Diets High in Fiber and Vegetable Protein Are Associated with Low Lumbar Bone Mineral Density in Young Athletes with Oligoamenorrhea

Elizabeth Barron, MA; Natalia Cano Sokoloff, MD; Giovana D. N. Maffazioli, MD; Kathryn E. Ackerman, MD; Ryan Woolley; Tara M. Holmes, RD; Ellen J. Anderson, MS, RD; Madhusmita Misra, MD, MPH

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ABSTRACT

Background Associations of bone mineral density (BMD) with specific food components, including dietary fiber and isoflavones (that have a negative association with serum estrogen), are unclear and need to be determined, particularly in populations more likely to consume large amounts of these nutrients (such as young athletes).

Objective To determine dietary intake of specific food components in athletes with oligoamenorrhea (OA) compared to athletes with eumenorrhea (EA) and nonathletes (NA), and associations of the dietary intake of these nutrients with lumbar spine BMD.

Design and subjects This cross-sectional study evaluated 68 OA, 24 EA, and 26 NA individuals aged 14 to 23 years. Measurements included 4-day food records, a dual x-ray absorptiometry scan evaluating lumbar spine BMD and body composition, and hormone levels. Multivariate analysis was used to estimate associations of nutrients with lumbar spine BMD.

Results Compared with EA and NA, OA had higher intake of fiber, phytic acid, and vegetable protein (all *P* values <0.0001). Intake of isoflavones, genistein, and daidzein was higher in OA than NA (P=0.003 and P=0.0002, respectively). OA had lower consumption of energy from saturated fatty acids than NA (P=0.002). After controlling for confounders such as body weight, menstrual status (indicative of estrogen status), calcium intake, and serum vitamin D (known BMD determinants), lumbar spine BMD *z* scores were inversely associated with dietary fiber (β=−.30; P=0.01), vegetable protein (β= −.28; P=0.02), phytic acid (β=−.27; P=0.02), genistein (β=−.25; P=0.01), and daidzein (β=−.24; P=0.01), and positively associated with percent energy from fatty acids (β=.32; P=0.0006).

Conclusions Compared with EA and NA, OA had a higher dietary intake of fiber, vegetable protein, and phytic acid, which were inversely associated with lumbar spine BMD *z* scores. Further studies are needed to assess dietary recommendations for OA to optimize bone accrual.
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YOUNG WOMEN PARTICIPATING IN SPORTS THAT involve leanness, aesthetics, and endurance are at risk of developing the female athlete triad, the interrelationship between low energy availability, menstrual dysfunction, and low bone mineral density (BMD).[1] Athletes with oligoamenorrhea (OA) may be able to maintain a relatively stable weight while having a lower energy intake by diverting available energy from nonlife-threatening physiologic processes, such as reproduction, toward those necessary for survival.[2-4] Oligoamenorrhea is associated with low estrogen levels, increased bone resorption, and low BMD.[5] Although weight-bearing activity has a positive influence on bone in regularly menstruating athletes,[6] this effect is lost in those with menstrual dysfunction.[7] Twenty percent to 50% of OA have low BMD and 10% to 13% have osteoporosis.[1,7] Our group and others have reported a higher prevalence of stress fractures in this population as well as greater bone loss at the lumbar spine in relation to other bone sites.[7-10]

Current treatment strategies for the female athlete triad are focused on increasing energy intake, reducing physical activity, or both.[11] Adding a daily calorie supplement may help improve energy balance by providing additional calories and cause menstrual restoration.[12] However, the influence of such interventions on BMD remains unclear.[13] In addition, although BMD improves somewhat with weight gain and menstrual resumption, athletes may never completely normalize their BMD,[14] particularly when oligoamenorrhea begins during the adolescent years of peak growth (age 11 to 14 years in girls with 90% of peak bone mass accrued by

18 years).[15] It is thus possible that along with optimizing energy intake, it is essential to optimize intake of specific nutrients that affect bone.[11,16,17]

Optimizing calcium and vitamin D intake may have a favorable effect on bone mineralization[18]; however, certain other nutrients (such as an excess of dietary fiber) may be associated with unfavorable bone outcomes. Although diets rich in fiber are generally recommended for beneficial health effects such as weight regulation[19] and protection against chronic disease,[20,21] a diet low in energy density and high in fiber has been linked to female endurance athletes with menstrual dysfunction.[22-24] In addition, certain athletes have been reported to favor a diet rich in vegetable protein, composed of whole grains, soy products, beans and legumes, and fruits and vegetables.[25] These diets are also high in dietary fiber, phytic and oxalic acid, and phytoestrogens, and low in saturated fat.[24,26-28] Dietary fiber can bind to and reduce absorption of phytoestrogens[29] and its overconsumption may thereby negatively affect bone. In addition, phytates are known to bind minerals, protein, and starch, reducing their digestion and absorption.[27] Although the intake of these dietary components at recommended levels in healthy individuals may not affect bone, the overconsumption of these food components in OA in a state of chronic energy deficiency may be detrimental. Few studies have comprehensively examined dietary nutrient composition in athletes in relation to bone.

