The Association between Bone Mineral Density, Lifestyle Factors, and Body Composition in a Fit College Population

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The aim of this dissertation was to explore the determinants of bone mineral density and weight change in a fit, college-aged population. Specifically, this dissertation is a series of four papers that examined the determinants of bone mineral density (BMD) at multiple skeletal sites in men and women at college entrance, BMD differences related to prior participation in sports, and lastly, weight changes in women during four years at university. The subjects were 891 students, 755 males and 136 females of various racial backgrounds, entering one class at the United States Military Academy (USMA) at West Point. This was a unique population because these college students are healthier, fitter and engage in more positive health behaviors than other college populations. The data for these papers came from a larger Department of Defense funded prospective study examining longitudinal changes in BMD and the risk factors for stress fractures.

Upon arrival at USMA, a baseline questionnaire assessed prior exercise frequency, consumption of milk and other high calcium foods, caffeine and alcohol consumption, as well as tobacco and oral contraceptive use. Annual surveys assessed diet, menstrual function and contraceptive use. Academy staff measured height, weight and fitness annually. Varsity level sport specific information was collected from high school applications to assess skeletal differences in BMD associated with prior sport participation. Calcaneal BMD was measured by peripheral dual energy x-ray absorptiometry (pDXA). Peripheral-quantitative computed tomography (pQCT) was used to measure tibial bone density, circumference and cortical thickness. Spine and hip BMD were measured in all women and a subset of male cadets. Body composition was assessed using bio-electrical impedance. The Eating Disorder Inventory-2 was given to all participants in their final year of university to assess eating behaviors.

Baseline BMD was approximately one standard deviation above young normal at the calcaneus and hip. There were significant gender and racial differences in baseline BMD at multiple skeletal sites. African American men had significantly higher hip, spine and heel BMD and greater tibial mineral content and cortical thickness than Caucasians and Asians men. Similarly, African American women had significantly higher calcaneal and spine BMD than Caucasians. Higher caffeine intake in men had a deleterious effect on BMD. Oral contraceptive use in women was associated with reduced BMD and bone size. Women who had approximately normal menstrual cycles evidenced higher BMD at all sites, greater tibial mineral content and tibial cortical thickness as compared to those who had 9 or less menstrual cycles in the year prior to entry. Sport specific differences in BMD were apparent. Prior participants of high loading sports (football) had significantly more BMD at multiple sites while participants
in non-loading sports (swimming) had less BMD as compared to participants in other sports, even after controlling for body mass index (BMI).

During their four years at university, the Caucasian women studied had small but significant weight, body fat and BMI increases, while fitness scores also significantly increased. Younger age of menarche was associated with increased body fat at graduation. The use of depot medroxyprogesterone acetate was positively associated with a change in body fat at graduation. A number of measures of eating disorders, including a sense of ineffectiveness, body dissatisfaction, interpersonal distrust and maturity fears, were associated with graduation weight, body composition, BMI and changes in these variables during the four years at university. The most significant predictors of graduation weight and change in weight were better performance on the standardized fitness test and entry weight. There was a small subset of women studied who gained weight, but not body fat. This study on weight change demonstrated that weight gain is a complex social, physical and psychological issue that can impact college-aged women.

Both osteoporosis and obesity are life course diseases that may be influenced by existing behaviors in youth and those acquired in university. Therefore, studying the determinants of BMD and weight change in this population may help public health educators determine strategies that could positively influence the current obesity and osteoporosis epidemics.
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There are few occasions in life that you have the opportunity to acknowledge people who have helped you achieve an important goal. The completion of a doctoral education is one such moment. It is a privilege to be able thank my family, my friends and my faculty advisors who have supported me in pursuit of my doctoral education.

First, I would like to thank my family for their support and encouragement. My parents’ interest and enthusiasm in education never wavered, long after they could no longer help me with my assignments. My father would be particularly delighted with this achievement and my mother has served as my morale booster my entire life. This degree, at times, tested her cheerleading abilities. Of course, I am eternally grateful to my husband, Rhys. I am lucky to have someone who understood what it would take to finish. He is my friend, my confidante and tireless supporter. I would not have made it without his love and support. I am also grateful to my children, Cory and Luke, who supported this effort even when it meant that mommy might miss a swim meet, Girl Scout, Cub Scout or school function. I will always be grateful for my Rothman text and Newark Airport.

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Finally, I would like to recognize the cadets who participated in this study. The
demand on their time at the United States Military Academy was great. Their willingness
to participate in this study is a tribute to their character. I appreciate not only what they
did here but what they are doing for our Country. It is easy to forget that without their
time and effort, none of this would be possible.
DEDICATION

This dissertation is dedicated to my wonderful family. They have each way contributed to my success. They each have provided me immeasurable joy. I am grateful every day that they are in my life. I would also like to dedicate this dissertation to the West Point Class of 2002 and to the Members of the Long Grey Line who have died in Service to our great Country. May they Rest in Peace.
Chapter 1: Review of the Literature

I. Overview

A. Peak Bone Mass

Peak bone mass, a proxy measure for maximal bone strength, is of great interest and importance to military populations and the population at large. When higher bone mineral density is attained at a young age there is a subsequent reduction in the risk of childhood fracture, stress fracture, osteoporosis and related fractures occurring later in life.\textsuperscript{1, 2} Bone mass accumulates through childhood and adolescence until peak bone mass is reached. Bone mass remains relatively stable during the third and fourth decade of life with only a small decline. In women there is then a more precipitous drop in bone mass that occurs after menopause.\textsuperscript{3, 4}

Osteoporosis is a public health crisis in the making. Clinically, osteoporosis is defined by the World Health Organization as bone mineral density that is 2.5 standard deviations below young normal bone mass as measured in a population age 20-40.\textsuperscript{5} Bone mass in later life is a result of peak bone mass attained and subsequent bone loss. Measures of decreased bone density (low bone mass and osteoporosis) are clearly related to fracture risk both in postmenopausal women, and older men.\textsuperscript{4} It is anticipated that 50\% of Caucasian women will suffer an osteoporotic fracture after the age of 50. For men the picture is only slightly better with one out of every four men having a fracture related to osteoporosis in their lifetime.\textsuperscript{6} There are several challenges associated with controlling this burgeoning epidemic. Even the concept of osteoporosis as a disease of the elderly must be changed. Osteoporosis is a disease with childhood onset and consequences at an older age, a life course disease. Skeletal development is related to genetics, hormonal status, poor calcium intake and exercise as a child.\textsuperscript{7-10} This makes
intervention later in life difficult and relegated to bone mineral density maintenance, prevention of bone loss, and therapeutic interventions for fracture prevention. The development of osteoporosis is painless, often, there are no overt indications that the disease is present and diagnosis only occurs as a result of a fracture. Osteoporosis treatment and the direct costs associated with an osteoporotic fracture are staggering. The total direct health care costs associated with osteoporosis and osteoporotic fracture in the United States alone is approximately 14 billion dollars a year. An osteoporotic fracture is a serious condition with a six-month mortality rate post-hip fracture of 10 to 20%. Fifty percent of the survivors require a gait assistance device, and 25% will require assisted or nursing home care. In addition to these outcomes, there is a substantial loss in quality of life associated with a fracture as well as fear of fracture. Given these morbidity and mortality statistics in conjunction with the aging population, the importance of achieving peak bone mass, to prevent a weak skeleton later in life, should not be underestimated. The most effective prevention strategy is maximizing both the public’s understanding of bone health as well as implementing public health programs that increase bone density during childhood and young adulthood.

There are numerous factors that influence the attainment of peak bone mass. Genetics accounts for approximately 60-80% of peak bone mass attained. Numerous protective and detrimental factors influence an individual’s ability to attain their peak bone mass. The modifiable protective factors include, but are not limited to, physical activity and proper dietary habits including sufficient calcium and vitamin D intake. The negative modifiable factors can include alcohol consumption, smoking, and improper management of endocrine dysfunction. The positive associations between dietary intake of calcium and BMD in children
and retrospectively in adults are well documented. In examining the attainment of peak bone mass, Heaney et al (2000) identified load bearing exercise (e.g. hiking, jumping and dancing), calcium and Vitamin D intake, as factors that can assist an individual in achieving their pre-determined full genetic potential of bone mass. His graphical depiction for these data (Figure 1.a) illustrates the long-term consequences of having inadequate exercise and calcium intakes at a young age.

Figure 1. a- Factors Effecting Peak Bone Mass

**B. Nutrition and Lifestyle Variables**

Nutrition plays a critical role in the development of peak bone mass. There are a number of positive and negative nutritional influences on peak bone mass. Nutrients that have been
reported to exhibit a positive impact on bone are calcium, protein, vitamins C, D, and K, as well as phosphorus, copper, manganese, fluoride and zinc. However, like most dietary data the relationships to bone are modest. Like other systems in the body, bone is complex living tissue and therefore has many nutritional needs. What is currently understood about the role of nutrients involved in bone development is outlined in a simplified form in Table 1.1. However, one nutrient, calcium, is the most commonly researched and cited with respect to bone density and therefore requires a more detailed overview for two reasons. First, most other nutrients involved in bone development are both available in the Western diet and appear to be adequately consumed while calcium is not.\textsuperscript{19,20} Second, growth and strength are both highly dependent on the constant availability of calcium during skeleton formation and then skeletal maintenance.
### TABLE 1.1 - The Potential Role of Nutrients in Bone Health

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Example Sources</th>
<th>Hypothesized Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium (Ca)</td>
<td>Dairy, leafy vegetables, supplements and supplemented foods</td>
<td>Mineralize skeleton</td>
</tr>
<tr>
<td>Vitamin D</td>
<td>Sunlight, milk, infant vitamins, adult supplements</td>
<td>Calcium transport</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>Green peppers, citrus, strawberries, tomatoes, supplements</td>
<td>Collagen formation</td>
</tr>
<tr>
<td>Vitamin K</td>
<td>Cabbage, cauliflower, spinach, leafy vegetables made by the bacteria in gastrointestinal tract.</td>
<td>Gamma –carboxylation of glutamic acid residues in osteocalcin</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>Animal products</td>
<td>cofactor for enzymes involved in the synthesis of various bone matrix</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>Eggs, Bran, cereal, meats, soda</td>
<td>Mineralize skeleton</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>Nuts, seeds, spinach, legumes</td>
<td>Influences bone quality (microarchitecture- a key to bone strength)</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>Red meats, leafy vegetables, supplements</td>
<td>Collagen synthesis</td>
</tr>
<tr>
<td>Copper</td>
<td>Oysters, nuts, dried legumes, cereals, potatoes, vegetables, meat</td>
<td>Collagen crosslink formation</td>
</tr>
<tr>
<td>Fluoride</td>
<td>Water, supplements, toothpaste</td>
<td>Mineralize skeleton</td>
</tr>
<tr>
<td>Caffeine</td>
<td>Coffee, Tea, Chocolate, Sodas</td>
<td>Decreases GI calcium absorption</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>Trace in foods, supplement, food additive</td>
<td>Increases urinary calcium excretion</td>
</tr>
<tr>
<td>Fat</td>
<td></td>
<td>May decrease calcium absorption</td>
</tr>
<tr>
<td>Protein</td>
<td>Meat, fish diary, legumes</td>
<td>Malnutrition causes growth retardation probably mediated by leptin and IGF-1. Low protein intake in youth is associated with lower bone mass</td>
</tr>
</tbody>
</table>
1. **Calcium**

Calcium is a threshold nutrient.\(^{21}\) Calcium is also the most abundant mineral in the body. About 99% of calcium is stored in bones and teeth. Individuals consuming calcium at levels below the threshold will not have the ability to attain their full allocation of BMD; however, consumption above the threshold value does not provide additional benefit. Besides the important role calcium plays in bone development and later bone maintenance and health, calcium is also an important nutrient in heart and muscular function. It is estimated that 50% of Americans fail to consume recommended daily intake (RDI) of calcium. The concern over calcium (and Vitamin D) intakes and what appropriate RDIs should be, led to a call by both the Canadian and American governments to the Institute of Medicine requesting that the current literature on both Vitamin D and calcium be reviewed and new nutrient reference values and recommended dietary intakes be developed. The new recommendations were published on November 30, 2010 but even with the new recommendations, the debate continues, although not regarding the important role of calcium in peak bone mass.\(^{22}\) The recommended intakes have varied over the years and vary by organization. Table 1.2 shows the current recommendations by the Institutes of Medicine.
Calcium is the most abundant mineral in the body. Bones serve as the calcium reserve for periods of low calcium intake helping to maintain constant levels of calcium in the blood. The demand for calcium is lifelong. In utero, fetal bone development is influenced by maternal behavior. The fetus’ calcium needs are met at the expense of the mother’s bones if an inadequate amount of calcium is consumed. In addition, insufficient maternal vitamin D consumption is associated with reduced bone mineral acquisition in utero. This period is important because infants are born with only 2-3% of their total calcium. The continual need for calcium is a
function of both bone growth and bone remodeling. There are periods of increased demand for calcium including pregnancy, lactation, adolescent growth and advanced age when the body’s use of calcium is less efficient or the needs are greater. There may also be an increase in calcium demands created by exercise since some studies indicate a substantial amount of absorbable calcium is lost in sweat during a bout of strenuous exercise.\textsuperscript{25, 26} The body will always maintain required serum calcium levels, even to the detriment of bone health, since the skeleton serves as a ready supply of serum calcium.

2. \textit{Vitamin D}

Vitamin D is a fat soluble vitamin. It is produced when skin is exposed to the ultra violet light from sunlight which then triggers Vitamin D synthesis. There are limited dietary sources of Vitamin D including fatty fish, liver, fish oils, and some mushrooms. More recently fortified foods also supply vitamin D. Vitamin D is essential for calcium absorption and transport of calcium across the intestinal mucosa. Vitamin D is essential for both bone growth and bone remodeling. Vitamin D deficiency can lead to rickets in infants and children and osteomalacia in adults. Vitamin D has other functions besides promoting calcium absorption for bone health. Vitamin D is important to immune function and cell growth. The important role Vitamin D plays is well recognized in both the medical and nutritional communities. In fact, through supplementation there has been a reduction in many Vitamin D deficiencies. This was achieved by making Vitamin D a supplement in milk and it is the only vitamin regularly prescribed to infants. This Vitamin D supplementation route is considered one of the top ten nutritional successes of the 20\textsuperscript{th} Century.\textsuperscript{27} However, despite this success, Vitamin D deficiencies still occur
in a variety of populations. Supplementation is often frequently recommended in the elderly populations when the demands for Vitamin D increases while the exposure to sun and metabolic efficiency of the skin may concurrently decrease.

3. Deleterious Bone Elements

Several nutrients negatively alter the body’s calcium balance and therefore are considered to be detrimental to bone health. The negative impact of excessive use of these nutrients has been documented in relation to both bone development and bone maintenance. The substances of greatest concern are salt and caffeine. Other lifestyle factors can also produce a negative effect on bone. These include smoking, excessive alcohol consumption and the use of steroids. In addition, eating disorders have been associated with decreased bone mineral density.

4. Physical Activity

Physical activity has been reported to exhibit a protective effect on bone health at all ages. It is generally accepted that load bearing physical activity is beneficial in both the acquisition and the maintenance of bone mineral density although the greatest impact appears to occur in pre-pubertal periods. Bone has the ability to adapt to increased mechanical loads created by high impact exercises and subsequently become stronger. Bone mass has also been found to decrease without load or in micro-gravity environments.
5. **Childhood Exercise**

There is evidence that exercise in childhood may confer lifelong benefits to the bone by maximizing peak bone mass. Furthermore, some exercise behaviors established in childhood may continue into adulthood. Alternatively, lack of physical activity or a decrease in physical activity is associated with a decrease in bone mass or an inability to achieve peak bone mass. Not only is the existence of an exercise program important in children but the timing of exercise, whether it occurs pre- or post puberty is critical. The greatest benefit is seen in children who engage in higher impact sports in their pre-pubertal period. Findings indicate that these children significantly increase their BMD, bone geometry and bone mineral content (BMC). There is ample evidence from both cross-sectional and cohort studies that sport-specific differences occur in bone acquisition; those sports producing the greatest skeletal impact provide the greatest benefit. The exact contribution made by participation in specific sports has been difficult to examine. This is primarily due to limitations of these studies, which have only been conducted among elite athletes or small populations and predominantly cross sectional evaluations.

6. **Adult Exercise**

Adult exercise research in the field of osteoporosis is aimed at assessing the effectiveness of exercise routines on skeletal health including their intensity as well as their duration. The primary goal of adult exercise research is to understand how to prevent bone loss and fractures in
postmenopausal women and older men. Many meta-analyses have been completed with mixed results; however most indicate that different forms of aerobics, low intensity walking, resistance and any small amount of loading exercise can be effective in maintaining the BMD of the spine and or hip in postmenopausal women. In addition, the benefits of exercise on BMD in adults, as in children, is lost if the exercise program ceases; therefore the exercise program must be continued to maintain the skeletal benefits. An additional benefit associated with adult exercise, particularly strength training programs, is an increase in muscular control and function. This muscular control provides greater stability to the patient which affords additional protection against falls and fractures.

7. Sport Specific Research

Another area of considerable research has been focused on the differential benefits on bone that certain sports provide. In studies comparing the bone density and muscle mass of athletes engaged in a variety of sports, swimmers consistently have the lowest BMD compared with athletes that engage in forms of exercise that require greater weight bearing. In some studies swimmers and water polo players had bone density no different than their non-athletic controls. There is also evidence to show that the sport specific anatomical site, where the greatest mechanical loading occurs, will have a greater BMD when compared to other skeletal sites.
8. **Endocrine Function**

Proper endocrine function in both males and females is essential for proper growth and maintenance of BMD. Disruptions in normal endocrine function can occur because of disease, diet, excessive exercise, or drug use. Later age at onset of menarche, and thus a later and shorter exposure to estrogen, has also been associated with lower BMD.\(^{51, 52}\) Similarly, there are numerous studies that have associated amenorrhea/oligomenorrhea with decreased bone mass. There is a considerable body of literature addressing the effects of oral contraceptive pills on bone mass. The results of these studies are mixed showing either small but significant gains in BMD at some sites while others have found no association between the use of birth control pills and bone density.\(^{53}\) Similarly, studies of the levonorgestrel releasing intra-uterine system (LNG-IUS) showed no deleterious effects on BMD with short term or prolonged use.\(^{54, 55}\) However, use of depot medroxyprogesterone (DMPA) has been associated with lower bone density.\(^{53, 56, 57}\) A proper analysis of endocrine research has, to date, been difficult to conduct and those that are methodologically stronger have small numbers and small measures of effect.

9. **Body Composition**

There has been considerable debate on which of the anthropometric variables -- weight, and lean body mass or fat mass -- is the most important predictor of BMD. Generally, an increase in weight, whether lean or fat, will cause an increase in loading and consequently an increase in BMD. Alternatively, a better lean to fat ratio can be a proxy measure for a fit lifestyle and exercise, which may also increase BMD. Despite this debate, lean body mass has been identified
as a significant positive correlate of BMD in both genders and in all ages. An improvement in body composition (greater lean mass) is associated with a subsequent improvement in BMD. In many studies, the best predictor of BMD has been fat free mass.\textsuperscript{58} Alternatively, fat mass has been negatively correlated with BMD and bone mineral content (BMC).\textsuperscript{59} In addition to the skeletal benefits, there is a substantial body of evidence that proper weight and better body composition is associated with the reduction in of a number of diseases including obesity and obesity related diseases, with potential improvements in quality of life.

\textbf{C. Conclusion}

The importance of understanding modifiable risk factors that contribute to peak bone mass is critical for improving public health. There is a need for further research, verification, and adoption into lifestyle changes. Achieving higher peak bone mass can prevent early childhood fracture, as well as provide protection against fractures later in life. Osteoporosis is a burgeoning epidemic. It is a common but complex disease that requires not only an understanding of the large genetic component but also the environmental factors like diet and exercise. It is through this understanding that the course of the disease can be altered. Longitudinal studies examining the role and the relationship of childhood and adolescence factors in acquisition of bone mass are essential.
II. The Study

A. Background

The fit population at the United States Military Academy offers a unique opportunity to carefully examine a large population of healthy young adults and examine factors that may increase BMD at a critical period of life. Furthermore, many of the confounders that have plagued other studies, such as inadequate control for alcohol and smoking, are more naturally controlled for by the requirements of the academy. This series of papers will attempt to identify those factors that are easily modifiable and provide significant gains in BMD. If gains in bone mineral density can be clearly identified, even in a fit population, then the implications for the general population could be even greater. Longitudinal studies examining the role and the relationship of childhood and adolescence lifestyle factors that impact the acquisition of bone mass are essential. A significant weakness in the literature related to BMD and sports may be more fully understood by examining both physical aptitude and fitness. It is from studies such as these that the looming osteoporosis epidemic can be dealt with most effectively by developing primary prevention strategies to maximize peak bone mass.

B. Study Population

Study subjects were recruited from the United States Military Academy Class of 2002. Prior to their arrival at the academy, each cadet was mailed an information packet about the study and a sample consent form. This enabled the all entering cadets and their families ample
opportunity to read and understand the aims of the study prior to arriving and without the stress of the academy. During their first week at the academy all members of the class were formally briefed on the study objectives and risks and invited to participate in a four year prospective study examining the accrual of peak bone mass and the determinants of stress fractures. Approximately 70% of the class or 891 (males = 755, females = 136) members provided written informed consent. The Institutional Review Board (IRB) of Keller Army Community Hospital (KACH), West Point NY approved the study. While the study had racial diversity, greater than 83% of the cadets reported being Caucasian, which mirrors the cadet population. The ratio of males to females in the study is approximately 5 to 1. Ethnic and racial information was self reported on entry applications into the academy. The exact distribution of those participating in the study is shown in TABLE 1.3. The racial and gender distribution did not differ from the overall entering population distribution.

TABLE 1.3- GENDER AND RACIAL DISTRIBUTION OF STUDY SUBJECTS

<table>
<thead>
<tr>
<th>RACE</th>
<th>Caucasian</th>
<th>Asian</th>
<th>Black</th>
</tr>
</thead>
<tbody>
<tr>
<td>MALE</td>
<td>653</td>
<td>38</td>
<td>64</td>
</tr>
<tr>
<td>FEMALE</td>
<td>108</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>TOTAL</td>
<td>761</td>
<td>53</td>
<td>77</td>
</tr>
</tbody>
</table>
C. Data Sources

1. Participants

There were a number of sources for the data. A primary source of lifestyle data was drawn from the participants’ self administered questionnaires. The questionnaires included baseline lifestyle assessment, annual calcium specific food frequency questionnaires (FFQ), injury assessment, and menstrual function assessments which included use of birth control. Surveys are attached in Appendix A. The Academy imposed strict time restrictions and limited our access to the cadets to less than 30 minutes a year; therefore the questionnaires had to be brief to accommodate this requirement.

2. Academy Records

Numerous sources of data were gathered from Academy records. The Admissions office provided data on race and sports participation prior to entry as well as scores on the Physical Aptitude Exam (PAE). The Department of Physical Education (DPE) provided information on the annual Army Physical Fitness Test (APFT) and participation in club sports. These measures are described in detail in fitness measures section below.
3. Physical Measures

There were numerous physical measures taken on the participants during each annual visit. These included BMD at two sites, heel and tibia for all participants and hip and spine bone density on a subset of subjects. Bone mineral density at the heel, hip and spine was assessed using dual energy x-ray absorptiometry (DXA). DXA technology assesses the density of the bones in mg/cm². While DXA results do not produce a true density, they are considered a reasonable proxy for bone strength. A true volumetric measure of bone mineral density was acquired of the tibia using peripheral quantitative computer tomography (pQCT). Body composition was measured annually by bio-electrical impedance. Height and weight was measured annually and reported by Academy personnel. One blood sample was taken at baseline for examination of various genetic traits as well as bio-markers which are described in section D.6.

