ABSTRACT

Our aim was to determine differences in total body, femoral, and regional tibial bone mineral density (BMD; g/cm²) measures in swimmers who were symptomatic versus asymptomatic for medial tibial stress syndrome (MTSS) following 8 weeks of weight-bearing training. Sixty-six Division I swimmers participated in 8 weeks of weight-bearing training. Thirty-five swimmers had symptoms of MTSS (S-MTSS), and 31 reported no MTSS symptoms (A-MTSS). Total body and femoral BMD was assessed through dual-energy x-ray absorptiometry scanning. Total body scan was used to manually create tibial regions. Differences were assessed using independent t tests. The S-MTSS group had significantly lower BMD values than the A-MTSS group in the total body, as well as several tibial regions, and all measured femoral sites. Lower BMD measures in swimmers may increase the likelihood of developing MTSS during weight-bearing training. Clinically, preventative means for MTSS should include focusing on bone accrual year-round through weight-bearing exercises. [Athletic Training & Sports Health Care. 2013;5(4):160-167.]

The pathology of medial tibial stress syndrome (MTSS) is similar to that of a tibial stress fracture. MTSS has been described as a mild form of a stress reaction due to an increase in bone remodeling and decreased bone mass accrual, which may result in the development of stress fractures. Several factors, including changes in training, footwear, terrain, and muscular imbalance, have all been reported as possible causes of MTSS. Multiple studies have investigated MTSS in runners, volleyball players, and athletes in other weight-bearing sports in an attempt to identify factors contributing to MTSS and stress fractures and to prevent their occurrence. However, few studies have focused on the development of MTSS and stress fractures in sports where the majority of participation occurs in a nonweight-bearing environment, such as swimming.

Studies that have investigated MTSS and bone mass in swimmers have compared the data with other athletes of a weight-bearing sport and determined that the bone mineral density (BMD; g/cm²) of a typical competitive swimmer is comparatively low. Athletes with low BMD may be more vulnerable to stress reactions in specific skeletal sites when weight-bearing training is initiated or if the intensity of the training is high and introduced or increased abruptly. A similar response has been reported in military recruits. Recruits who enter the first 8 weeks of training (consisting of walking, running, marching) having no previous acclimatization to exercise, and thus experience a higher rate of stress fractures, MTSS, and other lower-leg injuries.

The correlation between MTSS and a decrease in regional BMD has been described in a limited number of studies using dual-energy x-ray absorptiometry (DXA) scans. Bone mineral density scan-
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ning of the area experiencing MTSS on the tibia has been reported to be abnormally low.\textsuperscript{12,13} It has been suggested that there may be a significant relationship between BMD and MTSS symptoms; however, the relationship has not been fully elucidated.\textsuperscript{12} Several studies reported low tibial BMD bilaterally in some athletes with unilateral pain,\textsuperscript{12,13} which suggests that a decreased regional BMD precedes the MTSS. Our purpose was to determine whether there was a difference in the total body, femoral, and tibial region BMD measures in swimmers with and without MTSS after 8 weeks of dry-land, weight-bearing training.

METHOD

Participants

All participants were members of a single Division I varsity swimming team, who participated in a coach-directed, 8-week, team-based, dry-land physical training program. All participants completed an institutional approved consent form for the protection of human subjects. A series of questionnaires were completed prior to the 8-week program (Health and Medical Questionnaire, a baseline physical activity questionnaire, and a Lower-Leg Symptoms Questionnaire). Following the 8-week dry-land training program, the Lower-Leg Symptoms Questionnaire and total body and regional DXA scans were completed.

Study Design

The study was a posttest cohort design. Participants were divided into 2 groups: symptomatic for MTSS (S-MTSS) and asymptomatic for MTSS (A-MTSS). Symptoms of MTSS were reported at any time during the 8-week study at which time the participant was included in the S-MTSS group. Total body and regional bone mineral content (BMC) and BMD measurements were the dependent variables.

Questionnaires

A Health and Medical Questionnaire, a baseline physical activity questionnaire, and a Lower-Leg Symptoms Questionnaire were administered to determine whether the participants had previous or recent symptoms of MTSS.\textsuperscript{4}

The Health and Medical Questionnaire included questions regarding participant demographics, history of previous BMD assessment, any supplementation or medications taken, and, for the female participants, menstrual cycle status and oral contraceptive use. The purpose of this questionnaire was to identify any confounding factors that might influence the results of the BMC and BMD measures. No participants reported use of additional supplementation or medications known to have an osteogenic effect, other than daily multivitamins and postexercise protein recovery drinks. Eight of the 32 female participants reported oral contraceptive use exclusively for birth control.

