Published in final edited form as:

J Sports Sci. 2002 June ; 20(6): 463–469. doi:10.1080/02640410252925134.

Bone mineral density in triathletes over a competitive season

Barbara S. McClanahan^{1,*}, Kenneth D. Ward¹, Chris Vukadinovich¹, Robert C. Klesges¹, Linda Chitwood², Stephen J. Kinzey², Stan Brown², and Dennis Frate²

¹Center for Community Health, The University of Memphis, Memphis, Tennessee

²Department of Exercise Science and Leisure Management, University of Mississippi, University, Mississippi, USA

Abstract

There is evidence from previous cross-sectional studies that high volumes of certain sports, including running, swimming and cycling, may have a negative impact on bone mineral density. The aim of the present study was to evaluate prospectively the effects of high athletic training in individuals who engage in high volumes of all three of these activities (triathletes). Bone mineral density for the total body, arms and legs was determined by dual-energy X-ray absorptiometry in 21 competitive triathletes (9 men, 12 women) at the beginning of the training season and 24 weeks later. Age, body mass index, calcium intake and training volume were also recorded to examine potential mediators of bone mineral density change. Men had greater bone mineral density at all sites than women. No significant changes were observed over the 24 weeks for either total body or leg bone mineral density. Bone mineral density in both arms increased by approximately 2% in men ($P < 0.03$), but no change was observed for women. Change in bone mineral density at all sites was unrelated to age, body mass index, calcium intake and training volume. The results suggest that adverse changes in bone mineral density do not occur over the course of 6 months of training in competitive triathletes.

Keywords

athletes; dual-energy X-ray absorptiometry; exercise; skeleton; sport; training

Introduction

The beneficial health effects of moderate exercise are well established (Morris, 1994; Pate *et al.*, 1995). Prospective studies have reported that physical activity reduces the risk of coronary heart disease (Paffenbarger *et al.*, 1984; Lakka *et al.*, 1994), diabetes mellitus

*Address all correspondence to Barbara S. McClanahan, Center for Community Health, The University of Memphis, Psychology Building 310, Memphis, TN 38152, USA. b.mcclanahan@mail.psy.memphis.edu.

Full terms and conditions of use: <http://www.tandfonline.com/page/terms-and-conditions>

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

Publisher's Disclaimer: The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae, and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

(Manson *et al.*, 1992; Moy *et al.*, 1993), essential hypertension (Paffenbarger *et al.*, 1983; Arroll and Beaglehole, 1992), colon cancer (Lee and Paffenbarger, 1994) and osteoporosis (Nelson *et al.*, 1991; Gutin and Kasper, 1992). The importance of establishing and maintaining optimal bone mass to guard against the debilitating results of osteoporosis is well documented (Ross, 1996).

There is strong evidence that exercise increases bone mineral. Positive effects of exercise on bone mineral density have been observed for individuals engaged in recreational athletic activity as well as competitive athletes engaged in usual volumes of training for that particular sport. Both strength-training activities (i.e. high impact-loading activity such as weight-lifting) and weight-bearing endurance or aerobic exercise (e.g. running or cross-country skiing) produce these positive effects on bone mineral. Typically, the greatest bone mineral changes occur in the regions affected by the particular type of exercise, although positive changes are noted in other areas as well (Pirnay *et al.*, 1987; Conroy *et al.*, 1993; Heinonen *et al.*, 1993; Hamdy *et al.*, 1994).

Although there is cogent evidence that moderate exercise can increase bone mineral, there also is evidence that high volumes of exercise can have deleterious effects on bone. Active loading and non-weight-bearing endurance training (e.g. cycling, swimming) has been shown in several studies to be associated with decreased bone mineral. For example, adolescent cyclists have been shown to have lower total body and leg bone mineral density than sedentary adolescents (Rico *et al.*, 1993a,b).