D. Outcome and Exposure Variables

1. Lifestyle Assessments

The baseline questionnaire assessed past exercise, lifestyle and dietary habits, as well as personal and familial history of fracture. The questionnaire assessed the number of hours of exercise per week in the year prior to entering the Academy to gauge past physical activity
levels. This was divided into four exercise categories: 1-3, 4-6, 7-10, or 11+ hours a week. Milk consumption was assessed at baseline. Milk consumption was determined by using 4 categories of glasses of milk consumed per day: none, < 1, 1-2, or 3 or more glasses per day. Further detail on the amount and frequency of consumption of additional calcium containing foods was assessed in the FFQ and a daily average in mg/day was calculated. Alcohol intake was assessed using 5 categories: less than once a month, 1-3 times a month, 1 to 2 times a week, 3 to 5 times a week and daily. This was a very rough measurement of alcohol consumption and therefore alcohol equivalents were not calculated for this study. Because of the participants’ age and their interest in health, exercise and the academy restrictions, it was not anticipated that there would be high alcohol consumption. Three categories determined caffeine consumption: none, 1 to 3 and more than 3 caffeine containing drinks a day. Similarly, the measurement of caffeine was a rough assessment of intake and calculated as milligrams of caffeine per day. Salt intake was a dichotomous, yes/no response to salting of food. In addition, an open-ended question was used to gather information on the types of nutritional supplements cadets were taking. Type of tobacco product (dip, chewing tobacco or cigarettes), amount and duration was also determined. Participants were asked about personal lifetime fracture history and site of fracture. Family history of adult fracture was examined for mother, father, grandparents, aunts and uncles. Female cadets were asked age at menarche, history of contraceptive use, past use of oral contraceptives and frequency of menstrual cycles prior to academy entry. Menstrual function and use of oral contraceptives was assessed annually in all females. Surveys are in Appendix A.
2. Bone densitometry

Quantitative measures BMD were assessed in the left calcaneus using the PIXI peripheral
dual-energy x-ray absorptiometry (DXA) (GE Lunar Corp, Madison, WI, USA). The bone
mineral density as assessed by DXA is a value given in mg/cm². In addition, bone mineral
content (BMC) is reported in milligrams. The left tibia density and geometric parameters were
assessed using a peripheral XCT 2000 scanner (pQCT; Norland Medical Systems Inc., Ft
Atkinson, Wisconsin, USA). The bone mineral density as assessed by pQCT is a true density
and the value is given in mg/cm³. A randomly selected subset of male cadets and all consenting
female cadets had their total hip and spine BMD assessed using a mobile DXA Lunar DPX-IQ.
The coefficient of variation in vivo for the heel DXA BMD, tibia pQCT BMD, Spine and Hip
BMD by DXA were 1.0, 1.2, 1.5, and 1.5 respectively. These tests are considered the gold
standard for bone density measurements. Sample study BMD results and NHANES comparative
data are in Appendix B.

3. Fitness Measures

(a). The Army Physical Fitness Test (APFT) –The Army standardized fitness test is
given twice a year to all military members. Upon entry into the academy, all members of the
class were administered the fitness test by trained Academy personnel. This standardized fitness
test measures upper body strength, abdominal and leg flexor strength and aerobic fitness by
testing the number of full body push-ups, complete sit ups each for two minutes and a timed two
mile run. These absolute numbers are then translated into a point value from 0-100. The absolute values of the number of repetitions differ for men and women but the assigned scores are age and gender standardized. Failure of any one event, a score of less than 60, is failure of the test. As an example of the fitness required a 17-21 year old male must run two miles in 13 minutes to score 100 and 15:54 to pass. Similarly, for a 17-21 year female maximum and minimal passing times are 15:36 and 18:54 for a two-mile run, respectively. APFT score card is in Appendix C.

(b). The Physical Aptitude Exam (PAE) - The PAE is an admission requirement to West Point. This test is standardized for gender and tests strength, agility, speed and endurance. The examination consists of the following five events: pull-ups (men)/flexed-arm hang (women); standing long jump; modified basketball throw; push-ups and 300-yard shuttle run. Each cadet is required to get a minimum score for entry. The results of the PAE by quintile are listed below in Table 1.4 with the mean for entry.
TABLE 1.4 PAE Quintiles for Entry

<table>
<thead>
<tr>
<th></th>
<th>Pull Ups</th>
<th>Flexed Arm Hang</th>
<th>Standing Long Jump</th>
<th>Basketball Throw</th>
<th>300-Yard Shuttle</th>
<th>Push Ups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Raps) Men</td>
<td>(Seconds) Women</td>
<td>(Ft.) Men</td>
<td>(Ft.) Women</td>
<td>(Ft.) Men</td>
<td>(Ft.) Women</td>
</tr>
<tr>
<td><strong>Top Quintile</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>62.2</td>
<td>9'4&quot;</td>
<td>7'5&quot;</td>
<td>92'</td>
<td>60'</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
<td>50.5</td>
<td>9'10&quot;</td>
<td>7'2&quot;</td>
<td>85'</td>
<td>54'</td>
</tr>
<tr>
<td>13</td>
<td>13</td>
<td>40.5</td>
<td>9'5&quot;</td>
<td>6'10&quot;</td>
<td>77'</td>
<td>48'</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>37.0</td>
<td>9'4&quot;</td>
<td>6'8&quot;</td>
<td>75'</td>
<td>47'</td>
</tr>
<tr>
<td><strong>Middle Quintile</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>34.0</td>
<td>8'3&quot;</td>
<td>6'7&quot;</td>
<td>73'</td>
<td>48'</td>
</tr>
<tr>
<td>10</td>
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<td>8'2&quot;</td>
<td>6'6&quot;</td>
<td>72'</td>
<td>43'</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>28.6</td>
<td>8'0&quot;</td>
<td>6'5&quot;</td>
<td>70'</td>
<td>42'</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>27.0</td>
<td>8'4&quot;</td>
<td>6'4&quot;</td>
<td>69'</td>
<td>40'</td>
</tr>
<tr>
<td><strong>Bottom Quintile</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
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<td>6'2&quot;</td>
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<td>38'</td>
</tr>
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<td>7</td>
<td>20.5</td>
<td>7'8&quot;</td>
<td>6'1&quot;</td>
<td>64'</td>
<td>35'</td>
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<td>6</td>
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<td>18.4</td>
<td>7'7&quot;</td>
<td>6'0&quot;</td>
<td>62'</td>
<td>34'</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>16.2</td>
<td>7'6&quot;</td>
<td>5'11&quot;</td>
<td>60'</td>
<td>31'</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
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<td>7'5&quot;</td>
<td>5'10&quot;</td>
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<td>3</td>
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<td>7'3&quot;</td>
<td>5'7&quot;</td>
<td>55'</td>
<td>28'</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>8.2</td>
<td>7'1&quot;</td>
<td>5'3&quot;</td>
<td>52'</td>
<td>27'</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>6.0</td>
<td>7'11&quot;</td>
<td>5'3&quot;</td>
<td>48'</td>
<td>24'</td>
</tr>
</tbody>
</table>

* Run on 26-yard course
**The minimum number of push-ups that are required within a 2-minute span on the Army Physical Fitness Test are listed for men and women.

Source 62

4. Anthropometric Measures

(a). Height and Weight — Academy personnel assessed height and weight at entry. Height was measured in inches and weight in pounds. Subsequent annual height measurements were recorded as part of the Army’s annual height/weight requirement.

(b). Body Mass Index (BMI) - BMI or the Quetelet index is a body mass calculation, and is based on the ratio of weight (in kg) to height (in meters squared).
(c). **Body Composition** - The Tanita 305 total body fat analyzer was used to assess weight, bio-electrical impedance, percent body fat, fat mass, lean body mass and total body water. The primary variable of interest was percent body fat. The test retest correlation coefficient was 0.99.

5. **Sports Participation**

   (a). **Prior to Entry** - Each academy application was reviewed for sports participation in the three years prior to academy entry. This is a requirement of academy entrance and is an important part of the scoring process that leads to admission. In an initial review of all participants, less than 1% did not participate in sports prior to academy entrance. In some cases, the applicant had sports participation, but in a club external to the high school or prep school. The form that each study participant filled out was co-signed and verified by the high school, prep school or college from which they were applying.

   (b). **At the Academy** - During each participant’s time at the academy, the Department of Physical Education at West Point maintained rosters of those cadets who engaged in competitive club athletics but were not classified as NCAA level athletes. These lists were provided annually to the study team.

6. **Biomarkers**

   A single blood collection occurred the first week of entry in the academy. All genetic markers including the Vitamin D Receptor gene, and biochemical markers related to bone and calcium metabolism, were taken from this sample. The serum samples were stored at -70 Celsius and the whole bloods were stored at -20 Celsius before being shipped to Scotland for genetic
analysis. The Insulin Like Growth Factor-1 (IGF-1) assays were performed at the Helen Hayes Hospital Clinical Research lab using an IRMA kit with a pre-assay extraction that frees the IGF-1 from the binding proteins. The manufacturer of the kit is Diagnostic Systems Labs (Webster, Texas). IGF-1 appears to play an important role in bone remodeling. Osteoblasts and pre-osteoblasts secrete IGF-1. IGF-1 has been positively associated with BMD at multiple sites. Similarly, it has been suggested that variations in the Vitamin D receptor gene may be responsible for some of the variation in both BMD and body weight.

D. Ethical Concerns

1. Consent

The proposed research was approved by the Keller Army Hospital IRB. The participants were provided with a briefing and if interested signed an informed consent. Even though many participants would be considered children because of their age (under 17), they were considered emancipated upon entry into the academy and therefore could provide consent. An effort was made at the initial consent briefing to ask all Academy personnel to leave the room so there would be no perception of coercion to participate in the study. This was particularly important in a rank structure environment, such as USMA.
2. **Data Storage**

The data was and still are kept under lock and key. Only study personnel have access to the raw data and none of the reports have any identifying individual characteristics.

3. **Information Access**

In the rare case that academy personnel wished to view any data, a written release was collected from the study participant. The requests were primarily for medical reasons including bone fracture. The participants themselves had complete access to their data and were able to request it through a study website or when the investigators were on site.

III. **Methodologic Improvements**

The proposed studies offered a number of advantages over related studies conducted in the past. First, the age of the population was prior to the expected age of attainment of peak bone mass and presumably a number of cadets would have attained peak bone mass while participating in the study. The ability to quantify the percentage of participants that attained peak bone mass during this period and to examine the associated characteristics would add substantially to the body of scientific literature. This population was predominately male, and few studies have been conducted examining peak bone mass acquisition in males. This study population was young and fit and they engaged in relatively few of the confounding behaviors
that were deleterious to bone. It was hoped that this would allow a better insight into the effects of fitness and sport specific BMD variation. Both the sample size, 891, and the duration of the study offered substantial improvements over past studies. This was a four-year study that allowed for five measurements, a baseline at entry and four annual follow up measurements. The accuracy of the academy record keeping system was judged to be excellent and many of the variables used in this study were provided by the academy. Additionally, many of the academy-collected measures have been validated and standardized. Since fitness and physical aptitude exams were mandatory for all cadets, we have 100% ascertainment of those variables. Prior studies in sports and BMD have not evaluated these variables. One variable that has not been tested anywhere in the literature is physical aptitude as it relates to bone mineral density. The reason the PAE variable is of interest is it can be used to help dispel the concern that all college athletes or athletes in general self select into a sport because they are physically more capable. Finally, because the academy carefully tracks all graduates we have excellent methods available to follow up on the participants during their 10 year reunion to further assess the process of bone mineral acquisition, bone loss and body composition changes in the third and forth decade of life. The following four chapters will address the following hypotheses to enhance the literature with respect to bone mineral density and overweight or obesity in college aged students.

Chapter 2 and 3

Chapters two and three both present the results of descriptive, cross sectional analysis of lifestyle determinants associated with baseline bone density measures. Gender and race are
important predictors of bone mineral density so analyses will be completed separately by race and gender or these variables will be controlled for when appropriate and then pooled if there are no differences. As part of this study, average bone mineral density at different sites will be compared to population norms to provide insight into the population being studied. Specifically, the following hypothesis are made:

**Hypothesis 1a:** There will be distinct differences in baseline bone mineral density between genders and races.

**Hypothesis 1b:** Lifestyle and environmental elements including calcium consumption, oral contraceptive use, smoking, alcohol, age at menarche, prior history of exercise will have an impact on bone even at college entry when peak bone mass has not yet been achieved.

**Hypothesis 1c:** Personal and family fracture history will be predictive of lower BMD at multiple sites.

Chapter Four provides the results from a cross sectional study that examined physical aptitude, sport specific participation and fitness levels as they related to bone density measures at different skeletal sites. Sports will be examined by similar sport type. In addition, sport specific differences in BMD and fitness were examined. IGF-1 was examined as a mediator in the fitness/sport/BMD relationship. The apriori hypotheses for this study were:

**Hypothesis 3a:** Sports confer different site specific loading benefits. Sports with higher loads will convey a greater benefit.
**Hypothesis 3b:** Lifestyle and environmental elements including calcium consumption, smoking, and prior history of exercise will have an effect on sport specific bone acquisition.

**Hypothesis 3c:** The Physical Aptitude Exam and Army Physical Fitness exam have different underlying constructs and therefore will have different impact on bone mineral density in the sports participants.

**Hypothesis 3d:** IGF-1, a growth hormone mediator, will serve as a mediator in the relationship between sport, fitness, PAE and BMD.

Finally, Chapter Five is a four-year prospective cohort study. The main outcome variable was body composition, BMI and weight change in women. The unit of analysis will be the individual. Other variables of interest include fitness, physical aptitude, sports participation and calcium consumption, and the vitamin D receptor genome. The use and type of birth control and age of menarche was also analyzed as potential predictors of body composition and changes in weight and body composition. The specific hypotheses for this study are:

**Hypothesis 5a:** There will be no or little weight change in the first year but weight gain will occur in the second year when there are greater freedoms in food choices.

**Hypothesis 5b:** Lifestyle and environmental elements including calcium consumption and prior history of exercise will be positively associated with a smaller change in body composition.

**Hypothesis 5c:** Age of menarche and use of DMPA will be negatively associated with
changes in BMI, weight, and changes in percent body fat.

IV. SPECIFIC METHODOLOGIC ISSUES

A. CONSTRUCT VALIDITY

The basic building block for validity of any study is construct validity. To have construct validity one must ask the question- “Are you measuring what you think you are?” Or, are the operationalized concepts of the variables of interest reasonably well measured given the limitations of technology and the ethical considerations of human research.

1. Outcome variable-

(a). Bone Density- The outcome variable of greatest interest in this series of studies is bone mineral density. This is a proxy measure for bone strength. Bone strength or the strength of any material is in part based on its ability to resist fracture. However, bone mineral density is only one of the components of bone strength; the other components are micro-architecture and elasticity. At this point, micro-architecture and elasticity are difficult to measure in vivo. BMD is the best predictor of fracture that exists today and therefore remains a good measure of bone strength for two reasons. First, from an engineering standpoint the strength of any material is the square of its density and second, numerous studies trying to approximate bone micro-architecture found only a small increase in the ability to predict fracture. For these reasons, the bone
densitometry measures used are not only reasonable but the best predictor of fracture that is currently available. DXA approximates bone mineral density as mg/cm\textsuperscript{2}, which is an areal density and not a true volumetric measure. Nevertheless, DXA is considered the gold standard for the measurement of bone mineral density and thus was used to assess the spine, hip and heel in this study. In addition, true volumetric density of the tibia was acquired.

(b) Body Composition- There are numerous methodologies to assess body composition and there is some debate on identifying the current gold standard. One reasonable, portable and cost-effective method of assessing body composition is bio-electrical impedance analysis (BIA). The difficulty associated with using body composition in any model related to BMD is that both have a strong genetic component and can also be an indicator of other lifestyle factors including exercise. BIA is based on the differences in conduction of electrical current between muscle fat and water. While it is not the gold standard it is a good measure of body composition and has good reliability. The test-retest correlation coefficient is 0.99 and the correlation with the presumed gold standard hydrostatic weighing is $r = 0.84^{63}$.

2. Exposure Variables

(a). Calcium Intake- The literature is replete with information about the difficulty in assessing the levels of intake of a particular nutrient. The measurement of calcium in this study is not immune to the problems inherent with any food frequency questionnaire (FFQ). Some of the problems associated with the use of FFQs include individual interpretation of portion size, variation in quantities of nutrient in the same foods and recall of diet. While it is preferable to
assess total food intake, in practical terms a timed self-administered questionnaire using a targeted assessment of calcium is the best and most cost effective measure of assessing a nutrient available for this population. Minor sources of calcium that were not assessed in this targeted assessment should not substantially change the outcome. The FFQ used in this study was not tested against a food diary. Food diaries are an alternative method for assessing dietary intake. In a recent comparison of 3-day food diaries and a short calcium specific food frequency questionnaire the difference in calcium intake between the methods was 51.3 mg (P>0.05), which did not differ significantly from zero. A Pearson's correlation coefficient of 0.56 was obtained between the two methods.

(b). Sports Participation- Specific sports participation was provided prior to entry by the study participant but was validated by the counselor at that institution. Official DPE and ODIA records provided sports participation while at the academy. This is a well controlled variable. The primary threat to construct validity is the assumption that, as an example, football at one high school and football at another high school were played with equally loading and intensity and the time during the season of play were similar. This is clearly not the case prior to entry. The assumptions about play and intensity while at the academy are reasonably well founded because of the structured nature of sports participation. There is also some concern that different positions may load differently. An example would be the diver who is on the swim team who has considerably more weight bearing then the traditional swimmer. Therefore, to separate out the differences that can occur between sports, within sport differences in loading will be assessed.
3. Potential Confounders and Mediators

In these studies, it may be important to differentiate sports participation at different levels and fitness. Fitness is not easily measured and is generally considered to have multiple facets including flexibility, cardio respiratory endurance, muscular strength and endurance and body composition. Each element of these components has its own measurement gold standard. As an example currently the gold standard for cardio respiratory fitness is considered to be maximal oxygen uptake (VO2 max) during high intensity exercise. However, the Army has a standardized test that takes into consideration two of the four components of fitness, strength and endurance as well as cardio respiratory fitness. In a review of the literature, Knapik found that the two mile run is highly correlated with VO2 max and is therefore a good measure of the cardio respiratory component of fitness. In addition, his review found that the sit-up and push-up portion of the test were a good measure of muscular strength and endurance; therefore the use of the APFT can be considered a valid measure of fitness65. This test is conducted under timed and controlled procedures and provides definitive and quantitative results that were not subject to interviewer bias.

4. Conclusion

These proposed studies did not always use the “gold standard” for the measurement of each of the variables of interest because of the field conditions of the study. Despite this, there is considerable construct validity. The validity of the study was not compromised by the operationalization of the measurements. Finally, Chapter Six provides a brief summary of the
study findings of the four previous chapters. It provides a synopsis of whether the study hypothesis was met, implication of the findings for social and medical policy, and a direction for future research. This chapter also highlights some of the strengths and limitations of the research presented here.

B. Internal Validity

Specifically, internal validity deals with the idea of causation. Internal validity addresses the question, “If there is an association between the exposure and outcome, was it caused from the exposure as measured to the outcome as measured?” Additionally, are the exposed groups and the unexposed groups similar with the exception of the exposure variable? If the groups were not exchangeable then any statement of cause would be incorrect. Specifically, in this study, we would like to be able to infer that the exposure of interest, exercise and/or diet had an impact on bone mineral density. Several types of bias can threaten internal validity. There are some potential threats to internal validity in this study that will be discussed below.

(a) Selection Bias- More specifically, the type of selection bias that poses the most concern is self-selection into the sport of choice. As a means of illustrating this concern, the 10 year old who is small in stature and in a low percentile for weight is unlikely to select as his sport of choice a high impact and high loading sport like football, but might be more attracted to cross country or swimming. This concern is not limited to this study. All the studies that examine sports differences are limited by the sports selection that their participants made many years earlier.
(b) **Confounding**- Confounding always presents a threat to internal validity. It is fortunate that many of the confounders associated with BMD have been explored and have been readily identified in this study. These include but are not limited to age, gender and race. The age range in this study is relatively small and will be considered (controlled) but is not anticipated to have a great effect on study outcome. Race and gender will be examined and controlled for carefully and may provide some interesting insights into the nature of the differences.

(c) **Information Bias**- Loss to follow-up is the greatest concern in this study. There will be two main reasons that participants will be lost to follow-up. The first is that participants will leave the academy voluntarily or will be separated from the academy because of an inability to meet academic, military, physical, honor or medical standards. Academy records indicate that 308 members of the class graduating in 2002 withdrew from the academy. The Academy database classifies departures based on the following codes:

11-Resigned Cadet Basic Training
64-Resigned Conduct
65-Resigned Honor
67-Resigned Motivation
68-Resigned Personal
69-Resigned Misconduct
71-Separated Academic
72-Separated Military Development
73-Separated Academic & Mil Dev
74-Separated Conduct
75-Separated Honor
76-Separated Medical
77-Separated Weight Control Program
78-Separated Physical Fitness Program
79-Separated Misconduct

With the exception of departure codes 76, 77, and 78, there is no plausible reason to assume that failure to meet academy standards is associated with either the exposure or outcome of interest. There were 5 cadets who were separated under those codes. The second reason that participants were lost to follow up was they no longer had interest in the study or found the time demands of the academy too great to continue participating. Officially, only one of the 891 cadets withdrew from our study for lack of time, the exact reason the other 163 participants did not complete the study is unknown. However, it can be assumed with relative confidence that this was unrelated to BMD, body composition or the exposures of interest.

(d) Conclusion- The causal relationships inferred from the findings of this study will not be substantially compromised by the identified threats to internal validity.

3. External Validity

External validity is a measure of generalizability. In other words, can the conclusions made about diet and exercise and their contributions to the acquisition of BMD be extrapolated to other populations? While the initial assumption to this question might be “no,” this is not the case at
all. Small increases in this population may translate into larger gains for the population at large, who may be further away from achieving their full genetic potential for bone mass than this fit population. While participants in this study are not representative of the population of all college-aged students, because of the stringent medical and physical requirements for entry, this study may help distinguish which modifiable factors can contribute most to bone density for this group.

Chapter Six provides a brief summary of the study findings of the four previous chapters. It provides a synopsis of whether the study hypotheses were met, implications of the findings for social and medical policy, and a direction for future research. This chapter also highlights the strengths and limitations of the research presented here.
References


Chapter 2: Determinants of bone mass and bone size in a large cohort of physically active young men

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Abstract

The determinants of bone mineral density (BMD) at multiple sites were examined in a fit college population. Subjects were 755 males (mean age = 18.7 years) entering the United States Military Academy. A questionnaire assessed exercise frequency and milk, caffeine, and alcohol consumption and tobacco use. Academy staff measured height, weight, and fitness. Calcaneal BMD was measured by peripheral dual energy x-ray absorptiometry (pDXA). Peripheral-quantitative computed tomography (pQCT) was used to measure tibial mineral content, circumference and cortical thickness. Spine and hip BMD were measured by DXA in a subset (n = 159). Mean BMD at all sites was approximately one standard deviation above young normal (p < 0.05). African Americans had significantly higher hip, spine and heel BMD and greater tibial mineral content and cortical thickness than Caucasians and Asians. In Caucasians (n = 653), weight was a significant determinant of BMD at every skeletal site. Prior exercise levels and milk intake positively related to bone density and size, while caffeine had a negative impact. There was an apparent interaction between milk and exercise in BMD at the heel, spine, hip and tibial mineral content and cortical thickness. Our data confirm the importance of race, body size, milk intake and duration of weekly exercise as determinants of BMD and bone size.
Introduction

The Surgeon General recently highlighted bone health as an important public health issue in the United States and 20% of osteoporosis occurs in men. Bone mass accumulates throughout childhood and adolescence until peak bone mass is reached during the third decade of life. When higher BMD is attained at a young age (higher peak bone mass) there is a subsequent reduction in the risk of childhood fractures, stress fractures, and possibly osteoporosis and related fractures later in life. Studies indicate that a larger bone size is also related to a reduced risk of fracture. Genetic factors account for between 60–80% of the variance in peak bone mass and bone size. However, an individual male may not achieve his genetically determined bone mass/size, if environmental and lifestyle conditions are not permissive.

