

The Consequences of Modern Military Deployment on Calcium Status and Bone Health

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KEYWORDS

• Bone health • Calcium • Deployment • Sweat calcium loss

The United States has been at war in Iraq and Afghanistan for more than 6 years. The Army leadership strives to ensure the safety, health, and performance of soldiers in combat. (Throughout this paper, the term “soldier” is used to refer to Army service members). However, a protracted war such as the one currently underway weakens soldiers physically and mentally. Because these soldiers return multiple times to combat areas, health care providers are keenly aware of the effect of deployment on health in general and bone health in particular.

Deployment experiences can include heavy body armor, environmental extremes, and changes in diet and exercise habits. Soldiers in Iraq and Afghanistan also experience dehydration, fatigue, and psychological stress. As a result, many military health care providers believe that deployment conditions can lead to deterioration in soldiers’ physical and mental health.

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By December 2009, more than 36,000 people were wounded in action, and countless others have had physical problems that can last for months or years after their overseas duty from the wear and tear of war.¹ Musculoskeletal and connective tissue disorders were the predominant illness and injury-related category for ambulatory visits in military clinics and facilities in 2008, accounting for 24% of all visits, a 15% increase from 2004.² The most common complaints involved the back, neck, knees, shoulders, and feet. Soldiers reported a wide range of injuries, including intervertebral disc disorders, back pain, joint disorders, and stress fractures.² In a 2006 report of the postdeployment health concerns of more than 118,000 returning service members, 2 of 4 main health concerns of members of each military service (Army, Navy, and Air Force) were musculoskeletal.³

Soldiers with physical limitations are not fit and ready to be deployed, and this has a negative effect on a unit's readiness for deployment. Because of the resulting work restrictions, lost work days, and discomfort, musculoskeletal injuries have a significant effect on the health and readiness of the US Army in peacetime and in conflict.⁴

In 2006, we conducted a study to identify musculoskeletal injury data on outpatient visits of an infantry unit assigned to Fort Lewis, Washington. The unit consisted of 2329 male and female soldiers who had recently been deployed to Iraq for 12 months. The analysis of this query revealed an 11% (n = 252) incidence of fractures, dislocations, sprains, and strains. These results were consistent with those of a previous health assessment survey at this military installation.³

To further evaluate injuries associated with bone health, we used the Defense Medical Epidemiology Database (DMED) to identify stress fractures in soldiers aged 18 to 29 years (**Table 1**).⁵ This study found approximately 20.5 stress fractures per 1000 soldiers, a substantial rate given the lost work time for medical attention and physical therapy (which involves strengthening exercises at the hospital or gym and can require absences from work for up to 2 hours 3 times a week).

In September 2008, the US Army had 1,097,050 active, National Guard, and Reserve soldiers, of whom 85% were enlisted men and women (ie, have a lower rank than commissioned officer).⁶ Sixty-eight percent, or 634,095, of enlisted soldiers were between 17 and 29 years of age.⁷ This age range coincides with the period of peak bone mass that occurs when the growth in the size of the bones and the accumulation of bone mineral has stabilized.¹

Genetic factors account for 60% to 80% of peak skeletal mass, and hormonal status and environmental factors (including calcium intake and loss and weight-bearing exercise) influence the rest.^{8,9}

One might expect that the physical exercise required for military occupations and the availability of high-quality dietary options in military dining facilities would place today's soldiers at low risk of poor bone health.⁹ However, like other young adults, soldiers often make poor food choices when they are not deployed. These poor

ICD-9 Code	Location of Stress Fracture	Number of Injuries	Rate per 1000 Soldiers
733.93	Tibia or fibula	27	7.1
733.94	Metatarsals	8	2.11
733.95	Other bone	43	11.35

Abbreviation: ICD-9, International Classification of Diseases, 9th revision.
Source: DMED.

food choices, combined with the relaxed daily physical training requirements for nondeployed soldiers, threaten their optimal bone health.

