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Title of Study: The association of bone stress injuries with body mass index percentile drop and eating disorder diagnoses in adolescent athletes

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The association of bone stress injuries with body mass index percentile drop and eating disorder diagnoses in adolescent athletes

Abstract

Context: Adolescence is a critical period for bone development. Due to an elevated risk for low body mass index (BMI) and/or low energy availability, certain adolescent athletes are at increased risk of bone stress injury (BSI) and eating disorders (ED). Despite this risk, the incidence of ED in patients with BSI is unclear.

Objectives: To compare the incidence of premorbid drop in BMI percentile in a sample of adolescent athletes diagnosed with a BSI between 2005 to 2016. We also evaluated the relative risk of developing an ED for this sample, compared to a sex-, age- (+/-6 months), and time-matched (+/-2 years) sample of active adolescents with knee pain.

Design: Retrospective cohort study

Setting: Data collected through the Rochester Epidemiology Project.

Patients: 187 adolescent (ages 13-18) athletes with BSI and 187 active adolescents with knee pain.

Main Outcome Measures: Conditional logistic regression was used to assess whether premorbid weight loss was a risk factor for BSI. A stratified log-rank test was used to evaluate the association between ED diagnosis and case-control status up to 5 years post-injury.

Results: Patients with BSI had 1.53 times the odds of premorbid BMI percentile drop compared to controls (95% CI: 0.83-2.12, $p = 0.17$). A total of 14 patients with BSI had ED diagnoses following injury compared with 8 controls ($p = 0.13$). Patients from weight-based/aesthetic sports had 1.93 times the odds of BSI compared to controls (95% CI 1.23-3.02, $p = 0.0040$). The Kaplan-Meier estimates indicate that the case group had greater risk of ED diagnosis.

Conclusions: Results suggest a trend toward greater drop in BMI percentile and increased frequency of ED diagnoses in the BSI group compared to controls. The documented co-occurrence of weight loss, stress fractures and EDs in adolescent athletes should inform guidelines for screening and treatment of adolescent athletes with BSI.

Key Words: Stress fracture, bone stress injury, eating disorder, BMI, adolescent, REDs

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Key Points:

1. Adolescent athletes with BSI trended toward a greater premorbid drop in BMI percentile and higher frequency of ED diagnoses compared to the control group.
2. Adolescent athletes from aesthetic/weight-based sports and sports with high ground impact and dynamic status had higher odds of BSI.
3. Athletes may not seek care for eating disorders, but most do for a sports injury which can provide an opportunity to identify low energy availability and eating disorders in patients with BSI.

Introduction:

Adolescence (age 13-18 years) is a critical time for bone development, with 50% of peak bone mass developing during this time.[1] Well-established contributors to low bone mass during adolescence include weight loss, low body mass index (BMI), and low energy availability.[1] Low energy availability occurs when dietary energy intake minus exercise energy expenditure normalized to lean body mass or fat-free mass is not adequate to support optimum physiologic function.[2] Low energy availability contributes to bone stress injury through the suppression of estrogen, testosterone, leptin, triiodothyronine, and insulin-like growth factor 1, and the upregulation of adiponectin involved in the regulation of bone modeling and remodeling.[3-5] Increases in cortisol and catecholamines in combination with LEA have also been shown to impair bone modeling.[6] Adolescent female athletes, especially those in aesthetic/weight-based sports (e.g. dance, figure skating, wrestling) and endurance sports with low BMI and low energy availability are at an elevated risk of bone stress injury.[7-11] Further, aesthetic/weight-based sport-athletes may also be more susceptible to eating disorder psychopathology compared to non-aesthetic/weight-based sports, due to the perception that weight/shape significantly alters performance in sport.[12-16]

