IJSPT

ORIGINAL RESEARCH

LOWER EXTREMITY OVERUSE BONE INJURY RISK FACTORS IN COLLEGIATE ATHLETES: A PILOT STUDY

Mark F. Reinking, PT, PhD, SCS, ATC[1]
Tricia M. Austin, PT, PhD, ATC[1]
Jason Bennett, PT, PhD, SCS, ATC[1]
Ann M. Hayes, PT, DPT, OCS[1]
William A. Mitchell, MD[2]

ABSTRACT

Background and Purpose: There is limited evidence regarding risk factors for lower extremity overuse bone injury (LEOBI) in collegiate athletes. The purposes of the study were to: 1) determine incidence of LEOBI in selected sports and its impact on athletic participation and ADL, 2) assess risk relationships between LEOBI and selected risk factors, and 3) establish the viability of using calcaneal densitometry as a screening tool to identify risk for LEOBI.

Study Design: Prospective analytical cohort design

Methods: Collegiate athletes in selected sports (swimming/diving, women's soccer, field hockey, cross-country/track) at one university were invited to participate. Consenting athletes completed an initial questionnaire including demographic information, history, and menstrual function. Measurements included height/weight, hip abductor strength, foot posture index, and calcaneal bone mineral density. Athletes were monitored for potential LEOBI for nine months and an algorithm was used to determine if physician referral was required. The primary outcome of interest was the occurrence of physician-diagnosed LEOBI. If LEOBI was diagnosed by the physician, the athlete completed a follow-up visit including a repeat bone mineral density scan. All athletes were invited for a repeat scan at the end of the year and completed a final questionnaire. Athlete demographics were summarized using descriptive statistics and differences in continuous risk factors were analyzed using t-tests and ANOVA. Finally, risk relationships for categorical variables were analyzed using chi-square and relative risk.

Results: 84 athletes (64 female, 20 male) consented to participate. Over the study period, eight athletes (one male, seven females) were diagnosed with LEOBI (LEOBI group), five with stress fractures and three with medial tibial stress syndrome. The other 76 athletes who did not have a diagnosis of LEOBI were placed in the non-LEOBI group. Five of the eight were cross-country/track athletes; no swimming/diving athletes had bone injury. Sport (cross-country/track) had a significant relative risk value of 2.26 (95% CI = 1.18-4.32) for LEOBI. There was no association between LEOBI occurrence and sex, hip abductor strength, body mass index, foot type, and menstrual function. There was no difference in bone mineral density at initial or follow-up measures between LEOBI and non-LEOBI groups ($p > .05$) when analyzing all athletes. When analyzing ground-based athletes only at follow-up ($n = 44$), athletes with LEOBI had lower bone mineral density of right ($p = .05$) and left ($p = .07$) calcaneus. The relative risk for developing LEOBI based on calcaneal bone mineral density below the mean of the study participants was 2.1 (95%CI = 1.09-3.35) on the left and 1.53 (95% CI = .80- 3.06) on the right.

Conclusion: The incidence of LEOBI in this population of athletes was approximately 10%. Risk factors were sport (cross-country/track) and decreased left calcaneal bone mineral density. This study supports the use of calcaneal bone mineral density as a screening measurement for LEOBI risk and suggests the need for further investigation into additional LEOBI risk factors.

Level of evidence: 2

Key words: Bone density, medial tibial stress syndrome, overuse injury, risk, stress fracture

[1] Department of Physical Therapy & Athletic Training, Saint Louis University, Saint Louis, MO, USA
[2] Department of Family & Community Medicine, Saint Louis University, Saint Louis, MO, USA

CORRESPONDING AUTHOR
Mark F. Reinking, PT, PhD, SCS, ATC
Saint Louis University
Department of Physical Therapy & Athletic Training
3437 Caroline Mall
Saint Louis, MO 63104
E-mail:reinking@slu.edu

INTRODUCTION

Stress fractures[1-4] and medial tibial stress syndrome (MTSS)[5-9] are lower extremity overuse bone injuries (LEOBI) that result from microtrauma to bone. LEOBI is commonly experienced in the athletic population[2-5,8,10-13] with evidence suggesting that these conditions adversely affect not only athletic participation,[12-14] but also activities of daily living (ADL).[15] Furthermore, premenopausal bone fractures including stress fracture increase the risk for future fractures in a woman's life.[16,17] Presently, the impact of LEOBI on athletic participation and ADL in collegiate athletes is not clearly quantified, and there is an incomplete understanding of the risk factors for the development of LEOBI. Because of this lack of evidence, evidence-based prevention strategies for LEOBI do not currently exist.

Stress fractures involve microstructural bone failure, and recent evidence suggests that MTSS, which presents as pain along the posteromedial border of the distal two-thirds of the tibia, also involves changes in bone tissue.[6,7,18,19] Lower extremity (LE) stress fracture annual incidence rates in collegiate track and field athletes range from 11%[20] to 21%,[21] and two studies prospectively examining stress fracture occurrence across multiple collegiate sports reported an annual incidence ranging from 1.9%[2] to 3.7%.[3] MTSS is a common condition in athletes, especially among runners.[5,8,12,13,22] with incidence reported in a range of 4%-35%.[23,24] In a study of collegiate female athletes across multiple sports, 22% developed MTSS or stress fracture (tibial or fibular) over the course of a single fall season.[22]

There is a need for LEOBI risk factor identification in order to develop screening measures and prevention strategies. van Mechelen[25] proposed a sport injury prevention model involving four steps: (1) identifying the extent of the injury problem, (2) understanding the etiology and mechanism of injury, (3) introducing appropriate preventative measures, and (4) assessing the effectiveness of those measures. In a recent systematic review[26] of overuse injury prevention, the authors concluded that there is little objective evidence supporting current interventions to prevent LEOBI. One potential reason for this paucity of evidence is that the second step of van Mechelen's model, understanding the etiology and mechanisms of injury, has been inadequately investigated. Failure to identify risk factors will not allow the shift toward an evidence-based prevention and intervention focus.