Several cross-sectional studies have found that children, adolescents and young adults (college students) who are involved in competitive swimming have lower bone mineral density at several sites, including the lumbar spine and hip, than athletes engaged in impact loading sports (Risser *et al.*, 1990; Grimston *et al.*, 1993; Fehling *et al.*, 1995; Nichols *et al.*, 1995). In comparing the bone mineral density of swimmers and non-athletes, several studies have found that swimmers have similar (Nilsson and Westline, 1971; Orwoll *et al.*, 1989; Fehling *et al.*, 1995; Dook *et al.*, 1997) or lower (Risser *et al.*, 1990; Nichols *et al.*, 1995; Taaffe *et al.*, 1995) bone mineral density at various sites. The results of these cross-sectional studies suggest that activities such as swimming and cycling provide insufficient skeletal loading, compared with resistance or weight-bearing activities, to promote bone mineral density growth and may actually impede the achievement of maximal peak bone density.

There also is evidence that intense weight-bearing endurance activity can decrease bone mineral density. There are reports of compromised skeletal health in long-distance endurance male athletes (Bilanin *et al.*, 1989; MacDougall *et al.*, 1992; Hetland *et al.*, 1993). For example, in a study of 120 male runners and non-runners, Hetland *et al.* (1993) reported a negative correlation between the distance run weekly and the bone mineral density of long-distance runners. Lumbar bone mineral content in this study was 19% lower among elite runners ($>100 \text{ km} \cdot \text{week}^{-1}$) than non-runners. In addition, bone turnover parameters were 20–30% higher in the elite runners.

Despite the relatively long duration of the bone remodelling cycle, it appears that high activity may induce negative bone mineral density changes rather quickly. A study of elite

collegiate basketball players (Klesges *et al.*, 1996) found a 3.3% decrease in bone mineral density over 4 months. Because low bone mineral density increases the risk of stress fractures in highly active individuals (Myburgh *et al.*, 1990) and because stress fractures are quite common (Johnson *et al.*, 1994), any reductions in bone mineral density, especially in competitive athletes, must be viewed with concern.

Given that high volumes of swimming, cycling and long-distance running may have a negative impact on bone mineral density, we wished to determine whether athletes who engage in relatively high volumes of all three activities (triathletes) were at risk for bone mineral density loss during training. As such, the specific aims of this study were: (1) to assess changes in bone mineral density of the whole body, arms and legs among competitive athletes over 6 months of training, and (2) to examine the influence of potential determinants of bone mineral density change (age, body mass index, training volume and calcium intake).

Methods

Participants

Potential participants were recruited by word-of-mouth from several local triathlete and running clubs. Inclusion criteria included having competed in at least one triathlon in the previous 2 years and to be training, or planning to begin training, for a competition during the upcoming season. The exclusion criteria included: (1) women who were pregnant or not normally menstruating (fewer than 11 menses in the past 12 months), (2) a history of any metabolic bone disorder or bone cancer and (3) the current use of a diuretic. Twenty-one individuals were eligible and agreed to participate (9 males, 12 females). All protocols and the consent form were approved by the Institutional Review Board of The University of Memphis.

Procedures

Triathletes were screened over the telephone to determine eligibility. Eligible males were scheduled for their first laboratory visit and females were instructed to call the research office on the first day of their next menstrual cycle to schedule their assessment. Recognizing that dual-energy X-ray absorptiometry (DEXA) emits minimal radiation and that no safe level of radiation has been established for developing fetuses, all DEXA scans on females were scheduled within the first 10 days of their menstrual cycles to minimize the risk of scanning anyone who might be pregnant.

At the first laboratory visit, the procedures were explained to the participants, who provided written informed consent. They were then trained to complete diet records and physical activity diaries, had their height and weight measured, and underwent DEXA testing to determine bone mineral density (described below). The participants completed diet records for 7 days (5 weekdays and 2 weekend days) during the week before the second and third laboratory visits, which occurred at weeks 12 and 24 of the study. At the second laboratory visit, the participants handed in diet and physical activity records and had their height and weight measured. The same procedures were adopted during the third laboratory visit, at which time bone mineral density also was reassessed.

Measures

Bone mineral density—Bone mineral density was assessed by dual-energy X-ray absorptiometry (Hologic QDR-2000, software version 7.1; Hologic, Inc., Waltham, MA) just before and immediately after the competitive triathlete season with 24 weeks intervening. Dual-energy X-ray absorptiometry was developed as a clinical tool for the assessment of osteoporosis. It has become a widely used technique for bone mineral density assessment because of its high *in vitro* precision (<1.0%) (Going *et al.*, 1993), low radiation exposure (0.5 mRem per whole body scan) and low burden.