The terminology used to characterize the physiological and psychological effects of LEA on athletes has evolved over time. Since 1992, the concept of the Female Athlete Triad has been used to refer to the frequently observed combination of disordered eating and irregular menstrual cycles eventually leading to a decrease in endogenous estrogen and other hormones, resulting in low bone mineral density in athletes[17]. Robust research on the Female Athlete Triad established the relationship between low energy, hormonal changes and bone stress injuries[17]. However, through continued scientific investigation it became clear that the definition was overly limited, and the term Relative Energy Deficiency in Sport (REDs), was first described by the International Olympic Committee in 2014.[4] REDs is a syndrome resulting from relative energy deficiency that affects many aspects of physiologic function. REDs in athletes can manifest as iron deficiency, low bone density/fractures, eating disorders, decreased gastrointestinal function, decreased performance, mood changes, and, when relevant, menstrual irregularities.[4,18] Given the association of low energy availability on bone development, a diagnosed bone stress injury should increase suspicion of undiagnosed low energy availability, REDs, and/or an eating disorder, especially in athletes from aesthetic/weight based sports.

Eating disorders and disordered eating in athletes often go undetected and unaddressed by team coaches, healthcare professionals, and school nurses. In addition to a widespread lack of knowledge about eating disorders amongst these professionals,[7] patients may present with no historical height and/or weight data with which to contextualize weight loss. Further, misperceptions about who eating disorders typically impact (i.e., visibly emaciated, young, White, cisgender, females) may delay detection in the numerous patients who do not fit these stereotypes.[19-21] These factors contribute to delayed detection of disordered eating and eating disorders, a delay that can have serious consequences for the psychological and physical health of these young athletes including irreversible loss of bone mineral density, longer injury recovery times, high risk of suicide, and high healthcare costs.[22-23] As such, it is imperative to develop a better understanding of the incidence and presentation of eating disorders and disordered eating, characterized by LEA and/or a loss of BMI percentile, in adolescent athletes with bone stress injuries. This information can ultimately be used to improve prevention, early identification and treatment of disordered eating in this population.

The primary aim of this population-based, retrospective cohort study was to compare the incidence of premorbid BMI percentile drop (defined as ≥ 5 BMI percentile point drop over the preceding two years) in a community-based sample of adolescent athletes diagnosed with a bone stress injury between 2005 to 2016. We also aimed to compare the proportion of these patients who develop a diagnosed eating disorder to a sex-, age- (±6 months), and time-matched (±2 years between injuries) control group of active adolescents with knee pain.

Methods

Participants:

We utilized data from the Rochester Epidemiology Project (REP) database to identify both our case and control patients and obtain their demographics and clinical characteristics. The REP is a population-based medical records-linkage system across clinics, hospitals and other medical facilities in Minnesota and Wisconsin established in 1966.[24-26] The REP captures full-text, person-level inpatient, outpatient, and emergency department data on all medical conditions seen by participating providers in the above-described geographic regions, regardless of patient age, sex, ethnicity, socio-economic or insurance status. The REP's data linkage methods have been validated and have shown high sensitivity (ability to correctly link records that belong to the same person) and specificity (ability to correctly exclude linkage of records not belonging to same person).[24] The REP is considered one of the foremost population-based research resources worldwide.[25]

This longitudinal retrospective chart review study used population-based data provided by the REP to identify and characterize all adolescent patients (ages 13-18 years at diagnosis) with a diagnosis of bone stress injury from 2005-2016 using ICD-9 (733.9) and ICD-10 (M84.3) diagnosis codes. Bone stress injury describes the spectrum from bone stress inflammation/reactions to stress fractures. Subjects were excluded if they had a diagnosed condition that was associated with rapid weight loss, weak bone density, or were at risk of gastrointestinal malabsorption. These included subjects who were wheelchair bound or have notable handicaps, had a diagnosis of celiac disease, tropical sprue, Whipple's disease, inflammatory bowel disease (including Crohn's and ulcerative colitis), cystic fibrosis, osteoporosis, osteogenesis imperfecta, active rickets disease, malignant bone cancer, other or nonspecified intestinal malabsorption, or if the bone stress injury was coded incorrectly.