The most consistent LEOBI risk finding is that athletes who have a history of a stress fracture or MTSS are at higher risk for the reoccurrence of those conditions.[10,12,13,22] However, most other evidence pertaining to LEOBI or other LE overuse injury risk factors is relatively weak or conflicting. In a study by Niemuth et al,[27] a group of recreational runners reported an association between hip abductor weakness and LE overuse injury including stress fractures and MTSS. This finding of hip abductor weakness was supported by Verrelst et al[28] for athletes with exertional medial tibial pain. Regarding abnormal foot biomechanics as a risk for LEOBI, some evidence suggests that excessive pronation is a risk factor,[5,29-34] other evidence suggests excessive supination is a risk factor,[35,36] and a third group of studies have not supported either as a risk factor.[8,12,13]

Neely[37] reported a high body mass index (BMI) was a risk factor for LEOBI in military men and women, but low BMI was only a risk factor for military females. Other investigators have not found any association between body composition and LEOBI.[22,38,39] Goldberg and Pecora[2] and Ohta-Fukushima et al[40] found a relationship between athlete-reported increase in training and stress fracture occurrence. Several investigators have reported that menstrual dysfunction is a risk factor for stress fractures in athletic women,[4,38,41,42] however, the association of MTSS and menstrual dysfunction has not been substantiated. A risk relationship has been shown between LEOBI and low bone mineral density (BMD) as measured using dual-energy X-ray absorptiometry (DXA).[7,43] Prouteau et al[44] used ultrasound densitometry to examine risk of stress fracture in athletic women and found no difference in calcaneal speed of sound (SOS) or broadband ultrasound attenuation (BUA) between those athletes with a history of stress fracture and a control group. As this was a cross-sectional study, the authors did not control for the chronology of stress fracture diagnosis in the injured group. Chatzipapas et al[45] and Lappe et al[46] used calcaneal ultrasound to examine risk for stress fracture in military personnel and both found ultrasound density measures to be predictive of stress fracture risk.

In order to prevent and/or more effectively treat LEOBI in the future, a better understanding of its risk factors is crucial. Therefore, the authors established three purposes for this study: 1) to determine the incidence of LEOBI over one academic year in selected intercollegiate sports with confirmatory medical diagnoses and describe the impact of LEOBI on athletic participation and ADL (specifically walking and stair climbing), 2) to assess risk relationships between LEOBI and selected potential modifiable risk factors including hip abductor strength, foot type, body mass index (BMI), changes in training, calcaneal bone density, history of LEOBI, and menstrual function, and 3) establish the viability of using calcaneal densitometry as a screening tool for LEOBI.

METHODS

This study was approved by the Saint Louis University Institutional Review Board. It was a prospective analytical cohort design in which collegiate athletes in selected sports at one National Collegiate Athletic Association (NCAA) Division I university were followed for one academic year (August 2012 to May 2013). Sports were selected based on highest occurrence of LEOBI as recorded in the university intercollegiate athletic injury reports from the previous two years. Research team members attended team meetings for selected teams, described the research study to athletes, and answered any questions pertaining to the study. Athletes who elected to participate in the research study completed informed consent.

Participants

Athletes on the swimming/diving team, women's soccer team, field hockey team, and cross-country/track team (including running and field events) were invited to participate. Participants were between 18 and 23 years of age and were free of current lower extremity injury. Exclusion criteria consisted of: 1) age less than 18 years, 2) not a member of the swimming/diving, women's soccer, field hockey or cross-country/track teams, 3) unable to perform double limb stance with symmetrical weight-bearing.

Procedures

Risk factor data was collected on all participants prior to the start of the 2012-2013 fall season. Participants were monitored over the academic year for the development of LEOBI. Participants received monthly email reminders asking them to report any lower extremity pain to their team athletic trainer (AT). At the end of the study period, two groups were formed, participants with LEOBI and participants without LEOBI during the academic year.

Preseason Questionnaire

Participants completed a web-based questionnaire including gender, academic collegiate year, athletic collegiate year, sport, use of foot orthotics, lifetime history of diagnosed lower extremity stress fracture, history of medial leg pain in the last 12 months, and for women, menstrual function history.

Height and Weight

A standard scale was used to measure weight (pounds) and a wall-mounted tape measure was used to measure height (inches). BMI (kg/m^2) was calculated using the height and weight measures converted to the metric system.

Isometric Hip Abductor Strength

Hand-held dynamometry (Microfet, Hogan Industries, Draper, UT) was used to measure bilateral isometric hip abductor strength in sidelying using the standard muscle testing position described by Kendall.[47] Randomization of the initial test leg was determined by coin flip. Participants were then placed in sidelying and the test leg placed into 30 degrees of hip abduction. The tester stabilized the hip proximally at the iliac crest and provided an adduction force at the knee approximately two cm proximal to the lateral epicondyle.[27] The break-test method was used to elicit a maximal effort with the tester blinded to the force being produced during the test. The muscle contraction was performed for two seconds and repeated two times, with a 30 second rest period between each effort. The average force (in Newtons) was calculated for the two trials.

Foot Posture Index

The Foot Posture Index – 6 (FPI-6) is a criterion based visual assessment of midfoot, forefoot, and rearfoot posture,[48] and has been used in other studies examining the relationship of foot posture and injury.[49-53] Six regions of the foot are scored using a 5-point Likert scale and summed to provide a composite score with lower numbers reflecting a more supinated foot and higher numbers a more pronated foot. The FPI-6 was performed with the subject in relaxed double limb stance with symmetrical weight bearing with their arms at their side and head in neutral. The examiner moved around the subject based on the region of the foot being assessed and a score was recorded. The composite score was calculated and used to classify foot posture categorically as: highly pronated, pronated, neutral, supinated, or highly supinated.