High levels of physical activity and adequate calcium intake have been shown to improve accrual of peak bone mass, although data in males are limited. Numerous studies indicate that tobacco use and excessive alcohol and caffeine consumption are associated with lower bone mass in young adults. However, there is little known about the impact of these lifestyle factors on bone size. The purpose of this cross sectional study was to examine the influence of milk intake and exercise levels in the prior year, body size and race on bone mineral density and bone size in a physically fit male college age population.
Methods

Subjects

Subjects were college-aged males recruited from the United States Military Academy Class of 2002, West Point, NY. The Institutional Review Board (IRB) of Keller Army Community Hospital (KACH), West Point, NY, approved the study. During their first week at the Academy, all members of the class attended a presentation describing the study objectives and associated risks, and were then invited to participate. The military academy has stringent medical requirements for attendance; therefore, no exclusion criteria were required for this study. Approximately 70% of all the males in the class (n = 755) provided written informed consent.

Lifestyle assessments

A self-administered baseline questionnaire was used to assess exercise, lifestyle and dietary habits in the year prior to Academy entrance. Race data was provided from Academy records. Exercise (weekly average) was categorized as: 1–3, 4–6, 7–10, or 11 + hours /week during the prior year. Daily milk consumption was assessed as: <1, 1–2, or 3 or more 8 ounce glasses a day. Four questions assessed calcium intake including daily milk consumption and weekly servings of yogurt, cheese and high calcium content vegetables (0, 1–3, 4–6 or 7 + serving per week). Daily caffeine consumption was divided into three categories: none, 1 to 3 and >3 caffeine containing drinks a day. Alcohol intake was assessed using 5 categories: less than once a month, 1–3 times a month, 1 to 2 times a week, and 3 to 5 times a week or daily. Tobacco use was assessed by type (dip, chew, or cigarettes), dose and duration. Cadets were given a baseline fitness test. The test had three components: a 2 mile run, 2 minutes of push ups
and 2 minutes of sit ups. All three events are graded from 0–100 with better performers receiving a higher score.

**Bone densitometry and anthropometric measures**

Academy personnel measured each cadet’s height and weight in their physical fitness uniform that consists of a standard issue t-shirt, nylon shorts and socks. These measurements were used to calculate Body Mass Index (BMI: weight (kg)/height (m²)). BMD (g/cm²) of the left calcaneus was measured by DXA (pDXA; Pixi, Lunar, Madison, WI) in all cadets. Peripheral quantitative computed tomography (pQCT; Stratec, Germany XCT-2000) was used to image a single slice at the two-third distal tibia. The distal third of the tibia was determined by a manual measurement of tibial length between the base of the patella and the styloid process to the closest centimeter. The 2/3 site was then located by the pQCT scanner after placing a positioning light of the gantry above the styloid process. Bone mineral content (mg per 1 mm slice of bone), bone density (mg/cm³), cortical thickness (mm) and periosteal circumference (mm) were measured. Cortical thickness was derived using the circular ring model, using a threshold of 710 mg/cm³ to define cortical bone. This model calculates a mean cortical thickness from measures of total bone area and cortical bone area. In a randomly selected subset (n= 159) of male cadets, total hip and spine BMD (lumbar vertebral bodies: L2–L4) were measured using standardized positioning devices and the high-resolution software mode in a mobile DXA scanner (DPX-IQ, Lunar, Madison WI). The short-term coefficient of variation for each bone measurement was calculated by scanning 10 individuals on each machine twice. The coefficient of variation for bone density in vivo was 1.0%, 1.2%, 1.5% and 1.5% for the calcaneus by pDXA, tibia by pQCT, and spine and total hip by DXA respectively.
**Statistical analysis**

The relationships between lifestyle factors measured continuously (e.g. height and weight) and bone variables were examined using correlation analyses and, where appropriate, with linear regression to control for potential confounders. Effects of categorical lifestyle variables such as alcohol consumption were coded from 1 to n based on the number of categories assessed. Differences in the effect of categorical variables on bone indices were assessed using analysis of variance using Sidak post hoc analysis. The relationships between BMD at different skeletal sites with fitness measures including running score were assessed by linear regression. Comparisons between cadets and reference populations were performed using t-tests for independent groups. For each skeletal site, a step wise multiple regression model was created for Caucasian males evaluating all covariates that had biologic plausibility and were significant in the univariate analysis. Creating a cross-product term and evaluating it as an independent predictor in the site-specific regression models evaluated the interaction of milk intake and physical activity. The level of significance for alpha was set at 0.05 for all statistical tests. All analyses were performed with SPSS statistical software (Version 13.0 for Windows, SPSS Inc., Chicago IL.)

**Results**

**Population characteristics**

There were 755 male cadets enrolled in the study of which eighty six percent were Caucasian (n = 653), eight percent were African American (n = 64) and six percent were Asian (n = 38). The mean (± SD) age at entry was 18.7 (± 1.03) years. Table 2.1 provides a summary of
the distribution of lifestyle variables separately for Caucasians, African Americans and Asians.

Most cadets (74%) exercised more than 7 hours per week and had an average calcium intake over 1000 mg/day, with the majority of calcium (64%) coming from milk. Only 5.4% of male cadets smoked and only 18% consumed alcohol more than once per week. Caucasians consumed significantly more alcohol than either Asians or African Americans ($p < 0.02$) while Asians consumed significantly less caffeine than any other race ($p < 0.01$). There were no significant differences in the lifestyle characteristics between those men that had central DXA measurements and the whole group; however, cadets with central DXA had a significantly shorter height (1.03 inches) and lower weight (10.03 pounds) than the entire group of men.

**Table 2.1**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD (Caucasians)</th>
<th>Mean ± SD (African Americans)</th>
<th>Mean ± SD (Asians)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>18.7 ± 1.05</td>
<td>18.5 ± 0.94</td>
<td>18.5 ± 0.73</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exercise (hrs/week)</th>
<th>Percentage (n)</th>
<th>Percentage (n)</th>
<th>Percentage (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3</td>
<td>5.5 (34)</td>
<td>6.3 (4)</td>
<td>10.5 (4)</td>
</tr>
<tr>
<td>4-6</td>
<td>19.5 (127)</td>
<td>23.3 (15)</td>
<td>19.5 (6)</td>
</tr>
<tr>
<td>7-10</td>
<td>30.9 (201)</td>
<td>28.1 (18)</td>
<td>30.9 (13)</td>
</tr>
<tr>
<td>11-</td>
<td>44.1 (287)</td>
<td>42.2 (27)</td>
<td>44.1 (15)</td>
</tr>
<tr>
<td>Milk (glass/day)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>4.4 (29)</td>
<td>4.7 (3)</td>
<td>3.9 (3)</td>
</tr>
<tr>
<td>&lt; 1</td>
<td>17.0 (111)</td>
<td>28.1 (18)</td>
<td>13.2 (5)</td>
</tr>
<tr>
<td>1-2</td>
<td>47.4 (309)</td>
<td>43.8 (28)</td>
<td>50.0 (19)</td>
</tr>
<tr>
<td>3+</td>
<td>31.1 (203)</td>
<td>23.4 (15)</td>
<td>28.9 (11)</td>
</tr>
<tr>
<td>Caffeinated (Drinks/day)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>17.1 (111)</td>
<td>14.3 (9)</td>
<td>36.8 (14)</td>
</tr>
<tr>
<td>1-3</td>
<td>70.3 (457)</td>
<td>76.2 (40)</td>
<td>57.8 (22)</td>
</tr>
<tr>
<td>3+</td>
<td>12.6 (82)</td>
<td>9.5 (6)</td>
<td>3.2 (2)</td>
</tr>
<tr>
<td>Alcohol Consumption</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than once a month</td>
<td>57.8 (375)</td>
<td>78.1 (50)</td>
<td>66.7 (22)</td>
</tr>
<tr>
<td>1-3 times a month</td>
<td>22.7 (147)</td>
<td>15.6 (10)</td>
<td>30.3 (10)</td>
</tr>
<tr>
<td>1-2 times a week</td>
<td>14.6 (95)</td>
<td>4.7 (3)</td>
<td>9.1 (3)</td>
</tr>
<tr>
<td>3-5 times a week</td>
<td>4.0 (24)</td>
<td>1.6 (1)</td>
<td>0.0 (0)</td>
</tr>
<tr>
<td>Daily</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
</tr>
<tr>
<td>Smokers</td>
<td>5.1 (44)</td>
<td>4.7 (2)</td>
<td>12.1 (5)</td>
</tr>
</tbody>
</table>

Note: Listed at Table 1 in the published article.
Racial differences

There were significant racial differences in height, weight, and BMI as shown in Table 2.2. Asian males weighed less, were shorter and had a lower BMI than Caucasians or African Americans (all \( p < 0.013 \)). Mean calcaneal BMD in African-Americans was significantly higher than either Caucasian or Asian males and, in all races, was higher than the manufacturer's population average in all races (Table 2.2; \( p < 0.03 \)). African Americans had significantly higher tibial mineral content (\( p < 0.03 \)). Tibial geometry also differed by race; African Americans had significantly larger periosteal circumference and greater cortical thickness than Asians or Caucasians. African Americans also had significantly higher BMD of the hip (\( p < 0.008 \)) than either Caucasians or Asians but there were no significant differences in spine BMD after controlling for weight. Racial differences have been well reported. 26, 27

Table 2.2 Racial Differences in Anthropometric Measures and Bone Mineral Density

<table>
<thead>
<tr>
<th>Anthropometric Variables</th>
<th>Caucasians n = 653</th>
<th>African Americans n = 64</th>
<th>Asians n = 38</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (inches)</td>
<td>70.2 (± 2.7)</td>
<td>69.5 (± 2.9)</td>
<td>65.6 (± 2.4)*</td>
</tr>
<tr>
<td>Weight (pounds)</td>
<td>173.4 (± 29.0)</td>
<td>172.5 (± 29.4)</td>
<td>154.8 (± 22.3)*</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.7 (± 3.4)</td>
<td>25.1 (± 3.6)</td>
<td>23.1 (± 2.9)*</td>
</tr>
<tr>
<td>Bone Mineral Density/Size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcaneal BMD (g/cm²)</td>
<td>0.706 (± 0.13)</td>
<td>0.852 (± 0.17)*</td>
<td>0.666 (± 0.14)</td>
</tr>
<tr>
<td>Lumbar Spine BMD (g/cm²)</td>
<td>1.282 (± 0.13)</td>
<td>1.309 (± 0.19)</td>
<td>1.272 (± 0.13)</td>
</tr>
<tr>
<td>Total Hip BMD (g/cm²)</td>
<td>2.444 (± 0.15)</td>
<td>1.356 (± 0.20)*</td>
<td>1.159 (± 0.09)</td>
</tr>
<tr>
<td>Distal Tibia BMD (mg/cm³)</td>
<td>810 (± 85.1)</td>
<td>813 (± 84.8)</td>
<td>811 (± 92.3)</td>
</tr>
<tr>
<td>Tibial Mineral Content (mg)</td>
<td>354.8 (± 44.7)</td>
<td>390.0 (± 53.9)*</td>
<td>344.6 (± 40.3)</td>
</tr>
<tr>
<td>Cortical Thickness (mm)</td>
<td>6.17 (± 0.78)</td>
<td>6.41 (± 0.90)</td>
<td>6.06 (± 0.79)</td>
</tr>
<tr>
<td>Periosteal Circumference (mm)</td>
<td>73.7 (± 5.7)</td>
<td>76.3 (± 5.8)*</td>
<td>72.9 (± 5.1)</td>
</tr>
</tbody>
</table>

*p < 0.05 vs. other races
Determinants of bone density in Caucasian males

Calcaneus

Height and weight were correlated with calcaneal BMD ($r = 0.33$, $r = 0.53$, respectively, both $p < 0.001$). For each additional ten pounds of weight there was a 4% increase in heel BMD. Prior exercise history was positively related to calcaneal BMD with approximately 3% higher calcaneal BMD with each 3 additional hours of exercise per week. ($p < 0.002$ for trend; Figure 2.a).
Figure 2.a

The impact of weekly average exercise in the prior year (shown as: 1–3, 4–6, 7–10, or 11 + hours/week) on various bone variables.

*p < 0.05

**p < 0.01 vs. all others
Caffeine consumption was negatively related to calcaneal BMD in Caucasians (2.5% lower for 2 or more cups per day consumed). Lower milk consumption translated into a 4% lower calcaneal BMD between cadets with low (1 or fewer glasses) vs. higher daily milk intake (Figure 2.b; \( p < 0.03 \)). Total calcium was related to heel BMD (\( r = 0.12; \ p < 0.01 \)), but daily dairy calcium had a higher correlation (\( r = 0.17; \ p < 0.01 \)). Alcohol and tobacco intake were not related to calcaneal BMD (both \( p < 0.5 \)). Table 2.3 presents the results of a stepwise regression analysis, with the best predictors of calcaneal BMD being height, weight, caffeine intake and the cross product of milk and exercise.

**Figure 2.b**
Impact of milk intake in the prior year (shown as: <1, 1–2, or 3 or more 8 ounce glasses a day) on various bone variables.
Tibial mineral content

Weight and height were significantly correlated to tibial mineral content \( (r = 0.60 \text{ and } r = 0.39 \text{ respectively; } p < 0.001) \). Prior exercise history was positively correlated to tibial mineral content \( (r = 0.23; p < 0.001) \) and there was a significant 5\% difference in tibial mineral content between those in the highest exercise group versus all others \( (p < 0.001; \text{ Figure 1}) \). Milk consumption was related to tibial mineral content (Figure 2.b) and there was a 5\% lower tibial content between those consuming less than one glass of milk per day as compared to those consuming more milk \( (p < 0.03) \). Total calcium intake was correlated to tibial mineral content \( (r = 0.16; p < 0.10) \), alcohol and tobacco use had no apparent relationship with tibial mineral content (both \( p < 0.2 \)). Higher caffeine intake was related to a significant decrease in tibial mineral content \( (p < 0.05) \). The regression model that best predicted mineral content in the tibia included weight, run score, caffeine, and the cross product term of milk and exercise (Table 2.3).
Table 2.3 Skeletal Site Regression Models

<table>
<thead>
<tr>
<th>Table 3: Skeletal site regression models</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Calcaneal Density</strong></td>
</tr>
<tr>
<td>(SE)</td>
</tr>
<tr>
<td>0.025 - (0.117)</td>
</tr>
<tr>
<td>0.004(weight) - (0.002)</td>
</tr>
<tr>
<td>0.002(weight) - (0.001)</td>
</tr>
<tr>
<td>0.001(milk*exercise) - (0.001)</td>
</tr>
<tr>
<td>0.019(coffee) - (0.008)</td>
</tr>
<tr>
<td>p</td>
</tr>
<tr>
<td>0.34</td>
</tr>
<tr>
<td>R² = 0.26</td>
</tr>
</tbody>
</table>

| Lumbar Spine Density                   |
| (SE)                                   |
| 0.180 - (0.016)                        |
| 0.003(weight) - (0.001)                |
| 0.114(smoke) - (0.005)                |
| 0.414(milk*exercise) - (0.041)        |
| 0.095(milk) - (0.043)                  |
| 0.98(exercise) - (0.044)              |
| p                                       |
| 0.35                                    |
| R² = 0.26                               |

| Total Hip Density                      |
| (SE)                                   |
| 1.608 - (0.324)                        |
| 0.003(weight) - (0.003)                |
| 0.012(weight) - (0.003)                |
| 0.110(smoke) - (0.059)                |
| 0.006(milk*exercise) - (0.003)        |
| p                                       |
| 0.26                                    |
| R² = 0.49                               |

| Tibial Density                         |
| (SE)                                   |
| 128.999 - (105.744)                    |
| 9.147(height) - (1.528)                |
| 1.791(milk*exercise) + (0.930)         |
| 0.613(calf score) = (0.224)            |
| 0.349(weight) + (0.169)                |
| p                                       |
| 0.09                                    |
| R² = 0.45                               |

| Tibial Mineral Content                 |
| (SE)                                   |
| 127.332 - (15.774)                     |
| 1.099(height) - (0.602)                |
| 0.515(calf score) + (0.055)            |
| 0.006(milk*exercise) - (0.395)         |
| 7.581(coffee) - (0.838)                |
| p                                       |
| 0.09                                    |
| R² = 0.45                               |

| Cortical Thickness                     |
| (SE)                                   |
| 7.192 - (0.670)                        |
| 0.088(height) - (0.049)                |
| 0.388(milk*exercise) - (0.042)         |
| 0.039(height) - (0.014)                |
| p                                       |
| 0.11                                    |
| R² = 0.31                               |

| Periosteal Circumference               |
| (SE)                                   |
| 12.85 - (5.57)                         |
| 0.001(weight) - (0.001)                |
| 0.475(height) - (0.001)                |
| 0.766(coffee) - (0.076)                |
| p                                       |
| 0.37                                    |
| R² = 0.31                               |

Tibial size

Weight was correlated with cortical thickness (r = 0.24; p < 0.001) and peristeal circumference (r = 0.52; p < 0.001). While height was correlated with peristeal circumference (r = 0.43; p < 0.001). Prior exercise significantly correlated to cortical thickness (r = 0.13; p < 0.002) and peristeal circumference (r = 0.18; p < 0.005). Cadets in the highest exercise group had 5.8% higher cortical thickness compared to those in the lowest exercise group (p < 0.04; Figure 2.a).

Alcohol intake had no apparent influence on tibial size (peristeal circumference; p < 0.97) or cortical thickness (p < 0.24). Total calcium intake was positively correlated to cortical thickness (r = 0.18; p < 0.001) and peristeal circumference (r = 0.10; p < 0.001). Daily milk consumption was positively associated with cortical thickness and peristeal circumference, such that cortical
thickness was significantly lower (5.9%) in the lowest milk intake categories compared to the highest milk intake group ($p < 0.04; p < 0.01$; Figure 2.b). There was a significant interaction between milk intake and prior exercise in relation to cortical thickness (Figure 2.c). Males with high prior exercise duration only showed a skeletal benefit of the exercise if milk intake was greater than one glass per day.

**Figure 2.c**- Interaction between milk and exercise during the prior year on cortical thickness of the tibia.

The models best predicting cortical thickness and periosteal circumference are provided in Table 2.3.
Lumbar spine and total hip

Weight was significantly correlated with both hip and spine BMD \((r = 0.41\) and \(r = 0.52\) both \(p < 0.001\)). Each additional 10 pounds of weight was associated with a 0.03 g/cm\(^2\) (2.4%) incremental gain of BMD of the spine and 0.05 g/cm\(^2\) in the hip (4 %). Those cadets who had the highest prior exercise levels (>11 hours per week) had 5.1% higher hip BMD \((p < 0.016)\) and 5.4% higher spine BMD \((p < 0.008)\) then those with lower levels (Figure 2.a). Total calcium was correlated with the hip \((r = 0.20; p < 0.02)\) but not the spine. Caffeine and alcohol intake had had no apparent effect on hip BMD (both \(p < 0.15\)). Cadets with low milk intake (<1 glass/day) had 4% lower spine and 6% lower hip BMD compared to those cadets whose intake of milk was 3 or more glasses per day \(p < 0.07\) and \(p < 0.04\) respectively). However, smoking was negatively associated with both the hip \((p < 0.03)\) and spine \((p < 0.04)\). In smokers, spine and hip BMD measured an average of 8–10% lower than in non-smokers (both \(p < 0.04\)). The most parsimonious regression model for spine BMD included weight, milk consumption, past exercise, smoking and the product term of milk and exercise. The addition of height to the same factors in the hip density model (Table 2.3) explained 35% of the variance in hip BMD.

Discussion

In this large sample of fit males, healthy lifestyles, including exercise and milk consumption, were found to be critical for optimal bone density and bone size. There was also an apparent synergistic effect between milk consumption and exercise with regard to bone density at multiple skeletal sites as well as on the cortical thickness of the tibia. It was also found that smoking and excessive caffeine consumption could have had a negative impact on the skeletal
parameters in this cohort.

Racial differences in bone mass, bone geometry and size still exist even when controlling for height and weight, although as shown in other studies, the magnitude of those differences is smaller after controlling for body size. The differences in tibial cortical thickness and circumference have not been shown previously and may help explain the lower fracture rates in African Americans. Our study confirmed the findings of other studies that racial differences in BMD exist, and there are also differences in bone size and geometry even after controlling for height and weight. Limited power precluded us from having race specific models for each skeletal site.

Weight and height were consistent predictors of bone density at all sites as has been shown in prior studies; however weight and height are also related to tibial size. This is not surprising since genetic factors, including height and weight, can account for between 60–80% of the variation in BMD. In this study, significant racial differences in BMD at the total hip and tibial mineral content persisted even after controlling for weight.

The positive effect of exercise on BMD is supported by this study. Even in a fit population, with BMD at the upper end of the normal range, higher levels of exercise were associated with higher bone mass. Periosteal circumference, or size of the tibia, as well as the tibial mineral content were significantly influenced by prior exercise levels presumably due to the impact of increased mechanical loading from exercise. Since there may be few periods in life where bone size can be altered, taking advantage of this relationship in young adults may be important to a future reduction in fracture risk.
In this cohort of males, milk was significantly related to cortical thickness, hip and heel BMD and tibial mineral content. These findings support prior studies suggesting that milk intake is an important factor in increasing bone density and bone size in young adults. Milk intake may be a marker for calcium intake alone or for an overall healthy diet, or may reflect the influence of some other important nutrient in milk such as protein or Vitamin D. It is likely that the skeletal benefit of milk based calcium is a result of many factors. Although there was not a significant interaction, the negative effect of caffeine was minimized at higher levels of milk intake, as has been previously reported. This may indicate that the negative effect of caffeine on bone may be due primarily to reduced milk intake or to a reduced absorption of calcium at higher levels of caffeine intake. The negative dose response relationship between caffeine and calcaneal BMD has been reported in other populations. Smoking also had a deleterious effect on hip and spine BMD in these otherwise healthy young men, as has been previously reported. This may relate to reduced osteoblast function in males who smoke or perhaps a more rapid metabolism of hormones (estrogen and testosterone) that may affect BMD in men.

A unique aspect of our study was the ability to determine factors that predict tibial size and mineral content in these young men. A skeleton that is more resistant to fractures should not only have a higher mineral content or density but also a larger bone size (circumference) and cortical thickness. The critical periods during which bone size can be maximized are likely to occur at an early age, prior to attainment of peak bone mass and this could be evaluated in this young adult cohort. Tibial size (periosteal circumference) was found to be related to genetically modulated characteristics including height and weight, as well as lifestyle factors including exercise and nutrition.
Mathematical models, including linear regression, are limited to evaluating the determinants of bone health in an additive way. This may not represent the true biologic relationship. Therefore, we examined a number of cross product terms. The milk-exercise cross product proved to be significant in the tibial mineral content and cortical thickness model as well as for BMD of the calcaneus, hip, and spine. The milk–exercise interaction has been reported elsewhere and is biologically plausible.\textsuperscript{45-47} The mechanical stimulus created by the exercise forces the bone to remodel to adapt to these new loads and repair damage incurred by fatigue created by the strains of exercise. The higher milk consumption creates a greater supply of calcium and possibly other needed nutrients and therefore, a larger more dense bone. The significant cross product term of milk and exercise is indicative of a synergistic interaction between the daily milk consumption and regular exercise.