Adolescents with knee pain were chosen as the control group, as a representative group that included active individuals with stress to the lower extremity in the absence of bone stress injuries. Patellofemoral pain and patella tendonitis were considered as potential control group diagnoses, but it was determined that an insufficient number of providers used these diagnoses in their clinical documentation. As such, in order to ensure a representative control group, we elected to use the more common diagnosis of knee pain, which is often correlated with overuse such as patellofemoral pain or tendinitis which overlaps with bone stress injuries. In an effort to ensure the knee pain was related to active individuals and not traumatic, controls were excluded via chart review if they did not injure themselves while being active or if their knee pain was a result of significant trauma such as a motor vehicle accident.

This study was approved by the Mayo Clinic and XXX Medical Center Institutional Review Boards who review all REP research proposals. All REP studies must comply with the Mayo Clinic Research Authorization (Minnesota State privacy law-statute 144.335, 1997) that requires that individuals provide permission for their medical records to be used in research studies.

Data extraction:

A REP database-trained statistician used data macros to obtain data on patient demographics including age, race/ethnicity, sex assigned at birth, BMI percentile, comorbid diagnoses at index visit, as well as medical and psychiatric diagnoses at all visits following index appointment. Manual medical chart review by a family medicine resident, two licensed psychologists, and a pediatric medicine faculty trained in REP data extraction was performed to confirm age, sex assigned at birth and current gender identification, and obtain additional information including the date of bone stress injury diagnosis and where they were diagnosed, the injured bone(s), if there was imaging evidence of a stress fracture, the athlete's sport, previous stress fracture history, and use of weight loss medications.

Sports classifications:

The adolescents in this study participated in 23 different sports. Sports were grouped based on a standardized classification of the degree of static and dynamic components, as described by Mitchell, J. et al, and Maron et al. (Table 1).[27-28] The dynamic component of each sport was defined in terms of the estimated percentage of maximal oxygen uptake (Vo2 max) achieved and results in an increasing cardiac output.[27-28] The increasing static component is related to the estimated percentage of maximal voluntary contraction reached and results in an increasing blood pressure load.[27-28] Table 1a lists the sports that have the highest impact with the ground based on the sports with the highest ground reaction forces.[29] We also classified our sports based on aesthetic/weight-based versus non-aesthetic/weight-based sports (Table 2). Of participants in the study, 5.6% did not play any sport but were included in the analysis as they were recreationally active.

Statistical Analyses

The CDC SAS macro and reference data were used to calculate BMI percentile by age and sex. Time-series plots were used to visualize BMI percentile in the 2-year period preceding injury. Pre-morbid weight loss was defined as a BMI percentile 5 points lower than any preceding value. Conditional logistic regression was used to test the association between case-control status and the presence of pre-morbid BMI percentile drop. The odds ratio of cases having pre-morbid weight loss compared to controls was estimated with a 95% confidence interval and *p*-value, where $p<0.05$ is statistically significant. Kaplan-Meier curves and negative log-log plots were used to visualize the association between case-control status and diagnosis of eating disorder following injury. The stratified log-rank test was used to test the association between case-control status and diagnosis of eating disorder following injury.

Cases and controls were matched in a 1:1 ratio using age and date of diagnosis. Age was limited to within 6 months and date of injury was limited to within 2 years. Age was weighted 4 times higher than the date of diagnosis when calculating distance between pairs of observations.

The data analysis for this paper was generated using SAS software, Version 9.4 for Linux. Copyright © 2024 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA. Study data were collected and managed using REDCap (Research Electronic Data Capture) electronic data capture tools hosted at Mayo Clinic (XXX).[30-31] REDCap is a secure, web-based software platform designed to support data capture for research studies, providing 1) an intuitive interface for validated data capture; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures for seamless data downloads to common statistical packages; and 4) procedures for data integration and interoperability with external sources.[30-31]

Results

Patient sample characteristics

The final sample consisted of a cohort of 187 13–18-year-old athletes diagnosed with bone stress injury between 2005-2016 and a control cohort of 187 sex-, time-, and age-matched active adolescents with knee pain. The demographics of our study population are shown in Table 3. Fifty eight percent of our sample were females, and 42% were males. The mean age at diagnosis of bone stress injury was 16.1. The control patients were 94.7% non-Hispanic, similar to the case patients (96.3%). The recorded BMI percentile closest to recorded bone stress injury in the controls was 70th percentile compared with the 58th percentile for cases.

