracture before study enrollment. Bennell and colleagues [1] have found that 60% of athletes with a stress fracture over their prospective 12-month observation period had experienced a previous stress fracture. There was a strong recruitment bias in this sample because nearly 40% of all athletes who volunteered to participate in the study had a history of at least one previous stress fracture [1].

Several studies provided varying details regarding concurrent and subsequent stress fractures. Six studies reported more than one stress fracture occurring in 4% to 11% of athletes [1,8,21,23,25,27]. None of the authors commented on whether concurrent fractures were symptomatic or diagnosed only through imaging. Courtenay and colleagues [20] found bilateral stress fractures in 16 athletes (7 tibias, 7 fibulas, and 2 metatarsals), whereas Ha and colleagues [23] reported 7 bilateral stress fractures of the tibia and 2 bilateral fibular stress fractures. Only Sullivan and colleagues [27] reported a reoccurrence of a fracture at the same site as a previous fracture (fibula). Hulkko and Orava [28] found that 9% of total fractures occurred in athletes with a previous fracture, reported during their study period, whereas Bennell and colleagues [1] and Ha and colleagues [23] found rates of 7% and 3%, respectively.

The time period from diagnosis to return to full sports participation varied greatly when reported. Johnson and colleagues [2] found a range of 8 to 17 weeks to return to full activity in eight collegiate athletes with femoral stress fractures. Two studies reported cumulative data regarding the timing of return to sports

Table 6
Time elapsed from treatment to full recovery

Study	Tib	Fib	MT	Nav	Tars	Fem
Benazzo et al [25]	4.8 mo	NR	NR	5.96 mo	NR	NR
Johnson et al [2]	NR	NR	NR	NR	NR	10.8 wk
Matheson et al [13]	11.7 wk	7.7 wk	7.9 wk	NR	17.3 wk	7.5 wk
Taunton et al [30]	4.5 wk	2.4 wk	3.5 wk	NR	10 wk	3.5 wk

Abbreviations: Fem, femur; Fib, fibula; MT, metatarsal; Nav, Navicular; NR, not recorded; Ses, sesamoid; Tars, tarsal; Tib, tibia.

[21,23]. Athletes returned to play at 1.5 months in the series by Ha and colleagues [23], whereas Ohta-Fukushima and colleagues reported that 65% of cases were healed within 12 weeks. Matheson and colleagues [29] and Taunton and colleagues [30] both reported resumption of activity by injury site (Table 6). Matheson and colleagues [29] found an average time to recovery of 12.8 weeks (range, 2–96 weeks) for all fractures, whereas Taunton and colleagues reported a mean time of only 4.8 weeks to "full recovery" [29,30]. Benazzo and colleagues [25] reported a return to activity time far in excess of other studies, likely because of their requirements for study subjects to be asymptomatic and have radiographic evidence of complete fracture healing. Overall, the published data on time missed because of injury have limited clinical application because of the differences in sports, symptoms at the time of presentation, methods of diagnosis, severity of injuries, and return to competition criteria.

Arendt and colleagues [8] have classified stress fractures into four grades based on MRI findings. They found significant differences in time elapsed from diagnosis to return to play, depending on fracture grade [8]. The mean time to resumed play for all athletes was 8.4 weeks; however, recovery time varied from an average of 3.3 weeks for grade 1 injuries to 14.3 weeks for grade 4 injuries [8]. They also found that 20 of 22 foot stress fractures were grade 3 or 4 at the time of diagnosis, suggesting a possible delay in diagnosis [8]. A longer duration of symptoms before diagnosis of tarsal stress fractures was also reported in two additional studies [29,30]. The evidence conflicts as to whether a delay in diagnosis adversely affects recovery time [21,29,30].

Table 7
Fractures requiring surgical fixation

Study	Surgery/total SF (%)	Tib	Fib	MT	Nav	Tars	Fem	Ses	Ulna
Benazzo et al [25]	2/49 (4.1)	1	0	0	0	1	0	0	0
Ha et al [23]	11/169 (6.5)	0	0	0	5	0	4	1	1
Hulkko et al [28]	26/314 (8.3)	7	0	4	3	1	3	4	3
Ohta et al [21]	4/222 (1.8)	1	0	0	0	0	0	0	3

Abbreviations: Fem, femur; Fib, fibula; MT, metatarsal; Nav, Navicular; Ses, sesamoid; SF, surgical fixation; Tars, tarsal; Tib, tibia.

Several stress fractures have been described as "high risk" for delayed union or progression to nonunion [31,32]. Although the cumulative data clearly indicate that the majority of stress fractures heal with conservative treatment, 43 patients were reported to have required surgical fixation (Table 7). In this review, tarsal navicular and tibial fractures were the most ominous injuries encountered, because nearly 40% (17/43) of surgeries were performed for fixation of these two types of fractures. Tibial stress fractures were not classified by anterior or posterior location. The only three career-ending injuries documented resulted from navicular stress fractures. The available evidence suggests that early diagnosis of a tarsal navicular stress fracture requires a high index of suspicion. Navicular stress injuries should not go unheeded, because this type of injury may portend a worse outcome than other stress fractures. Future research is needed to explore preventative strategies of these potentially devastating injuries.

SUMMARY

The pathophysiology of stress fractures is well understood, but a lack of quality epidemiologic data remains. Injuries to the tibia and metatarsals are the most frequent stress fractures reported in the literature. There is a clear association between increasing training volumes and increased risk of stress fracture, but little is known beyond this association. There is a pressing need for large prospective studies to better establish the risks of stress fracture by sport, age, and gender. Such studies would allow a better delineation of specific fracture sites and estimates of injury risk and lay the foundation for future prevention strategies.

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