More than a decade before the start of the Global War on Terrorism, Armstrong and colleagues¹⁰ reported that soldiers had low calcium intake. These investigators said that soldiers could accumulate a substantial calcium deficit over time because of the combined effects of sweat loss and low dietary intake. Today, in a well-resourced war zone, evidence indicates that soldiers' dietary calcium intake is still low. Deficient calcium ingestion in an arid desert climate with an average temperature of 40 to 43°C (105–110°F) in summer months is likely to compound the effects of excessive dermal losses of calcium.¹¹

Although the physical demands on soldiers vary depending on the type of work they do, every service member needs protection from the highly lethal weapons and improvised explosive devices of today's battlefield. Nonmedical Army personnel in Iraq and Afghanistan are required to wear 16 kg (35 lb) or more of personal body armor 24 hours a day, 7 days a week. This requirement is partly responsible for the unprecedented number of musculoskeletal complaints reported by service members seen in medical clinics in the combat area and on their return to the United States.¹² Furthermore, this body armor load, in conjunction with high environmental temperatures (ambient and inside heavy armored vehicles) contributes to increased sweating and accompanying dermal mineral loss, including calcium loss.

Literature on the effect of calcium lost through sweat on bone health is sparse and the few research findings available are inconclusive. Studies of basketball players and firefighters, for example, found that athletes experienced a significant decrease in bone mass density (BMD) during the basketball season but firefighters experienced no net loss of BMD during a 4-month training course.¹³

Investigators have studied the amount of calcium and other minerals lost through sweat, but these studies involved different environmental conditions than those experienced by soldiers in Iraq and Afghanistan. In 2 of these studies, the investigators measured whole-body sweat calcium concentration during exercise.^{14,15} In the study conducted by Shirreffs and Maughan,¹⁵ mean sweat calcium concentration was 52 ± 36 mg/L during exercise in a warm (34.5°C) humid environment. Costa and colleagues¹⁶ found exercise sweat calcium concentrations of 72 ± 10 mg/L in individuals fed a space diet from NASA and 74 ± 17 mg/L in those who received a purified formula. Both groups had similar calcium intake and the study took place in a cooler (24.5°C) environment than the Shirreffs and Maughan study.¹⁵

The previous studies were also conducted using an assortment of collection methods that precludes generalization of the results. For example, sweat collection methods have included total body measurements and regional measurements on, for example, the back or arm. In 2 studies that compared whole-body sweat mineral content with regional measurements taken from the back or arm, higher mineral concentrations were found in the sweat from regional sites.^{17,18} The investigators concluded that using regional measurements to estimate mineral losses could lead to an overestimation of total body sweat mineral losses.

Investigators have also studied sweat calcium loss using regional measurements during exercise.^{13,19} Although the range of sweat calcium loss seems to be broad, the studies using regional sites and similar methodologies to collect the sweat have had similar findings. These studies found mean sweat calcium concentrations of 30 ± 5 mg/L for runners and 44 ± 12 mg/L for firefighters.^{13,18}

Understanding the effect of sweat calcium loss in deployed soldiers is particularly important to nurse case managers working in military health care settings because their critical functions include keeping service members healthy and fit for duty and

expediting care to return injured soldiers to their jobs. Nurse case managers are uniquely positioned to assess the effects of diet, exercise, and metabolism on the current and future health and wellness of each soldier. These nurses also coordinate specialty consultations and education to minimize long-term disability and maximize productivity in the military environment.

Several Department of Defense agencies recognize the need for further research on dietary calcium requirements for military service members during daily unit activities in the United States and during combat operations. In addition, these agencies have called for evidence supporting the link between calcium intake and bone health.

We conducted a study to help better define the links between diet, environment, and bone health in soldiers in the desert conditions that most experience in current combat environments. The study had 3 specific aims: (1) to determine the feasibility of quantifying sweat calcium loss in soldiers in a desert climate under conditions of intense physical training; (2) to examine the effect of calcium loss on short-term bone health using biochemical markers of bone formation and resorption, and dual-energy x-ray absorptiometry (DXA) to assess bone mineral quality; and (3) to describe the potential effects of self-reported exercise and dietary habits on bone health in soldiers.