Calcaneal Densitometry
Calcaneal bone mineral density (cBMD) was determined quantitatively using the Sahara clinical bone sonometer (Hologic, Inc, Waltham, MA). The authors chose to examine cBMD using ultrasound densitometry for three reasons. First, there is no exposure to ionizing radiation with this measurement unlike DXA, an important consideration when studying a young adult population. Second, the ultrasound densitometer is a relatively inexpensive and portable device which requires minimal operator training and minimal time to use. Third, ultrasound densitometry has been shown to have similar prediction capability for fracture risk as compared to DXA.[54-56]

Prior to each day of testing, calibration of the densitometer was assessed as described by manufacturer guidelines. The tester then applied an oil based coupling gel (Hologic, Inc.) to both transducer pads. Participants were seated in a straight-back chair approximately 12-18 inches from the scanner and the bilateral heels were inspected for abrasions or open sores. The tester cleaned the sides of the heels with a towelette and dried the heel prior to testing. The subject's foot was then placed into the foot well with the heel firmly in the heel cup and the foot aligned with the positioning line located between the second and third toe. The positioning aid was then lowered and the subject's leg position adjusted to within two finger widths between the anterior tibia and positioning aid. The positioning aid was firmly secured to the leg with a strap and the subject was instructed to remain still during the test. The subject's heel placement was checked to ensure proper placement and the measurement was then initiated. The transducer pads moved to the measurement position and the measurement was completed in less than 10 seconds. Speed of sound (m/s) and an estimate of the subject's cBMD (g/cm^2) was calculated by the unit. The measures were recorded and the steps were repeated for the subject's opposite heel.

LEOBI Diagnosis
The LEOBI diagnostic process involved the team athletic trainers (AT) and one designated university sports medicine physician who was a member of the research team. Participants with symptoms suggestive of LEOBI as determined by the team athletic trainer were asked to rate their pain using the Nirschl scale (Table 1).[57] Referral to the physician was based on the following algorithm: 1) athletes without LEOBI history presenting with Nirschl Levels 1-3 pain (pain not interfering with activity) suggestive of LEOBI were monitored and routine interventions were provided by the AT; 2) athletes with a history of LEOBI presenting with Nirschl Levels 1-3 pain suggestive of a new occurrence of LEOBI received routine interventions by the AT and were referred to the physician; 3) athletes presenting with Nirschl Levels 4-7 (pain interfering with activity) suggestive of LEOBI received routine interventions provided by the AT and were referred to the physician.

The physician performed an examination of the referred athletes to establish a medical diagnosis for the athlete's condition. The clinical criteria for diagnosis of medial tibial stress syndrome and stress fracture were based on Kortebein et al[58] and physician-selected provocative tests (Table 2). Examination by the physician included radiographs, bone scans, and/or MRI if indicated based on standard care.

Follow-Up of Athletes Diagnosed with LEOBI
Athletes diagnosed with LEOBI by the physician were asked to participate in a brief follow-up exam with a member of the research team. The follow-up was scheduled within a week of diagnosis and included a structured interview with the athlete with questions regarding training changes prior to the injury diagnosis and the impact LEOBI had on daily activities and athletic participation. Female athletes were queried regarding changes in menstrual function. Repeat calcaneal ultrasound densitometry also was performed at this time on all athletes diagnosed with LEOBI.

Table 1. *Nirschl Rating Scale*[44]

Level	Description
Level 1	Stiffness or mild soreness after specific sport activity. Pain is usually gone within 24 hours.
Level 2	Stiffness or mild soreness before specific sport activity that is relieved by warm-up. Symptoms are not present during specific sport activity, but return afterward, lasting up to 48 hours.
Level 3	Stiffness or mild soreness before specific sport activity. Pain is partially relieved by warm-up, is minimally present during activity, but does not interfere with the activity.
Level 4	Similar to Level 3 pain but more intense. Pain interferes with activity causing the athlete to alter training or performance of the sport. Mild pain occurs with activities of daily living, but does not cause a major change in them.
Level 5	Significant (moderate or greater) pain before, during, and after activity, causing alteration of activity. Pain occurs with activities of daily living (walking, stair climbing), but does not cause a major change in them.
Level 6	Level 5 pain that persists even with complete rest. Pain disrupts simple activities of daily living.
Level 7	Level 6 pain that also disrupts sleep consistently. Pain is aching in nature and intensifies with activity.

Table 2. *Medial Tibial Stress Syndrome and Stress Fracture Differential Diagnosis*

	Medial Tibial Stress Syndrome	Stress Fracture
Presentation	Middle or distal, diffuse, posteromedial tibial pain with use	Focal bone pain progressively worsening
Exam	Diffuse tenderness along posteromedial tibia No focal percussion pain No distant percussion pain Provocative tests* negative Neurovascular evaluation normal	Focal tenderness Focal percussion pain present Distant percussion pain present Provocative tests* positive Neurovascular evaluation normal
*Tuning fork, single leg hop, fulcrum test		

All athletes were asked to participate in repeat calcaneal densitometry at the end of the academic year unless they had undergone a measurement within the past three months. At the time of repeat measurement, athletes were asked to complete a final questionnaire that included sport, use of foot orthotics, occurrence of medial leg pain over the past academic year, and for women, menstrual function over the past academic year.

Data Analysis

The primary outcome of interest was the occurrence of diagnosed LEOBI. Overall participant demographics were analyzed using descriptive statistics with breakdown by percentage of all athletes and by sport. Incidence rates of LEOBI during the academic year were calculated for all athletes and by sport. Potential risk relationships were investigated using independent t-tests or ANOVA for continuous measures which included quantitative BMI, hip abductor strength, cBMD, and SOS. Chi-square was used to analyze categorical measures including sex, sport, categorical BMI, FPI-6, previous LEOBI, and menstrual function. Relative risk for LEOBI was calculated using 2x2 contingency tables with LEOBI/no-LEOBI cross-tabulated with bivariate potential risk factors. Data pertaining to changes in training and the effect of LEOBI on sport participation and

ADL acquired in interviews of athletes with diagnosed LEOBI were summarized by frequency counts. Although efforts were made to collect all data points from all participants, if there were missing data, the analyses were conducted with a smaller sample size.

