

Physical fitness and vegetarian diets: is there a relation?^{1,2}

David C Nieman

ABSTRACT The available evidence supports neither a beneficial nor a detrimental effect of a vegetarian diet on physical performance capacity, especially when carbohydrate intake is controlled for. Concerns have been raised that an emphasis on plant foods to enhance carbohydrate intake and optimize body glycogen stores may lead to increases in dietary fiber and phytic acid intake to concentrations that reduce the bioavailability of several nutrients, including zinc, iron, and some other trace minerals. There is no convincing evidence, however, that vegetarian athletes suffer impaired nutrient status from the interactive effect of their heavy exertion and plant-food based dietary practices to the extent that performance, health, or both are impaired. Although there has been some concern about protein intake for vegetarian athletes, data indicate that all essential and nonessential amino acids can be supplied by plant food sources alone as long as a variety of foods is consumed and the energy intake is adequate. There has been some concern that vegetarian female athletes are at increased risk for oligoamenorrhea, but evidence suggests that low energy intake, not dietary quality, is the major cause. In conclusion, a vegetarian diet per se is not associated with improved aerobic endurance performance. Although some concerns have been raised about the nutrient status of vegetarian athletes, a varied and well-planned vegetarian diet is compatible with successful athletic endeavor. *Am J Clin Nutr* 1999;70(suppl):570S–5S.

KEY WORDS Exercise, endurance, athlete, carbohydrate, meat, iron, protein, creatine, vegetarian diet, humans

EFFECT OF A VEGETARIAN DIET ON PERFORMANCE

Vegetarian dietary practices have been associated with many health benefits, including lower death rates from ischemic heart disease, diabetes, and certain forms of cancer (1–6) and lower risks of dyslipidemia, hypertension, and obesity (7–10). Most vegetarians have higher intakes of fruit and vegetables, dietary fiber, antioxidant nutrients, phytochemicals, and folic acid than do nonvegetarians, and lower intakes of saturated fat and cholesterol (11–14), which have been related to lower risk of chronic disease (15–20).

The question of whether the multiple benefits of vegetarian dietary practices extend to enhanced physical fitness and performance has been explored since the early 20th century, when a few simple studies reported greater muscular endurance in vegetarian than in nonvegetarian subjects, but these results were not confirmed in subsequent research (21). In 1970, Cotes et al (22) compared thigh-muscle width, pulmonary function measures,

and cardiorespiratory response to submaximal cycle ergometry exercise in 14 vegan and 86 nonvegetarian women. Ventilation responses during rest or exercise did not differ between the groups, and thigh muscle width was similar. The authors concluded that the lack of animal protein did not impair the physiologic response to submaximal exercise.

Williams (23) studied the effect of a vegetarian diet on running performance (5–8-km test runs). The subjects completed the runs before and after the 2-wk test diet, and then again 2 wk after resuming a nonvegetarian diet. No significant differences in performance were found between the trials, suggesting that the vegetarian diet had neither a beneficial nor a detrimental effect on aerobic endurance.

Physical fitness, anthropometric, and metabolic indexes were compared by Hanne et al (24) in 49 vegetarian and 49 nonvegetarian male and female Israeli athletes who were matched for age, sex, body size, and athletic activities. No significant differences were found between groups in pulmonary function, aerobic and anaerobic capacities, arm and leg circumferences, hand grip and back strength, hemoglobin, or total serum protein.

Twenty-one overweight women consumed a lactoovo vegetarian diet for 5 wk in which all meals were prepared, weighed, and served in a research kitchen (25). Half of the subjects were randomly assigned to an exercise program of walking, jogging, or both (five 45-min sessions/wk at an intensity of 60% $\dot{V}O_{2max}$) whereas the other half remained sedentary. Submaximal and maximal cardiorespiratory measures improved significantly in those who exercised, but no improvement was seen in the women who consumed the vegetarian diet without exercise.

Snyder et al (26) studied 2 groups of female runners who were matched for age, weight, and distance run per week. One group regularly consumed a semivegetarian diet (<100 g red meat/wk) whereas the other group consumed a diet that included red meat. No significant difference in maximal aerobic capacity was found between the 2 groups.