Fractured bone and sport distribution

Of our patient sample, 97.3% had bone stress injuries in weight-bearing bones. Athletes in high ground-impact sports were at 6.88 times the odds of having a BSI compared with athletes in non-ground-impact sports (95% CI: 3.28-14.43, $p < 0.0001$). There were also 1.93 times the odds that BSI occurred in adolescent athletes in aesthetic/weight-based sports compared with controls (95% CI: 1.23-3.02, $p = 0.004$). In athletes from sports with higher dynamic levels, there was 12.81 higher odds of having a BSI compared with athletes in sports with low dynamic levels (95% CI: 2.85-57.7, $p < 0.001$), and 6.41 times in sports with moderate dynamic levels compared with low dynamic levels (95% CI: 1.46-28.2, $p = 0.014$).

Association of pre-morbid BMI percentile change

There were 91/187 matched pairs with BMI change data available for both patients and controls. Premorbid BMI percentile drop (≥5%) in the preceding 2 years of injury was observed in 46.8% of patients compared with 36.4% of controls. This corresponded to an estimated 1.53 times the odds (95% CI: 0.83-2.8, $p = 0.17$) of having pre-morbid weight loss in patients diagnosed with bone stress injury compared with controls (Table 4). In high impact sports, the odds of pre-morbid weight loss for cases were 1.86 times that of controls (95% CI: 0.74-4.66, p= 0.19).

Eating disorder diagnoses following bone stress injury

A detailed list of ICD10 and ICD9 diagnosis codes used to identify eating disorder diagnoses post-bone stress injury are shown in Table 5. A total of 14 patients with bone stress injuries had eating disorder diagnoses up to 5 years following injury compared with 8 controls. A 5-year cut off was assigned based on age of most diagnosed eating disorders in the USA (age 13-24) and we wanted to capture the often-delayed diagnoses of eating disorders.[32] There was an association between bone stress injury diagnoses with eating disorder diagnoses up to 5 years post-injury (Figure1). The stratified log-rank test p-value was 0.13 between cases and controls. The chi-square test statistic was 2.33 with 1 degree of freedom. The Kaplan-Meier estimates indicate that the case group had slightly greater risk of eating disorder diagnosis in the early part of the curve where most patients are still followed. For cases, the 5-year estimated survival rate without eating disorder diagnosis was 92% (95% CI: 87%-95%). For controls, the 5- year estimated survival rate without eating disorder diagnosis was 95% (95% CI: 91%-98%). This does not change based on sport.

Discussion

This community-based, longitudinal chart review study explored the association of bone stress injury with pre-morbid BMI percentile drop in adolescent athletes. This study also examined the association of bone stress injury with future eating disorder diagnosis. Our data suggests that there is an association between premorbid weight loss and bone stress injury in this population. This association was not statistically significant. These findings are in line with other studies that have found that weight loss may be associated with a higher risk of stress fracture.[7-10]

Our findings further underscored an association of bone stress injury diagnoses with subsequent eating disorder diagnoses within 5 years after injury. This association was not statistically significant. However, this finding has important implications for eating disorder detection. It is fairly common for eating disorders to go unrecognized in young patients for a lengthy period of time and as such, our documented rates of eating disorder diagnoses are likely underestimates of the true prevalence of these conditions in our sample and the control group. The relatively small number of eating disorder diagnoses likely limited the power of our study.