METHODS

Design

The study had a prospective, descriptive, longitudinal design with repeated measures. The study took place in 2 locations in Washington State. The first location was a military training site in the Yakima desert of eastern Washington. This desert climate at this site was similar to the current combat environment, which enhanced our ability to generalize the study findings to deployed soldiers. The second location was Madigan Army Medical Center (MAMC) in Tacoma, Washington. At MAMC, data on diet, exercise, and bone mineral density were collected before and after participating soldiers were deployed to Iraq.

Participants

Fifty-two nondeploying soldiers participated in the sweat calcium data collection in the desert in September 2008. An additional 53 soldiers were recruited at MAMC where data was collected before and after their 15-month deployment in Iraq.

Study Procedures

The MAMC and Uniformed Services University of Health Sciences institutional review boards approved this study. Written informed consent was obtained from all soldiers who participated in this study.

Sweat Calcium Measurement

The commander of a male infantry unit gave us access to soldiers scheduled for training in the Yakima desert. The sweat collection method was adapted from procedures used at the University of Texas at Houston and endorsed by the Gatorade Institute (Ed Coyle, PhD, Houston, TX, USA, and Craig Horswill, PhD, Gainesville, FL, USA, personal communication, January 2007).

We collected data on 2 occasions, 1 week apart in September 2008. Temperatures ranged from 6°C in the morning to 29°C by 2 PM.

During these data-collection visits, research team members were dressed in civilian attire with no evidence of rank or position to avoid any suggestion of coercion. At the start of the first visit, the principal investigator (PI) briefly explained the study

procedures and asked for volunteers to have their sweat calcium level measured. Volunteers signed a consent form.

The PI checked all consent forms for completeness, measured the height and weight of volunteers, restocked supplies, and answered questions from participants.

For the sweat collection, soldiers assembled in the unit area wearing the Army physical training uniform consisting of shorts and a tee shirt. The research team collected sweat samples between 6:00 AM and 8:00 AM; the temperature was between 6 and 10°C.

The PI chose the type of sweat patch used in this study to collect sweat samples for analysis after discussions with many experts at research centers around the United States. The patch that most investigators recommended was no longer available. However, the research team used an alternate patch with much success, although the technique needs refinement because a large volume of the sweat sample was lost if the patch became unsecured. Experts warned of a 20% failure rate, which was one reason for using 2 sweat patches (on the arm and back) on each soldier.

Study personnel first cleaned the arm and back sites chosen for the sweat patch applications with distilled water. Gauze sponges were then affixed to the skin of one upper arm and the right lower back and the sponges were secured with Tegaderm (3M, St Paul, MN, USA) clear film after using Skin Prep (Smith & Nephew, London, UK) to promote adherence to the skin. The soldiers were then instructed to perform vigorous exercise for 30 to 45 minutes under the guidance of the senior ranking soldier in each group; each senior ranking soldier was given a stopwatch to monitor the length of the exercise period. Most soldiers participated in group physical training for 35 minutes.

Individual 0.5-L bottles of water containing no added calcium were available to participants for hydration during exercise. The soldiers kept track of the number of bottles of water they consumed during the exercise period to enable the team to accurately calculate their sweat rate.

After exercising, all soldiers returned to the unit area to have their sweat patches removed by research team members. Immediately after removing the saturated gauze sponges, they were placed in 60-mL syringes. Depressing the syringe barrel forced the sweat sample through a filter into a 15-mL test tube. The specimens were augmented with 10 mL of distilled water for optimal extraction later and the test tubes were capped for transportation and storage. The sweat specimens were placed in a Coleman cooler overnight and the cooler was delivered to the laboratory at MAMC the following day. At MAMC, the samples were placed in a freezer at -57°C until the analysis was performed.