An important issue in the use of DEXA technology is the precise standardization of procedures (Roubenoff *et al.*, 1993). Thus, careful attention to quality control, standardization and calibration were followed throughout the investigation. The system used in this study was calibrated daily against a spinal phantom in the anteroposterior/lateral, array and single beam modes to ensure against systematic deviations. After performing quality control scans, all information is entered into the quality control database and is monitored for the life of the DEXA machine. The particular unit used in this study has an extremely low error rate, with a coefficient of variation less than 0.47% to date. Test–retest reliability on humans in our laboratory has been measured by conducting serial DEXA scans taken approximately 30 min apart. Both intra-operator and inter-operator reliability were assessed and found to be equivalent. Mean deviations for total bone mineral density, leg bone mineral density, total body lean tissue and leg lean tissue averaged 0.31% and the mean intra-class correlation was 0.985, suggesting highly reliable and valid measures of bone density.

The participants were positioned on the scanning table following a standardized protocol. Initial scan analysis, including the placement of baselines (cuts) distinguishing bone and soft tissue, edge detection and regional demarcations for all sites, was done by computer algorithms (version 7.1, Hologic). Subsequent visual inspections and adjustments were made as needed by the same trained technician to obtain whole-body and regional bone mineral density. Total body scan sub-regions are reported, including left and right arms (cut placed at head of humerus) and legs (cut placed at neck of femur), pelvis and torso (left and right ribs, thoracic spine, lumbar spine).

Calcium intake—To assess calcium intake, the participants completed 7 days of diet records on two occasions during training (weeks 12 and 24 of the study). During the first laboratory visit, they were trained by a nutrition research assistant, using detailed instructions and drawings of serving sizes, on how to complete diet records. All triathletes had previous experience of keeping detailed records of their food intake for training purposes. At the second and third laboratory visits, food records were reviewed with a nutritionist and analysed for nutrient content using the DINE III nutrient analysis system. Average calcium intake during training was calculated as the mean intake from the 14 days of diet records.

Training volume—The participants established their own training regimen and completed a training diary each day for the duration of the study. They were instructed in the proper

documentation of mode of exercise (run, bike, swim, weight-lifting, other), exercise intensity (heart rate, rating of perceived exertion), duration (minutes) and frequency of training bouts. Volume of training for each session was calculated according to the methods of Foster (as described by Krieder *et al.*, 1998). For each training session, each participant's rating of perceived exertion (RPE) was multiplied by the duration (time) to yield volume of training. Weekly training volumes were then calculated.

Anthropometry—Anthropometry was performed using standardized methods. Body mass was measured with the participant standing on a level platform scale with a beam and moveable weights; the participant wore shorts and a T-shirt but no shoes. The scale was routinely calibrated using standardized certified weights. Height was measured to the nearest centimetre using a wall-mounted stadiometer. The participants were asked to stand erect with heels, buttocks and upper back touching the stadiometer and were positioned so that the chin was level. A horizontal headboard was used to contact the most superior point of the head and height was recorded. All measurements were taken twice and the reported values are the means of the repeated measurements. The body mass index was calculated from body mass and height ($\text{kg}\cdot\text{m}^{-2}$).

Statistical analysis

Two-way repeated-measures analyses of variance were used to assess changes in bone mineral density during training as a function of time and sex. Significant ($P < 0.05$) time $\times$ sex interactions were followed up using analyses of simple main effects (Pedhazur, 1982). Separate analyses were conducted for total body, right arm, right leg, left arm and left leg bone mineral density. To evaluate potential mediators of bone mineral density change, Pearson product-moment correlation coefficients were calculated for age, body mass index, mean calcium intake and mean training volumes.

Results

All 21 participants who enrolled completed the study. All females maintained normal menstrual cycles throughout the study. Group means and standard deviations of the participants' characteristics are presented in Table 1. Estimated weekly training volume during the study (calculated as $\text{RPE} \times \text{minutes of training}$) was 7104 ± 5852 and did not differ significantly between men and women ($P = 0.802$).