The well-established elevated risk of disordered eating and eating disorders in athletes [33], particularly in aesthetic sports, suggests this is a population where improved eating disorder awareness is likely beneficial. Low BMI and its associations can be normalized in some sports where eating disorders are likely prevalent, such as aesthetic sports. Such a delay in detection often results in the illness becoming more entrenched and difficult to treat. There are several well-established barriers to patients with eating disorders presenting for eating disorder assessment and/or care, including misperceptions about the illness and the considerable stigma associated with the illness, as well as logistical barriers to accessing eating disorder care. However, fewer barriers exist for patients presenting to sports medicine or primary care clinics with a bone stress injury and, as such, these settings can provide an important point of contact for eating disorder screening. If providers in these settings view bone stress injury as an independent risk factor for eating disorders and consider them as a potential contributor to the bone stress injury, they can improve early eating disorder detection and timely referral to appropriate treatment. Screening for eating disorders in these patients can not only improve outcomes for the eating disorder but also for preventing irreversible bone loss.

The bone and sport distribution for our patients diagnosed with BSI was compelling. Previous literature has described the most commonly affected sites for bone stress injury in adolescents to be in the lower limb,[34] and in sports with higher ground-impact,[35] which are both supported by our study. Furthermore, athletes in aesthetic and weight-based sports in our study had a much higher odds of BSI, further supporting studies that show that energy imbalance is an important predicting factor for BSI in adolescent athletes. Focusing on athletes from these higher-risk sports when it comes to BSI and eating disorder education, screening, and awareness becomes increasingly important.

Limitations of this study include the retrospective chart review methodology, which limits conclusions that can be drawn from these data and the questions we were able to answer. In addition, only a subset of patients had enough height and weight data to calculate the BMI percentiles during the two years prior to their bone stress injury diagnosis. This missing data reduced our sample size and may have resulted in underestimates of BMI percentile loss over the preceding two years. Finally, by including patients with all forms of eating disorders (e.g. restrictive versus binge versus bulimia), our data may have been skewed. It would be important to identify trends in the types of eating disorders in patients with bone stress injury in a larger sample.

Despite these limitations, our findings support an association of bone stress injury with pre-morbid weight loss, as well as a possible relationship between bone stress injury and future eating disorder diagnoses. The higher odds of BSI in aesthetic/weight-based sports also supports an association between BSI and REDs diagnoses. These findings highlight the need for clinicians to collect and review height, weight and BMI data for all patients presenting to well child visits and sports medicine visits, especially those with a history of or are suspected of having a bone stress injury. Athletic trainers and primary care physicians (PCPs) should also keep these findings in mind when an athlete presents with BSI. Athletic trainers and PCPs often have long-standing relationships with student athletes and are well positioned to assist with screening through preparticipation examinations and training room evaluations.

Height, weight, and BMI are not routinely collected in sports medicine and orthopedic practices which can impact ability to detect situations of LEA and/or eating disorder diagnosis. BMI percentile data will provide additional screening for REDs and eating disorders to inform further eating disorder assessment and treatment. Such data can also support future research in this area. More studies with a larger patient population are needed to further explore this association to substantiate these findings.

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Figure 1: Kaplan-Meyer Plot Describing Cumulative Incidence of Eating Disorder Diagnosis in Cases and Controls After Injury