Reliability

To assess the reliability of the calcaneal densitometry (SOS, cBMD), the field hockey team was randomly selected to have repeated density measures of both feet at time of initial data collection. For FPI-6 reliability, the FPI-6 of 15 volunteers was assessed with the tester blinded to name and person and could only visualize the lower leg and foot. Volunteers were then presented in random order for a second assessment of FPI-6. Intrarater reliability was calculated using intraclass correlation coefficients (3,1) for cBMD and FPI-6. SPSS version 20.0 (Chicago, IL) was used for all data management and analysis.

RESULTS

A total of 150 intercollegiate athletes from four sports were invited to participate in the study, and 84 (56%) completed informed consent. Of the 84 athletes who completed initial testing, 54 (64%) returned for follow-up testing in May 2013. Athletes were contacted multiple times and provided with multiple data collection times to encourage follow-up. Reasons for non-participation in follow-up were unknown. All data points were collected on all 84 athletes at initial visit except cBMD for one athlete was not collected because of narrow heel size. All data points were collected on all 54 athletes at time of follow-up. Participant demographics are summarized in Table 3. Mean BMI was significantly different between sport teams (Table 4); athletes on the cross-country/track team had significantly lower BMI than those on the field hockey and swimming/diving teams.

Over the academic year, eight of the 84 athletes (9.5%) were diagnosed with LEOBI; five with stress fractures (one metatarsal, two tibial, one femoral, and one pubic ramus) and three with MTSS. No swimming/diving athletes were diagnosed with LEOBI; five of the athletes with LEOBI were cross-country/track athletes, two were soccer athletes, and one was a field hockey athlete. A 2 x 2 contingency table (Table 5) between sport (cross-country/track, not cross-country/track) and LEOBI occurrence revealed a significant relative risk value of 2.26 (95% CI = 1.18-4.32) for the development of LEOBI in cross-country/track athletes. There was no significant association between the development of LEOBI and sex ($p = .43$), BMI ($p = .51$), foot type (R $p = 1.0$, L $p = .76$), hip abductor strength (R $p = .28$, L $p = .61$), and menstrual function during the study period ($p = .57$) in this group of athletes. Also, there was no significant association between the occurrence of LEOBI and a history of exercise-related leg pain (ERLP) over the past 12 months ($p = .12$) or a history of stress fracture ($p = .43$). Of the eight athletes with confirmed LEOBI, three athletes were unable to participate in practice or competition following injury for a week or greater, and only one of those reported that their LEOBI interfered with ADL.

The calcaneal densitometer measures (SOS, cBMD) for all athletes at the initial and follow-up visit showed no significant difference ($p > .05$) between the athletes who did and did not develop LEOBI,

Table 3. *Participant demographics*

Sport	Gender		Year in University				
	Male	Female	FR	SO	JR	SR	5th Year
Field Hockey	0	15	3	7	4	1	0
Soccer	0	24	9	7	5	3	0
Swimming/Diving	7	12	4	9	2	4	0
Cross-country/Track	13	13	6	12	6	1	1
Total	20	64	22	35	17	9	1

FR = freshman, SO=sophomore, JR=junior, SR=senior

Table 4. *BMI (mean and categorical) by sport*

	Mean BMI (kg/m^2)	Underweight (< 18.5 kg/m^2)	Normal (18.5-24.9 kg/m^2)	Overweight (25.0-29.9 kg/m^2)
Field Hockey	23.29	0	12	3
Soccer	22.14	0	22	2
Swimming/Diving	23.22	0	14	5
Cross-Country/Track[a]	20.97	3	22	1
ALL	**22.23**	**3**	**70**	**11**

[a]Significantly lower than field hockey and swimming/diving (p<.05)

Table 5. *2 x 2 Contingency Table (Sport x LEOBI)*

Sport	LEOBI	No-LEOBI	Total
XC/Track	5	21	26
Not XC/Track	3	55	58
Total	**8**	**76**	**84**

LEOBI=lower extremity overuse bone injury
XC=Cross-country
Chi-square=4.12 (p=.042); RR=2.26 (95% CI=1.18 – 4.32)

although there was a trend towards decreased SOS and cBMD values in the athletes who developed LEOBI at both measurement times (Table 6). Comparison of calcaneal densitometer measures (SOS, cBMD) across the four sport teams using a one-way ANOVA was significant, with the swimming/diving team showing the lowest density measures (Table 7). Using post-hoc Tukey LSD analysis, the authors found that the swimming/diving and field hockey teams had significantly lower calcaneal densitometer measures than the women's soccer and cross-country/track teams.

As swimming/diving athletes had significantly lower cBMD and SOS bilaterally than the other three teams ($p < .005$), less dry-land training as compared to previous years, and no occurrence of LEOBI during the academic year, the calcaneal densitometer measures were analyzed (SOS, cBMD) for the sports that were ground-based (cross-country/track, field hockey, women's soccer). This analysis revealed a significantly lower R cBMD in the LEOBI group ($p = .05$), and a trend towards decreased L cBMD in the LEOBI group ($p = .07$) at the follow-up measure (Table 8). To examine risk of developing LEOBI based on cBMD, the authors dichotomized the ground-

Table 6. *Initial (n = 84) and follow-up (n = 54) calcaneal densitometry measures by group*

Measure	LEOBI Group (Mean ± SD)	No-LEOBI Group (Mean ± SD)
R SOS (Initial)	1595.0 ± 25.5	1606.3 ± 37.1
L SOS (Initial)	1597.4 ± 38.5	1605.0 ± 33.1
R cBMD (Initial)	.661 ± .119	.715 ± .152
L cBMD (Initial)	.645 ± .137	.704 ± .141
R SOS (Follow-up)	1587.1 ± 29.9	1603.3 ± 33.6
L SOS (Follow-up)	1593.2 ± 33.7	1605.0 ± 31.7
R cBMD (Follow-up)	.619 ± .140	.694 ± .130
L cBMD (Follow-up)	.649 ± .150	.715 ± .137