Some of the soldiers who contributed sweat samples also volunteered to provide a complete-void urine specimen so that the study team could calculate total body sweat rate; these calculations also required height and weight measurements to adjust for body surface area. Vertical height was measured to the nearest 0.1 cm using a portable stadiometer (Seca, Terre Haute, IN, USA) and weight was measured using a lightweight prezeroed digital scale that accommodated up to 181 kg (Detecto, Youngstown, OH, USA). All other soldiers provided a spot-void urine specimen for calcium analysis.

Urine specimens were placed in Ziplock bags, each bag coded with the participant's identification number, and the bags were packed on ice in a second Coleman cooler for transport to MAMC. Because sweat calcium measurement is not a routine clinical test, the PI conducted the analyses in the clinical investigations laboratory (author MM) using the Quantitative Colorimetric Calcium Assay Kit (BioAssay Systems, Hayward, CA, USA). The PI conducted all tests twice and a senior molecular

biologist provided quality control supervision for the analysis. Standard curve plots for individual analyses were all within an acceptable range.

Diet, Exercise, and BMD Data Collection

For the diet, exercise, and BMD phase of this study, the commander of a noninfantry unit that was preparing to deploy gave permission for the PI to solicit male and female volunteers. Soldier volunteers consented to complete diet and exercise questionnaires, have blood drawn to assess bone turnover, and undergo DXA to assess bone mineral density. These volunteers completed the predeployment data collection at the hospital outpatient clinic. At MAMC, 3 stations were set up for data collection: one for completing the questionnaires, one for the DXA procedure, and one for a brief physical examination by a nurse practitioner. Soldiers were instructed to go to the laboratory to have their blood drawn in between the other stations.

The soldiers completed the Block Food Frequency Questionnaire (FFQ, NutritionQuest, Berkeley, CA, USA) twice, once before their deployment to Iraq and once on their return. The FFQ solicits recall for the previous year, asking questions such as "In the past year, how many times did you drink milk?" Answer choices for this question are "once a day, once a week, once a month, or more frequently." The FFQ captures information on food eaten at home, in restaurants, or as take-out, and it is sensitive to different cultural preferences.²⁰ NutritionQuest conducted a comprehensive nutrient analysis of foods and supplements that soldiers reported in their FFQ responses and prepared a report on the dietary intake of each participating soldier.

The study used the Baecke Habitual Physical Activity Questionnaire (the Netherlands) to assess physical activity during work, sports, and leisure. Each occupation is coded by the level of physical work involved. The work and leisure subscales are scored from 1 to 5, with 1 for never and 5 for always/very often. The sport score was determined by assigning values to the sports according to their intensity, the amount of time spent doing the sport, and frequency of the activity. A formula was then applied to calculate the final physical activity score.²¹

Soldiers presented to the MAMC Department of Nuclear Medicine for the DXA scan (Prodigy, Lunar Corp, Madison, WI, USA) wearing Army physical training clothes. A dedicated DXA technician performed the scans. The DXA scan involved lumbar spine and femur readings; outputs included T score, Z score, and BMD. The T score compares the individual's BMD in standard deviations with the average peak BMD in healthy young adults.²² The Z score compares the individual's BMD with the mean BMD of persons in the same age group.²² Age and ethnicity are considered in these comparisons; female gender, low body mass index (BMI, calculated as weight in kilograms divided by the square of height in meters), tobacco use, high bone turnover rates, and family history of osteoporosis all contribute to a higher risk of osteoporosis.²³

During the physical examination, the soldiers underwent a body composition assessment that included measurements of height in inches using a Harpenden stadiometer, weight in pounds using an electronic scale, BMI, and waist circumference using a plastic-coated tape at the minimal abdominal circumference (women) or the navel level (men) rounded down to the nearest 0.5 in.²⁴ The physical examination also included a body fat-water analysis using near-infrared reactance (NIR) technology (Futrex, Inc, Hagerstown, MD, USA). During the physical examination, the practitioner documented the soldier's family history of bone disease; endocrine or eating disorder; menstrual irregularities; and alcohol, tobacco, or dietary supplement use, including use of vitamins, minerals, and body-building protein powder. Participants received a copy of their body composition report and study personnel educated them about

their optimal body weight, BMI, and hydration if their NIR analysis results indicated low hydration status.