Whole-body bone mineral density averaged $1.14 \pm 0.10 \text{ g}\cdot\text{cm}^{-2}$ (mean $\pm$ s) in men and $1.04 \pm 0.04 \text{ g}\cdot\text{cm}^{-2}$ in women. These values are within the range of values observed for more than 200 other young adult athletes observed in our laboratory, with mean values falling at the 60th percentile for women and the 33rd percentile for men.

Whole-body bone mineral density increased an average of 0.8% (range = -3.4% to 2.8%) across the training season. The change in whole-body bone mineral density was not statistically significant ($P = 0.132$) and there was no significant time $\times$ sex interaction ($P = 0.101$).

Small and statistically non-significant decreases were observed for bone mineral density in the right leg (mean change = -1.6%; range = -2.7% to 5.5%) and left leg (mean change = -1.9%; range = -5.2% to 5.5%) (P -values > 0.274). Time $\times$ sex interactions were not significant at either leg site (P -values > 0.296).

Significant time $\times$ sex interactions for bone mineral density were observed at both the right and left arms (P < 0.023). To decompose these interactions, changes in bone mineral density were analysed separately by sex at each arm site. For men, bone mineral density increased significantly at both the right arm (mean change = 2.0%; range = -4.8% to 2.3%; P = 0.024) and left arm (mean change = 1.7%; range = -1.2% to 6.2%; P = 0.029). No significant changes for women occurred at either the right arm (mean change = 0.9%; range = -4.8% to 2.3%; P = 0.361) or left arm (mean change = 1.4%; range = -1.2% to 6.2%; P = 0.079).

Calcium intake, age, training volume and body mass index were not significantly associated with bone mineral density change at any bone site (all P -values > 0.10).

Discussion

Although exercise (particularly moderate weight-bearing activity) as a means to increase bone mass is well established (Gutin and Kasper, 1992), there is evidence from recent cross-sectional and prospective studies that high volumes of certain activities may have negative effects on bone mass. In particular, athletes engaging in high volumes of running, swimming and cycling have been shown to have bone mineral density lower than either athletes engaging in lower volumes of these activities or non-athletes (Bilanin *et al.*, 1989; Myburgh *et al.*, 1990; Klesges *et al.*, 1996). Because competitive triathletes usually engage in high volumes of all three of these activities, we wished to determine whether negative changes in bone mineral density occur during training in these athletes.

Our results indicate that negative changes in bone mineral density did not occur for the total body or at the arms or legs for male and female triathletes over the course of 6 months of training. A small and statistically non-significant increase in whole-body bone mineral density was recorded (0.8%), whereas a small but non-significant decrease was observed for both the right and left legs (-1.6% and -1.9%, respectively). The only statistically significant bone mineral density changes were observed at the arms, where increases of approximately 2% occurred for men but not women. To the best of our knowledge, this is the first study to evaluate bone mineral density changes in competitive athletes over the course of several months of training. Given previous evidence that highly competitive athletes may be at risk for training-related bone mineral density loss, our findings of no negative bone effects are encouraging.

There are several reasons why no changes in whole-body or leg bone mineral density (either negative or positive) were observed in this study. First, triathletes are unique in that they engage in three sports that have different loading characteristics. It is possible that simultaneously engaging in three training regimens 'masks' distinct advantages or disadvantages of impact versus weight-bearing regimens on bone mineral density. From a mechanical loading perspective, skeletal responses in the legs would be expected, owing to

the impact imposed from the running component of triathlete training. However, this may be offset by the substantial time and energy that triathletes devote to the non-loading activities of swimming and cycling, which require considerable exertion but impose little strain on bone.

Secondly, since these athletes had been active for several years, their skeletal systems may have become acclimatized to exercise training such that skeletal changes would only be manifested if significant training alterations were imposed. Given the long-term consistent nature of triathlete training and from reported training volumes, it would appear that this particular group of triathletes altered training very little over 6 months. A third issue is the relatively short follow-up in the present study. Since bone formation generally takes more than 12 weeks and bone mineralization requires another 3–4 months (Dalsky *et al.*, 1988), changes in whole-body and regional bone mass at the measured sites may not have been apparent after 24 weeks. It is noteworthy, however, that other prospective studies, similar to the present study in both the length of the follow-up and the absence of training volume changes during assessment, *have* observed changes in bone mineral density. These include increases in bone mineral density among gymnasts (Nichols *et al.*, 1994) and decreases in bone mineral density among basketball players (Klesges *et al.*, 1996). Finally, the bone sites assessed in this study (total body, arms and legs) capture both cortical and trabecular bone. It is possible that more marked changes would have been observed during the study if bone sites that are high in trabecular content (e.g. hip or lumbar spine) had been assessed, since trabecular sites are more metabolically active and responsive to changes in mineral homeostasis (Riggs and Melton, 1986).