A series of reports has been published about 110 runners who competed in a 1000-km race conducted over a 20-d period in West Germany (27–29). Before and during the race, 60 of the runners consumed a conventional Western diet and 50 consumed

¹From the Department of Health, Leisure, and Exercise Science, Appalachian State University, Boone, NC.

²Reprints not available. Address correspondence to DC Nieman, Department of Health, Leisure, and Exercise Science, Appalachian State University, Boone, NC 28608. E-mail: niemandc@appstate.edu.

TABLE 1

Dietary, hematological, and metabolic comparisons between vegetarian and nonvegetarian healthy, nonobese, physically active, elderly women¹

Characteristic	Vegetarians (n = 19)	Nonvegetarians (n = 12)
Age (y)	72.3 ± 1.4	69.5 ± 1.0
BMI (kg/m ²)	22.5 ± 0.6	24.2 ± 0.8
Sum of 3 skinfold thicknesses (mm)	71.7 ± 5.1	85.2 ± 5.5
Dietary		
Energy (kJ/kg body wt)	100.4 ± 6.7	95.8 ± 9.2
Carbohydrate (% of total energy)	61.4 ± 1.6	48.9 ± 1.7 ²
Fat (% of total energy)	30.4 ± 1.2	36.9 ± 2.0 ²
Cholesterol (mg/MJ)	15.1 ± 2.5	32.7 ± 2.9 ²
Hematologic		
Hemoglobin (g/L)	144 ± 2	146 ± 3
Glucose (mmol/L)	4.60 ± 0.9	5.13 ± 0.1 ²
Total cholesterol (mmol/L)	5.41 ± 0.20	6.48 ± 0.29 ²
Metabolic		
Systolic blood pressure (mm Hg)	145 ± 4	142 ± 5
$\dot{V}O_2$ max (ml·kg ⁻¹ ·min ⁻¹)	23.8 ± 1.5	21.9 ± 0.8
Maximal ventilation (L/min)	52.9 ± 3.8	51.2 ± 3.4

¹Data from reference 30.

²Significantly different from vegetarians, $P < 0.05$ (Student's *t* test).

a lactoovovegetarian diet. During the race, the diets for both groups were formulated to ensure a similar intake of carbohydrate by both groups ($\approx 60\%$ of total energy). Diet had no effect on the performance of the runners: half of each group finished the 20-d race, the order of finishers was not influenced by the diet, and the average running time of the vegetarian runners was not significantly different from that of the nonvegetarians.

Nineteen long-term vegetarian (mean duration vegetarianism 46 y) and 12 nonvegetarian healthy, physically active elderly women (mean age: 71 y) were compared on the basis of a variety of hematologic, anthropometric, and metabolic factors (30) (**Table 1**). Although the vegetarian subjects had significantly lower blood glucose and cholesterol concentrations, no differences between groups were found for submaximal and maximal cardiorespiratory and electrocardiographic indexes measured during graded treadmill testing. The authors concluded that a long-term vegetarian diet may be associated with several benefits, but these do not include improved cardiorespiratory fitness.

Two reports were published on a study in 8 well-trained, male athletes in Denmark who consumed either a lactoovovegetarian or a nonvegetarian diet for 6 wk in a crossover design (31, 32). Both diets consisted of 57% of total energy as carbohydrates, 14% as protein, and 29% as fat. Maximal aerobic capacity, aerobic endurance time to exhaustion, muscle glycogen concentrations, and isometric strength were not affected significantly by changes in the diet (**Figure 1**).

Animal product intake was measured and related to $\dot{V}O_2$ max in a group of 80 women who varied widely in age (27–72 y), body mass (52–156 kg), maximal aerobic power (12.7–50.7 mL·kg⁻¹·min⁻¹), meat intake (1.1–31.6 meat exchanges/d), milk intake (0–4.2 milk exchanges/d), dietary cholesterol (30–530 mg/d), and vitamin B-12 intake (0.8–14.4 μ g/d) (33). Maximal aerobic power was not related with meat intake ($r = -0.13$, $P = 0.324$), an animal product index created by combining meat and milk exchanges ($r = -0.127$, $P = 0.339$), dietary cholesterol ($r = -0.160$, $P = 0.239$), or vitamin B-12 intake ($r = 0.065$, $P = 0.635$). A multiple regression analy-

sis, using models to control for age and body composition, failed to alter these findings.