This study has a number of limitations. First, it is not possible, as with all cross sectional studies, to establish a temporal relationship between diet, exercise and the acquisition of greater bone mass. Second, our baseline questionnaire was self-administered and therefore is limited by individual recall. The dietary questionnaire was limited because of time constraints and did not allow an assessment of factors that may be important including vitamin D, protein, other nutrients and total caloric intake. In addition, we only assessed exercise history and milk consumption in the past year and we cannot know whether these behaviors were consistent over time. An additional limitation of the study may be its external validity: our study population is clearly more fit than the normal college age population. Therefore these findings may not be readily generalizable, although this study indicates that lifestyle variables, including exercise, may still have an impact on BMD. Finally, the statistical power, calculated post hoc ranged from 57 to 92 %. Some of the risk factors including smoking and alcohol intake could not be fully
explored because of relatively small sample sizes, limited variability and limited power.

In conclusion, BMD and bone size are determined by a complex combination of genetic, lifestyle, and nutritional factors. In our study height, weight, prior exercise and milk intake, smoking and caffeine intake were the most frequent and important predictors of bone mineral density and bone size in these fit young men. In addition, the interaction between milk consumption and exercise history was a significant predictor of bone size at the tibia and BMD at all skeletal sites. This information can assist in confirming intervention strategies for parents, schools and pediatricians during the critical years of bone development and the attainment of peak bone mass as suggested by the Surgeon General's report on Bone Health\textsuperscript{1}. These bone healthy behaviors should include higher milk intakes, adequate levels of exercise, limited caffeine intake and avoidance of tobacco products. Promotion of these behaviors associated with higher peak bone mass in males may help prevent stress fractures and osteoporosis and related fractures later in life.
References


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Chapter 3: The influence of lifestyle, menstrual function, and oral contraceptive use on bone mass in female military cadets

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Abstract

The purpose of this study was to determine the influence of menstrual irregularity, oral contraceptive use and other factors on bone mineral density (BMD) and bone size at different skeletal sites in 135 college-aged women. Menstrual history, oral contraceptive use, exercise history, and nutritional factors including calcium, caffeine, and alcohol intake as well as tobacco use were determined by written survey. Height, weight and fitness levels were measured. Spine and hip BMD were measured by dual x-ray absorptiometry (DXA), calcaneus BMD by peripheral DXA, and tibial bone mineral content (BMC) and size by peripheral Quantitative Computed Tomography (pQCT). The mean age at entry was 18.4 ± 0.8 years. Weight and prior exercise were positively related to BMD at every site and to tibial bone size. Milk intake was positively related to calcaneal BMD, tibial BMC and cortical thickness. Women who had ≥ 10 menstrual cycles in the year prior to BMD measurement had higher BMD at all sites as well as a greater tibial mineral content and cortical thickness than women who had oligomenorrhea/amenorrhea (≤ 9 cycles in the prior year; all p <0.05; except total hip p=0.10). Oral Contraceptive (OC) users had significantly lower BMD in the spine (p<0.02) and calcaneus
(\(p=0.06\)), smaller tibial periosteal circumference and lower tibial mineral content (\(p<0.09\)) than non-OC users. Milk intake was positively related to calcaneal BMD, tibial BMC and cortical thickness. Fracture history was an important predictor of spine, hip and heel BMD. In a fit population of college-aged women, OC use and oligomenorrhea were associated with statistically reduced BMD and bone size. Prior exercise, milk intake and weight were positively related to bone density and size. Understanding these relationships could improve skeletal health in young women.

Key Words: Bone mineral density, bone size, menstrual function, oral contraceptives
Introduction

Osteoporosis is a major public health concern as highlighted by the recent Surgeon General’s report.¹ A key osteoporosis prevention strategy is to increase early accrual of bone mineral density (BMD). A higher BMD and larger bone size attained in childhood and maintained through the third decade of life has been related to a subsequent reduction in the risk of childhood fracture, stress fracture, osteoporosis and osteoporotic fractures later in life.²⁻⁵ Therefore, it is important to understand factors that can be modified to improve the accrual of peak bone mass and increase bone size.⁶⁻⁸

Genetic factors account for 60-80% of the variance in peak bone mass.⁷,⁸ Failure to achieve the genetically pre-determined complement of bone mass is often related to sub-optimal environmental and lifestyle conditions and in women. Bone accrual can also be limited by eating disorders and oligo- and amenorrhea.⁹⁻¹¹ Oral contraceptive (OC) use may have an effect on bone accrual but its exact role is unclear. There is some evidence attributing a modest benefit of oral contraceptive use to spine and hip BMD. Alternatively, several recent studies have shown either no effect or negative effects of oral contraceptives on bone density. The impact of OC on bone size is less understood.¹²⁻¹⁵ The type of contraception, age at first use and level of exercise may alter the impact of OC use on bone health.⁶,¹⁶,¹⁷ Observational studies of OC use on bone mass may be confounded by the underlying reason for oral contraceptive use. In fact, 4-9% of women use oral contraceptives for reasons other than birth control, including amenorrhea or oligomenorrhea.¹⁸ There are many other factors that positively influence BMD including high levels of physical activity and adequate calcium intake.⁶,¹⁹,²⁰
The purpose of this cross sectional study is to examine the influence of various factors associated with BMD including calcium intake, exercise history, fitness levels, body size, menstrual function and oral contraceptive use on bone mineral density and bone size in physically fit college age women.

**Methods**

**Subjects**

The Institutional Review Board (IRB) of Keller Army Community Hospital (KACH), West Point, NY, approved the study. All cadets entering the United States Military Academy (USMA) Class of 2002, West Point, NY were sent a study information packet, including a sample consent form and study protocol, prior to their arrival at the Academy. During a presentation during their first week at the Academy, the study objectives and the associated risks were described. Seventy percent of all eligible women in the class agreed to participate and provided written informed consent. There were no differences between those who elected to participate and those who did not with regard to race or age. One hundred and thirty five women consented to participate in a 4-year prospective study examining the determinants of peak bone mass and stress fractures. Since there are stringent medical requirements for entrance into USMA, including disqualification due to severe polycystic ovarian disease and other diseases that affect BMD, no additional exclusion criteria were needed to admit a healthy cohort (Army Regulation 40-501, Chapter 2). Race was self reported and collected from USMA applications. The largest subset was Caucasian women (n=107); therefore analyses will focus on this group. When appropriate, we will evaluate racial differences.
Lifestyle Assessments

Exercise, dietary and other lifestyle factors in the year prior to entering USMA were evaluated by baseline questionnaire by allowing cadets to pick from categories to expedite data collection. Exercise was quantified as the number of exercise hours per week and divided into four categories of 1-3, 4-6, 7-10, or 11+ hours per week. Four questions assessed calcium intake including daily milk consumption (divided into 4 categories: none, <1, 1-2, or 3 or more 8 ounce glasses per day) and weekly servings of yogurt, cheese and high calcium content vegetables (0, 1-3, 4-6 or 7 + serving per week). From these responses, an average daily calcium intake was calculated (mg/day). Daily caffeine intake was divided into three categories: none, 1 to 3 and more than 3 caffeine containing drinks a day. Alcohol intake was categorized as: less than once a month, 1-3 times a month, 1 to 2 times a week, and 3 to 5 times a week. Tobacco use was assessed by type (dip, chew, or cigarettes), dose, and duration. Lifetime history of personal skeletal fracture and site of fracture were determined by questionnaire. Cadets reported their age at menarche, current use of birth control pills and prior use of birth control pills. Prior use was considered any use of oral contraceptives in the past for greater than 3 months. Current users included individuals taking OC for at least 3 months, including at entry to USMA. Frequency of menstrual cycles in the year prior to entering USMA was categorized as <4 (amenorrhea), 4-9 (oligomenorrhea), or 10-12 (normal) times in the past year for women without OC use.
Fitness and Anthropometric Measures

Academy personnel measured each cadet’s height and weight at entry in standard athletic clothing in stocking feet; height was measured using a standard scale in the same uniform. Body Mass Index (BMI) was calculated as weight in kilograms divided by height in meters squared. Trained Academy personnel administered the Army Physical Fitness Test (APFT) to all cadets upon entry into USMA. This test measures upper body and abdominal strength and aerobic fitness. It includes the number of full body push-ups and bent leg sit-ups completed in two-minute segments as well as a timed two-mile run. These three events (sit-ups, push-ups and a two-mile run) are then each converted into an age and gender standardized score ranging from 0-100. Faster running times, higher numbers of push-ups and sit-ups earn higher scores. The sum of these three scores represents the overall assessment of fitness with a range of 0-300.

Bone Densitometry

The left total hip and lumbar spine (L1-L4) BMD (gm/cm²) were measured using a mobile DXA scanner (DPX-IQ, General Electric-Lunar, Madison, WI). The coefficient of variation (CV) (%) in vivo were determined by measuring eight individuals twice, including repositioning, and the CV% was 1.5% and 1.5% respectively for spine and left total hip in this population. During this study there was no impact of movement of the mobile DXA, based on no significant change in the phantom measurements as part of the daily quality control program for DXA measurements. BMD (g/cm²) of the left calcaneus was assessed using peripheral dual-energy x-ray absorptiometry (DXA) (Pixi, Lunar, Madison,WI). The coefficient of variation in vivo for the calcaneus pDXA was 1.0%. Peripheral QCT (Stratec XCT2000; Germany) was used to image a single slice at the two-third distal tibia. To identify the site, the distal third of the tibia was determined by manual measurement of tibial length between the base of the patella and the
The pQCT was positioned at the 2/3 site after placing a positioning light of the gantry above the styloid process. The tibia was chosen because it is a major site of stress fractures in military cadets. Bone mineral content (mg per 1 mm slice of bone) and cortical thickness (mm) as a result of combined periosteal and endosteal circumferences (mm) were measured. Cortical bone was identified at a threshold above 710 mg/cm³. Cortical thickness was derived using the circular ring model, which calculates a mean cortical thickness from measures of total bone area and cortical bone area. The coefficient of variation was 2.2% for tibial mineral content and 3.2% for cortical thickness.

**Statistical Analysis**

Student’s t-test were used to examine the differences in BMD among dichotomous lifestyle variables and non-parametric tests were used (Kruskal-Wallis Test) to test differences between variables that are not normally distributed such as menstrual cycle frequency. The relationships between lifestyle determinants and BMD were examined using Pearson’s correlation analyses and, where appropriate, with linear regression to control for potential confounders. Effects of categorical lifestyle variables on BMD were also assessed using analysis of variance. The relationships between BMD at different skeletal sites with fitness measures were assessed by linear regression. In Caucasian women, a multiple regression model was created using all covariates that had biologic plausibility and were significant in the univariate analysis. The level of significance for alpha was set at 0.05 for all statistical tests. All analyses were performed with SPSS statistical software (Version 13.0 for Windows, SPSS Inc., Chicago IL).
Results

Population Characteristics

There were 136 women enrolled, including 108 Caucasians, 13 African Americans and 15 Asians. Overall, the women cadets in this study had healthy behaviors with 77% reporting they exercised more than 7 hours a week, and reporting a higher than average daily calcium intake approximately equal to the recommended daily intake (RDI) for this age group of 1000 mg calcium per day. Most (97%) were tobacco free, and only 10% admitted to consumption of more than two alcoholic beverages per week (although alcohol intake may be underestimated in this underage population). All women had experienced menarche and approximately 10.7% of the women currently used oral contraceptives and there was no reported use of Depo-Provera. There were previous fractures reported in 34% of women.
Table 3.1 provides anthropometric measures and physical fitness scores by menstrual function category in all non-OC users. There were no significant differences across categories. There were also no significant differences for any of these variables when comparing current OC use to non-OC users. The raw results from the fitness test are provided including the numbers of push-ups and sit-ups in two minutes and run score based from 0-100 on the two-mile run test.

The average number of full body push-ups completed in two minutes was 31.49 ± 13.12 and the average number of sit-ups was 55.19 ± 15.88 for these women. Their run times for the two-mile run test ranged from 13 minutes 23 seconds to 22 minutes 39, with 50% of the women running faster than an 8.37 pace per mile. Total APFT score was more than one standard deviation better.
than similar aged female recruits that enter basic training, a group that more closely represents
the general population.\textsuperscript{21}

Table 3.2 Multiple Linear Regression Models for Bone Density in Caucasian Females

<table>
<thead>
<tr>
<th>Bone Density Measures</th>
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<td>Baseline BMD results for the calcaneus, left total hip, spine (L1-L4) and tibia as well as tibial dimensions are reported by menstrual function category and oral contraceptive use in Table 3.1. T-scores were calculated based on the reference population from Lunar for the spine (average t score for the spine = +0.6) and for the total hip (average t-score was +1.2) using the NHANES database.</td>
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<th>Racial Differences</th>
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<td>Although there were no significant racial differences in total hip BMD, African American women had slightly higher spine and calcaneus BMD when compared to other races ((p&lt;0.05) as compared to Caucasians). However, all races had significantly higher calcaneal, spine and hip baseline BMD than the expected population average ((p&lt;0.025)). African American</td>
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women had significantly larger periosteal circumference and tibial mineral content when compared to the other races \( (p<0.02) \). There were no racial differences seen in cortical thickness.

**Predictors of BMD in Caucasian Women**

**Lumbar Spine and Total Hip**

Milk consumption and total calcium intake had no apparent effect on BMD at the spine or hip. There was no apparent effect from caffeine, alcohol or smoking on spine or hip BMD. BMD was 3\% higher in the spine and 4\% higher in the hip when comparing the highest exercise level to the other levels for the year prior to entering USMA (hip; \( p=0.063 \); spine; \( p=0.14 \)). Age at menarche was also not a determinant of spine or hip BMD. Women who had either amenorrhea or oligomenorrhea in the prior year had significantly lower spine and hip BMD (Figure 3.a; both \( p<0.03 \)). Never-users of OCs had significantly higher BMD in the spine when compared with current OC users (Figure 3.b; \( p<0.03 \)). Women with prior fractures had higher BMD at both the spine (1.26 ± 0.14 vs. 1.20 ± 0.10; \( p < 0.04 \)) and total hip (1.18 ± 0.12 vs. 1.12 ± 0.12; \( p < 0.02 \)) compared to those who did not have a fracture.
Figure 3.a. (In published copy, this was Figure 1)

BMI, height and weight were all modestly correlated with both spine BMD (r = 0.23, r = 0.36 and 0.41, all p<0.01) and total hip BMD (r = 0.31; r = 0.21, and 0.37; all p<0.01). Each ten-pound increase in weight was responsible for an approximate 2.5% increase in BMD. None of the fitness variables correlated with spine or total hip BMD.

In all Caucasian women, approximately 26% of the variation at the spine was explained by weight, fracture history, and current OC use. At the total hip 23% of the variation was explained by weight, fracture history and number of menstrual cycles.
Calcaneus

Total daily calcium intake was modestly correlated with calcaneal BMD ($r = 0.194$; $p<0.05$). Women with the lowest daily milk intake (<1 glass per day), compared to all higher intakes of milk, had 13% lower calcaneal BMD ($p<0.01$). Caffeine, alcohol, and tobacco usage were not significantly related to calcaneal BMD in the young women in our study population.

Prior exercise was also significantly correlated with calcaneal BMD ($r=0.37$; $p<0.001$). Age of menarche was not related to calcaneal BMD. Women who reported either amenorrhea or
oligomenorrhea had lower calcaneal BMD (Figure 3.a: $p<0.05$). A comparison of current OC users to all other women showed lower calcaneal BMD in current OC users ($p<0.06$). Women with a personal history of fractures had, on average, 6.7% higher calcaneal BMD than those women with no personal fracture history ($p<0.03$).

BMI and weight were moderately correlated with calcaneal BMD ($r = 0.414$ and $r = 0.450$, both $p<0.01$). Neither height nor any of the fitness parameters were correlated with calcaneal BMD.

Calcaneal BMD in Caucasian women was best predicted by body weight and glasses of milk consumed per day. These two variables accounted for 25% of the variation in calcaneal BMD. Each additional 10 pounds of body weight was associated with a 0.02 g/cm$^2$ or 3.4% incremental increase in calcaneal BMD. An increase in milk consumption of one glass per day was related to a 4.3% higher calcaneal BMD.

**Tibial Mineral Content and Geometry**

Women with low milk intake had 6% lower tibial mineral content than those drinking three or more glasses of milk daily ($p =0.06$). There was a marginal difference in cortical thickness at different milk intakes ($p < 0.08$) but there was no effect of milk on periosteal circumference. Total daily calcium had no apparent effect on tibial mineral content or geometry in our population. Caffeine intake had a borderline significant negative impact on tibial mineral content ($p=0.07$), but no relationship with cortical thickness or periosteal circumference. There was no relationship between smoking or alcohol with tibial BMC, cortical thickness or periosteal circumference.

Women reporting the lowest exercise category had 8% lower tibial cortical thickness and 6% lower tibial mineral content than women reporting the highest exercise levels. Additionally,
when comparing the two highest groups with the two lowest exercise groups there was a
significant difference in both cortical thickness \((p>0.01)\) and tibial mineral content \((p>0.04)\) but
not periosteal circumference. There was no significant relationship between age of menarche
and any of the tibial parameters. Those women with oligomenorrhea or amenorrhea in the year
prior to entering USMA had significantly smaller cortical thickness \((p<0.001)\) in part related to a
larger endosteal circumference \((p< 0.009)\), and these women also had significantly lower tibial
BMC \((p < 0.005; \text{Figure 3.a})\). As compared to OC users, tibial BMC was higher \((p < 0.015)\) and
periosteal circumference was larger in non-OC users \((p < 0.018)\). There was no difference in
cortical thickness between OC users and non OC users. There was no association seen between
prior fracture and any tibial parameter.

Height was positively correlated with tibial BMC \((r = 0.39; p>0.01)\), and periosteal
circumference \((r = 0.34; p>0.01)\), but not with cortical thickness. Weight was positively
correlated with the three tibial parameters: tibial BMC \((r = 0.58; p>0.01)\), cortical thickness \((r =
0.25; p>0.01)\), and periosteal circumference \((r = 0.50; p>0.01)\). BMI was moderately correlated
with tibial mineral content \((r = 0.43; p>0.01)\), cortical thickness \((r = 0.27; p<0.01)\) and periosteal
circumference \((r = 0.43; p>0.01)\). Of the fitness measures, run score was modestly correlated
with both tibial mineral content and cortical thickness \((r =0.23, r =0.24, \text{respectively, both}
p<0.04)\) but not periosteal circumference. Sit-ups and push-ups were not correlated with any
tibial parameter.

Results of the regression analyses for each of the tibial parameters in Caucasian women
are presented in Table 3.3. Regular menstrual function or OC usage and weight were important
predictors in three out of three models while run score was important in two out of three.
Discussion

In this cohort of 107 young Caucasian women, we found that prior exercise and weight were important and consistent positive determinants of BMD at all sites, tibial BMC and cortical thickness. Physical fitness, primarily run score, was an important predictor of tibial BMC and cortical thickness. Milk consumption had an important influence on bone density of the heel and was marginally related to tibial BMC and cortical thickness. Prior studies have suggested that milk-based calcium intake is an important factor in increasing bone density and bone size.\textsuperscript{19, 20} The use of oral contraceptives had a negative effect on calcaneal and spine BMD, tibial mineral content and bone size as evidenced by a smaller periosteal circumference at the tibia. We found that one of the strongest negative predictors of bone density was oligomenorrhea that occurred in 13\% of women or amenorrhea that occurred in 5\% of this population. This prevalence of amenorrhea/oligomenorrhea is slightly higher than what has been reported in a Danish study, although the Danish population was likely to have had lower levels of exercise than these women entering the USMA.\textsuperscript{22} In fact, women in USMA who had oligomenorrhea or amenorrhea (32\% of whom were avid exercisers with >11 hours exercise/week), had lower bone mineral density at
all skeletal sites, less BMC at the tibia and a smaller tibial cortical thickness through an increase in endosteal circumference.

The fact that body weight was an important factor for skeletal health is not surprising since genetic factors, including weight, can account for between 60-80% of the variation in BMD.\textsuperscript{2, 8, 23, 2} In this extremely fit population, weight may have also been related to muscle mass. In previous studies, high muscle mass has been associated with higher BMD while low muscle mass was associated with poor low BMD.\textsuperscript{25}

The benefits of exercise on bone health are supported by this study. Both a measure of average weekly exercise in the prior year and run score, a fitness measure used by the Army, were found to be important predictors of bone density and tibial size. Long bone cross-sectional growth has also shown to be strongly driven by mechanical load associated with increased weight and exercise during growth.\textsuperscript{26} In this cohort weight was also a significant predictor of periosteal circumference, with exercise and weight influencing cortical thickness of the tibia.

The high prevalence of prior fracture experienced by the women in this study (34%) may be related more to an active lifestyle and selection of activities with higher loads or greater risk than other women in this age group, rather than to a difference in bone mass. In fact, a personal history of fractures was significantly related to higher BMD at three sites: spine, total hip and calcaneus. There was no difference in any of the fitness measures or amount of prior exercise between those who fractured and those who did not. The type of exercise, rather than the amount, might have been more important to personal fracture risk. Alternatively, this could be explained by the suggestion that individuals with a genetic predisposition to poor bone quality, who engage in weight bearing exercise, gain more skeletal benefit from exercise than those without this predisposition.\textsuperscript{27}
Prior studies evaluating the impact of OC use on BMD at different skeletal sites have provided mixed results with no clear consensus. \textsuperscript{12-14, 28} There is some indication that OC use at a younger age may suppress endogenous production of hormones and that the OC replacement dose of estrogen is inadequate and may compromise the large increases in bone mass during peak bone mass accrual. \textsuperscript{16} In this study of young women, \textsuperscript{10}7\% reported being current OC users. OC use was associated with significantly lower bone mineral density at the spine and heel, but not the hip, in agreement with some but not all data that have been reported previously. Furthermore, we found that OC users had less tibial BMC and a unique finding of smaller tibial size. The OC users in this study did not report higher prior exercise levels or perform better on the running test. In this study, it was not known why women were prescribed OCs; it may have been because of menstrual irregularity or for contraception. If OCs were used for oligomenorrhea or amenorrhea, the residual deleterious effects of this could have created the BMD deficit. However, our comparison group did not exclude women with oligomenorrhea or amenorrhea from the non-OC users group, which would bias the results toward finding no effect of OC use on bone.

A unique aspect of our study was the ability to assess periosteal circumference and cortical thickness of the tibia as important measures of bone size and strength. Oligomenorrhea and amenorrhea were related to a smaller cortical thickness, in part, a result of a larger endosteal circumference. Conversely, the use of oral contraceptives led to a smaller periosteal circumference and this smaller bone size could result in less bone strength. A prior study of women aged \textsuperscript{18-31} years on oral contraceptives revealed a reduced cross-sectional area and cross-sectional moment of inertia in the femoral neck, also indicating reduced mechanical strength.\textsuperscript{12} Thus, as shown elsewhere, an interruption in normal menstrual function or any alteration in estrogenic state, such as oral contraceptive use, may
alter the mechanostat set point of bone.  

Periosteal growth, which enlarges bone diameter, accelerates at puberty in males. However, in females, periosteal growth is inhibited by estrogen at puberty and of interest we found that females on OCs had a smaller periosteal circumference. Cortical thickness can also be increased by apposition of endocortical bone but in females with oligomenorrhea or amenorrhea this may be prevented, and may in part explain the significantly larger endosteal circumference in women who have abnormal menstrual function.

This study had some limitations. Our baseline questionnaire included a brief self-administered food frequency questionnaire. The data was grouped to ensure the surveys were completed as quickly as possible but some important data may have been lost due to grouping. In addition, many other dietary factors not assessed on our questionnaire may be important determinants of bone health including total caloric intake, however, due to time constraints our dietary assessment had limited scope. Milk consumption was on average very high in this cohort, limiting ability to see an effect, except when comparing highest to lowest intakes. Our population of women was very fit, with above average BMD, therefore our external validity is limited. Finally, the inherent problems associated with cross sectional studies including the establishment of a temporal relationship exist in this study.