We unexpectedly found reductions in bone mineral density for males in both arms. Since triathlete training requires very little loading of the arms, this result was not anticipated. The reason for bone mineral density loss in the arms of male triathletes may be most easily discovered with further analysis of activity-specific training volumes and better documentation of the potential determinants of bone density. We evaluated the potential influence of age, calcium intake, training volume and body mass index on bone mineral density change, but did not detect any significant relationships. Since losses in arm bone mineral density of female triathletes were not noted, possible differences in training between the sexes might not have been captured by training volume. On the other hand, it is possible that male right and left arm bone mineral density may have been sacrificed because of the body's need to maintain calcium in the legs where the impact loading of running imposed the greatest and most immediate need.

Although we were not able to demonstrate an effect of dietary calcium intake on bone mineral density change, it is noteworthy that calcium intake was relatively low among this sample, especially the women. Calcium intake during training averaged approximately 1200 mg·day⁻¹ in men and 800 mg·day⁻¹ in women. These estimates are similar to those reported in other studies of athletes (Kirchner *et al.*, 1995; Slawson *et al.*, 2001). The NIH Consensus Conference (National Institutes of Health, 1994) recommended an optimal daily intake of 1200–1500 mg of calcium for adolescents and young adults, and calcium needs are likely to be even higher among athletes engaged in high volumes of training (Clarkson and Haymes, 1995; Klesges *et al.*, 1996). Low calcium intake in young adult competitive triathletes is a

major concern because of its potential to jeopardize optimal bone mineral density and thereby increase the risk of training-related bone injuries and future osteoporosis (Lewis and Modlesky, 1998).

This study makes an important contribution to the literature on bone health in athletes by documenting an absence of negative bone mineral density change during triathlete training. Several limitations to this study should be noted, however. First, the sample size was relatively small ($n = 21$), which limited our power to detect statistically significant effects. With repeated-measures data for 21 participants, we had sufficient statistical power ($\alpha = 0.05$ and $\beta = 0.20$) to detect bone mineral density changes on the order of 5%. The magnitude of this change is consistent with that observed in another study of training-related bone mineral density changes in competitive athletes (Klesges *et al.*, 1996). Secondly, because a control group was not available, we cannot rule out the possibility that factors unrelated to the participants' training regimen (e.g. seasonal effects on bone mineral density) might have contributed to the observed changes. Thirdly, in exploring potential mediators of bone mineral density change, we relied on self-report measures of calcium intake and training volume, which are not the most sensitive measures. However, the use of daily records to measure these variables, and the excellent adherence of the participants to data collection, increase our confidence in the accuracy of the results. Fourthly, as noted above, the bone sites chosen may not have been optimal to detect relatively short-term changes in bone mineral density. Future studies should use larger sample sizes, extend follow-up to longer training periods and include the assessment of bone sites high in trabecular content, such as the hip and spine.

Despite these limitations, our results suggest that there are no negative effects on bone mineral density of the total body, legs and arms during usual competitive triathlon training. This is important given the potentially devastating effects of osteoporosis and the importance of optimizing peak bone mass in young adults to prevent training injuries and future osteoporosis.

Acknowledgments

This research was supported by grant R29 AR 448909-01 from the National Institute of Arthritis, Musculoskeletal, and Skin Diseases.