Together, these studies indicate that a vegetarian diet, even when practiced for several decades, is neither beneficial nor detrimental to cardiorespiratory endurance, especially when carbohydrate intake, age, training status, body weight, and other confounders are controlled for.

SPECIAL CONCERNS FOR ATHLETES CONSUMING VEGETARIAN DIETS

Endurance athletes have been urged to emphasize carbohydrates in their diet to optimize muscle and liver glycogen stores (34). At the high intensities necessary for athletic training and competition, the metabolism of body carbohydrate reserves provides the major fuel for muscle contraction and when these carbohydrate reserves reach low concentrations, the result is fatigue (35). Carbohydrate intakes of ≈ 500 – 800 g/d (8 – 10 g·kg body wt⁻¹·d⁻¹) and as 60–70% of energy intake have been recommended for athletes training intensively for >60 – 90 min/d (34–36).

A near-vegetarian diet is often necessary for athletes to take advantage of high-carbohydrate plant foods such as cereals, pasta, grains, dried fruits, and legumes. In one study, $>75\%$ of 347 marathon runners reported higher intake of fruit, vegetables, and whole grains and lower intakes of red meat and eggs compared with their prerunning dietary habits (37). Nonetheless, in most studies, carbohydrate intakes by endurance athletes fall below recommended amounts, although there are some noteworthy exceptions (eg, Tarahumara Indian ultramarathon runners and triathletes) (34, 37, 38).

Iron, zinc, and trace minerals

Concerns have been raised that an emphasis on the consumption of plant foods to enhance carbohydrate intakes by athletes may increase dietary fiber and phytic acid intakes to concentrations that reduce the bioavailability of several nutrients, including zinc, iron, and some trace minerals (39, 40). Furthermore,

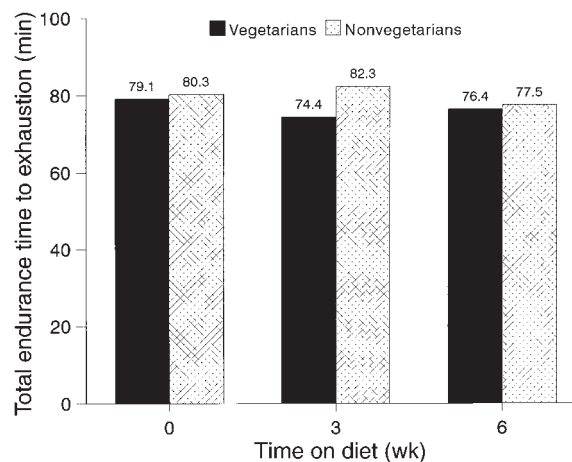


FIGURE 1. Total endurance time to exhaustion on a cycle ergometer or treadmill among 8 athletes who consumed a vegetarian or nonvegetarian diet for 6 wk each in a crossover design. Carbohydrate intake was kept the same for each dietary regimen (57% of total energy). There were no significant differences between groups. Data from reference 32.

nonheme iron from plant food sources is more poorly absorbed than is heme iron from animal products, increasing the risk of sports anemia in endurance athletes, who are already at high risk of iron deficiency resulting from exercise-induced iron losses (34). These concerns may be especially apparent in certain subgroups such as female adolescent athletes (41).

Most studies of long-term vegetarian nonathletes who avoid dietary extremes indicate that despite the apparent lower bioavailability of some minerals, the iron, zinc, and trace element status (as measured in serum, hair, and urine) appears to be adequate (42, 43). Dietary intake of iron is typically above recommended amounts in vegetarians, but serum ferritin concentrations and other iron-status indicators are often lower than those in nonvegetarians, although anemia is rare (11, 44–49).

Although inhibitors of dietary iron absorption are present in plant-based foods, such as phytates in grains and tannic acid in tea, plant foods also contain enhancers of dietary iron absorption, such as vitamin C and citric acid found in fruit and vegetables (14, 43). Although considered controversial, there is some evidence that a reduction in body iron stores may be associated with reduced risks of both coronary artery disease and cancer (50–52). Thus, the lower ferritin concentrations found in vegetarians may actually be advantageous, but further research is needed before this hypothesis can be accepted.