Conclusion

In conclusion, prior exercise and running score, a measure of fitness, are positive determinants of both BMD and bone size in our population of physically active young women. Milk intake may also have a positive impact on skeletal health. Physicians, coaches and trainers should consider menstrual status when examining the health of their athletes, as it appears that
oligomenorrhea and amenorrhea may be important to bone health, affecting both bone density and size. Compounding this issue, OC use for menstrual irregularity may not be the most practical solution to menstrual irregularity since there may in fact be further detrimental impact on the attainment of peak bone mass and bone size. Attaining high peak bone mass and ideal skeletal geometry is important to prevent both stress fractures and osteoporotic fractures later in life, particularly for women. Therefore, further longitudinal studies are warranted to examine the impact of nutrition, exercise, menstrual function and OC use on accrual of peak BMD as well as peak bone size.
References


Chapter 4:
The Impact of Varsity Sports, Fitness and Physical Aptitude on Bone Mineral Density

Abstract

This study assessed the impact of fitness level, physical aptitude and sports participation on bone mineral density (BMD) and bone size in active young males. Subjects were 546 male Caucasian students entering the United States Military Academy (USMA) who played one of ten high school varsity sports and 34 male Caucasian non-varsity controls. USMA personnel assessed height, weight and fitness level. Each subject took a physical aptitude exam (PAE) to meet academy entry requirements. Calcaneal BMD was measured by peripheral dual X-ray absorptiometry (pDXA). Tibial BMD, periosteal circumference and cortical thickness were measured by peripheral quantitative computed tomography (pQCT). Spine and hip BMD were measured by DXA in a subset (n=122). These skeletal characteristics, fitness, anthropomorphic and physical aptitude measures of players in each sport were compared among sports and to a control group of cadets who played no varsity sport. Basketball players were taller and wrestlers were shorter than controls (both \( p < 0.05 \)). Football players were significantly heavier than controls (\( p < 0.001 \)) while swimmers and cross country runners were lighter (both \( p < 0.05 \)). Participants in football, basketball, baseball and wrestling performed better on the PAE (all \( p < 0.04 \)) than controls. At the calcaneus, football players had higher BMD (\( p < 0.004 \)), while swimmers had lower BMD (\( p < 0.04 \)) than controls. BMD at multiple skeletal sites was different among players of different sports and remained significant after controlling for body mass index (BMI). Football and basketball players had greater calcaneal BMD than tennis, wrestlers, swimmers, cross country runners and golfers. Swimmers and golfers had significantly lower hip
BMD than football and basketball players. In addition, golfers had lower spine BMD when compared to football, baseball and wrestling (all p<0.05). The sport differences may illustrate the impact of loading and site specific activity of each sport on BMD. BMI, physical aptitude, fitness and certain sports were found to be determinants of bone mass and size at various skeletal sites in young, healthy males. These findings suggest that engaging in certain sports, improving fitness and greater physical aptitude may confer a significant benefit to BMD and bone size, even in an overall fit population.

**Keywords**: bone mineral density, physical aptitude, fitness, exercise, sports
Introduction

During the first and second decades of life, it is important to accrue as much bone mass as possible until achieving peak BMD in the third decade of life. As much as 60–80% of peak bone mass is genetically determined, but understanding the environmental components that influence BMD is an important strategy in the prevention of osteoporosis. Failure to achieve and then maintain peak bone mass may not only increase the immediate fracture risk but also increase the risk of osteoporosis-related fractures later in life. Research has shown that physical activity and the mechanical loads created by specific load bearing exercises are important mechanisms for enhancing the size and strength of bone and bone mineral density. Alternatively, a lack of weight bearing physical activity, a reduction in physical activity and degrees of weightlessness have been associated with bone loss at multiple sites. Therefore, enhancing bone mineral density and understanding the environmental components that can influence the genetic potential of BMD could be important in the prevention of osteoporosis.

Young, healthy male athletes represent an important study population because they have engaged in activities that have not only stimulated a specific adaptive response at loaded skeletal sites but may also have increased their muscle strength and lean mass. Studies have identified body mass index (BMI), muscle mass and body composition as having a genetic component and also to be predictors of BMD at different sites. Cross-sectional and longitudinal studies show that the osteogenic effect of load-bearing physical activity is site specific. Skeletal sites exposed to the greatest mechanical stress and strains have higher bone mineral density (BMD) than unloaded sites and higher BMD than the same sites in controls. In addition, some high impact sport activities seem to provide skeletal benefits not only to the loaded sites but also to the entire skeletal system. However, few studies have specifically assessed individual fitness
levels and/or physical aptitude in BMD studies in athletes.\textsuperscript{7,18} Therefore, the aim of this study was to examine whether past participation in specific sports, performance on physical fitness tests or physical aptitude were associated with site specific BMD.

**Material and Methods**

**Subjects**

All subjects were recruited from one incoming class at the United States Military Academy (USMA), West Point, New York. Prior to arriving at the academy, each cadet received an information packet with a description of the study and a sample consent form. The Institutional Review Board (IRB) of Keller Army Community Hospital (KACH), West Point, N.Y., approved this study. During cadets’ first week at USMA, study objectives and risks were described to all members of the class, and they were invited to participate. Written informed consent was provided by 755 male cadets (653 Caucasians). There are stringent medical requirements for entry to USMA; therefore, there were no exclusion criteria. Of the 653 Caucasians, 546 were included in this analysis because they played one of ten varsity sports, including football, baseball, basketball, soccer, swimming, tennis, golf, wrestling, cross-country and lacrosse. Thirty-four Caucasian males entering in this class who played no varsity sports were used as the control group.

**Anthropometric Measures**

Academy personnel measured cadets’ height and weight at entry. Cadet height was measured in stocking feet, and weight was measured in a standard physical training uniform of
T-shirt and shorts using a calibrated balance scale. BMI was calculated as kilograms of body weight per height in meters squared (kg/m²).

**Bone Densitometry**

BMD (g/cm²) of the left calcaneus was measured by peripheral dual-energy X-ray absorptiometry (DXA) (Pixi, GE-Lunar, Madison, Wis.). The distal third of the left tibia was determined by a manual measurement of tibial length between the base of the patella and the styloid process to the closest centimeter. The peripheral quantitative computed tomography scanner (pQCT; Stratec XCT-2000) located the 2/3 site after placing a positioning light of the gantry above the styloid process. Bone mineral density (mg/mm3), cortical thickness (mm) and periosteal circumference (mm) were measured. A mobile DXA scanner (DPX-IQ, Lunar, Madison, Wis.) was used to measure the spine and hip in a randomly selected subset (n=122).

The short-term coefficient of variation (CV %) for each machine was calculated by scanning 10 individuals on each machine twice. The coefficient of variation for in vivo BMD of the calcaneus, spine and total hip were 1.0%, 1.5% and 1.5%, respectively. The CV% was 3.2% for cortical thickness.

**Measurement of Sports Participation in 546 Caucasian Male Cadets**

Every cadet in the United States Military Academy submits a detailed application that includes sports played in high school, level of ability achieved (e.g., junior varsity or varsity) and duration in number of years played. An official in the applicant’s school verified sports participation. While Caucasian male cadets entering this class participated in 24 different sports, the ten sports with the highest participation were selected for this analysis. In addition, outdoor track was excluded from the analysis because there is a great deal of diversity in different
activities included in outdoor track, and this diversity would preclude examining site specific differences. Where multiple sports were reported, the sport of longest duration was selected. A self-administered baseline questionnaire assessed exercise hours per week on average in the year prior to academy entrance.

Fitness and Physical Aptitude

Before entrance to USMA, all cadets are required to take a Physical Aptitude Exam (PAE) as part of the admissions process. The PAE is used to assess the candidate’s ability to meet the academy’s rigorous physical program. It is a test of explosive power, strength, agility, speed and endurance. The exam consists of five events: pull-ups (men)/flexed-arm hang (women), standing long jump, modified basketball throw, push-ups and a 300-yard shuttle run. Each event is equally weighted in the scoring, and a higher score indicates better performance. Raw scores are converted to a numerical score and are event- and gender-specific. The possible range of PAE scores is 0–800, although failure to pass the PAE will prevent applicants from meeting the qualifications for admission.

Upon entry and twice a year in subsequent years, every cadet is required to take the Army Physical Fitness Test (APFT). This standardized fitness test consists of pushups, measuring upper body strength/endurance; sit-ups, measuring abdominal and hip flexor strength/endurance; and a timed 2-mile run test designed to measure cardio-respiratory endurance. Performance results from each event are converted into an age and gender standardized score, ranging in value from 0 to 100, with better performance being awarded a higher point total; the minimum passing score for each event is 60. The total score, the sum of these three scores, represents the overall assessment of fitness and has a potential range of 0 to
300. The running event has been highly correlated with VO$_2$ max and is considered a good proxy measure for cardio-respiratory fitness.$^{21}$

**Statistical Analysis**

All analyses were performed with PASW statistical software (Version 18.0 for Windows, SPSS Inc., Chicago). Analysis included standard descriptive statistics for all male Caucasians (n= 546) who participated in 1 of 10 varsity sports in high school and a control group (n=34) who played no varsity sport. Analysis of Variance (ANOVA) with Fischer Least Square Differences (LSD) post hoc pair-wise comparison of sports and controls was used to determine differences in anthropometric, fitness, aptitude and bone measures across sports. The relationships between fitness scores, physical aptitude scores and BMD were examined using partial correlation analyses controlling for BMI. Generalized linear models were used to assess sport differences while controlling for BMI with Least Significant Differences (LSD) post hoc pair-wise comparisons. Age is also an important variable in BMD acquisition but was not controlled for in this population with only a five-year age range. The relationship between BMD at different skeletal sites and its determinants was modeled using linear regression. Each sport was put into the regression model as a variable to examine if there were sport specific effects on the bone parameter being modeled. The level of significance for alpha was set at 0.05 for all statistical tests. Results are given as the mean ± standard deviation unless otherwise stated.
Results

Participant Characteristics

The physical characteristics of participants categorized by sport are shown in Table 4.1. Of these 580 participants, 34 did not participate in any high school varsity sport, and they served as the control group. Swimmers and wrestlers were slightly younger than controls (both \( p < 0.01 \)). Basketball players were taller (\( p < 0.004 \)) while wrestlers were shorter (\( p < 0.005 \)) than controls. Football players were heavier and had a greater BMI (\( p < 0.001 \)) while cross country runners were lighter and a lower BMI than controls (\( p < 0.01 \)).

Fitness Measures

Wrestlers and cross country runners had higher overall scores than controls on the APFT (\( p < 0.05 \)). There were also significant sport differences in performance of the three components of the APFT and PAE that related to the athletes’ sport of choice. Cross-country runners, wrestlers and soccer players performed significantly better on the 2-mile run (all \( p < 0.05 \)). Only wrestlers performed more pushups than the non varsity controls. Football, basketball, baseball and wrestling performed significantly better on the PAE than controls on the overall score (\( p < 0.05 \); Table 4.1). Similarly, those who participated in upper body centric sports like swimming and wrestling performed better on the pull-ups (\( p < 0.001 \) and \( p < 0.024 \), respectively) than controls.
## TABLE 4.1 Baseline Characteristics by Sport (Mean ± Standard Deviation)

<table>
<thead>
<tr>
<th></th>
<th>Football (n=182)</th>
<th>Soccer (n=70)</th>
<th>Basketball (n=40)</th>
<th>Tennis (n=17)</th>
<th>Wrestling (n=54)</th>
<th>Cross Country (n=73)</th>
<th>Swim (n=22)</th>
<th>Golf (n=17)</th>
<th>Baseball (n=48)</th>
<th>Lacrosse (n=23)</th>
<th>No Varsity Controls (n=34)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (years)</strong></td>
<td>18.8 ± 1.98</td>
<td>18.7 ± 1.2</td>
<td>18.9 ± 0.97</td>
<td>18.8 ± 1.1</td>
<td>18.5 ± 0.8*</td>
<td>18.4 ± 0.78</td>
<td>18.7 ± 0.98</td>
<td>18.6 ± 1.1</td>
<td>18.6 ± 1.2</td>
<td>18.9 ± 1.2</td>
<td>19.1 ± 1.3</td>
</tr>
<tr>
<td><strong>Height (inches)</strong></td>
<td>76.7 ± 2.7</td>
<td>69.6 ± 2.5</td>
<td>72.1 ± 3.2*</td>
<td>70.4 ± 2.8</td>
<td>68.7 ± 2.3b</td>
<td>69.6 ± 2.5</td>
<td>69.0 ± 2.7</td>
<td>69.8 ± 2.4</td>
<td>70.2 ± 2.4</td>
<td>70.5 ± 2.7</td>
<td>70.3 ± 2.8</td>
</tr>
<tr>
<td><strong>Weight (pounds)</strong></td>
<td>193.4 ± 34.5**</td>
<td>163.2 ± 22.4</td>
<td>178.1 ± 26.0</td>
<td>162.4 ± 21.3</td>
<td>163.7 ± 19.9</td>
<td>155.2 ± 18.9*</td>
<td>156.0 ± 19.7</td>
<td>161.6 ± 23.7</td>
<td>173.4 ± 22.4</td>
<td>172.2 ± 18.9</td>
<td>170.6 ± 26.9</td>
</tr>
<tr>
<td><strong>BMI (kg/m2)</strong></td>
<td>23.1 ± 3.8**</td>
<td>23.7 ± 3.7</td>
<td>24.1 ± 4.0</td>
<td>23.1 ± 3.8</td>
<td>23.1 ± 4.3</td>
<td>22.5 ± 3.9</td>
<td>23.0 ± 3.8</td>
<td>23.4 ± 3.5</td>
<td>24.7 ± 3.9</td>
<td>24.4 ± 2.6</td>
<td>24.2 ± 2.9</td>
</tr>
<tr>
<td><strong>PAE Score Range</strong></td>
<td>562.3 ± 79.9**</td>
<td>531.0 ± 55.7</td>
<td>571.1 ± 61.2**</td>
<td>541.0 ± 61.2</td>
<td>567.4 ± 71.2**</td>
<td>534.0 ± 66.1</td>
<td>545.6 ± 57.4</td>
<td>520.3 ± 55.3</td>
<td>589.8 ± 70.1**</td>
<td>523.3 ± 56.1</td>
<td>513.1 ± 64.7</td>
</tr>
<tr>
<td><strong>Pull Ups (number)</strong></td>
<td>9.1 ± 4.7</td>
<td>9.7 ± 4.5</td>
<td>9.7 ± 3.9</td>
<td>11.2 ± 4.3</td>
<td>13.7 ± 4.3**</td>
<td>11.0 ± 4.0</td>
<td>13.4 ± 3.7</td>
<td>10.1 ± 3.7</td>
<td>10.5 ± 3.8</td>
<td>9.7 ± 3.3</td>
<td>9.3 ± 3.3</td>
</tr>
<tr>
<td><strong>Long Jump (inches)</strong></td>
<td>97.4 ± 7.5</td>
<td>93.1 ± 6.6</td>
<td>98.8 ± 7.8**</td>
<td>94.2 ± 5.3</td>
<td>96.2 ± 6.0</td>
<td>94.2 ± 6.4</td>
<td>94.3 ± 6.2</td>
<td>94.3 ± 5.8</td>
<td>96.8 ± 7.1</td>
<td>95.0 ± 5.9</td>
<td>94.9 ± 6.9</td>
</tr>
<tr>
<td><strong>Shuttle Run (seconds)</strong></td>
<td>58.4 ± 1.8**</td>
<td>58.7 ± 2.5</td>
<td>57.7 ± 3.0**</td>
<td>59.1 ± 4.1</td>
<td>58.3 ± 25.4**</td>
<td>58.2 ± 25.4</td>
<td>59.5 ± 17.0</td>
<td>59.9 ± 10.2</td>
<td>58.5 ± 20.6</td>
<td>59.0 ± 15.6</td>
<td>59.6 ± 3.2</td>
</tr>
<tr>
<td><strong>Basketball throw (feet)</strong></td>
<td>75.2 ± 9.3**</td>
<td>69.9 ± 7.5</td>
<td>74.0 ± 8.3**</td>
<td>72.0 ± 7.1</td>
<td>66.8 ± 8.7</td>
<td>64.9 ± 8.8</td>
<td>67.1 ± 7.4</td>
<td>68.8 ± 7.4</td>
<td>78.6 ± 8.9**</td>
<td>58.7 ± 7.1</td>
<td>66.6 ± 6.6</td>
</tr>
<tr>
<td><strong>Fitness Test (APFT) (0-300)</strong></td>
<td>207 ± 38.6</td>
<td>222 ± 26.8</td>
<td>218 ± 34.4</td>
<td>203 ± 34.4</td>
<td>231 ± 29.1**</td>
<td>226 ± 24.3</td>
<td>224 ± 27.2</td>
<td>210 ± 29.2</td>
<td>216 ± 28.1</td>
<td>212 ± 40.8</td>
<td>210 ± 40.8</td>
</tr>
<tr>
<td><strong>Push Up Score (0-100)</strong></td>
<td>73.0 ± 14.0</td>
<td>71.4 ± 13.1</td>
<td>73.4 ± 16.5</td>
<td>71.5 ± 11.2</td>
<td>78.2 ± 13.6**</td>
<td>70.8 ± 13.9</td>
<td>76.6 ± 10.7</td>
<td>71.0 ± 13.7</td>
<td>72.1 ± 13.7</td>
<td>71.0 ± 17.3</td>
<td>70.7 ± 17.3</td>
</tr>
<tr>
<td><strong>Sit Up Score (0-100)</strong></td>
<td>65.2 ± 13.1</td>
<td>68.9 ± 11.6</td>
<td>67.7 ± 14.4</td>
<td>65.9 ± 11.4</td>
<td>72.8 ± 13.7</td>
<td>67.0 ± 13.7</td>
<td>73.7 ± 12.8</td>
<td>67.6 ± 12.5</td>
<td>67.2 ± 12.5</td>
<td>67.2 ± 12.4</td>
<td>68.1 ± 11.9</td>
</tr>
<tr>
<td><strong>Run Score (0-100)</strong></td>
<td>68.3 ± 10.1</td>
<td>81.7 ± 12.4**</td>
<td>73.3 ± 19.1</td>
<td>65.7 ± 20.7</td>
<td>79.9 ± 12.8**</td>
<td>88.3 ± 11.2</td>
<td>73.3 ± 20.7</td>
<td>71.1 ± 19.1</td>
<td>77.3 ± 10.5</td>
<td>77.6 ± 10.5</td>
<td>71.2 ± 19.3</td>
</tr>
</tbody>
</table>

The sign indicates the direction from the non varsity sport control group mean and the letter is the significance level.

α p<0.001  β p<0.01  γ p<0.05

* Fewer seconds is a better result on the shuttle run
Bone Density Measures

BMD of the calcaneus, hip, spine and tibia, as well as bone size, are reported in Table 4.2 by sport, and differences to the control group are indicated. The differences among sports, controlled for BMI, are discussed by skeletal site below. The importance of controlling for BMI is highlighted in Table 4.3, which shows the distribution of BMI as classified by the National Heart, Lung, Blood Institute standard reference points.22

### Table 4.2  Skeletal Parameters by Sport (Mean ± SD)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Football (n=182)</th>
<th>Basketball (n=40)</th>
<th>Soccer (n=70)</th>
<th>Tennis (n=17)</th>
<th>Wrestling (n=54)</th>
<th>Cross Country (n=75)</th>
<th>Swim (n=22)</th>
<th>Golf (n=17)</th>
<th>Baseball (n=48)</th>
<th>Lacrosse (n=23)</th>
<th>Non Varsity Controls (n=24)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Calcaneal BMD (g/cm²)</strong></td>
<td>0.780 ± 0.124</td>
<td>0.730 ± 0.130</td>
<td>0.712 ± 0.131</td>
<td>0.634 ± 0.096</td>
<td>0.649 ± 0.113</td>
<td>0.647 ± 0.102</td>
<td>0.578 ± 0.125</td>
<td>0.654 ± 0.112</td>
<td>0.715 ± 0.122</td>
<td>0.702 ± 0.088</td>
<td>0.687 ± 0.115</td>
</tr>
<tr>
<td><strong>Spine BMD (g/cm²)</strong></td>
<td>1.35 ± 0.151</td>
<td>1.287 ± 0.131</td>
<td>1.232 ± 0.092</td>
<td>1.223 ± 0.126</td>
<td>1.302 ± 0.121</td>
<td>1.238 ± 0.126</td>
<td>1.239 ± 0.087</td>
<td>1.126 ± 0.136</td>
<td>1.356 ± 0.169</td>
<td>1.19 ± 0.162</td>
<td>1.235 ± 0.169</td>
</tr>
<tr>
<td><strong>Total Hip BMD (g/cm²)</strong></td>
<td>1.300 ± 0.136</td>
<td>1.291 ± 0.110</td>
<td>1.248 ± 0.130</td>
<td>1.153 ± 0.149</td>
<td>1.272 ± 0.153</td>
<td>1.177 ± 0.132</td>
<td>1.138 ± 0.055</td>
<td>1.380 ± 0.144</td>
<td>1.301 ± 0.276</td>
<td>1.200 ± 0.163</td>
<td></td>
</tr>
<tr>
<td><strong>Tibial Cortical thickness (mm)</strong></td>
<td>4.86 ± 0.084</td>
<td>4.47 ± 0.665</td>
<td>4.79 ± 0.708</td>
<td>4.24 ± 0.683</td>
<td>4.45 ± 0.812</td>
<td>4.57 ± 0.674</td>
<td>4.36 ± 0.588</td>
<td>4.74 ± 0.813</td>
<td>4.67 ± 0.672</td>
<td>4.83 ± 0.921</td>
<td>4.25 ± 1.02</td>
</tr>
<tr>
<td><strong>Periosteal Circumference (mm)</strong></td>
<td>84.1 ± 9.1</td>
<td>82.8 ± 7.0</td>
<td>78.8 ± 5.3</td>
<td>77.0 ± 6.9</td>
<td>78.5 ± 7.9</td>
<td>78.1 ± 5.6</td>
<td>77.3 ± 8.9</td>
<td>74.9 ± 4.1</td>
<td>74.9 ± 4.1</td>
<td>80.2 ± 4.1</td>
<td>79.2 ± 9.8</td>
</tr>
<tr>
<td><strong>Tibial BMD (mg/cm³)</strong></td>
<td>803 ± 81.8</td>
<td>775 ± 79.5</td>
<td>825 ± 67.5</td>
<td>786 ± 97.9</td>
<td>801 ± 89.4</td>
<td>811 ± 75.3</td>
<td>801 ± 77.2</td>
<td>762 ± 63</td>
<td>793 ± 63</td>
<td>810 ± 79.0</td>
<td>777 ± 133.1</td>
</tr>
</tbody>
</table>

*The sign indicates the direction from the control group.

a  p<0.05
Calcaneus

Calcaneal BMD of controls was not significantly different from BMD of those in the sports studied, with the exception of football players, who had higher calcaneal BMD (p<0.005), and swimmers, who had lower BMD at this heel site (p<0.05). After controlling for BMI and examining sport differences, both football and basketball had significantly greater BMD at the calcaneus, compared to five other sports: tennis, wrestling, swimming, cross country and golf and controls (all: p<0.05). Swimmers had significantly lower calcaneal BMD after controlling for BMI than controls and many other sports, except golf, wrestling and tennis.