LEOBI=lower extremity overuse bone injury
SOS= Speed of sound (m/s), cBMD= calcaneal bone mineral density (g/cm^2)
All p values > 0.05

Table 7. *Bone densitometry measures by sport*				
Sport	**R SOS**	**L SOS**	**R cBMD**	**L cBMD**
Field Hockey	1594.8 ± 26.8	1600.7 ± 24.6	.667 ± .110	.687 ± .098
Soccer	1625.8 ± 40.3	1619.1 ± 37.8	.786 ± .179	.758 ± .169
Swimming/Diving	1580.7 ± 27.9[a]	1579.9 ± 20.7[a]	.627 ± .115[b]	.610 ± .084[b]
XC/Track	1610.8 ± 30.8	1610.5 ± 32.3	.729 ± .128	.714 ± .141

SOS= Speed of sound (m/s), cBMD= calcaneal bone mineral density (g/cm^2)
XC=Cross-country
R SOS F=7.44 (p=.000); L SOS F=6.30 (p=.001)
R cBMD F=5.18 (p=.003); L cBMD F=4.54 (p=.005)
[a]Significantly lower than soccer and cross-country/track ($p<.05$)
[b]Significantly lower than soccer ($p<.05$)

Table 8. *Initial and follow-up bone densitometry measures of ground-based athletes by group (n = 64 athletes at initial, n = 44 at follow-up)*		
Measure	**LEOBI Group (Mean ± SD)**	**Non-LEOBI Group (Mean ± SD)**
R SOS (Initial)[a]	1595.0 ± 25.5	1615.0 ± 35.9
L SOS (Initial)[a]	1597.4 ± 38.5	1613.4 ± 32.3
R cBMD (Initial)[a]	.661 ± .119	.745 ± .151
L cBMD (Initial)[a]	.645 ± .137	.735 ± .143
R SOS (Follow-up)[a]	1587.1 ± 29.9	1610.3 ± 32.9
L SOS (Follow-up)[a]	1593.2 ± 33.7	1612.0 ± 30.0
R cBMD (Follow-up)[b]	.619 ± .140	.722 ± .127
L cBMD (Follow-up)[c]	.649 ± .150	.745 ± .129

LEOBI=lower extremity overuse bone injury
SOS= Speed of sound (m/s), cBMD= calcaneal bone mineral density (g/cm^2)
[a]$p>.05$
[b]$p=.05$
[c]$p=.07$

based athletes into two groups for each foot, those with cBMD greater than or equal to the ground-based athletes group mean, and those with cBMD below the ground-based athletes group mean. The relative risk for developing LEOBI based on L cBMD below the group mean was 2.1 (95% CI = 1.09-3.35) and based on R cBMD below the group mean was 1.53 (95% CI = .80- 3.06).

From the cBMD reliability study (Table 9), the intra-class correlation coefficient values ($ICC_{3,1}$) were all greater than 0.95, indicating a high level of measurement consistency. The intratester correlation coefficient value ($ICC_{3,1}$) for the FPI-6 was .82 (95% CI .61-.92) aggregated across both feet.

DISCUSSION

The first purpose of this study was to quantify the incidence of LEOBI in a select group of collegiate athletes during an academic year with confirmatory medical diagnosis, and to describe the impact of the

Table 9. *Calcaneal densitometer reliability (n = 15)*

Measure	T1	T2	ICC $_{3,1}$
L cBMD	0.687	0.693	0.953
L SOS	1600.7	1602.8	0.974
R cBMD	0.667	0.678	0.980
R SOS	1594.8	1600.0	0.969

SOS= Speed of sound (m/s), cBMD= calcaneal bone mineral density (g/cm^2)

LEOBI on sport and ADL. Ten percent of athletes developed LEOBI over the academic year, five with stress fractures and three with MTSS, and all were female except one. The incidence of stress fracture in this study (5/84 = 6%) across all four sports was slightly higher than the previously reported range of 1.9%[3] to 3.7%[2] in a mixed group of collegiate athletes. Among the cross-country/track athletes in the current study, 15% (4/26) developed stress fractures, well within the range of 11%[20] to 21%[21] previously described in college track and field athletes. The incidence of MTSS in this study (3/84 = 3.6%) is on the low end of the incidence range of 4%-35% described in the literature.[23,24]

In the physician referral algorithm, an athlete either had to have 1) a Nirschl pain rating of 4 or greater, meaning that their LEOBI was interfering with sport participation, or 2) a Nirschl pain rating between 1 and 3 (non-interfering pain) with a history of LEOBI. Of the eight athletes diagnosed with LEOBI by the physician, three were referred to the physician with a Nirschl pain of 4 or greater, and five had a pain rating of less than 4, but had a history of LEOBI. In the latter group, all five athletes reported that the LEOBI pain had either no effect or a minimal effect on sport participation including practice and competition, and none of these athletes had any interference in ADLs. The group of athletes who had a Nirschl pain rating of 4 or greater were all cross-country/track athletes and all reported they were unable to practice or compete in their sport because of LEOBI. Only one of these three athletes reported that LEOBI significantly interfered with ADLs; the other two athletes reported pain with ADLs but no ADL interference.

The second purpose of this investigation was to determine if there was a risk relationship between the occurrence of LEOBI and potential modifiable risk factors. The potential factors selected: hip abductor strength, foot type, BMI, changes in training, calcaneal bone density, previous episode of LEOBI, and menstrual function, were based on the authors' research experience and the evidence summarized in the introduction. In this group of 84 athletes, no significant association was found between the occurrence of LEOBI and hip abductor strength, foot type, BMI, changes in training, previous episode of LEOBI, or menstrual function.

Although two studies have shown an association between hip abductor weakness and overuse injury,[27,28] this relationship was not found in the current study. Niemuth et al[27] used a hand-held dynamometer to assess hip abductor strength as was done in the current study, but his study population was a group of 30 injured recreational runners and a random group of 30 non-injured runners. Also, Niemuth et al[27] et al defined "injury" to include any lower extremity overuse injury. Verrelst et al[28] used an isokinetic device to measure hip abductor strength in a group of collegiate freshmen female students in physical education and followed them over a three month period for the occurrence of exertional medial tibial pain. Their definition of injury was limited to medial tibial pain associated with exercise. In both studies, subjects were not intercollegiate athletes and the definition of injury differed from the one used in the current study.