Various groups of athletes have been reported to be at risk of iron deficiency, although, as in vegetarians, iron deficiency anemia is rare (34, 53, 54). There is a growing consensus, however, that mild iron deficiency has little or no meaningful effect on the health or performance capabilities of athletes (34). Low intake of dietary iron, increased hemolysis, decreased iron absorption, and increased iron loss in sweat, feces, and urine have all been implicated as factors that may reduce body iron stores in some athletes, especially females (34, 53). In one large study of 1743 Finnish men, the duration and frequency of physical activity were associated inversely with serum ferritin concentrations (51). The authors speculated that reducing the amount of stored iron could be one mechanism through which exercise training decreases the risk of coronary artery disease (50, 51).

There has been some concern that vegetarian female endurance athletes may be at special risk of iron deficiency (39, 40). A significant proportion (30–50%) of endurance athletes, especially women, have been reported to be semivegetarians with low intakes of meat products (26, 39). Snyder et al (26) compared iron status in 9 nonvegetarian and 9 semivegetarian female runners and reported lower serum ferritin and higher total-iron-binding capacity in the semivegetarians. Serum iron, percentage transferrin saturation, and hemoglobin concentrations, however, were not significantly different between the groups.

Seiler et al (28) also reported lower ferritin concentrations in vegetarian than in nonvegetarian runners, both male and female. However, no impairment in ability to compete in a 20-d, 1000-km race was measured in the vegetarian runners. During the 1000-km race, dietary iron intake was higher in the vegetarian group, but the iron was of the nonheme variety from legumes, dried fruit, nuts, vegetables, and grain products. High intake of vitamin C together with the avoidance of tea appeared to enhance iron absorption because blood indicators of iron status were similar in the vegetarian and nonvegetarian runners (29). The Tarahumara Indians of Mexico, renowned for their extraordinary endurance as long-distance runners, have been found to have normal blood hemoglobin concentrations despite diets that consist of 90% corn

and pinto beans (38, 55). In the study of 8 athletes who consumed a vegetarian or nonvegetarian diet for 6 wk (crossover design), despite an extremely high fiber intake while consuming the vegetarian diet (98 and 47 g/d, respectively), blood hemoglobin, serum iron, and serum transferrin concentrations did not differ significantly between dietary groups (31, 32).

Despite the lower bioavailability of some trace elements such as zinc, copper, manganese, and selenium in vegetarian diets, most studies have failed to show that vegetarians have impaired trace element status (14, 42). It appears that the bodies of vegetarians can adapt by increasing the absorption of trace elements, although concerns have been raised that adolescents, who have higher zinc requirements for growth, who consume vegetarian diets may have suboptimal zinc status (42, 48).

Several studies have shown that acute exercise alters blood concentrations of trace elements, suggesting that exercise leads to a redistribution of body tissues (56, 57). There is some evidence that an acute bout of exercise increases urinary zinc excretion (56). However, most studies have failed to find that indicators of trace element status are different between athletes and nonathletes (57). Concerns have been raised that athletes, especially adolescents, who avoid meat may have difficulty maintaining adequate amounts of zinc in their bodies (40). Insufficient data exist to determine whether these concerns are warranted. Beef, pork, and poultry are major sources of zinc in the United States (58). Milk and cereal products, legumes, and nuts are also good sources of zinc, but the zinc in these sources is less bioavailable than that in meat (40, 56, 58).

Vegetarian athletes should eat foods with ample amounts of iron and zinc (eg, fortified breakfast cereals, legumes, and nuts and seeds), include vitamin C sources with each meal, and avoid heavy tea intake (40). Iron, zinc, and trace element supplementation may be necessary for some vegetarian athletes who have poor diets, but the supplements should include no more than 100% of the recommended dietary allowance to avoid negative interactions with the absorption or function of other nutrients (56, 59).

Although there are some concerns about the trace-mineral status of vegetarian athletes, their dietary practices may be of benefit in another area of current interest in sports nutrition (13). There is increasing evidence that heavy exertion produces an oxidative stress that leads to the generation of oxygen free radicals and lipid peroxidation (60–63). Antioxidant enzymes provide the first line of defense, with antioxidant nutrients such as vitamins E, C, and A providing a second line of defense (62). Chronic physical training augments the physiologic antioxidant defenses in several tissues (61). People who exercise regularly and intensely should eat foods rich in antioxidants (60). Vegetarian athletes with high intakes of fruit, vegetables, and whole grains have a special advantage. The role of antioxidant supplements is still controversial (63).