References

- Arroll B, Beaglehole R. Does physical activity lower blood pressure: a critical review of the clinical trials. *Journal of Clinical Epidemiology*. 1992; 45:439–447. [PubMed: 1588350]
- Bilanin J, Blanchard M, Pussek-Cohen E. Lower vertebral bone density in male long distance runners. *Medicine and Science in Sports and Exercise*. 1989; 21:66–70. [PubMed: 2927303]
- Clarkson PM, Haymes EM. Exercise and mineral status of athletes: calcium, magnesium, phosphorus, and iron. *Medicine and Science in Sports and Exercise*. 1995; 27:831–843. [PubMed: 7658944]
- Conroy BP, Kramer WJ, Maresh CM, Fleck SJ, Stone MH, Fry AC, Miller PD, Dalsky GP. Bone mineral density in elite junior Olympic weightlifters. *Medicine and Science in Sports and Exercise*. 1993; 25:1103–1109. [PubMed: 8231753]
- Dalsky GP, Stocke KS, Ehsani A, Slatopolsky E, Lee WC, Birge S. Weight-bearing exercise training and lumbar bone mineral content in postmenopausal women. *Annals of Internal Medicine*. 1988; 108:824–828. [PubMed: 3259410]

- Dook JE, James C, Henderson NK, Price RI. Exercise and bone mineral density in mature female athletes. *Medicine and Science in Sports and Exercise*. 1997; 29:291–296. [PubMed: 9139166]
- Fehling PC, Alekel L, Clasey J, Rector A, Stillman RJ. A comparison of bone mineral densities among female athletes in impact loading and active loading sports. *Bone*. 1995; 17:205–210. [PubMed: 8541132]
- Going SB, Massett MP, Hall MC, Bare LA, Root PA, Williams DP, Lohman TG. Detection of small changes in body composition by dual energy X-ray absorptiometry. *American Journal of Clinical Nutrition*. 1993; 57:1699–1702.
- Grimston SK, Willows ND, Hanley DA. Mechanical loading regime and its relationship to bone mineral density in children. *Medicine and Science in Sports and Exercise*. 1993; 25:1203–1210. [PubMed: 8289606]
- Gutin B, Kasper MJ. Can vigorous exercise play a role in osteoporosis prevention? A review. *Osteoporosis International*. 1992; 2:55–69. [PubMed: 1536981]
- Hamdy RC, Anderson JS, Whalen KE, Harvill LM. Regional differences in bone density of young men involved in different exercises. *Medicine and Science in Sports and Exercise*. 1994; 26:884–888. [PubMed: 7934763]
- Heinonen A, Oja P, Kannus P, Sievanen H, Manttari A, Vuori I. Bone mineral density of female athletes in different sports. *Bone and Mineral*. 1993; 23:1–14. [PubMed: 8274875]
- Hetland ML, Haarbo J, Christiansen C. Low bone mass and high bone turnover in male long distance runners. *Journal of Endocrinology and Metabolism*. 1993; 77:770–775.
- Johnson AW, Weiss CB, Wheeler DL. Stress fractures of the femoral shaft in athletes – more common than expected: a new clinical test. *American Journal of Sports Medicine*. 1994; 22:248–256. [PubMed: 8198195]
- Kirchner EM, Lewis RD, O'Connor PJ. Bone mineral density and dietary intake of female college gymnasts. *Medicine and Science in Sports and Exercise*. 1995; 27:543–549. [PubMed: 7791585]
- Klesges RC, Ward KD, Shelton ML, Applegate WB, Cantler ED, Palmieri GM, Harmon K, Davis J. Changes in bone mineral content in male athletes. *Journal of the American Medical Association*. 1996; 276:226–230. [PubMed: 8667568]
- Krieder, RB.; Fry, AC.; O'Toole, ML. *Overtraining in Sport*. Champaign, IL: Human Kinetics; 1998.
- Lakka TA, Venalainen JM, Rauramaa R, Salonen R, Tuomilehto J, Salonen JT. Relation of leisure-time physical activity and cardiorespiratory fitness to the risk of acute myocardial infarction in men. *New England Journal of Medicine*. 1994; 330:1549–1554. [PubMed: 8177243]
- Lee IM, Paffenbarger RS Jr. Physical activity and its relation to cancer risk: a prospective study of college alumni. *Medicine and Science in Sports and Exercise*. 1994; 26:831–837. [PubMed: 7934755]
- Lewis RD, Modlesky CM. Nutrition, physical activity, and bone health in women. *International Journal of Sport Nutrition*. 1998; 8:250–284. [PubMed: 9738135]
- MacDougall JD, Webber CE, Martin J. Relationship among running mileage, bone density, and serum testosterone in male runners. *Journal of Applied Physiology*. 1992; 73:1165–1170. [PubMed: 1400032]
- Manson JE, Nathan DM, Krolewski AS, Stampfer MJ, Willett WC, Hennekens CH. A prospective study of exercise and incidence of diabetes among US male physicians. *Journal of the American Medical Association*. 1992; 268:63–67. [PubMed: 1608115]
- Morris JN. Exercise in the prevention of coronary heart disease: today's best buy in public health. *Medicine and Science in Sports and Exercise*. 1994; 26:807–814. [PubMed: 7934752]
- Moy CS, Songer TJ, LaPorte RE, Dorman JS, Kriska AM, Orchard TJ, Becker DJ, Drash AL. Insulin-dependent diabetes mellitus, physical activity, and death. *American Journal of Epidemiology*. 1993; 137:74–81. [PubMed: 8434575]
- Myburgh KH, Hutchins J, Fataar AB, Hough SF, Noakes JD. Low bone density is an etiologic factor for stress fractures in athletes. *Annals of Internal Medicine*. 1990; 113:754–759. [PubMed: 1978620]
- National Institutes of Health Consensus Conference. Optimal calcium intake. NIH Consensus Development Panel on Optimal Calcium Intake. *Journal of the American Medical Association*. 1994; 272:1942–1948. [PubMed: 7990248]