The baseline physical activity questionnaire was used to assess the participants’ baseline dry-land training activity status. This questionnaire was used to determine how acclimated to land physical activity the participants were before the 8-week dry-land training program, which was conducted in the first 2 months of the collegiate season.

Physical Examination and MTSS Evaluation

Participants who reported symptoms of MTSS prior to or during the coach-directed, 8-week, dry-land training were evaluated via an orthopedic physical examination that included assessment of location and intensity of pain. MTSS was classified based on the following: pain or soreness along the length of the medial tibia with or without point tenderness and no history of traumatic incidence. Tenderness was assessed via visual analog scale (VAS). The size and location of pain was documented to determine whether the symptoms were consistent with a lower-leg bone stress reaction injury. All administered treatments for lower-leg bone stress reactions were documented throughout the 8-week study period.

At the conclusion of the training, an additional Lower-Leg Symptoms Questionnaire was completed (Figure). This questionnaire provided the opportunity to assess those who may not have sought treatment but had pain that did not limit participation. The Lower-Leg Symptoms Questionnaire consisted of questions regarding the presence of pain or soreness in the lower legs and included a schematic of the lower legs. Participants who responded yes to the presence of symptoms were asked to mark the location of their pain on a schematic drawing of the leg. Those who marked their pain or soreness as having occurred along the length of the medial tibia were included in the symptomatic group.
DXA Scans
At the conclusion of the coach-directed, 8-week dry-land training, total body BMC (g), total body BMD (g/cm²), total body fat-free mass (FFM; kg), total body mineral-free lean mass (MFL; kg) total body fat mass (kg), total body percent fat (%Fat), and BMC and BMD of 3 regions of the tibia (proximal, middle, and distal thirds) were performed using a Lunar DPX-IQ (Lunar Inc, Madison, Wisconsin) bone densitometer. The BMD for each of the 3 tibial areas were manually created by measuring the length of each tibia and dividing it into equal thirds by length, using the analysis software from the total body DXA scan.

In addition, a separate right proximal femur scan was performed for each participant to determine the BMC and BMD of the femoral neck, greater trochanter, lesser trochanter, and Ward’s triangle. All scans were performed by a single trained investigator (J.L.C.), certified by the state of Kentucky and the International Society of Clinical Densitometry (ISCD). In accordance with the ISCD recommendations, precision of the regional BMD measures was assured by performing total body scans and regional BMD analyses 2 times, for an independent sample of 27 able-bodied participants. The resulting precision for the leg BMD measurements was 0.0128 g/cm², or 0.86%.

Because the tibial analyses used in this investigation were unique and the intra- and interanalyses precision was unknown, we had 2 independent investigators analyze the tibias of each participant 2 times. The resulting intratester analysis precision was ($r^2 = 0.98; P < .0001$) for the right and ($r^2 = 0.96; P < .0001$) for the left distal tibial BMD measures. The intertester analysis precision was ($r^2 = 0.98; P < .0001$) for the right and ($r^2 = 0.96; P < .0001$) for the left distal tibial BMD measures.14

Dry-Land Training
The dry-land training regimen consisted of 8 weeks of various weight-bearing exercises, including road running, stair climbing, and agility exercise. This regimen was implemented daily by the varsity team coaches, and the volume of various exercises was documented daily; however, it should be noted that athletes’ compliance with this daily regimen was not recorded.

Statistical Analysis
Means and standard deviations were calculated for all dependent measures. Two-tailed, independent t tests were used to evaluate the differences between symptomatic and asymptomatic groups. Comparisons between asymptomatic and symptomatic groups were conducted for the participants’ demographics and baseline physical activity. In addition, total body BMC, BMD, FFM, fat mass and %fat, tibial thirds BMC and BMD, and right proximal femur variables of interest, including BMC and BMD of the femoral neck, greater trochanter, lesser trochanter, and Ward’s triangle, were compared between the groups. Alpha level was set a priori at $P \leq .05$ for all analyses performed using SPSS software (version 12.0; IBM Corporation, Armonk, New York).