The bone health indices measured before deployment included osteocalcin for bone turnover, bone-specific alkaline phosphatase level for bone formation, tartrate-resistant acid phosphatase (TRAP) level for bone resorption, total calcium level, or some combination of these indices (**Table 2**). Postdeployment indices measured were the same as before deployment, and carboxyterminal telopeptide, a marker of bone resorption, and insulin-like growth factor-1 (IGF-1), an endocrine marker, were also measured. Because the TRAP analysis was technically cumbersome, this test was not done after deployment. Serum calcium levels were measured before and after deployment and vitamin D levels after deployment.

On completion of predeployment data collection, each participant received a \$25 gift card for the Army's retail services.

The PI maintained e-mail contact with unit leaders and a few soldiers throughout the soldiers' deployment period to sustain a connection that would facilitate postdeployment data collection. On return from deployment, participants underwent the bone health tests. After completing these procedures, participants again received a gift card.

RESULTS

Demographic Characteristics

The study sample consisted of 105 soldiers assigned to Fort Lewis, Washington, from August 2007 to May 2009. This sample included 52 male soldiers who participated in the sweat calcium assessment and did not deploy to Iraq, and 53 male and female soldiers who did deploy to Baghdad, Iraq, and completed diet, exercise, and BMD assessments before their deployment. Twenty-seven percent ($n = 14$) of the soldiers in the sweat collection study voluntarily provided a complete-void urine specimen; the remaining 73% ($n = 38$) provided a spot-void urine specimen. Eighteen of the soldiers who deployed to Iraq returned for follow-up data collection.

Age was the only demographic variable recorded for soldiers participating in the sweat collection; their mean age was 25.1 years (range 19–39 years).

The demographic characteristics of the 53 volunteers who participated in the pre- and postdeployment data collection are presented in **Table 3**. Thirty-two percent of these soldiers ($n = 17$) reported tobacco use at baseline; several more soldiers began smoking and some who already smoked began smoking more cigarettes each day during deployment. Before deployment, 53% of participants in the pre- and postdeployment data collection reported alcohol use, with 32% ($n = 17$) admitting to

Table 2

Bone turnover marker levels in male and women soldiers before and after deployment to Iraq: pre- and postdeployment study (N = 53)

	Before Deployment				After Deployment			
	Men		Women		Men		Women	
	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
Calcium (mg/dL)	43	9.4 (0.3)	22	9.7 (0.3)	15	9.74(0.29)	7	9.57(0.35)
Vitamin D (ng/L)					10	25.5. (3.3)	5	39.4 (7.9)
BS alkaline phosphatase (μ g/L)	10	16.8 (3.1)	5	11.3 (4.8)	11	17.6 (4.9)	7	11.5 (4.3)
Osteocalcin (ng/L)	10	26.6 (6.1)	5	19 (9.3)	11	13.1 (4.4)	7	17.6 (9.3)
TRAP (U/L)	29	4.78 (1.32)	19	4.78(1.10)	4	4.35 (1.32)	5	4.12 (0.63)

Characteristic	
Age in years, mean (SD)	23.1 (3.9)
Female gender, n (%)	19 (35.8)
Ethnicity ^a n (%)	
Caucasian	26 (50.0)
African American	13 (25.0)
Hispanic	9 (17.3)
Asian	2 (3.9)
Pacific Islander	1 (1.9)
Other	1 (1.9)
Rank, n (%)	
Officer	4 (7.6)
Enlisted	49 (92.4)

^a One missing observation.

consuming at least 3 drinks a week and 11.3% consuming up to 12 drinks a week. Alcohol consumption was prohibited during the deployment period.