The evidence pertaining to the relationship between foot type and LEOBI is conflicting with some studies supporting a risk relationship[5,29-34] and others not supporting the relationship.[8,12,13,49,50,52] Varying among studies is the specific measurement used to assess foot type including navicular drop,[5,8,12,13] static rearfoot position,[30,32] medial longitudinal arch,[12] standing foot angle,[31] plantar pressure,[34] the FPI-6,[49,50,52] and foot kinematics during gait.[34] The authors assessed foot type using the FPI-6,[48] a scoring tool that uses scores observations of the rearfoot, midfoot, and forefoot in order to create a composite score that allows the foot to be classified as highly pronated, pronated, neutral, supinated, or highly supinated. The current results were consistent with those studies that did not find a relationship between foot type and injury,[8,12,13,49,50,52] three of which used the FPI-6.[49,50,52]

In a narrative review of risk factors for ERLP, Neely[37] reported an association of high or low BMI with ERLP occurrence, but this evidence was drawn from studies of ERLP in military populations only. In this group of collegiate athletes, BMI was not associated with the incidence of LEOBI, consistent with findings of other studies involving collegiate athletes. [22,38]

Two of the eight injured athletes in the current study described training changes in the two months preceding the injury diagnosis as "abrupt." While all injured athletes reported an increase in training volume prior to their injury, most athletes (6/8) described the change as a gradual increase in volume. Two previous studies of overuse bone injury in high school and collegiate athletes[2,40] reported an association of self-reported increased training volume and stress fracture occurrence. Goldberg and Pecora[2] reported that freshman athletes were more at risk for stress fracture occurrence and speculated that the increase in training from high school to college was a causal factor. Only two of the eight injured athletes in the current study were freshman, and one of those reported an abrupt increase in training prior to injury.

Menstrual function in female athletes was not associated with the development of LEOBI in this sample. Of the eight injured athletes, seven were female but only one athlete (14%) reported either amenorrhea or oligomenorrhea in the past year, and three (43%) in their lifetime. Of the non-LEOBI group of female athletes, eight (24%) reported either amenorrhea or oligomenorrhea in the past year, and 17 (30%) in their lifetime Although the association of menstrual dysfunction and overuse bone injury is well-established,[4,38,41,42] the current results did not corroborate with these findings. This difference may be accounted for by the current study's reliance on self-report of menstrual function as well as the prospective rather than cross-sectional design.

For all athletes, there was no significant difference in cBMD or SOS between LEOBI and no LEOBI groups at the initial measurement and follow-up, However, based on unique circumstances associated with the swimming/diving athletes over the course of the study, the authors decided to examine athletes in ground-based sports separately. In the two years prior to the current study, the swimming/diving team was among the top three teams for numbers of athletes with stress fracture. During the academic year of this study, there was an intentional decrease in "dry-land" training of the athletes on the swimming/diving team. The authors believe that this had a strong effect on the absence of LEOBI among these athletes. At the follow-up densitometry measurement for the ground-based athletes only, the athletes with LEOBI had a significantly lower cBMD in the R foot ($p = .05$) and a difference trending toward significance ($p = .07$) in the L foot. The presence of L cBMD less than the group mean increased the risk of developing LEOBI by two-fold. In spite of the relatively small number of athletes with LEOBI in this pilot work, these data support previous findings that have shown an association between decreased BMD and LEOBI using DXA.[7,43] Although Prouteau el al[44] did not find a difference in cBMD or SOS between female athletes with and without a history of stress fracture, they did find a difference in the fractal parameter of trabecular bone. This parameter is an indirect measure of trabecular micro-architecture, and the authors reported that when this parameter was combined with BMI at birth, it correctly identified 85% of female athletes in the stress fracture group. This evidence supports the current finding of a bone difference between those who do and do not develop LEOBI. It is noteworthy, however, that the current study was a prospective cohort design whereas the Proteau et al study[44] was cross-sectional and did not control for the time elapsed from stress fracture diagnosis.

The third purpose of the current study was to establish the viability of using calcaneal densitometry as a screening tool for LEOBI. Overall, the cBMD and SOS measures were found to exhibit high reliability. These results, combined with the differences observed in bone density between athletes with and without LEOBI in a small pilot sample, provide support for the use of calcaneal densitometry as a screening tool to identify athletes at risk for LEOBI.

A history of LEOBI has been shown to be a risk factor for the development of a new occurrence in multiple studies,[10,12,13,22] and a recent systematic review of MTSS risk factors[24] found a history of MTSS to be one of the strongest risk factors for the development of MTSS. In the initial questionnaire, athletes were queried about both a history of stress fracture and a history of ERLP. Although neither of these contingency tables revealed a statistically significant risk association, five of the eight injured athletes (62.5%) reported a history of ERLP whereas 34% of the non-injured athletes reported a history of ERLP.

The authors recognize several limitations of the current study. First, the sample of collegiate athletes was limited to athletes in one midwestern NCAA Division I university. Second, although all athletes in the four selected sports were invited to participate, only slightly more than half of those athletes consented to participate. The authors are aware of multiple athletes in the group that did not consent to participate who also presented with LEOBI symptoms, but as these athletes were not consented, no risk data is available for these athletes. Third, the authors relied on the athletes' self-report of symptoms of LEOBI to the team athletic trainer in order to apply the decision rules pertaining to physician referral and potential LEOBI diagnosis. Fourth, the authors recognize that only a small sample size of athletes were diagnosed with LEOBI over the academic year, limiting statistical power to effectively detect differences. Finally, there are limited data pertaining to calcaneal density in an active collegiate-aged population.