Hip and Spine

Football and baseball players had significantly higher hip BMD than controls (both p<0.04) while golfers were lower (p<0.03), but differences did not persist after controlling for BMI. However, there were other differences in BMD among players of different sports that remained after controlling for BMI. Golfers had lower BMD of the hip when compared to players in six sports including football, soccer, basketball, wrestling, lacrosse and baseball. Similarly, swimmers had lower hip BMD when...
compared to football, basketball, wrestling and baseball. At the spine, football and baseball had greater BMD when compared to controls ($p < 0.007$ and 0.02, respectively). This only remained significant in football players after controlling for BMI ($p < 0.04$). In addition, football had greater spine BMD than both soccer and golf (both $p < 0.02$).

**Tibial Measures**

When compared with the control males, soccer players had greater BMD in the left tibia ($p < 0.01$); no other differences among players of any sport and the controls were found. Soccer players also had greater tibial BMD than basketball and golf (both $p < 0.01$). However, when the study examined tibial periosteal circumference, both football and basketball players had a greater circumference than controls, and this difference persisted after controlling for BMI. In addition, both basketball and football players had significantly greater tibial circumference when compared to players of all other sports except lacrosse and each other (all $p < 0.05$). Football, lacrosse and soccer had a greater cortical thickness than the controls (all $p < 0.05$). After controlling for BMI, football players had significantly greater tibial cortical thickness than wrestlers, golfers or controls (all $p < 0.03$). Golfers had significantly lower cortical thickness when compared to football, soccer, lacrosse, cross country and baseball players.

**Physical Aptitude Measures (PAE), Fitness Measures and Bone Parameters**

In a partial correlation controlling for BMI, the PAE exam was significantly and positively correlated to hip and spine BMD ($r = 0.185$ and $r = 0.276$; both $p < 0.04$).
Alternatively, the fitness test (APFT), was only slightly correlated to cortical thickness ($r=0.155; \ p<0.001$).

**Cross-Sectional Indicators of BMD and Bone Size**

Using linear regression, BMI was a significant positive indicator of BMD and every other skeletal parameter (Table 4.4), except tibial BMD. PAE was an indicator of spine, hip and calcaneus BMD. Sports with greater skeletal loading (football, basketball) had a significant positive relationship with tibial size, specifically, periosteal circumference. Fitness was the only variable of significance in the model explaining the variation of tibial BMD and also in the model explaining the variation seen in cortical thickness. Football, baseball, basketball, lacrosse and soccer participation were significant positive indicators of BMD at multiple skeletal sites when entered into the regression model. Alternatively, swimming and wrestling participation were negative indicators of calcaneal BMD. Playing football was positively associated with spine, hip and calcaneus BMD, even after controlling for BMI in the model.
Discussion

Fitness, BMI, muscular strength and underlying physical aptitude all may play a role in skeletal health, yet it is difficult to isolate the individual effects of each of these on the skeleton. After investigating whether participation in specific sports, physical fitness or physical aptitude best predicted BMD, the main findings of this study were: (1) The physical aptitude exam was a better determinant than fitness for spine BMD and cortical thickness; (2) there were sport specific differences in BMD and bone size, even after controlling for BMI differences. Loading sports, including football, conferred greater skeletal benefits than some other loading sports, while swimming and golf, non-loading sports, did not seem to create forces that stimulated skeletal adaptation based on bone size or density.
The physical aptitude exam given to cadets is a tool used to assess their ability to deal with the physical demands of USMA and military life. The concept of using motor fitness tests to assess physical aptitude is not unique to the military but is also being used as a method of predicting talent in young athletes. Aptitude tests can include skill-based, explosive power, agility and/or anaerobic capacity tests; the PAE given to cadets contains each of these elements. Similar to bone mineral density, physical aptitude appears to be genetically influenced. Therefore, it is of interest that the PAE was a predictor of BMD at certain skeletal sites (e.g., the spine, hip and calcaneus). Other studies have shown that fitness tests have a significant positive relationship to total body bone mineral content (BMC) and BMD at the radius and various hip sites. Fitness has also been cited as a correlate or predictor of BMD in numerous studies. In this study, fitness score was a significant determinant of BMD and cortical thickness at the tibia, a site that is truly weight bearing. The tibia is, in fact, the only site where true density is assessed, and the measure of cortical thickness is important for bone strength and reduction in fracture risk.

It has been hypothesized that repetitive muscular contraction, either natural or electrically stimulated, can create strains high enough to permit bone remodeling and maintenance of BMD, even in the absence of weight-bearing activity. Swimming would illustrate this, however, in the current study; male swimmers had significantly lower BMD values at the heel than participants in most other sports, even after controlling for BMI. Other studies have also found swimmers to have lower BMD as compared to participants in soccer, rugby and fighting sports, including karate and judo. In addition, swimmers had lower BMD at the hip than those in other sports.
Conversely, one high impact weight-bearing sport, football, had a positive effect on heel BMD, even after controlling for BMI.

An interesting finding is the impact that loading sports had on bone size. In addition to BMD, bone strength and fracture risk reduction was related to bone size. This study found that both football and basketball were independent positive indicators of bone size based on periosteal circumference. Another important measurement of bone size was tibial cortical thickness. It should be noted that even after controlling for BMI, football players had significantly greater cortical thickness of the tibia than controls. Also related to cortical thickness was performance on the fitness test, which might be an indicator of past exercise loading, specifically through compression. Bones, as an active tissue, have high compressive strength and limited tensile strength; therefore, loading would add to the strength index of the bone.

Male runners in this study had decreased BMD at the calcaneus when compared to football, basketball and soccer players even after controlling for BMI. However, BMD of runners was still higher than swimmers. These findings fit into the concept that athletes may self-select into sports where they are likely to be successful, and size may be a critical attribute in some sports. This potential for self-selection makes comparisons among athletes difficult, since study data are typically collected years after selection into a sport was made. There was also a negative correlation between cross-country training time as reported in their baseline survey of hours of exercise per week and lower BMD of the spine. This could again be attributed to self-selection or dietary restriction related to the desire for staying light for running or to suppression of hormones. MacKelvie found an inverse relationship between running mileage and testosterone levels. Lower mileage
runners had higher BMD while the BMD of the greatest distance runners was no different from the controls. In general, there are conflicting results on the association between running and BMD in males. In other sports, the study found tennis to have less impact on skeletal parameters of the lower extremities in players than expected. Specifically, both calcaneal BMD and periosteal circumference of tennis players were lower than that of football, soccer and basketball players. Other studies have shown that tennis is beneficial to BMD, at least at the playing arm when compared to the non-playing arm. However, there may be less loading on the lower extremities compared to many other sports leading to a smaller tibial size and heel density.

There are several limitations to this study. Since it is a cross-sectional study, it is not possible to establish a cause-and-effect relationship among sport participation, exercise and bone mass or size. The external validity of this study may be limited because this general study population was more fit than other college-age populations. The validity of the PAE actually to determine an aptitude for overall physical performance has not been fully proven, but it is highly correlated to physical success while at the academy.

The sample size for spine and hip BMD in some of the sports was limited to a subset of cadets; therefore, despite trends toward differences in measurements, no significance was found although an actual difference may exist. In addition, while members of the control group may not have participated in organized varsity sports in high school, they may have played club or another organized sport. Their fitness and PAE scores indicate that they were athletic; therefore, by using this control group, the study
may have underestimated the sport specific effects. All subjects had their left leg measured, so they may have underestimated any skeletal benefit since sport specific differences may have been mitigated by measuring the dominant leg in only 11% of the subjects and not the other 89% who are right-footed.

In conclusion, measures of physical aptitude and fitness may be novel determinants of bone mass. In addition, these measures may be used to predict bone size, which is an additional parameter of bone strength. Those performing poorly on physical aptitude tests and fitness tests might be provided with targeted education on bone health, exercise regimens and nutrition. The BMD differences that remained at multiple sites among sports (after controlling for BMI) seem to relate to the site-specific activity and loads on the skeleton that are created by training. Basketball players had significantly greater periosteal circumference than players in almost every other sport, perhaps related to force impact from activities related to jumping that could alter bone size. Swimmers had lower calcaneal BMD than the controls and six other sports after controlling for BMI. This is a nonload-bearing activity; in comparison with other sports at every skeletal site, swimmers had smaller bone or lower density compared with participants in loading sports. Alternatively, football players had significantly greater BMD and periosteal circumference than participants in many sports as well as control males. The data from this study support the findings of previous studies that loading sports including football, soccer and basketball could have a positive impact on bone mass and bone size. It is important to maximize peak bone mass and bone size to prevent fractures later in life. An understanding of the impact that sports have on the different skeletal sites will provide
useful information for athletes and their trainers to promote certain training activities that strengthen skeletal sites normally not impacted by their sport of choice.
References


Chapter 5:
Body Composition and Weight Changes in Physically Fit Females During Four Years at University

Abstract

This study examined body fat, body mass index (BMI) and weight changes in a fit female university population during a four-year period. Subjects were recruited from the United States Military Academy in the summer before their freshman year (n=108; mean age=18.4 ± 0.8) and were followed until graduation (n=79). Height, weight and fitness measurements were conducted at entry and each subsequent year. Body fat was assessed annually via bioelectrical impedance. Birth control type and duration of use, menstrual function and calcium intake were assessed annually by survey. Disordered eating was assessed during the final year at the academy. The Vitamin D receptor (VDR) gene DNA was isolated from whole blood (collected at baseline) according to standard protocols. Entry weight was 140.9±17.9 compared to 146.98±19.4 at graduation. Most weight gain (5.2 pounds; p< 0.001) occurred during the first year and remained until graduation, with a total average weight gain of 6.0 pounds (p=0.001). Mean percent body fat was 21.1% ± 3.4 at first measure and 23.1% ± 4.5 at graduation. During the second year at university, there was a significant increase of 1.8% body fat (p=0.001). This increase in body fat remained through graduation. Average BMI on entry was 22.8 ± 2.4, and at graduation, it was 23.6 ± 2.4. The prevalence of overweight/obese subjects based solely on BMI rose from 17.6% to 25.4% four years later. Fitness increased significantly in the first year (partial eta² =0.224; p=0.001) and remained significantly higher than baseline through graduation (p=0.001). Age at menarche was negatively associated with change in body
fat (r=−0.26; p=0.002). Two measures of the Eating Disorder Inventory-2 (EDI-2), interpersonal distrust and a sense of ineffectiveness, were significantly and negatively correlated with weight change and BMI change (r=−26; p=0.04 r= -0. 26 and p= 0.03 respectively). Body dissatisfaction, another measure on the EDI-2, was positively associated with current weight and BMI at graduation (r=0.31; p=0.008 and r= 0.26 and p= 0.03, respectively). The VDR was not associated with baseline body fat, entry weight or BMI, nor was it associated with a change in these variables. In the regression models examining predictors of weight and change in weight both models had weight at entry and fitness as the sole predictors. For BMI and change in BMI both models had a measure from the EDI. Fitness was also in the model for graduation BMI. The use of depot medroxyprogesterone acetate (DMPA) was associated with an increase in change in body fat while fitness was negatively associated with body fat change. In conclusion, even in this fit population there was evidence of both modest weight and fat gain during the college years. This study underscores the social and psychological complexity of weight gain in college-age women and provides further evidence that health promotion strategies should be directed at university students to help them develop positive health habits and deter weight gain, specifically fat gain.

**Keywords:** Fitness, body composition, weight gain, university, exercise, body mass index
Introduction

Obesity is a major health concern and an economic burden to most industrialized nations including the United States; therefore, understanding its causes and preventing its occurrence is a critical public health issue. The cost of obesity-related disease and disability is responsible, directly or indirectly, for increasing the worldwide burden of medical care on society. In the United States, obesity and obesity-related disease and disability were associated with health care costs in excess of $147 billion in 2006. Trends indicate that there is little progress in resolving this epidemic. Specifically, Wang reported that the prevalence of obesity rose in the United States from 13% to 32% in the four decades between 1960 and 2004. Current obesity prevalence is 33.8% for adults and 15.5% for children 12–19 years of age. With a life course approach targeting critical weight gain periods, opportunities may exist to change not only the current trends in obesity but also the progression of diseases associated with obesity, including metabolic syndrome, cardiovascular disease and diabetes.

Critical weight gain periods most often associated with obesity later in life include the neonatal period, early infancy, adolescence, college years and pregnancy. Understanding how to prevent weight gain during these periods may alter the onset of obesity later in life. In particular, the freshman year of college has been a period associated with weight gain. The reasons for weight gain during the university years have included a lack of parental control on food choices, peer influence, mandatory dining for freshmen who live on campus, alcohol consumption and stress. The American College Health Association recently reported that 36.7% of college students
were overweight or obese, according to their self-reported height and weight measurements.\textsuperscript{15} Many factors influence weight gain through life leading to adult obesity. These include faster infancy weight gain, maternal pregnancy weight, lack of physical activity, genetics, socioeconomic status (SES) of parents, social experience in high school and sleep deprivation.\textsuperscript{16-19} Besides the psychosocial issues related to food consumption and the imbalance in energy consumption and expenditure (positive energy balance) leading to obesity, a genetic predisposition has also been identified, one of the markers is through the Vitamin D receptor gene.\textsuperscript{20,21} Therefore, identifying those people at greatest risk for weight gain and providing targeted interventions during critical periods may ultimately alter long-term health outcomes, provide a better quality of life and reduce the economic burden of obesity.

The purpose of this study was: (1) to estimate the changes in body fat, weight and BMI in a fit female college population; (2) to determine whether body weight and body composition are associated with standardized fitness measures; and (3) to examine the role of Vitamin D receptor gene, specifically, BsmI, use of contraceptives, calcium intake and eating disorders in body weight and percent of body fat changes during the four years at university. These results may help practitioners and university staff to develop prevention methods to prevent weight gain during the college years. Suggested prevention methods might be to provide university students information on the importance of a healthy diet and the importance of exercise during a time of upheaval and change normally associated with weight gain.

\textbf{Methods}
All subjects were recruited from one incoming class to the United States Military Academy, West Point, N.Y. They were part of a larger study examining stress fractures and bone mineral density. This study was approved by the Institutional Review Board (IRB) of Keller Army Community Hospital (KACH), West Point, N.Y. Each cadet was sent a study information packet, which included a sample consent form prior to arrival at the academy. During their first week at the academy, all members of the class attended a formal presentation describing the study objectives and the associated risks, and were then invited to participate. Of 192 females, 136 (71%) gave written informed consent and provided the sample for this analysis. There was no difference in race or age among those who consented and those who did not. Academy medical and fitness requirements are stringent; therefore no exclusion criteria were required. All students at the United States Military Academy live on campus and are provided meals, family style, during their four years at the academy.

**Fitness and Anthropometric Measures**

Academy personnel measured each cadet’s height and weight upon entry and at each subsequent year. Cadets are measured in their physical fitness uniform, which includes a standard issue cotton T-shirt, running shorts and athletic socks. The height and weight measurements were used to calculate Body Mass Index: \( \text{BMI} = \frac{\text{weight (kg)}}{\text{height (m}^2)} \). Trained academy personnel administered the Army’s standardized fitness test to all cadets upon academy entry and each subsequent year. This test measures upper body and abdominal strength and aerobic fitness by counting the number of full body pushups and bent leg situps completed in two-minute segments and a timed 2-mile run.
Each of these three measures is then converted into an age and gender standardized score ranging from 0–100. The sum of these scores represents the overall assessment of fitness with a range of 0–300 with higher scores indicating a greater overall level of fitness. Body composition and fat mass (%) were measured using bioelectrical impedance (Tanita, model TBF-305, Tokyo). Body composition was assessed annually at the completion of each academic year but not at entry.

**Genetic Assessment**

The Vitamin D receptor (VDR) gene DNA was extracted from peripheral blood leukocytes using standard methodology (Nucleon II, Scotlab, UK), and stored in 96-well plates at ~20°C and analyzed at University of Aberdeen, Scotland.

**Questionnaire Data**

A self-administered baseline questionnaire provided information on exercise, lifestyle and dietary habits for the year prior to academy entrance. Race data was collected from academy records. Annual surveys were used to collect data on menstrual function, use of birth control by type and duration and calcium intake. Eating disorders and body satisfaction were assessed in the fourth year using the Eating Disorder Inventory-2 (EDI-2).²²

**Statistical Analysis**

All analyses were performed with PASW statistical software (Version 18.0 for Windows, SPSS Inc., Chicago). Chi square analysis test, means and standard deviations are reported on continuous variables of interest. Correlations were performed with
Pearson's correlation coefficient. A repeated measures ANOVA was used to examine differences among BMI, fitness and percent body fat at entry, exit and during periods of anticipated change. Mean imputation was used for missing anthropometric values in the intervening years but not at entry or end points. Statistical significance was set at p <0.05. A multiple linear regression model was created for the main outcomes of interest including weight, BMI and percent body fat and change in these variables, using those variables that either had biologic plausibility or were significant in the univariate model. Mini tab and SPSS were used to assess the relationship of the VDR genome to changes in weight, BMI and body fat.

Results

Population Characteristics

There were 136 female cadets enrolled in the study. Of these, 108 were Caucasian, 15 were Asian and 13 were African American. Upon entry, Asians were significantly lighter with lower BMI than either Caucasians or African Americans (both: p<0.01). Asians were also significantly shorter than Caucasians (p<0.01). There was not adequate statistical power to determine race specific changes in the main outcome variables (weight, BMI and percent body fat); therefore, the analysis in this paper is based on the Caucasian females who entered and then completed entry and exit measurements as well as many intervening measurements during the four-year study (n=79). Table 5.1 provides the average anthropometric measures at entry and study completion for the 79 Caucasians who completed the study and graduated from the academy.
The average BMI on entry was 22.8 ± 2.4 and upon graduation was 23.6 ± 2.4. Upon entry, 17.6% of women were identified as overweight or obese using BMI ≥ 25 as the delineator. There was a significant increase in BMI during the first year (partial eta² = 0.121; p=0.002) but no other significant changes in BMI during subsequent years. The largest percentage of women fell within the normal range of BMI with a high of 81% at entry and a low of 69% at graduation. There was also an increase in women who were classified as underweight from 1.3% at baseline to 5.6% at graduation. The prevalence of overweight/obese subjects, based solely on BMI, rose from 17.6% to 25.4% four years later.

Since BMI is a poor indicator of fat-free mass and true body composition status in fit, athletic populations, body composition analysis was added at the 2nd assessment. In a repeated measures ANOVA, there was a significant rise in body fat of 1.8% from

<table>
<thead>
<tr>
<th>Anthropometric Measures, Physical Fitness Scores and Body Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong>&lt;br&gt;n=79</td>
</tr>
<tr>
<td>Height (inches)</td>
</tr>
<tr>
<td>Weight (lbs)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
</tr>
<tr>
<td>Percent Body Fat</td>
</tr>
<tr>
<td>Fitness Scores (Range 0-300)</td>
</tr>
<tr>
<td>Calcium Intake (mg/day)</td>
</tr>
</tbody>
</table>

*Baseline body fat occurred at the end of the first year.*
end of first year to the end of second year (partial $\eta^2 = 0.287; p=0.001$), and this increase in body fat persisted until graduation (partial $\eta^2 = 0.22; p=0.001$). There were no significant changes in body fat after the first year. Annual assessment of the variables of interest while at university is presented in Table 5.2.

**TABLE 5.2 Average Key Outcome Variables Over Time**

<table>
<thead>
<tr>
<th>Measurement Time Point</th>
<th>Weight (lbs) Mean ± SD Range</th>
<th>BMI Mean ± SD Range</th>
<th>Percent Fat Mean ± SD Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Entry</td>
<td>140.9 ± 17.9 (103-190)</td>
<td>22.8 ± 2.4 (16.6-30.2)</td>
<td>N/A</td>
</tr>
<tr>
<td>Year 1 End of Freshman Year</td>
<td>146.1 ± 18.2 (102.5-207)</td>
<td>23.6 ± 2.2 (16.5-28.4)</td>
<td>21.1 ± 3.4 (10.8-29.2)</td>
</tr>
<tr>
<td>Year 2 End of Sophomore Year</td>
<td>146.7 ± 19.2 (108-219)</td>
<td>23.6 ± 2.3 (17.3-28.9)</td>
<td>22.9 ± 4.1 (14.8-37.3)</td>
</tr>
<tr>
<td>Year 3 End of Junior Year</td>
<td>146.7 ± 18.5 (108-208.5)</td>
<td>23.5 ± 2.3 (17.7-28.9)</td>
<td>22.9 ± 3.8 (15.1-36.4)</td>
</tr>
<tr>
<td>Year 4 End of Senior Year</td>
<td>146.9 ± 19.4 (103.5-217)</td>
<td>23.6 ± 2.4 (17.6-28.9)</td>
<td>23.1 ± 4.5 (14.6-35.5)</td>
</tr>
</tbody>
</table>

**Fitness Levels**

The average score on the fitness test on entry was 209.0 ± 37.2 (range 0-300). Fitness levels significantly improved during the first year at the academy with an initial increase of 42.6 points. The gain in fitness remained significant until graduation, with the average score on the fitness test at graduation being 285.2 ± 33.3 (partial $\eta^2 = 0.839; p=0.001$).

There were different relationships between the fitness test and each outcome variable: weight, BMI and body composition during the four university years. The correlation of these results and fitness are presented in Table 5.3. At baseline, higher
levels of exercise were significantly correlated to the entry fitness test (p=0.37; r= 0.002) but not to entry weight, BMI or baseline body fat. There were no significant correlations with any other exploratory variable and outcomes of interest at baseline. At graduation, there was a significant negative correlation between BMI and fitness performance (r= -0.37; p=0.001). In addition, in the senior year, there was a negative correlation between percent body fat and total fitness score (r= -0.28; p=0.02).

### Table 5.3 Correlations of Outcome Measures with Variables of Interest

<table>
<thead>
<tr>
<th></th>
<th>Graduation</th>
<th></th>
<th></th>
<th>Change</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BMI</td>
<td>Weight</td>
<td>Body Fat</td>
<td>BMI</td>
<td>Weight</td>
<td>Body Fat</td>
</tr>
<tr>
<td>Calcium</td>
<td>n.s.</td>
<td>n.s.</td>
<td>0.24</td>
<td>n.s.</td>
<td>n.s.</td>
<td>0.25</td>
</tr>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fitness</td>
<td>-0.37</td>
<td>-0.43</td>
<td>-0.28</td>
<td>n.s.</td>
<td>-0.28</td>
<td>-0.26</td>
</tr>
<tr>
<td></td>
<td>p=0.001</td>
<td>p=0.001</td>
<td>p=0.02</td>
<td></td>
<td>p=0.02</td>
<td>p=0.03</td>
</tr>
<tr>
<td>Age Of Menarche</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>-0.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p=0.02</td>
</tr>
<tr>
<td>Total Months OC</td>
<td>n.s.</td>
<td>n.s.</td>
<td>-0.29</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDI-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body Dissatisfaction</td>
<td>0.26</td>
<td>0.31</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td></td>
<td>p=0.03</td>
<td>p=0.008</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ineffectiveness</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>-0.26</td>
<td>n.s.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p=0.03</td>
<td></td>
</tr>
<tr>
<td>Interpersonal Distrust</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

n.s = non-significant

**Vitamin D Receptor Gene**
There was no association seen between the Vitamin D receptor gene polymorphism examined, BsmI, and weight, BMI or body fat in this study at baseline or completion.

**Calcium Intake**

During the four years at university, both dairy and total daily calcium consumption significantly declined (p=0.001). Neither weight, BMI nor body fat were correlated with dairy intake or total daily calcium intake at baseline. Average daily calcium consumption during the four year period was positively correlated with both body fat at graduation and percentage body fat change ($r=0.24; p=0.04$ and $r=0.25; p = 0.03$).

**Other Variables**

Body dissatisfaction from the Eating Disorder Inventory-2 was positively correlated with graduation weight and BMI. There was a significant negative correlation between total months of oral contraceptive use and body fat at graduation ($r=-0.29; p=0.02$).