Twenty-nine percent (n = 5) of female soldiers reported using oral contraceptives before deployment and none of the women reported amenorrhea. A urine human chorionic gonadotropin test was ordered for all women to determine their pregnancy status. Pregnancy was confirmed in 1 woman; she was ineligible for deployment and for continuation in the study. Another female soldier became pregnant during her deployment and returned to Fort Lewis; she did not return for study follow-up. Forty-three percent (n = 3) of the 7 female soldiers who returned for follow-up reported taking oral contraceptives or other estrogen treatment for birth control.

Weight and BMI

The mean BMI (25.9 kg/m²) of male soldiers in this study exceeded the acceptable BMI standard of 24.9 kg/m² before deployment and was essentially unchanged when the soldiers returned from deployment (Table 4). The mean BMI of female soldiers was within the normal range before and after deployment. However, some women's weight increased by up to 10 lb, their body fat increased by up to 2%, and their waist circumference grew by 2 inches by the time they returned from deployment.

Sweat Calcium Loss

The normal range of sweat calcium is 16 to 88 mg/L.¹⁷ Based on the standardized formula we used to calculate calcium losses, most soldiers in this study experienced normal sweat calcium losses (n = 47, mean [M] = 59.2 mg/L, standard deviation [SD] = 29.5 mg/L), yet 18% had losses that exceeded the normal range (n = 5, M = 111.2 mg/L, SD = 9.5 mg/L) (Table 5).

Impact of Calcium Deficits on Bone Health

During their 15 months of deployment, soldiers maintained calcium homeostasis, with a narrow range for normal values of 8.4 to 10.2 mg/dL.

Normal vitamin D levels are 30 to 100 ng (ng)/L; levels lower than 30 ng/L indicate vitamin D insufficiency and people with levels lower than 20 ng/L require treatment.

Table 4
Anthropometric characteristics of soldiers: pre- and postdeployment study (N=53)

	Before Deployment				After Deployment			
	Men		Women		Men		Women	
	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
Height (in)	32	70.1 (2.9)	19	64.7 (3.2)				
Weight (lb)	32	181.2 (27.4)	19	142.9 (25.3)	14	177.2 (23.4)	7	135.6 (9.6)
BMI (kg/m ²)	32	25.9 (3.4)	19	23.9 (3.1)	14	25.1 (3.6)	7	24 (2.1)
Body fat (%)	35	15.9 (4.4)	14	26.9 (4.7)	13	14 (6.5)	7	27.6 (3.5)
Waist circumference (inches)	35	34.3 (4.2)	13	28.8 (3.9)	14	31.6 (3.1)	7	29.3 (2.3)

The range of values for participating soldiers was 7 to 71 ng/mL, with only 3 of 18 soldiers having a vitamin D level higher than 30 ng/mL.

The expected range for changes in BMD of the femur over 15 months is $\pm 2\%$ for individuals aged 19 to 39 years. In this study, 6 of 18 (33%) participants had a BMD after deployment that was more than 2% lower than that shown by their initial DXA, but 1 participant's femur bone mass increased by 2.1% (Table 6). The expected range for changes in BMD of the lumbar spine is $\pm 1\%$ in this age category. Here too, findings were mixed, with decreases in lumbar spine BMD in 3 of 18 (17%) participants exceeding the expected 1% at postdeployment follow-up, suggesting bone loss. Conversely, lumbar spine BMD increased by more than 1% in 7 participants.

Effect of Exercise and Diet on Deployed Soldiers' Bone Health

Results for self-reported exercise are provided in Table 7. In general, exercise levels from work, sports, and leisure activities were similar before and after deployment.

DISCUSSION

The process of quantifying sweat calcium loss was feasible but logistically challenging. The amounts of calcium lost by soldiers in the current study (59.2 ± 29.5 mg/dL) are similar to those reported by previous investigators using a similar methodology.¹⁹ The intensity of the exercise and its short duration in this study make it difficult to estimate dermal calcium losses over a lengthy deployment when soldiers are wearing military uniforms, body armor, backpacks, water containers, and helmets in at least 30°C heat. It is apparent that a subset of soldiers in any unit may be at high risk of excessive calcium losses with uncertain consequences on bone health.