- Nelson ME, Fisher EC, Dilmanian FA, Dallal GE, Evans WJ. A 1-y walking program and increased dietary calcium in postmenopausal women: effects on bone. *American Journal of Clinical Nutrition*. 1991; 53:1304–1311. [PubMed: 2021138]
- Nichols DL, Sanborn CF, Bonnick SL, Ben-Ezra V, Gench B, DiMarco NM. The effects of gymnastics training on bone mineral density. *Medicine and Science in Sports and Exercise*. 1994; 26:1220–1225. [PubMed: 7799765]
- Nichols JF, Spindler AA, LaFave KL, Sartoris DJ. A comparison of bone mineral density and hormone status of periadolescent gymnasts, swimmers, and controls. *Medicine, Exercise, Nutrition and Health*. 1995; 4:101–106.
- Nilsson B, Westline N. Bone density in athletes. *Clinical Orthopedics*. 1971; 77:179.
- Orwoll ES, Ferar J, Oviatt S, McClung MR, Huntington K. The relationship of swimming exercise to bone mass in men and women. *Archives of Internal Medicine*. 1989; 149:2197–2200. [PubMed: 2802886]
- Paffenbarger RS Jr, Wing AL, Hyde RT, Jung DL. Physical activity and incidence of hypertension in college alumni. *American Journal of Epidemiology*. 1983; 117:245–257. [PubMed: 6829553]
- Paffenbarger RS Jr, Hyde RT, Wing AL, Steinmetz CH. A natural history of athleticism and cardiovascular health. *Journal of the American Medical Association*. 1984; 252:491–495. [PubMed: 6737639]
- Pate RR, Pratt M, Blair SN, Haskell WL, Macera CA, Bouchard C, Buchner D, Ettinger W, Heath GW, King AC, Kriska A, Leon AS, Marcus BH, Morris J, Paffenbarger RS Jr, Patrick K, Pollock ML, Rippe JM, Sallis J, Wilmore JH. Physical activity and public health: a recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *Journal of the American Medical Association*. 1995; 273:402–407. [PubMed: 7823386]
- Pedhazur, EJ. *Multiple Regression in Behavioral Research*. 2nd. Fort Worth, TX: Harcourt Brace Jovanovich; 1982.
- Pirnay R, Bodeux M, Crielaard JM, Franchimont P. Bone mineral content and physical activity. *International Journal of Sports Medicine*. 1987; 8:331–335. [PubMed: 3679648]
- Rico H, Revilla M, Hernandez ER, Gomez-Castresana F, Villa LF. Bone mineral content and body composition in postpubertal cyclist boys. *Bone*. 1993a; 14:93–95. [PubMed: 8334038]
- Rico H, Revilla M, Villa LF, Gomez-Castresana F, Del Buergo MA. Body composition in postpubertal boy cyclists. *Journal of Sports Medicine and Physical Fitness*. 1993b; 33:278–281. [PubMed: 8107481]
- Riggs BL, Melton LJ III. Involutional osteoporosis. *New England Journal of Medicine*. 1986; 314:1676–1686. [PubMed: 3520321]
- Risser WL, Lee EJ, Leblanc A, Poindexter HBW, Risser JMH, Schneider V. Bone density in eumenorrheic female college athletes. *Medicine and Science in Sports and Exercise*. 1990; 22:570–574. [PubMed: 2233193]
- Ross PD. Osteoporosis: frequency, consequences, and risk factors. *Archives of Internal Medicine*. 1996; 156:1399–1411. [PubMed: 8678708]
- Roubenoff R, Kehayias JJ, Dawson-Hughes B, Heymsfield SB. Use of dual energy X-ray absorptiometry in body composition studies: not yet a ‘gold standard’. *American Journal of Clinical Nutrition*. 1993; 58:589–591. [PubMed: 8237861]
- Slawson DL, McClanahan BS, Clemens LH, Ward KD, Klesges RC, Vukadinovich CM, Cantler ED. Food sources of calcium in a sample of African-American and Euro-American collegiate athletes. *International Journal of Sport Nutrition*. 2001; 11:199–208.
- Taaffe DR, Snow-Harter C, Connolly DA, Robinson TL, Marcus R. Differential effects of swimming versus weight-bearing activity on bone mineral status of eumenorrheic athletes. *Journal of Bone Mineral Research*. 1995; 10:586–593. [PubMed: 7610929]