**Predictors of Weight, BMI and Body Fat Change**

Two measures of the Eating Disorder Inventory-2, a sense of ineffectiveness and interpersonal distrust, were significantly and negatively correlated with weight change and change in BMI ($r=-0.26; p=0.03$ and $r=-0.24; p= 0.03$, respectively). During the four years at university, 16% of the women used DMPA, and 58.2% of the women used oral
contraceptives. There was no association between total months of oral contraceptive (OC) use and change in weight, BMI or body fat in any of the regression models. However, in the regression model examining predictors of change in body fat, total months DMPA use was positively associated with change in body fat. Better performance on the fitness exam was a negative predictor of change in body fat. Age at menarche was negatively associated with change in body fat (r=-0.26; p=0.02).

**TABLE 5.4 Regression Models Predicting Primary Outcomes of Interest**

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Constant</th>
<th>Predictors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Graduation Weight</strong></td>
<td></td>
<td>Weight at Entry - Fitness</td>
</tr>
<tr>
<td>$r^2=0.67$</td>
<td>126.04</td>
<td>0.61</td>
</tr>
<tr>
<td>(Standard Error)</td>
<td>(36.25)</td>
<td>(0.17)</td>
</tr>
<tr>
<td>$p=0.001$</td>
<td>0.003</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.002</td>
</tr>
<tr>
<td><strong>Graduation BMI</strong></td>
<td></td>
<td>Ineffectiveness - Fitness</td>
</tr>
<tr>
<td>$r^2=0.55$</td>
<td>34.60</td>
<td>0.92</td>
</tr>
<tr>
<td>(Standard Error)</td>
<td>(3.57)</td>
<td>(0.24)</td>
</tr>
<tr>
<td>$p=0.001$</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.002</td>
</tr>
<tr>
<td><strong>Graduation Body Fat</strong></td>
<td></td>
<td>Weight at Entry – Maturity Fears</td>
</tr>
<tr>
<td>$r^2=0.49$</td>
<td>-3.556</td>
<td>0.21</td>
</tr>
<tr>
<td>(Standard Error)</td>
<td>(8.26)</td>
<td>(0.06)</td>
</tr>
<tr>
<td>$p=0.001$</td>
<td>0.671</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.001</td>
</tr>
<tr>
<td><strong>Change in Weight</strong></td>
<td></td>
<td>-Weight at Entry - Fitness</td>
</tr>
<tr>
<td>$r^2=0.38$</td>
<td>127.34</td>
<td>-0.377</td>
</tr>
<tr>
<td>(Standard Error)</td>
<td>(36.25)</td>
<td>(0.17)</td>
</tr>
<tr>
<td>$p=0.007$</td>
<td>0.002</td>
<td>0.036</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.003</td>
</tr>
<tr>
<td><strong>Change in BMI</strong></td>
<td></td>
<td>Interpersonal Distrust</td>
</tr>
<tr>
<td>$r^2=0.26$</td>
<td>2.29</td>
<td>-1.63</td>
</tr>
<tr>
<td>(Standard Error)</td>
<td>(1.3)</td>
<td>(0.57)</td>
</tr>
<tr>
<td>$p=0.009$</td>
<td>0.093</td>
<td>0.009</td>
</tr>
<tr>
<td><strong>Change in Body Fat</strong></td>
<td></td>
<td>Total Number of months on DMPA - Fitness</td>
</tr>
<tr>
<td>$r^2=0.51$</td>
<td>32.4</td>
<td>0.143</td>
</tr>
<tr>
<td>(Standard Error)</td>
<td>(8.1)</td>
<td>(0.06)</td>
</tr>
<tr>
<td>$p=0.001$</td>
<td>0.003</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.003</td>
</tr>
</tbody>
</table>

As seen in Table 5.4, the main predictor variables associated with the outcome variables of interest, weight, BMI, and body fat at graduation, as well as changes in those variables were weight at entry and fitness. A regression model examining change in
body fat indicates that mean DMPA use (in months) in conjunction with performance on the fitness test explains 51% of the variation seen in body fat change during the four university years.

**Discussion**

Weight gain at university is a common and complex matter. Similar to other studies, this study observed that most weight gain occurred in the first year at university.\textsuperscript{10,13} However, there was significant variability in individual weight change during the freshman year with a range of 18.5 pounds lost to 22.0 pounds gained, with more than 25% of the women losing weight. Changes in physical activity are often associated with weight gain/loss.\textsuperscript{14} As would be expected, hours of exercise per week prior to entering the academy was associated with entry fitness test score ($r=0.374$; $p=0.002$) but not with weight or percent body fat. Graduation fitness test score was negatively associated with an increase in percent body fat ($r=-0.264$; $p=0.03$), indicating that those who gained fat, and not those who gained muscle, may have participated in less exercise and training for the fitness test. Entry weight was a positive predictor of graduation weight and body fat. In four of the six models, better performance on the fitness test was negatively associated with graduation weight and BMI, as well as changes in weight and body fat. In 11% of the women, there was weight gain, but no fat gain. In examining this subset of women, when the four-year weight change was modeled with body dissatisfaction score it accounted for 90% of the variability in weight change in this population ($r^2=0.9$; $p=0.008$). Better performance on the fitness test may be a proxy measure for higher physical activity while at the academy. In fact, in women who gained weight, there was significant negative correlation between improved fitness scores and percent body fat at graduation ($r=-0.382$; $p=0.04$).
There is a growing body of evidence that indicates that body adiposity is a heritable trait. In fact, Stunkard (1986) in his twin study found approximately 80% of adiposity is heritable. The Vitamin D receptor gene has been associated with adiposity body types. The study did not find a relationship between the BsmI VDR and BMI or body fat percentage at baseline or a change in these variables. However, this could be due to suppression of the phenotype based on the height/weight requirements imposed by the military. Expression of the underlying gene may also be limited by environmental factors or perhaps racial distributions that could not be evaluated here.

Higher dairy and calcium intake has been associated with lower body weight, improved body composition and weight loss in a number of studies. However, findings in this study did not support that hypothesis. In fact, there was a small, but positive correlation between dairy intake and increased adiposity. This difference may be due to the family style of eating with unlimited access to milk at the academy or the type of dairy consumed, including ice cream.

In the regression model, longer total use of DMPA was associated with an increase in body fat, not weight. Other studies exploring weight gain in young women have found an increase in weight associated with DMPA. The lack of weight change could be due to the strong external environmental pressure to maintain weight standards, fitness and appearance standards imposed by the military. There was no association between weight, BMI and percent body fat change and the use of oral contraceptives in the regression models. This study confirms other studies reporting the lack of association between weight gain in young women and oral contraceptive use. However, there was a small but significant negative correlation between body fat at graduation and oral
contraceptive use. Age at menarche was inversely associated with change in body composition, but not with body fat at baseline, confirming other studies. It is hypothesized that menarche begins when enough body fat has been established. It is interesting that body fat at entry was not associated with age of menarche but rather that change in body fat was.

Four measures of the Eating Disorder Inventory, interpersonal distrust, maturity fears, body dissatisfaction and a sense of ineffectiveness, were significantly and negatively correlated with weight change and BMI change. The interpersonal distrust measure is, according to Garner (1991), a measure of reluctance to form a personal relationship. The body dissatisfaction variable is related to a belief that changes in the body including hips, thighs and buttocks may be too fat. Maturity fears relates to the fear associated with the demands of adult life and ineffectiveness is a measure of insecurity and the feeling of having no control over their lives. The multiple occurrence of EDI-2 variables in both the univariate analysis and the regression models highlights the importance of the psychological aspects of weight gain and highlights the potential importance of counseling young adults.

This study has a number of limitations. First, an inherent problem associated with longitudinal studies is loss to follow-up. This study had a 28% loss to follow-up rate. Most of the loss related to women leaving the academy prior to graduation. There are many reasons that might cause a cadet to leave the academy, including medical issues that would preclude military service, academic failure, or dislike of the structure of military life. None of these is related to the study hypothesis. However, failure to
maintain fitness and/or weight standards is cause for dismissal from the academy. If some of the loss to follow-up was due to failure to maintain required weight or fitness, findings would have been biased to the null.

Another limitation is that body composition was not assessed until the end of the first year. Although weight gain was observed in the first year, it was also accompanied by a significant increase in fitness scores. Therefore, it cannot be determined whether first-year weight gain was associated with an increase in lean or fat mass or a combination of both. There was an increase in fat mass during the second year at the academy when students are afforded greater freedoms and, thus, less stringent dietary requirements. Perhaps the greater freedoms normally associated with the first year at most universities, which do not occur until the second year at USMA, contributed to this gain in fat mass from the second year and persisted to graduation, while levels of fitness also continued to increase. There is an additional concern that this may just be rebound weight and fat gain. The first summer and year at the academy are rigorous and many cadets lose weight during their summer training program; this could be the cause for the weight gain that is captured in this data set.

It is essential to examine body composition changes as they relate to BMI changes. In fact, nine women in the study had increased their BMI during the four-year study but had decreased their percentage of body fat; suggesting that the gain in weight calculated via the BMI technique was from lean mass, not fat mass. In this population, average percent body fat associated with overweight at entry was 23.12 ± 3.7 (range 16.0-29.2). Gallagher (2000) reported rates of healthy body fat by developing algorithms using BMI derived from large diverse populations and four compartment body fat
measurements. They predicted that a healthy percent body fat for women aged 20-29 with a normal BMI would be about 33%.³²

An additional limitation of the study is its external validity. The study population was athletic, fit and meeting strict medical and military requirements in order to enter the academy. The study population was clearly more fit than the normal college-age population and participants had greater concern for fitness and a healthy weight since these are requirements for continuation in the military. Therefore, these findings may not be readily generalizable outside of a fit, female population. However, this allows researchers to understand that lifestyle variables, including exercise, even in a fit population may influence weight gain and changes in body composition. .. An additional variable of interest in the current study, that was not fully explored, was smoking cessation. Only 3.8% of women in this cohort reported that they smoked at entry however patterns of smoking were not assessed in subsequent years.

Finally, some factors including racial differences could not be fully explored because of smaller sample sizes, limited variability and, thus, limited power. Similar to studies of other university students, students of all races gained weight. ³³ Socioeconomic status of parents, weight of parents, extra physical activity, an assessment of stress, and an assessment of eating disorders at baseline may have provided greater insight into what variables may contribute to weight gain at university. In addition, these young women were under a great deal of stress, it would have been advantageous to have biochemical markers of stress including cortisol to further understand if this, too, was a predictor of weight, BMI or body composition changes.
In conclusion, the results of this study indicate that, even in a population driven to be fit and healthy, there is a small amount of weight gain during the first year of college that remains through to graduation. In addition, there is a small but significant gain in body fat. Weight gain is a complex emotional issue. Researchers understand that ultimately weight gain is caused by the creation of a positive energy balance, but the underlying causes are often difficult to assess. This study’s data indicate that perhaps dealing with the issues of distrust or ineffectiveness may, in part, suppress weight gain. In addition, this study substantiates past findings that measurements of body composition may be a better method for assessing health risks than BMI, since BMI doesn’t always represent the underlying adiposity in fit populations. Theoretically, strategic dietary interventions aimed at the educated college student population could help prevent obesity later in life. Data from this study provide further evidence that there is a need to develop targeted intervention strategies including exercise and dietary counseling during the critical weight gain years to help derail the burgeoning obesity epidemic. By educating the large number of entering freshmen each year in American universities, public health officials might be able to reverse the trend to gain weight in this population and reduce the risk of overweight in the nation as a whole.
Acknowledgments

We are grateful to those cadets who took time from their busy schedules to participate in this study. Additionally, without the support of many of the staff and faculty at the United States Military Academy, this study would not have been successful. I am grateful to Dr. K Wippern who provided expert statistical advice for Chapter 5. This study was funded by a grant from the U.S. Army Medical Research and Materiel Command.
References


Chapter 6: Summary and Implications

I. Summary of Research Problem

Obesity and osteoporosis are burgeoning epidemics of the 21st century. The cost of obesity-related diseases in America is estimated at $147 billion, while the cost of osteoporosis was estimated at $17 billion in 2005. Osteoporosis is estimated to affect 75 million people in the United States, Europe, and Japan combined. There are more than 1 billion overweight and 300 million obese adults worldwide. Evidence is mounting that both diseases should be viewed in the context of the social epidemiologic framework: These diseases are the result of the life course of the individual. Both of these conditions, although influenced in some cases by genetic factors, may occur as the result of early lifestyle choices. Obesity and osteoporosis have gender differences in occurrence and etiology and result from a variety of causal pathways. There are critical human developmental periods and exposures for developing these diseases during the life course. One critical developmental period for both obesity and osteoporosis has been identified as the college or young adult years, when weight gain occurs and peak bone mass is attained.

The research conducted for this dissertation was presented in four chapters. These chapters examined potentially modifiable risk factors that may contribute to peak bone mass in a collegiate population and examined changes in body composition and weight during the college years. The primary focus of this study was to examine bone density and weight gain in a healthy, physically fit population.
II. Review of Data Used

Data for these papers were collected as part of a larger four-year prospective study on “Determinants of Stress Fracture and Bone Mass in Elite Military Cadets,” which was funded by the United States Army Medical Research Acquisition Activity (USAMRAA). These data provided an opportunity to examine lifestyle factors, physical activity, nutrition and endocrine function in a large, young and fit population and to determine the implications of these factors on body composition and the acquisition of peak bone mineral density. A further purpose of the grant was to examine risk factors associated with stress fractures, as well as longitudinal changes in bone mass. Stress fractures are a serious problem in the military for both lost time and money. The population selected for this study was the United States Military Academy class of 2002. Approximately 70% of the class or 891 members (755 males and 136 females) provided written informed consent and were subsequently enrolled in the study.

From the original data, and after the completion of a literature review (Chapter 1), specific aims of the research were proposed, presented and approved for a dissertation in accordance with departmental requirements. These aims were established to provide further information about the status of bone mineral density in this fit population, whether specific sports influence bone mineral acquisition and whether, even in this specific environment, body composition and weight gain would occur during the four years at university. The approved aims of the proposed dissertation were:
1. To examine the association between the variability in lifestyle characteristics with bone mineral density (BMD) at different skeletal sites. Specifically, to investigate the relationship of bone mineral density at the age of college entry with personal and family history of fracture, gender and racial differences, diet, prior exercise and other lifestyle factors.

2. To examine sports specific differences in BMD in a young, fit population at baseline. To determine whether fitness levels or load-bearing sports participation is a better predictor of BMD. Alternatively, to explore fitness as a mediator for those participating in non-weight-bearing sports. Finally, to examine the interrelationship among exercise, BMD and insulin-like growth factor (IGF-1).

3. To examine prospective changes in body composition during a four-year follow-up. Specifically, this study will explore the relative importance of diet, VDR, physical activity, fitness, physical aptitude, age of menarche, use of oral contraceptives, menstrual function and BMD as they relate to changes in body composition, weight and BMI changes in females.

The remaining portion of this chapter will summarize the findings reported in the four original research papers presented in Chapters 2 through 5. This will include a brief summary of the findings, their relationship to the a priori hypotheses, methodical strengths and weaknesses. Finally, the implications of this research to the field of public health as it relates to the fundamental political, social and educational strategy changes required to stem the osteoporosis and obesity epidemics will follow the summaries.
III. Summary of Chapter 2: Determinants of bone mass and bone size in a large cohort of physically active young men

a. Research Findings

i. Hypothesis 2.1: There will be racial and gender differences in bone mineral density and size at baseline.

1. Results *support* the hypothesis that gender is an important determinant in bone mineral density. Two papers instead of one were written to enable full exploration the gender-specific determinants related to BMD.

2. Results *support* the hypothesis that racial differences exist in BMD. African American men had significantly higher calcaneal, hip and spine BMD.

3. Results *support* the hypothesis that racial differences exist in bone size. African American men had significantly larger periosteal circumference and greater cortical thickness than Asians or Caucasians.

ii. Hypothesis 2.2: Lifestyle factors including exercise, diet, smoking and alcohol will be determinants of bone mineral density and bone size in this population.

1. Results *support* the hypothesis that caffeine was a negative determinant of BMD. Those men who consumed greater
quantities of caffeine had lower BMD at the heel and less tibial mineral content.

2. Results support the hypothesis that smoking was a negative determinant of BMD. Male smokers had lower BMD of the spine and hip.

3. Results support the hypothesis that prior exercise and milk intake was positively related to both BMD and bone size.

iii. Hypothesis 2.3: Personal and family history of fracture will be associated with lower bone mineral density.

1. Results did not support the hypothesis that personal history of fracture was a determinant of bone mineral density.

2. Results did not support the hypothesis that family history of fracture was a determinant of bone mineral density.

b. Strengths and Limitations

i. Strengths

1. This was a large, male study on BMD in a fit population free of many medical confounders.

2. The response rate on the baseline questionnaire, fitness results, height and weight were close to 100%.

3. Internal validity of this study was good. However, there may have been some measurement error in the baseline questionnaire.
4. The Honor Code may have ensured a greater level of integrity in the self reported data.

ii. Limitations

1. This population was very fit; therefore, a potential weakness is the generalizability and external validity. This population was not representative of the health status of the general college-aged population.

2. The baseline questionnaire included a brief self-administered food frequency questionnaire. The food items were grouped to ensure the surveys were completed quickly, did not violate the time allotted and prevented respondent burnout. However, some important data may have been lost because of grouping, which may also result in residual confounding. In addition, exercise was grouped into broad categories of one to three, four to six, seven to ten or eleven-plus hours a week, perhaps allowing residual confounding.

3. More detailed dietary factors may have enhanced the findings of the study but were not assessed on the baseline questionnaire. Of particular interest was an assessment of total caloric intake. Due to time constraints imposed by the academy, the dietary assessment had limited scope beyond a calcium assessment.
IV. Summary of Chapter 3: The Influence of Lifestyle, Menstrual Function, and Oral Contraceptive Use on Bone Mass in Female Military Cadets

a. Research Findings

i. Hypothesis 3.1: There will be racial and gender differences in bone mineral density and size at baseline.

1. Results support the hypothesis that racial differences exist in BMD. African American women had slightly higher bone mineral density at the spine and calcaneus when compared to other races.

2. Results support the hypothesis that racial differences exist in bone size. African American women had significantly larger periosteal circumference and tibial mineral content than both Caucasians and Asians.

ii. Hypothesis 3.2: Lifestyle factors including diet, exercise, smoking, age of menarche and oral contraceptive use will be associated with bone mineral density and bone size in this population

1. Results support the hypothesis that lifestyle and environmental elements can impact bone mass in fit, young college-age students. In women, milk intake and prior exercise history had a significant and positive association with bone mineral density at multiple sites.
2. Results *support* the hypothesis that there would be a difference in BMD in oral contraceptive users. Those women using oral contraceptives at entry had significantly lower BMD at the spine and calcaneus and a smaller tibial periosteal circumference and less tibial bone mineral content.

3. Results *did not support* that the hypothesis that age of menarche would have an effect on bone density and bone size. Earlier age of menarche did not have a positive effect on either bone size or density at any site.

iii. Hypothesis 3.3: Personal and family history of fracture will be associated with lower bone mineral density.

1. Results *partially support* the hypothesis that personal history of fracture was a determinant of bone mineral density. The direction of BMD was different than hypothesized. Women with prior history of fractures had significantly *higher* BMD at the spine and the hip.

2. Results *did not support* the hypothesis that family history of fracture was related to lower bone mineral density. There was no association found.
b. Strengths and Limitations
   i. Strengths
      1. The response rate on the baseline questionnaire, fitness results, height and weight were close to 100%.
      2. Internal validity of this study was good. However, there may have been some measurement error in the baseline questionnaire.
      3. The Honor Code may have ensured a greater level of integrity in the self reported data.
   ii. Limitations
      1. Data on diet, injury, calcium, menstrual function and family history of fracture were self-reported and subject to non-differential misclassification and recall bias. In particular, there was a concern that many of the participants did not know their parents’ or grandparents’ fracture history. This underreporting would have underestimated the findings and may have contributed to the lack of findings between cadet bone mass and family history of fracture.
      2. The baseline and follow-up questionnaires that were used to collect data on lifestyle variables including past exercise, calcium consumption, birth control, smoking, alcohol
consumption and menstrual function were self-administered and, therefore, are limited by individual recall and only provided annually.

V. Summary of Chapter 4: The Impact of varsity sports, fitness and physical aptitude on bone mineral density

a. Research Findings

i. Hypothesis 4.1: There will be sport differences in bone mineral density and bone size at different skeletal sites associated with the sport specific loading.

1. Results support the hypothesis that load-bearing sports confer a benefit to bone mineral density and confirm that non-weight-bearing sports, such as swimming, have less skeletal benefit.

2. Results support the hypothesis that load-bearing sports confer a benefit to bone size.

ii. Hypothesis 4.2 Fitness and physical aptitude will be a mediator in the sport –BMD relationship

1. Results support a the hypothesis that there was a different mechanism of action on bone density acquisition between the measures of fitness and physical aptitude. They were determinants of BMD at different skeletal sites.
2. Results *do not support* the hypothesis that fitness was a mediator for BMD.

iii. Hypothesis 4.3  IGF-1 will be positively associated with sport.

Results *do not support* a relationship between IGF and the sports studied.

b. Strengths and Limitations

i. Strengths

1. The internal validity of this study was strong on prior sports assessment and duration of participation. Each applicant was required to have his or her application to the academy validated by a high school official, and all data used in the study were taken directly from the initial academy application.

2. The academy’s internal assessment of the physical aptitude exam is that it is a good predictor of success and aptitude for the physical rigors of the academy; this may be inherently different from actual physical aptitude toward a specific sport.

3. No study, to date, has examined both fitness and physical aptitude and their relationship to BMD. This is a unique contribution to the literature.
ii. Limitations

1. There is concern that the groupings of hours and intensity of exercise could vary since different high schools and coaches have different approaches to training. However, this would not be systematic and would lead to general non-differential misclassification. This would move the finding to the null value.

2. There may be limited generalizability. The results, from this fit college-age sample may not be applicable to the general population, although these results may apply to other college athletes.

3. At a young age, larger boys with greater BMD could have self-selected into high impact, high-loading sports such as football.

4. The use of cross-sectional data does not permit exploring the temporal relationship between BMD and sport selection.

5. The control group for the study did not play a varsity sport in high school. However, participants may have played club or external sports that were not captured specifically as a high school sport. This could have caused an underestimation of the site-specific differences.
6. There were multiple comparisons made in this study; however, because there have been prior studies indicating that these variables examined were of interest to BMD research, it would have been overly conservative to eliminate variables statistically when they are important biologically. In addition, in many cases, the variables were highly significant.

7. There was not complete assessment of IGF so there was not significant power to explore this fully.

VI. Summary of Chapter 5: Body composition and weight changes in physically fit females during four years at university

a. Research Findings

i. Hypothesis 5.1 There will be weight gain and body composition changes in women during their four years at university

1. Results support the hypothesis that body fat and BMI increase during the four-year college period, even in a fit, weight conscious, motivated population.

2. Results support the hypothesis that there will be a change in body composition. On average there was a significant rise of 2% in body fat. These changes occurred, even while fitness levels were improving.
ii. Hypothesis 5.2 Oral contraceptive use, fitness level, age of menarche, calcium consumption and other lifestyle choices including eating behaviors/disorders will be associated with weight changes.

1. Results do not support an inverse relationship between weight gain and calcium consumption. Results indicate that calcium was positively correlated with body fat and body fat changes.

2. Results partially support a relationship between some elements of eating disorders and weight, BMI and body composition and their changes, including the constructs of ineffectiveness, body dissatisfaction, maturity fears, and interpersonal distrust in this population.

3. Results partially support a relationship between age of menarche and one of the main outcome variables, change in the percentage of body fat. However, neither BMI nor weight was associated with age of menarche.

iii. Hypothesis 5.3 The Vitamin D receptor gene will be associated with weight changes in this population

1. Results do not support the hypothesis that the specific vitamin D receptor allele, BsmI, was associated with BMI, weight gain, body fat or body fat gain in this population.
b. Strengths and Limitations

i. Strengths:

1. The construct validity of most of the variables, including the anthropometric and BMD measurements, was strong. Height and weight were measured by academy personnel on balanced/calibrated scales. In addition, the coefficient of variation on bone measurement machines was between 1–1.5%.