Although acclimatization occurs over time in any environment, not all minerals are affected equally. Studies suggest that although sweat calcium losses decrease with acclimatization to heat, urinary calcium losses do not change over time.²⁵ A larger sample of soldiers is needed to perform the definitive research necessary to advise

Table 5
Calcium losses in soldiers: sweat patch study (N = 52)

	Sweat Calcium Level (mg/L)	Sweat Rate (L/h)	Urine Calcium Level (mg/L)
Mean level	59.2 \pm 29.5	1.2 \pm 0.67	100.9 \pm 0.6
Range	6–119	0–2.4 (fluid loss)	<10.0–290.8
Normal range	16–88	Up to 2	\leq 220 mg/L

	Predeployment Level, Mean (SD) (n = 52)	Postdeployment Level, Mean (SD) (n = 18)
Femur BMD	1.15 (0.15)	1.1 (0.12)
Femur DXA, T score	0.6 (1)	0.3 (0.9)
Spine BMD	25 (0.12)	1.25 (0.12)
Spine DXA, t score	0.4 (1)	0.3 (1)

military commanders and health care professionals about the hazards of prolonged combat duty in a desert climate and its effect on mineral losses and bone health.

In general, the participants had normal bone turnover based on osteocalcin and TRAP results, although 10% (n = 5) of participants had lower than normal and 10% had higher than normal bone turnover rates at baseline. The differences in bone turnover rates could have been because of age differences among participants, with more rapid turnover occurring in younger soldiers. We plan to conduct further analyses to evaluate the associations between age, ethnicity, gender, endocrine status, alcohol and tobacco use, and bone turnover.

IGF-1 levels were assessed as a result of reports in the literature that prolonged periods of stress can negatively affect bone metabolism by increasing bone resorption; this can be identified by a decrease in levels of IGF-1. This biomarker is also useful for evaluating nutritional stress; underfeeding and protein-calorie deficits result in substantial reductions in IGF-1 concentration.²⁶ The normal IGF-1 concentration is 126 to 382 ng/mL; no soldier in the study had deficient or excess IGF-1 levels before or after deployment. Because of the high cost of bone turnover marker assessments and their lack of sufficient sensitivity and specificity to predict stress fracture risk, we recommend that investigators select the minimum number of tests needed to measure bone formation, bone resorption, and bone turnover for use in conjunction with DXA.²⁶

Vitamin D deficiency is now recognized as a widespread problem in many countries, including the United States.²⁷ The major source of vitamin D for most adults is sunlight exposure. Other sources include oily fish and fortified foods such as milk, cereals, and bread. The soldiers in this study met the minimum requirement for daily vitamin D intake of 200 IU for adults up to 50 years of age, but they were able to achieve this only by consuming supplemental vitamin D (see **Table 2**). The soldiers in this study were probably exposed to some sunlight during their deployment in a hot desert location, so one possible explanation for the low levels of vitamin D in this sample is the lack of dietary intake from fortified foods. Soldiers reported they did not consume large quantities of milk in Baghdad because of its unpleasant taste. Increased skin pigmentation, obesity, and the application of sunscreen also limit production of vitamin D and

Index	Before Deployment		After Deployment	
	n	Mean (SD)	n	Mean (SD)
Work	48	3.1 (0.5)	18	3 (0.4)
Sport	43	3.7 (1.2)	18	4.1 (1.5)
Leisure	48	2.8 (0.5)	19	3 (0.7)

could help explain the low vitamin D levels in this sample.²⁷ One study in Hawaii found that vitamin D levels in adults were lower than 30 ng/mL, despite an average of 15 hours per week of sun exposure over 3 months, providing further evidence that sunlight alone is not sufficient to maintain adequate vitamin D stores.²⁸