Table 1Characteristics of male and female triathletes (mean $\pm$ *s*)

Variable	Total sample (<i>n</i> = 21)	Men (<i>n</i> = 9)	Women (<i>n</i> = 12)	<i>P</i> [*]
Age (years)	34.1 $\pm$ 9.6	36.0 $\pm$ 12.6	32.8 $\pm$ 6.7	0.454
Body mass (kg)	63.0 $\pm$ 9.8	72.3 $\pm$ 5.2	56.1 $\pm$ 5.6	< 0.0001
Body mass index (kg·m ⁻²)	22.1 $\pm$ 2.5	22.9 $\pm$ 1.2	21.4 $\pm$ 3.1	0.136
Training volume (RPE [*] ·min)·day ⁻¹	7104	7489	6815	0.802
Calcium intake (mg·day ⁻¹)	994 $\pm$ 519	1222 $\pm$ 757	823 $\pm$ 319	0.122

^{*}
For *t*-test comparing men and women.

Bone mineral density ($\text{g}\cdot\text{cm}^{-2}$) of male and female triathletes over 6 months of training (mean $\pm$ s)

Table 2

Variable	Total sample ($n = 21$)		Men ($n = 9$)		Women ($n = 12$)	
	Baseline	Follow-up	Baseline	Follow-up	Baseline	Follow-up
Whole body	1.082 $\pm$ 0.091	1.083 $\pm$ 0.091	1.141 $\pm$ 0.105	1.134 $\pm$ 0.112	1.039 $\pm$ 0.045	1.045 $\pm$ 0.047
Left arm	0.746 $\pm$ 0.098	0.746 $\pm$ 0.090	0.848 $\pm$ 0.056	0.834 $\pm$ 0.066	0.670 $\pm$ 0.026	0.680 $\pm$ 0.026
Right arm	0.801 $\pm$ 0.110	0.797 $\pm$ 0.096	0.907 $\pm$ 0.083	0.889 $\pm$ 0.070	0.721 $\pm$ 0.031	0.727 $\pm$ 0.030
Left leg	1.157 $\pm$ 0.123	1.155 $\pm$ 0.125	1.278 $\pm$ 0.087	1.267 $\pm$ 0.109	1.066 $\pm$ 0.033	1.071 $\pm$ 0.044
Right leg	1.145 $\pm$ 0.104	1.144 $\pm$ 0.111	1.239 $\pm$ 0.088	1.239 $\pm$ 0.104	1.075 $\pm$ 0.040	1.072 $\pm$ 0.040