RESULTS
Thirty-five participants (19 women, 16 men) met the criterion for inclusion into the MTSS symptomatic group, and the remaining 31 (13 women, 18 men) expe-
rienced no pain or soreness related to MTSS and were thus included in the asymptomatic group. Among the 35 symptomatic participants, 26 reported symptoms in the proximal tibia, 33 reported symptoms in the middle tibia, and 32 reported symptoms in the distal tibia regions. Only 4 participants reported symptoms of MTSS to an orthopedist for physical evaluation, whereas the remaining 31 were identified using the Lower-Leg Symptoms Questionnaire. Two swimmers (1 in each group) had previously reported symptoms consistent with MTSS. No significant differences were noted between the symptomatic and asymptomatic groups for age, height, weight, body mass index, fat mass, lean tissue mass, or BMC (Table 1).

**Total Body and Regional BMD and BMC**

The symptomatic group had significantly lower regional BMD than did the asymptomatic group for femoral neck, Ward’s triangle, femoral trochanter, femoral shaft, total hip, right distal tibial third, left middle tibial third, and left distal tibial third (Tables 2-3). No significant differences were noted between groups (S-MTSS = 1.19 ± 0.07 versus A-MTSS 1.22 ± 0.09) for total body BMD or the proximal tibial thirds BMD (Table 3). However, differences in total body and regional BMD were found between sexes (Table 4). At all measured sites, the male participants had overall significantly higher BMD than did the female participants.

Significant differences were also found for the BMC in the left distal third of the tibias, the left proximal tibial third, the femoral neck, Ward’s triangle, the femoral trochanter, and the total hip \((P < .05)\). The BMC of the left proximal tibial thirds in the symptomatic group were significantly lower than asymptomatic group \((P = .04)\). The symptomatic group had significantly lower regional BMC than the asymptomatic group for femoral neck \((P = .009)\), Ward’s triangle \((P = .02)\), femoral trochanter \((P = .04)\), and total hip \((P = .02)\). No significant differences were found between groups for total body BMC, right tibial thirds BMC, or left tibia middle third BMC.

**Analysis of Symptom Location**

Four participants reported symptoms of MTSS prior to the conclusion of the 8-week, dry-land training. The location of symptoms varied in all 4 participants and was marked as follows: 2 participants reported bilateral symptoms in all thirds, 1 participant reported right middle and distal tibial third symptoms, and 1 participant reported symptoms in bilateral distal thirds.

**Analysis of Baseline Physical Activity and Dry-Land Training**

Prior to reporting to the first practice of the season, each swimmer reported jogging an average of 3.64 miles per week and exercised on dry land a total of 1.95 days per week. No significant differences were noted between groups (S-MTSS = 3.67 ± 4.67 miles per week; A-MTSS = 3.60 ± 3.77 miles per week) for baseline running mileage. The coach-directed training consisted of running approximately 3.72 miles per week and performing an average of 53 repetitions of various weight-bearing exercises per week.

**DISCUSSION**

We found significantly lower BMD values for the S-MTSS group compared with the A-MTSS group in the regions of bilateral distal tibial thirds; the left middle tibial third; and the right proximal femur, including femoral neck, Ward’s triangle, femoral trochanter, femoral shaft, and total hip. Our findings suggest that the presence of MTSS in swimmers may be associated with lower BMD scores in regions of the tibia and proximal femur.

It is important to note that our findings do not suggest that the differences in BMD are a result of the injury. Previous literature reports that a minimum
One of the most common factors for developing MTSS is a sudden increase in intensity, duration, or frequency of unaccustomed weight-bearing training, and this is consistent with our findings. Välimäki et al prospectively investigated the lumbar spine and total hip BMD of military recruits entering the first 8 weeks of basic training to evaluate the risk factors for stress fractures. The sample size was determined to be too small to reach significance; however, those recruits who suffered a stress fracture had common factors, such as poor physical conditioning, lower hip BMD, and BMC, and were taller than the other individuals.

Similar to the aforementioned studies, our participants had weight-bearing training in the months leading up to the 8-week, team-based, dry-land training. Participants trained individually as a means to prepare themselves prior to the sporting season. As we expected, there were no significant differences between groups for baseline training status in our study. Several studies have reported that differences in pretraining physical fitness in military recruits were ineffective in preventing tibial stress reaction injuries. Therefore, the level of weight-bearing training immediately prior to injury, although im-
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important, may contribute less than BMD as a risk factor for MTSS.

The pathophysiological cause of MTSS has not been fully elucidated and remains controversial among clinicians. Some experts consider MTSS to be the same as a tibial stress fracture or chronic exertional compartment syndrome of the deep posterior compartment, whereas others suggest that MTSS is a periostitis injury from a plantar flexor muscle. Our findings suggest that MTSS may be the result of fatigue failure in bone, where a metabolic imbalance between osteoclastic and osteoblastic activity occurs. Preexisting lower BMD values in the MTSS symptomatic group may indicate that the lack of appropriate previously applied strain as a result of strenuous activity and resulting lower BMD inadequately prepared those athletes for the 8 weeks of intense training. Furthermore, the unaccustomed, 8-week training regimen may have caused a metabolic overload in the bone, which may have led to MTSS symptoms.