BMD is the most predictive measure of fracture risk.²⁶ The Department of Defense has examined strategies for improving the bone health of service members, with a focus on decreasing the incidence of stress fractures during intense physical training and reducing the risk of osteoporosis.²⁹ The department's research efforts have been primarily directed at ways to prevent stress fractures in new military recruits. Despite these efforts, the number of stress fracture injuries over the past few years has increased among soldiers returning from lengthy deployments. Stress fractures are a particular concern in the combat environment, where soldiers are less likely to seek medical attention for an injury perceived as minor and the medical equipment needed for proper diagnosis might not be readily available. Furthermore, it has been shown that nonsteroidal antiinflammatory medications could slow down stress fracture healing.³⁰

The individual nutrient profiles showed that many study participants had a calcium deficit although, on average, the soldiers participating in the study were able to just meet or minimally exceed the military dietary reference intake (DRI) for calcium before and after deployment. The current military DRI and reference intake for garrison training (intense training and 1-day missions) for calcium is 1000 mg a day for men and women, the same as the Institute of Medicine's DRI.³¹ Military experts have questioned whether this intake level is sufficient for optimal performance of military duties, given the potential for excessive losses of calcium. The soldiers in this study reported that food in Iraq was plentiful and flavorful, with large serving sizes and no restrictions on second helpings.

The war in most areas of Iraq is fought from solid, functional, urban structures with abundant recreational facilities such as gymnasiums, basketball courts, and pools nearby. However, soldiers also have access to fast-food restaurants and all-you-can-eat dining facilities. When questioned, many soldiers in this study did not report participating in sports or physical activities during deployment that involved weight-bearing or resistance, activities that are most beneficial to bone health. To ensure optimal BMD and reduce their risk of musculoskeletal injury, soldiers clearly need assistance in making healthy diet choices and encouragement to adopt a lifestyle that includes more vigorous physical activity.

SUMMARY

Maintaining a fit and ready force is critical to this nation's defense and this requires physical fitness.^{24,32} The multitude of factors contributing to high bone turnover in the deployed environment, including stress, substantial sweat calcium losses, changes in diet and physical activity, body armor weight, and smoking, make all deployed soldiers vulnerable to musculoskeletal injuries and stress fractures. These injuries can affect bone health in later years for all soldiers, but especially those who are injured before they have achieved peak bone mass.

The most important modifiable risk factors associated with bone health include hormonal status, physical activity, and nutrition.³³⁻³⁵ Health promotion for all military personnel must focus on education about the role of nutrition and exercise in developing and maintaining strong bones. Such health promotion initiatives should target soldiers between the ages of 19 and 30 years because they have not yet achieved peak bone mass. With each soldier encounter, military nurses are in a position to

reinforce the importance of a healthy diet and regular weight-bearing exercise to promote strong bones.

Key areas of ongoing investigation include determining the dose of vitamin D necessary to maintain healthy levels in all military personnel, evaluating the influence of nutritional status on bone health, and examining the role of vitamin and mineral supplements on bone quality.²⁹ Future studies need to identify the most clinically useful bone health biomarkers, interventions that promote healthy nutrition and exercise in military service members, and strategies to minimize injury during military training and combat duty.

In this article, the authors highlight the potentially negative effect of the current combat environment on the bone health of young military men and women. These soldiers could be at risk of stress fractures and future bone disease as a result of an unhealthy diet and low physical activity levels during deployment. The authors examined a combination of physiologic biomarkers, including bone turnover and bone mineral density, and nutrition and exercise surveys to collect data on potential bone health risks related to deployment. Soldiers participating in the investigation of bone health before and after deployment did not have decreased bone density but the study did raise awareness of an issue that might otherwise go unnoticed as preventive care is typically focused on older adults. Several risk factors for musculoskeletal injury during deployment might be modifiable. Nurses have the necessary skills for counseling and monitoring behaviors that can minimize the risk of disabling musculoskeletal injuries that affect quality of life and unit readiness.

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