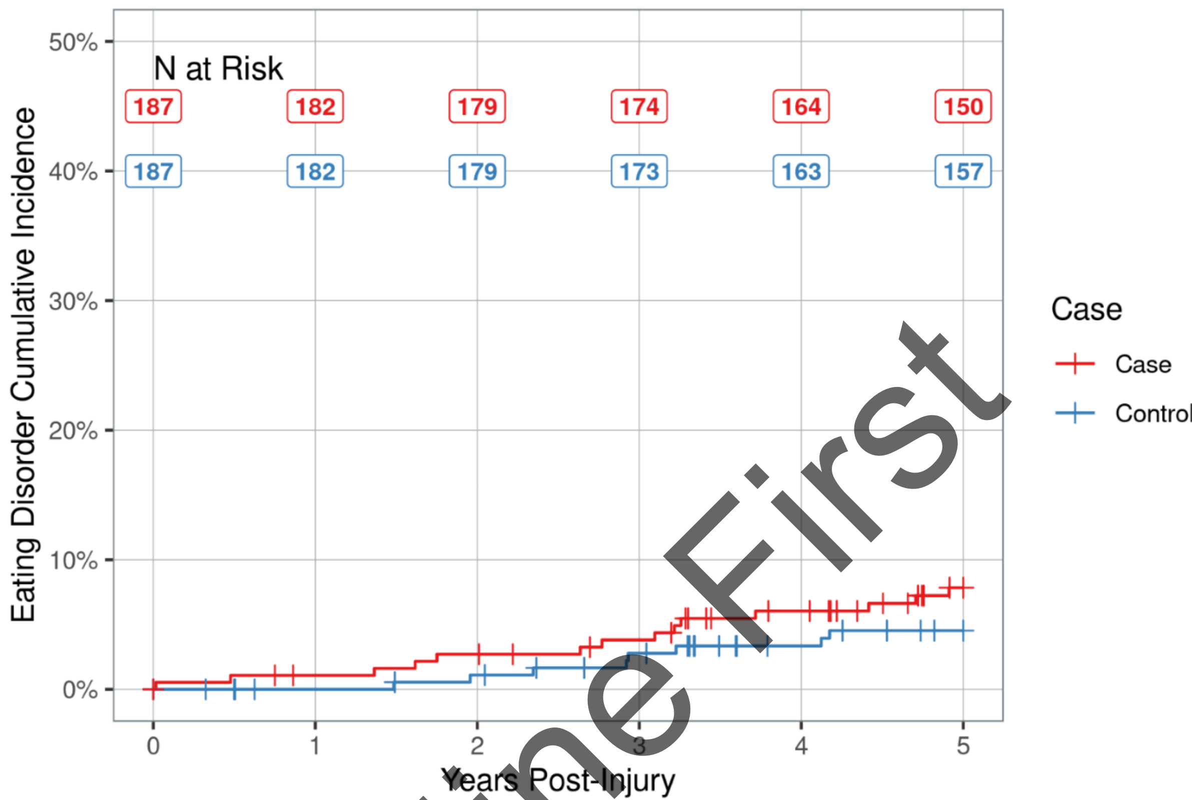

Table 1: Classification of Sports Based on Degree of Dynamic, Static, and Ground Impact

	Low Dynamic	Moderate Dynamic	High Dynamic
High Static	Softball	Wrestling, Skiing/Snowboarding, Gymnastics, Figure Skating, Martial Arts/Kung Fu	Dirt Biking, Road Biking
Moderate Static	Equestrian	Track and Field, Recreational Activity, Football, Dance, Cheerleading	Ice Hockey, Lacrosse, Basketball, Running/Cross Country, Swimming, Tennis
Low Static		Volleyball, Baseball	Soccer

Table 1a: High Ground-Impact Sports

High ground-impact sports:
Skiing/Snowboarding, Gymnastics, Track and Field, Football, Dance, Cheerleading, Lacrosse, Basketball, Running/Cross Country, Tennis, Soccer

Table 2: Classification of Sports Based on Aesthetics and/or Weight

Aesthetic and/or Weight Based	Not Aesthetic and/or Weight Based
Figure skating Dance Gymnastics Cheerleading Equestrian Wrestling Martial Arts/Kung Fu Running/Cross County	Softball, Skiing/Snowboarding, Track and Field, Recreational Activity, Football, Volleyball, Baseball, Dirt Biking, Road Biking, Ice Hockey, Lacrosse, Basketball, Swimming, Tennis, Soccer