Conclusions

From this pilot work of risk factors for LEOBI in collegiate athletes, the incidence of LEOBI was found to be approximately 10%. The identified risk factors for LEOBI based on significant relative risk values were sport (cross-country/track) and decreased L cBMD. Calcaneal BMD was a relatively stable measure over the nine-month period of study. These pilot data suggest need for further investigation into the predictive property of cBMD screening for LEOBI with a larger and more diverse sample as well as multi-year monitoring. Also, there is a need for additional cBMD data in college-aged individuals who are not intercollegiate athletes for comparison purposes.

REFERENCES

1. Bennell KL, Malcolm SA, Thomas SA, Wark JD, Brukner PD. The incidence and distribution of stress fractures in competitive track and field athletes. A twelve-month prospective study. *Am J Sports Med.* 1996;24(2):211-217.
2. Goldberg B, Pecora C. Stress fractures: a risk of increased training in freshmen. *Phys Sportsmed.* 1994;22(3):68-78.
3. Johnson AW, Weiss CB, Jr., Wheeler DL. Stress fractures of the femoral shaft in athletes--more common than expected. A new clinical test. *Am J Sports Med.* 1994;22(2):248-256.
4. Nelson BJ, Arciero RA. Stress fractures in the female athlete. *Sports Med Arthrosc.* 2002;10:83-90.
5. Bennett JE, Reinking MF, Pluemer B, Pentel A, Seaton M, Killian C. Factors contributing to the development of medial tibial stress syndrome in high school runners. *J Orthop Sports Phys Ther.* 2001;31(9):504-510.
6. Magnusson HI, Ahlborg HG, Karlsson C, Nyquist F, Karlsson MK. Low regional tibial bone density in athletes with medial tibial stress syndrome normalizes after recovery from symptoms. *Am J Sports Med.* 2003;31(4):596-600.
7. Magnusson HI, Westlin NE, Nyqvist F, Gardsell P, Seeman E, Karlsson MK. Abnormally decreased regional bone density in athletes with medial tibial stress syndrome. *Am J Sports Med.* 2001;29(6):712-715.
8. Plisky MS, Rauh MJ, Heiderscheit B, Underwood FB, Tank RT. Medial tibial stress syndrome in high school cross-country runners: incidence and risk factors. *J Orthop Sports Phys Ther.* 2007;37(2):40-47.
9. Reinking MF. Exercise-related leg pain: A review of the literature. *Int J Sports Phys Ther*. 2007;2(3):170-177.
10. Bennell KL, Malcolm SA, Thomas SA, et al. Risk factors for stress fractures in track and field athletes. A twelve- month prospective study. *Am J Sports Med.* 1996;24(6):810-818.
11. Rauh MJ, Margherita AJ, Rice SG, Koepsell TD, Rivara FP. High school cross country running injuries: a longitudinal study. *Clin J Sport Med.* 2000;10(2):110-116.
12. Reinking MF, Austin TM, Hayes AM. Exercise-related leg pain in collegiate cross-country athletes: extrinsic and intrinsic risk factors. *J Orthop Sports Phys Ther.* 2007;37(11):670-678.
13. Reinking MF, Hayes AM. Intrinsic factors associated with exercise-related leg pain in collegiate cross-country runners. *Clin J Sport Med.* 2006;16(1): 10-14.
14. Reinking MF, Austin TM, Hayes AM. Risk factors for self-reported exercise-related leg pain in high school cross-country athletes. *J Athl Train.* 2010;45(1):51-57.
15. Reinking MF, Austin TM, Hayes AM. A survey of exercise-related leg pain in community runners. *Int J Sports Phys Ther.* 2013;8(3):269-276.
16. Hosmer WD, Genant HK, Browner WS. Fractures before menopause: a red flag for physicians. *Osteoporos Int.* 2002;13(4):337-341.