The purpose of this cross-sectional study was to determine dietary macro- and micronutrient composition in adolescent and young adult OA compared with athletes with eumenorrhea (EA) and nonathletes (NA), and how group differences in nutrient intake may relate to lumbar spine BMD, the site most affected in OA and most likely to be influenced by onset or resumption of menses.[30-34] We hypothesized that specific patterns of nutrient intake in OA may have deleterious effects on bone.

SUBJECTS AND METHODS

Participant Selection

One hundred eighteen female participants aged 14 to 23 years were enrolled in this study at the Clinical Research Center of our institution between 2009 and 2014. Data being reported represent baseline data from an ongoing randomized controlled trial. Participants were recruited from local medical clinics, through contact with area coaches, advertising through social media, and postings around the Boston, MA, area. Sixty-eight athletes were OA, 24 athletes were EA, and 26 participants were NA. Inclusion criteria included a body mass index (BMI) between the 10th and 90th percentiles based on Centers for Disease Control and Prevention growth charts,[35] and a bone age $\geq$14 years (98% of adult height is reached at a bone age of 14 years). Athletes were categorized as OA if they had absence of menses for $\geq$3 months within a period of oligomenorrhea (cycle length >6 weeks) for $\geq$6 months, or absence of menarche at age $\geq$16 years. Athletes and controls were categorized as EA if they had $\geq$9 menses (cycle length 21 to 35 days) in the preceding year. Participants in both athlete groups were required to be engaged in $\geq$4 hours per week of aerobic weight-bearing training of the legs or $\geq$20 miles of running weekly for a period of $\geq$6 months in the previous year. Only endurance athletes engaged in weight-bearing activities of the legs were included in this study to minimize variation from different types of mechanical loading, and because such athletes, when OA, are known to be at risk of low BMD.[10] Endurance athletes were primarily track and field and cross-country athletes and dancers. We excluded rowers, swimmers, cyclists, and gymnasts because of potential variability in weight-bearing activity. NA participants could not engage in >2 hours of weight-bearing activity per week, and could not be involved in team sports. Exclusion criteria for all groups included use of medications that affect bone metabolism and conditions other than endurance training that cause amenorrhea. The study was approved by our institutional review board.

Study Protocol

Consent (if the participant was aged $\geq$18 years) or assent and parental consent (if the participant was aged <18 years) were obtained at the screening visit. Eligibility was determined through a history and physical examination; self-report of menstrual status; and laboratory tests, including a pregnancy test, complete blood count, and levels of thyroid stimulating hormone, follicle stimulating hormone, estradiol, calcium, phosphorus, and 25(OH) vitamin D. Height was measured on a single wall-mounted stadiometer as the average of three measurements, and weight on an electronic scale. BMI was calculated as the ratio of weight (in kilograms)/height (in meters^2). An x-ray of the wrist and hand was taken to determine bone age (or maturity).[36] BMD, fat mass, and lean mass were determined using dual-energy x-ray absorptiometry (Hologic QDR-Discovery A, Apex v13.3; Hologic Inc).

To assess dietary intake, participants completed a 4-day food and supplement diary validated for use in young women (3 weekdays and 1 weekend day).[37-39] Description of portion sizes and preparation methods were recorded and data analyzed by the Metabolism & Nutrition Research core of the Clinical Research Center of our institution using Nutrient Data System for Research (NDSR) software version 2008 developed by the Nutrition Coordinating Center at the University of Minnesota. The NDSR time-related database updates analytic data while maintaining nutrient profiles true to the version used for data collection. In a comparison of various methods of dietary intake assessment, 3-day food records had a higher correlation to estimates of food consumption from the reference method of a 9-day food record than did food frequency questionnaires.[40,41] The NDSR report includes averages of total energy intake, and intake of specific macro- and micronutrients. Participants completed the Bouchard 3-day activity record for estimates of daily energy expenditure.[42] Reliability assessment confirmed the reproducibility of the Bouchard record, with an interclass correlation of 0.96 for energy expenditure.[42] However, it includes both purposeful and nonpurposeful exercise activity, and its validity for assessing specifically exercise energy expenditure in athletic populations has not yet been determined.[43] Hours per week of exercise activity for the study population was assessed independent of the Bouchard questionnaire at the time of the screening visit.

Statistical Methods

Data were analyzed using JMP software (version 10, 2012, SAS Institute). The study sample was based on baseline