2. This study added to the body of literature by examining multiple outcomes of fitness, BMI and percentage of body fat where environmental conditions strictly prohibit obesity. In conjunction with the negative VDR finding, this could be indicative of suppression of a genotype by environmental conditions.

3. Prescription data such as OC and DMPA could be validated through the medical records.

ii. Limitations:

1. This study had a 28% loss to follow-up rate. This could be a threat to internal validity of the study. Failure to maintain fitness and weight standards could be cause for dismissal from the academy. If some of the loss to follow-up was, in fact, due to failure to maintain required weight standards,
that situation might lead researchers to underestimate findings in this study. However, an exploration of baseline characteristics of those lost to follow-up and those completing the study showed no significant differences between those populations.

2. There was no baseline body composition data, only height and weight. Body composition was added at the end of the first year. BMI, in this fit population, was not a good indicator of body composition or fatness. A portable Tanita Body Composition analyzer, with a printer to ensure accuracy of the data, was integrated into the study at the conclusion of the first year. Although weight gain was observed in the first year, it was accompanied by a significant increase in fitness scores. Therefore, it cannot be determined whether the first-year weight gain was associated with an increase in lean or fat mass.

3. Bioelectrical impedance body composition analyzers may be affected by the hydration level of the participant. Because body composition was measured in field conditions during the first year, there may be some overestimation of fat during baseline measurement due to dehydration of subjects. This may then lead to an
underestimation of total gain in body fat during the four years at university.

VII. Research Implications

To date, there has been limited research attempting to investigate the acquisition of bone mineral density in college aged populations, in particular in a fit population with a requirement to maintain a healthy lifestyle while in university. Many studies have examined BMD at younger ages and the positive impact of loading exercises in children or, alternatively, have examined exercise routines in peri- or post-menopausal women. In addition, research comparing sport-specific differences in BMD have examined older amateur athletes who had a longer duration of sports participation. The research presented in this study indicates that sport-specific differences are apparent at age 18. Specifically, data from this study suggests that at the age of 18, these young adults laid down a substantial portion of their bone mass and that intervention at this age or earlier is essential to mitigate the occurrence of osteoporosis. Achieving higher peak bone mass can prevent early childhood fracture as well as provide protection against fracture later in life. If factors affecting gains in bone mineral density can be clearly identified in a fit population, then the implications for the general population could be even greater.

Longitudinal studies examining the role and the relationship of factors in childhood and adolescence with regard to acquisition of bone are essential. The large, healthy and fit population at the academy offers an opportunity to examine factors that may increase BMD at a critical period of life. Furthermore, some of the confounders that have provided concern in other studies, including inadequate control for alcohol and smoking, are more
naturally controlled by the strict requirements of the institution. A significant weakness in the literature related to BMD and sports selection may be more fully understood by examining both physical aptitude and fitness and any interactions they may have with different sports. It is from these studies that the looming osteoporosis epidemic can be dealt with most effectively. Primary prevention strategies can be developed to maximize peak bone mass during adolescent and teen years through improved nutrition education and enhanced physical education programs.

The longitudinal study that examined changes in weight, body composition and BMI demonstrates that even in a highly motivated population that has external demands for fitness, maintenance of weight standards, military bearing and appearance, that significant changes did occur during the university period. According to Novak (2006), obesity has multiple and complex causal pathways. Novak demonstrates the complexity of obesity by examining the different life-course causes of obesity in men and women at age 30.12

This particular period in the life course, the university years, seems to be a critical juncture to future adiposity issues. A review of college weight gain in the medical literature shows that no less than 37 articles specifically address the topic of freshman weight gain. By addressing this period of stress, greater personal freedoms, inactivity and social change, the life-course potential transition from weight gain in college to obesity later in life can be changed.

The medical emphasis on adult treatment of these diseases must change. Public health practitioners need to change their fundamental approach from treatment at disease onset to prevention. In particular, universities should have mandatory health education
classes addressing these issues. Elementary schools, families and physicians must provide input and educational opportunities as well.

VIII. Future Research

Additional longitudinal studies are warranted to explore the acquisition of bone mineral density and weight gain over the life course. In addition, these studies should be explored in different populations with a full understanding of the population in question and an extensive examination of family history and genetics, bio-chemical markers, diet and exercise patterns. In addition to long term, population-specific research, the implementation of social, political and academic strategies are required to influence the future reduction of these diseases since their pathways are complex, with genetic, social, psychological and physical components.
References


APPENDIX A: SURVEYS

Menstrual Function Annual Survey Example

NAME: ____________________________
SSN: ____________________________

BACKGROUND: Recent studies have shown that there is a correlation between different types of birth control, menstrual function and bone density therefore please take time in completing this survey.

INSTRUCTIONS: Please check the boxes that apply to you.

<table>
<thead>
<tr>
<th>COW YEAR</th>
<th>DID YOU HAVE A PERIOD?</th>
<th>WHERE YOU ON BIRTH CONTROL?</th>
<th>WHAT TYPE OF BIRTH CONTROL?</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 2000</td>
<td>Yes</td>
<td>Yes</td>
<td>Oral</td>
</tr>
<tr>
<td>July 2000</td>
<td>Yes</td>
<td>Yes</td>
<td>Oral</td>
</tr>
<tr>
<td>August 2000</td>
<td>Yes</td>
<td>Yes</td>
<td>Oral</td>
</tr>
<tr>
<td>September 2000</td>
<td>Yes</td>
<td>Yes</td>
<td>Oral</td>
</tr>
<tr>
<td>October 2000</td>
<td>Yes</td>
<td>Yes</td>
<td>Oral</td>
</tr>
<tr>
<td>November 2000</td>
<td>Yes</td>
<td>Yes</td>
<td>Oral</td>
</tr>
<tr>
<td>December 2000</td>
<td>Yes</td>
<td>Yes</td>
<td>Oral</td>
</tr>
<tr>
<td>January 2001</td>
<td>Yes</td>
<td>Yes</td>
<td>Oral</td>
</tr>
<tr>
<td>February 2001</td>
<td>Yes</td>
<td>Yes</td>
<td>Oral</td>
</tr>
<tr>
<td>March 2001</td>
<td>Yes</td>
<td>Yes</td>
<td>Oral</td>
</tr>
<tr>
<td>April 2001</td>
<td>Yes</td>
<td>Yes</td>
<td>Oral</td>
</tr>
<tr>
<td>May 2001</td>
<td>Yes</td>
<td>Yes</td>
<td>Oral</td>
</tr>
</tbody>
</table>

1. If you were on birth control prior to entering the academy which type was it?

   Oral □   Depoprovera □   Norplant □
APPENDIX A

BASELINE QUESTIONNAIRE

Determinants of Stress Fracture and Bone Mass in Elite Military Cadets

Baseline Survey

Instructions: This survey is part of the "Determinants of Stress Fractures and Bone Mass in Elite Military Cadets Study." It will take you approximately 5 minutes to complete. It is important that you answer honestly and openly. It could affect the findings of the study which can prevent injuries/stress fractures. This information will be held in the strictest confidence.

Name __________________________ Company __________________________ SSN __________________________

Exercise History

1. During the past 2 years, what was your exercise pattern?
   a. 1 to 3 hours per week
   b. 4 to 6 hours per week
   c. 7 to 10 hours per week
   d. 11 or more hours per week

Nutritional Information

2. During the past 2 years, how many caffeine containing drinks did you have per day on average?
   a. None
   b. 1 to 3
   c. More than 3

3. During the past 2 years, how many glasses of milk did you have per day on average?
   a. None
   b. <1
   c. 1 to 2
   d. 3 or more

4. During the past 2 years, how many cups of yogurt did you have per week on average?
   a. None
   b. 1 to 3
   c. 4 to 6
   d. 7 or more

5. During the past 2 years, how many servings of cheese did you have per week on average (including pizza, macaroni and cheese, etc.)?
   a. None
   b. 1 to 3
   c. 4 to 6
   d. 7 or more

6. During the past 2 years, how many servings of broccoli, mustard greens, collards, or kale did you have per week on average?
   a. None
   b. 1 to 3
   c. 4 to 6
   d. 7 or more

7. During the past 2 years have you taken vitamins or diet supplement drinks/powders?
   a. Yes (what is the name of the supplement____________________)
   b. No

8. Do you salt your food?
   a. Yes
   b. No
APPENDIX A

Page 2 Baseline Survey

Alcohol Consumption

9. How would you characterize your alcohol consumption during the last year?
   a. less than 1 time a month
   b. 1 to 3 times a month
   c. 1 to 2 times a week
   d. 3 to 5 times a week
   e. daily

Tobacco Usage

10. Do you smoke?
    a. Yes
    b. No

   If yes, for how long have you been smoking? _______ Number of packs per day? _______

11. Do you use chewing tobacco?
    a. Yes
    b. No

   If yes, for how long have you been chewing tobacco? _______

12. Do you use "dip"?
    a. Yes
    b. No

   If yes, for how long have you been using "dip"? _______

Medical History

13. Have you ever had a bone break (fracture)?
    a. Yes where _______
    b. No

14. Has anyone in your family had a fracture as an adult?
    Mother Yes No
    Father
    Grandparents
    Aunts/Uncles

Women's Section

15. At what age were you when you started menstruating? _______

16. How many times in the last year did you have a menstrual cycle?
   a. 0 to 3 times
   b. 4 to 6 times
   c. 7 to 9 times
   d. 10 to 12 times

17. Are you currently taking the birth control pill (BCP)?
    a. Yes
    b. No

   If yes, for how long have you been taking the BCP? _______

18. If you took the BCP in the past, for how long were you taking it? _______
APPENDIX A

Food Frequency from Field Conditions

**FOOD FREQUENCY QUESTIONNAIRE: SUMMER 00**

Instructions: Please think about the foods you regularly ate over the past year, what size servings you ate, and how often you ate them. Then fill in the appropriate boxes. If you ate two medium bowls of cereal a day you would fill in the boxes like this:

**EXAMPLE:**

<table>
<thead>
<tr>
<th>Breakfast</th>
<th>Medium Serving Size</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>No. of Servings</th>
<th>Per day</th>
<th>Per week</th>
<th>Per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereal with Milk</td>
<td>1 med bowl</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**START HERE:**

<table>
<thead>
<tr>
<th>Dairy</th>
<th>Medium Serving Size</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>No. of Servings</th>
<th>Per day</th>
<th>Per week</th>
<th>Per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cottage cheese</td>
<td>½ cup</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cheese</td>
<td>2 oz or 2 slices</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>yogurt</td>
<td>1 cup</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tofu</td>
<td>2 oz</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Breakfast**

<table>
<thead>
<tr>
<th>Breakfast</th>
<th>Medium Serving Size</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>No. of Servings</th>
<th>Per day</th>
<th>Per week</th>
<th>Per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereal with Milk</td>
<td>1 med bowl</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Lunch**

<table>
<thead>
<tr>
<th>Lunch</th>
<th>Medium Serving Size</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>No. of Servings</th>
<th>Per day</th>
<th>Per week</th>
<th>Per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheese dishes, such as macaroni and cheese</td>
<td>1 cup</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pasta lasagna</td>
<td>2 slices</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sweets**

<table>
<thead>
<tr>
<th>Sweets</th>
<th>Medium Serving Size</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>No. of Servings</th>
<th>Per day</th>
<th>Per week</th>
<th>Per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice Cream or frozen yogurt</td>
<td>1 scoop</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Vegetables**

<table>
<thead>
<tr>
<th>Vegetables</th>
<th>Medium Serving Size</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>No. of Servings</th>
<th>Per day</th>
<th>Per week</th>
<th>Per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mustard or turnip greens or collards</td>
<td>½ cup</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beets, including beets, kidney, baked or black eye peas</td>
<td>¼ cup</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broccoli or kale</td>
<td>½ cup</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Beverages**

<table>
<thead>
<tr>
<th>Beverages</th>
<th>Medium Serving Size</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>No. of Servings</th>
<th>Per day</th>
<th>Per week</th>
<th>Per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass of milk</td>
<td>8 oz</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coffee/Tea (unflavored)</td>
<td>1 cup</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cola Product (unflavored diet or regular)</td>
<td>12 oz (1 can)</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To how many meals per day do you add salt? (circle the correct answer)

0  1  2  (3)  meals a day

Do you take any vitamin or nutritional supplements?  Yes  No

If yes, what is the name of your vitamin or nutritional supplement?

Do you take a calcium supplement or is calcium contained in your vitamin supplement?  Yes  No
# APPENDIX A

## Food Frequency from Online Application

![Food Frequency Survey Table](file:///C:/WINDOWS/TEMP/FoodSurvey.htm)

To how many meals per day do you add salt?

- 0 1 2 3 meals per day

Do you take any vitamin supplements?

- yes  no

Do you take a calcium supplement or is calcium contained in your vitamin supplement?

- yes  no
APPENDIX B- Samples of Results and Data

– Example of Spine DXA

Image not for diagnosis
3.63mm Hi-Res Fast DPX IQ 0.66x 2mm 1.44mm
708899: 457589 772 48-2002 11:144:56
T 2.3 (1.364)

1 See appendix on precision and accuracy.
2 Statistically 68% of repeat scans will fall within 1 SD (±0.01 g/cm²).
3 USA: AP Lumbosacral Reference Population, Young Adult Ages 20-40. See Appendix.
4 Retired for Age, Ethnic.
5 Standardized BMD for L2-L4 is 1369 mg/cm². See J Bone Miner Res 1994: 9:1503-1514

Comments:
APPENDIX B

SPINE DXA Results

### SPINE RESULTS
H.O.R.E.
Helen Hayes Hospital, West Neverstrand, N.Y. 10993

<table>
<thead>
<tr>
<th>Region</th>
<th>BMD$^1$ (g/cm$^2$)</th>
<th>Young Adult$^2$ T</th>
<th>Age Matched$^3$ Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>1.612</td>
<td>122</td>
<td>2.1</td>
</tr>
<tr>
<td>L2</td>
<td>1.529</td>
<td>123</td>
<td>2.4</td>
</tr>
<tr>
<td>L3</td>
<td>1.448</td>
<td>117</td>
<td>1.7</td>
</tr>
<tr>
<td>L4</td>
<td>1.412</td>
<td>114</td>
<td>1.4</td>
</tr>
<tr>
<td>L1-L2</td>
<td>1.472</td>
<td>123</td>
<td>2.3</td>
</tr>
<tr>
<td>L1-L3</td>
<td>1.462</td>
<td>121</td>
<td>2.1</td>
</tr>
<tr>
<td>L1-L4</td>
<td>1.449</td>
<td>119</td>
<td>1.9</td>
</tr>
<tr>
<td>L2-L3</td>
<td>1.483</td>
<td>120</td>
<td>2.0</td>
</tr>
<tr>
<td>L2-L4</td>
<td>1.489</td>
<td>118</td>
<td>1.8</td>
</tr>
<tr>
<td>L3-L4</td>
<td>1.431</td>
<td>115</td>
<td>1.6</td>
</tr>
</tbody>
</table>

### ANCILLARY SPINE RESULTS**

<table>
<thead>
<tr>
<th>Region</th>
<th>BMC (grams)</th>
<th>Area (cm$^2$)</th>
<th>Width (cm)</th>
<th>BMC/HA (g/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>22.56</td>
<td>15.72</td>
<td>4.68</td>
<td>3.36</td>
</tr>
<tr>
<td>L2</td>
<td>25.04</td>
<td>16.38</td>
<td>4.71</td>
<td>3.48</td>
</tr>
<tr>
<td>L3</td>
<td>30.55</td>
<td>21.10</td>
<td>5.49</td>
<td>3.64</td>
</tr>
<tr>
<td>L4</td>
<td>27.27</td>
<td>19.32</td>
<td>5.96</td>
<td>3.24</td>
</tr>
<tr>
<td>L1-L2</td>
<td>47.24</td>
<td>32.10</td>
<td>4.69</td>
<td>6.84</td>
</tr>
<tr>
<td>L1-L3</td>
<td>77.79</td>
<td>53.20</td>
<td>4.98</td>
<td>10.68</td>
</tr>
<tr>
<td>L1-L4</td>
<td>105.06</td>
<td>72.51</td>
<td>5.21</td>
<td>13.92</td>
</tr>
<tr>
<td>L2-L3</td>
<td>155.59</td>
<td>116.40</td>
<td>5.12</td>
<td>7.32</td>
</tr>
<tr>
<td>L2-L4</td>
<td>52.86</td>
<td>56.79</td>
<td>5.38</td>
<td>10.56</td>
</tr>
<tr>
<td>L3-L4</td>
<td>37.82</td>
<td>40.41</td>
<td>5.71</td>
<td>7.08</td>
</tr>
</tbody>
</table>

1 - See appendix on precision and accuracy.
Statistically 95% of repeat scores will fall within 1 SD (±0.1 g/cm$^2$).
2 - DXA AP spine Reference Population, Young Adult Ages 20-40. See Appendices.
3 - Matched for age, Izmar.
**Ancillary results for research purposes, not clinical use.
APPENDIX B

HIP DXA

FEMUR RESULTS
H.O.P.E.
Helen Hayes Hospital, West Haverstraw, N.Y. 10993

Left FEMUR BONE DENSITY

Department: 22 years 12/14/1979
71 in 205 lbs Other Male
Physician: 

Acquired: 05/06/2002 (4.6b)
Analyzed: 06/12/2002 (4.6b)
Printed: 06/12/2002 (4.6b)

TOTAL Comparison to Reference

<table>
<thead>
<tr>
<th>Region</th>
<th>BMD $^1$</th>
<th>Young-Adult2</th>
<th>Age-Matched3</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL</td>
<td>1.435</td>
<td>132</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>129</td>
<td>2.5</td>
</tr>
</tbody>
</table>

1 - See appendix on precision and accuracy.
2 - Statistically 68% of repeat scans will fall within 1 SD. (±0.02 g/cm²)
3 - USA Femur Reference Population, Young Adult Ages 26-45. See Appendices.
4 - Matched for Age, Ethnic.
5 - Standardized BMD for TOTAL is 1374 mg/cm². See J Bone Miner Res 1994; 9:1563-1514

Comments:
APPENDIX B

CALCANEAL pDXA Results

<table>
<thead>
<tr>
<th>Patient</th>
<th>Date of Birth</th>
<th>Sex</th>
<th>Age</th>
<th>T-score</th>
<th>Z-score</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>00/01/1990</td>
<td>Male</td>
<td>55</td>
<td>-2.15</td>
<td>-1.29</td>
<td></td>
</tr>
</tbody>
</table>

**Comparison to Reference**

- Result is off the chart
- Compared to young adult

**Bone Mineral Density (BMD)**

- **Left Os Calcis BMD**: 1.059 g/cm²
- **Percent of Young Adult**: 170.5%
- **T-score of Young Adult**: +4.9

*Precision error: SD = 0.61 gm/cm² (CV = 7%). Statistically 94% of repeat scans will fall within ± SD (see appendix B).*

**Comments:**

- **Developer:** Lunar Corporation
- **Address:** 313 W. Beltline Hwy., Madison, WI 53713
- **Phone:** 608-273-2663
- **Fax:** 608-274-2663
- **Acquired:** 5/15/2001
- **Analyzed:** 6/4/2001
- **Printed:** 6/4/2001

*Image: Left Os Calcis BMD 1, 1.059 g/cm², Percent of Young Adult 170.5%, T-score of Young Adult +4.9.*
APPENDIX B

PQCT SCAN OF THE TIBIA
APPENDIX B.

Results of Bio Electrical Impedance

<table>
<thead>
<tr>
<th>Mode</th>
<th>Athlete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>Female</td>
</tr>
<tr>
<td>Height</td>
<td>5ft 6.0in</td>
</tr>
<tr>
<td>Weight</td>
<td>131.51lb</td>
</tr>
<tr>
<td>BMI</td>
<td>21.2</td>
</tr>
<tr>
<td>Impedance</td>
<td>606Ω</td>
</tr>
<tr>
<td>Fat%</td>
<td>23.4%</td>
</tr>
<tr>
<td>Fat Mass</td>
<td>31.01lb</td>
</tr>
<tr>
<td>LBM</td>
<td>100.51lb</td>
</tr>
<tr>
<td>TBW</td>
<td>73.51lb</td>
</tr>
</tbody>
</table>
APPENDIX B

SAMPLE NHANES Data for HIP

<table>
<thead>
<tr>
<th>Region of interest</th>
<th>Mean (g/cm²)</th>
<th>Standard deviation (g/cm²)</th>
<th>Range</th>
<th>BMD cutoff values for:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Osteopenia*</td>
</tr>
<tr>
<td>Men (n = 382)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>femur neck</td>
<td>0.93</td>
<td>0.137</td>
<td>0.585-1.314</td>
<td>0.59-0.79</td>
</tr>
<tr>
<td>trochanter</td>
<td>0.78</td>
<td>0.118</td>
<td>0.496-1.258</td>
<td>0.49-0.66</td>
</tr>
<tr>
<td>intertrochanter</td>
<td>1.21</td>
<td>0.172</td>
<td>0.775-1.794</td>
<td>0.78-1.03</td>
</tr>
<tr>
<td>total femur</td>
<td>1.04</td>
<td>0.144</td>
<td>0.688-1.538</td>
<td>0.68-0.90</td>
</tr>
<tr>
<td>Women (n = 409)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>femur neck</td>
<td>0.86</td>
<td>0.12</td>
<td>0.56-1.283</td>
<td>0.56-0.74</td>
</tr>
<tr>
<td>trochanter</td>
<td>0.71</td>
<td>0.099</td>
<td>0.48-1.051</td>
<td>0.46-0.61</td>
</tr>
<tr>
<td>intertrochanter</td>
<td>1.09</td>
<td>0.142</td>
<td>0.717-1.588</td>
<td>0.74-0.95</td>
</tr>
<tr>
<td>total femur</td>
<td>0.94</td>
<td>0.122</td>
<td>0.635-1.379</td>
<td>0.64-0.82</td>
</tr>
</tbody>
</table>

*WHO diagnostic criteria*: Osteopenia, BMD value between 1-2.5 SD below mean of young adult reference group; Osteoporosis, BMD value >2.5 SD below mean of young adult reference group.

Reference

APPENDIX C

West Point Army Physical Fitness Test Sheet

<table>
<thead>
<tr>
<th>TEST ONE</th>
<th>TEST TWO</th>
<th>TEST THREE</th>
<th>TEST FOUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATE</td>
<td>SPACED</td>
<td>AGE</td>
<td>DATE</td>
</tr>
<tr>
<td>WEIGHT</td>
<td>BODY COMPOSITION</td>
<td>HEIGHT</td>
<td>INCHES</td>
</tr>
<tr>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>PULL-UP SCORE</td>
<td>INITIALS</td>
<td>POINTS</td>
<td>Pull-up Score</td>
</tr>
<tr>
<td>DIP-UP SCORE</td>
<td>INITIALS</td>
<td>POINTS</td>
<td>Dips</td>
</tr>
<tr>
<td>ALTERNATION</td>
<td>TOTAL POINTS</td>
<td>ALTERNATION</td>
<td>TOTAL POINTS</td>
</tr>
<tr>
<td>EVENT</td>
<td>TIME</td>
<td>GO</td>
<td>NO-GO</td>
</tr>
<tr>
<td>INITIALS</td>
<td>SIGNATURE</td>
<td>INITIALS</td>
<td>SIGNATURE</td>
</tr>
</tbody>
</table>

COMMENTS

Data Required by the Privacy Act of 1974

Indication of requesting information cannot be redacted. The record is open to public inspection. Use of this form prior to the effective date is not authorized.

DA FORM 705, JUNE 1990