17. Wu F, Mason B, Horne A, et al. Fractures between the ages of 20 and 50 years increase women's risk of subsequent fractures. *Arch Intern Med.* 2002;162(1):33-36.
18. Franklyn M, Oakes B, Field B, Wells P, Morgan D. Section modulus is the optimum geometric predictor for stress fractures and medial tibial stress syndrome in both male and female athletes. *Am J Sports Med.* 2008;36(6):1179-1189.
19. Gaeta M, Minutoli F, Vinci S, et al. High-resolution CT grading of tibial stress reactions in distance runners. *Am J Roentgenol.* 2006;187(3):789-793.
20. Nelson C. Which athletes are most at risk for stress fractures? *Sports Med Digest.* 2001;23(1):1-5.
21. Bennell KL, Malcolm SA, Brukner PD, et al. A 12-month prospective study of the relationship between stress fractures and bone turnover in athletes. *Calcif Tissue Int.* 1998;63(1):80-85.
22. Reinking MF. Exercise-related leg pain in female collegiate athletes: the influence of intrinsic and extrinsic factors. *Am J Sports Med.* 2006;34(9):1500-7.
23. Moen MH, Tol JL, Weir A, Steunebrink M, De Winter TC. Medial tibial stress syndrome: a critical review. *Sports Med.* 2009;39(7):523-546.
24. Newman P, Witchalls J, Waddington G, Adams R. Risk factors associated with medial tibial stress syndrome in runners: a systematic review and meta-analysis. *Open Access J Sports Med.* 2013;4:229-241.
25. van Mechelen W, Hlobil H, Kemper HC. Incidence, severity, aetiology and prevention of sports injuries. A review of concepts. *Sports Med.* 1992;14(2):82-99.
26. Thacker SB, Gilchrist J, Stroup DF, Kimsey CD. The prevention of shin splints in sports: a systematic review of literature. *Med Sci Sports Exerc.* 2002;34(1):32-40.
27. Niemuth PE, Johnson RJ, Myers MJ, Thieman TJ. Hip muscle weakness and overuse injuries in recreational runners. *Clin J Sport Med.* 2005;15(1):14-21.
28. Verrelst R, Willems TM, Clercq DD, Roosen P, Goossens L, Witvrouw E. The role of hip abductor and external rotator muscle strength in the development of exertional medial tibial pain: a prospective study. *Br J Sports Med.* 2014;48(21):1564-9.
29. DeLacerda FG. A study of the anatomic factors involved in shinsplints. *J Orthop Sports Phys Ther.* 1980;2(2):55-59.
30. Lilletvedt J, Kreighbaum E, Phillips RL. Analysis of selected alignment of the lower extremity related to the shin splint syndrome. *J Am Podiatry Assoc.* 1979;69(3):211-217.
31. Sommer HM, Vallentyne SW. Effect of foot posture on the incidence of medial tibial stress syndrome. *Med Sci Sports Exerc.* 1995;27(6):800-804.
32. Viitasalo JT, Kvist M. Some biomechanical aspects of the foot and ankle in athletes with and without shin splints. *Am J Sports Med.* 1983;11(3):125-130.
33. Willems TM, De Clercq D, Delbaere K, Vanderstraeten G, De Cock A, Witvrouw E. A prospective study of gait related risk factors for exercise-related lower leg pain. *Gait Posture.* 2006;23(1):91-98.
34. Willems TM, Witvrouw E, A DEC, D DEC. Gait-Related Risk Factors for Exercise-Related Lower-Leg Pain during Shod Running. *Med Sci Sports Exerc.* 2007;39(2):330-339.
35. Korpelainen R, Orava S, Karpakka J, Siira P, Hulkko A. Risk factors for recurrent stress fractures in athletes. *Am J Sports Med.* 2001;29(3):304-310.
36. Simkin A, Leichter I, Giladi M, Stein M, Milgrom C. Combined effect of foot arch structure and an orthotic device on stress fractures. *Foot Ankle Int.* 1989;10(1):25-29.
37. Neely FG. Intrinsic risk factors for exercise-related lower limb injuries. *Sports Med.* 1998;26(4): 253-263.
38. Bennell KL, Malcolm SA, Thomas SA, et al. Risk factors for stress fractures in female track-and-field athletes: a retrospective analysis. *Clin J Sports Med.* 1995;5(4):229-235.
39. Loud KJ, Gordon CM, Micheli LJ, Field AE. Correlates of stress fractures among preadolescent and adolescent girls. *Pediatrics.* Apr 2005;115(4):e399-406.
40. Ohta-Fukushima M, Mutoh Y, Takasugi S, Iwata H, Ishii S. Characteristics of stress fractures in young athletes under 20 years. *J Sports Med Phys Fitness.* 2002;42(2):198-206.
41. Bennell K, Matheson G, Meeuwisse W, Brukner P. Risk factors for stress fractures. *Sports Med.* 1999;28(2):91-122.
42. Nattiv A. Stress fractures and bone health in track and field athletes. *J Sci Med Sport.* 2000;3(3): 268-279.
43. Myburgh KH, Hutchins J, Fataar AB, Hough SF, Noakes TD. Low bone density is an etiologic factor for stress fractures in athletes. *Ann Intern Med.* 1990;113(10):754-759.
44. Prouteau S, Ducher G, Nanyan P, Lemineur G, Benhamou L, Courteix D. Fractal analysis of bone texture: a screening tool for stress fracture risk? *Eur J Clin Invest.* 2004;34(2):137-142.
45. Chatzipapas CN, Drosos GI, Kazakos KI, Tripsianis G, Iatrou C, Verettas DA. Stress fractures in military

men and bone quality related factors. *Int J Sports Med.* 2008;29(11):922-926.

46. Lappe J, Davies K, Recker R, Heaney R. Quantitative ultrasound: use in screening for susceptibility to stress fractures in female army recruits. *J Bone Miner Res.* 2005;20(4):571-578.
47. Kendall FP, Kendall FP. *Muscles : testing and function with posture and pain.* 5th ed. Baltimore, MD: Lippincott Williams & Wilkins; 2005.
48. Redmond AC, Crosbie J, Ouvrier RA. Development and validation of a novel rating system for scoring standing foot posture: the Foot Posture Index. *Clin Biomech (Bristol, Avon).* 2006;21(1):89-98.
49. Ramskov D, Jensen ML, Obling K, Nielsen RO, Parner ET, Rasmussen S. No association between q-angle and foot posture with running-related injuries: a 10 week prospective follow-up study. *Int J Sports Phys Ther.* 2013;8(4):407-415.
50. Nielsen RO, Buist I, Parner ET, et al. Foot pronation is not associated with increased injury risk in novice runners wearing a neutral shoe: a 1-year prospective cohort study. *Br J Sports Med.* 2014;48(6):440-447.
51. Cain LE, Nicholson LL, Adams RD, Burns J. Foot morphology and foot/ankle injury in indoor football. *J Sci Med Sport.* 2007;10(5):311-319.
52. Burns J, Keenan AM, Redmond A. Foot type and overuse injury in triathletes. *J Am Podiatr Med Assoc.* 2005;95(3):235-241.
53. Tweed JL, Campbell JA, Avil SJ. Biomechanical risk factors in the development of medial tibial stress syndrome in distance runners. *J Am Podiatr Med Assoc.* 2008;98(6):436-444.
54. Damilakis J, Maris TG, Karantanas AH. An update on the assessment of osteoporosis using radiologic techniques. *Eur Radiol.* 2007;17(6):1591-1602.
55. Frost ML, Blake GM, Fogelman I. Quantitative ultrasound and bone mineral density are equally strongly associated with risk factors for osteoporosis. *J Bone Miner Res.* 2001;16(2):406-416.
56. Lin JD, Chen JF, Chang HY, Ho C. Evaluation of bone mineral density by quantitative ultrasound of bone in 16,862 subjects during routine health examination. *Br J Radiol.* 2001;74(883):602-606.
57. Nirschl RP. Elbow tendinosis/tennis elbow. *Clin Sports Med.* 1992;11(4):851-870.
58. Kortebein PM, Kaufman KR, Basford JR, Stuart MJ. Medial tibial stress syndrome. *Med Sci Sports Exerc.* 2000;32(3 Suppl):S27-33.