One unique aspect of our study was the partitioning of the tibia into thirds for BMD analysis. The logic used in developing our procedure stemmed from the commonly used description of the development of MTSS occurring in the middle and distal thirds of the tibia. Only a few studies have examined BMD in the tibia in an attempt to relate it to MTSS or other tibial stress reactions. Beck et al examined only the distal third of the tibias of military recruits to relate BMD to stress fracture incidence; compared with healthy control participants, those with stress fracture had lower BMD in the tibias. Magnusson et al partitioned the tibia into 5 regions of interest in 18 male participants who were diagnosed with MTSS for comparison with 16 nonathletic control participants and 18 athletic, physically active control participants. DXA measurements were obtained while the participants were symptomatic, and 14 were evaluated again after recovery. Although not statistically significant, the symptomatic regions on the tibia had decreased BMD when compared with the 2 groups of control participants. It was also determined that this regional decrease in BMD improved after recovery from symptoms, possibly suggesting that MTSS symptoms develop as a result of the decrease in bone mineral density.

We found it clinically applicable to partition the tibia into thirds. This provided a methodology that could be efficiently and noninvasively performed by a clinician to describe signs and symptoms. As a result, we found significant differences in BMD between groups for both the distal tibial third and the left middle tibial third.

We studied swimmers because of the high prevalence of MTSS during their annual, 8-week, dry-land training session. Several previous studies have investigated BMD in various athletes, including swimmers, and determined that the swimmers had comparatively lower BMD values in the total body and hip. Swimmers not only train most often in a nonimpact environment, but it is also common for elite swimmers to train in 2 to 3 sessions per day. Furthermore, only 1 to 3 hours per week are typically dedicated to dry-land, weight-bearing training, most of which is aerobic training. The minimum effective strain stimulus theory states that the greatest osteogenic effect best responds to exercise conditions that consist of a high load, short duration, and repeated daily. Future research is needed to investigate the cause of this lower BMD in swimmers compared with other athletes, whether it may be attributed to the weightless training environment, exercise conditions, or some other stimulus.

Unlike the aforementioned results reported in previous studies, we found our swimmers to have normal BMD values. For further analysis, we compared the BMD of the femoral regions (femoral neck, Ward’s triangle, trochanter, and total hip) of the swimmers used in our study with those of swimmers used in previous literature; we found that our swimmers had higher values. Maimoun et al investigated the BMD in male swimmers, whereas Taaffe et al, Fehling et al, and Emslander et al all investigated the BMD of female swimmers. When comparing the male participants in our study to male swimmers in a previous study, our swimmers had higher BMD values for the proximal femoral regions. The male swimmers in the previous study had not been engaged in physical activity on dry land in the past 4 years. The female swimmers in the studies we reviewed were reported to have exercised on land for approximately 3 hours per week and approximately 2 hours per week. No dry-land physical activity for one female swimmer study prior to DXA scanning was reported. Our participants performed weight-lifting workouts 3 hours per week for at least 9 months of the year. Therefore, we
did not find the lower BMD measures compared with age- and sex-specific norms as previously reported in swimmers,2,5,10,29 and we propose that these differences were in part due to the weight-lifting regimen that was imposed.

LIMITATIONS
Some limitations of this study should be acknowledged. The comparison of our data to those from previous studies need to be compared carefully. It should be noted that the DXA scan and software used in those particular studies2,5,10,29 may be different than ours; therefore, the comparisons may not be equivalent. In addition, the coach-directed program was not explicitly monitored for compliance.

IMPLICATIONS FOR CLINICAL PRACTICE
The likelihood of developing MTSS during weight-bearing training in athletes unaccustomed to strenuous weight-bearing activity is higher in those with reduced BMD. The sequelae can be reduced with proper acclimatization.

CONCLUSION
In this study, we found that the S-MTSS group had significantly lower site-specific BMD and BMC measures than the asymptomatic group. Our findings suggest that lower BMD levels in the tibia and femoral regions may increase the risk of developing a stress reaction injury with the initiation of the vigorous 8 weeks of dry-land training. Clinically, preventative means for MTSS should include focusing on bone accrual year-round via bone-stimulating activities. Additional research is needed to support our findings and to apply them to additional athletic populations.

REFERENCES