Table 3: Patient Demographics

	Case Status	
	Control (N=187)	Case (N=187)
Sex, n (%)		
Female	108 (57.8%)	107 (57.2%)
Male	79 (42.2%)	80 (42.8%)
Age at Injury / Control DX		
N	187	187
Mean (SD)	16.1 (1.42)	16.1 (1.42)
Range	13.1, 18.9	13.0, 18.9
Race, n (%)		
1= Black	8 (4.3%)	4 (2.1%)
2= Asian	7 (3.7%)	7 (3.7%)
4= Am. Indian	1 (0.5%)	1 (0.5%)
5= Other/Mixed	7 (3.7%)	3 (1.6%)
6= White	162 (86.6%)	170 (90.9%)
98=Refusal	1 (0.5%)	0 (0.0%)
99=Unknown	1 (0.5%)	2 (1.1%)
Ethnicity, n (%)		
Non-Hispanic	177 (94.7%)	180 (96.3%)
Hispanic	10 (5.3%)	7 (3.7%)
BMI closest to Injury		
N	119	116
Median (IQR)	22.1 (20.2, 25.3)	21.3 (19.4, 23.2)
Range	15.6, 48.9	15.6, 49.1
BMI Percentile closet to Injury		
N	119	116
Median (IQR)	69.7 (49.4, 88.4)	58.1 (40.2, 81.7)
Range	3.1, 100.0	2.5, 100.0

Table 4: Weight Loss Changes Pre- and Post-Injury

Premorbid Weight Loss Pre-Injury (drop of 5% from CDC BMI growth chart), n (%)	Control (N=187)	Case (N=187)
No	84 (63.6%)	67 (53.2%)
Yes	48 (36.4%)	59 (46.8%)
Missing	55	61

Postmorbid Weight Loss Post-Injury (drop of 5% from CDC BMI growth chart), n (%)	Control (N=187)	Case (N=187)
No	74 (63.8%)	54 (51.9%)
Yes	42 (36.2%)	50 (48.1%)
Missing	71	83

Table 5: List of ICD10 Codes Used for Eating Disorder Diagnoses Following Bone Stress Injury

ICD 10 Codes	ICD 9 Codes
F50.00 Anorexia nervosa, unspecified F50.01 Anorexia nervosa, restricting type F50.02 Anorexia nervosa, binge eating/purging type F50.2 Bulimia nervosa F50.8 Other eating disorders F50.81 Binge eating disorder F50.89 Other specified eating disorder F50.9 Eating disorder, unspecified R63.0 Anorexia R63.4 Abnormal weight loss R63.6 Underweight Z72.4 Inappropriate diet and eating habits	307.1 ANOREXIA NERVOSA 783.0 ANOREXIA 783.2 ABNORMAL LOSS OF WEIGHT 783.21 LOSS OF WEIGHT 783.22 UNDERWEIGHT 307.5 OTHER AND UNSPECIFIED DISORDERS OF EATING 307.50 EATING DISORDER, UNSPECIFIED 307.51 BULIMIA 307.59 OTHER DISORDERS OF EATING

Supplementary Table 1: Comparison between type of sport played and location of bone stress injury in adolescent athletes

Sport	Tarsal	Tibia	Calcaneus	Femur_Shaft	Fibula	Metatarsal	Navicular	Lumbar_Vertebrae	Humerus	Femur_Neck	Pelvis	Metacarpal_Bone	Ulnar	Thoracic_Vertebrae
Baseball	1	1												
Basketball	2	2	1	1	3	7	1							
Cheerleading		1												
Dance		6			1	7								
Figure Skating						2								
Football	1	4	3	1	1	5	1							
Gymnastics		4			3	1								
Ice Hockey	1	2	2			1								
Lacrosse		3			1									
No Sport						1		1						
Recreational Activity		2				2			1					
Running	2	29		5	8	17	2			3	1			
Skiing/Snowboarding		1			1									
Soccer		11		2	5	8	1			2		1		
Softball					1	1								
Tennis		1	1			4							1	
Track and Field		20		3	3	10								
Volleyball	1	2				2								1
Wrestling		1				1								