Protein and creatine

All essential and nonessential amino acids can be supplied by plant food sources alone as long as a variety of foods is consumed and energy intake is adequate to meet needs (14, 64). The American Dietetic Association (14) has advised that consciously combining various plant foods within a given meal is unnecessary.

Although most vegetarian diets meet or exceed dietary recommendations for protein, they often provide less protein than do nonvegetarian diets (12, 26, 44, 49). Concerns have been raised that vegetarian athletes may have intakes that fall below



the added demands created by heavy exertion (39, 65). Studies indicate that athletes benefit from diets containing more protein than the current RDA of $0.8 \text{ g} \cdot \text{kg body wt}^{-1} \cdot \text{d}^{-1}$; strength-training athletes probably need $\approx 1.4\text{--}1.8 \text{ g} \cdot \text{kg body wt}^{-1} \cdot \text{d}^{-1}$ and endurance athletes $\approx 1.2\text{--}1.4 \text{ g} \cdot \text{kg body wt}^{-1} \cdot \text{d}^{-1}$ (65). Most athletes are able to meet these extra demands without protein supplementation by keeping dietary protein near 15% of total energy intake (65). Vegan athletes can achieve optimal protein intake by careful planning, with an emphasis on protein-rich plant foods such as legumes, nuts and seeds, and whole-grain products.

Creatine supplementation has been suggested as an ergogenic aid for athletes who engage in repeated bouts of short-term, high-intensity exercise (66, 67). Creatine is found in large quantities in skeletal muscle and binds to a significant amount of phosphate, providing an immediate source of energy in muscle cells (adenosine 5'-triphosphate). The purpose of consuming supplemental creatine is to increase the skeletal muscle creatine content in the hope that some of the extra creatine binds with phosphate and thus increases muscle-phosphocreatine content. During repeated bouts of high-intensity exercise (eg, five 30-s bouts of sprinting or cycling exercise separated by 1–4 min of rest), the increased availability of phosphocreatine may improve resynthesis and degradation rates, leading to greater anaerobic adenosine 5'-triphosphate turnover and greater high-power exercise performance (66).

The estimated daily requirement of creatine is $\approx 2 \text{ g}$. Nonvegetarians typically get $\approx 1 \text{ g}$ creatine/d from the various meats they ingest and the body synthesizes 1 g in the liver, kidney, and pancreas, using the amino acids arginine and glycine as precursors. Vegetarians generally have low body creatine pools, suggesting that inadequate dietary creatine from meat sources is not compensated for by increased endogenous creatine production (67).

Various studies have shown that consuming $\approx 20\text{--}25 \text{ g}$ creatine/d for 5–6 consecutive days significantly increases muscle creatine in most people, especially those with low amounts to begin with, ie, vegetarians (66–68). Four to 5 doses of 5 g each are usually consumed by dissolving 5 g creatine in $\approx 250 \text{ mL}$ of a beverage throughout the day. Each 5-g dose of creatine is the equivalent of 1.1 kg fresh, uncooked steak. Creatine supplementation for up to 8 wk has not been associated with major health risks, but the safety of prolonged creatine supplementation has not been established (66–71).

Some but not all studies have shown that supplemental creatine improves power performance during repeated bouts of short-term sprinting, cycling, and swimming (66–71). A recent randomized, double-blind study in vegetarian subjects failed to show any effect of creatine on power performance (69). Additional laboratory and field research is needed to help resolve the conflicting findings regarding the ergogenic efficacy of creatine supplementation (71). Creatine supplementation has no effect on aerobic exercise metabolism and performance (66, 67).


Hormonal alterations

High-fiber, low-fat vegetarian diets have been associated with reduced blood estrogen concentrations and increased menstrual irregularity (72–75). Frequent, vigorous exercise has also been related to menstrual irregularities (34). About 5–20% of women who exercise regularly and vigorously and $\approx 50\text{--}65\%$ of competitive athletes may develop oligoamenorrhea. The causes are hotly debated, but may include low energy intake, depleted fat stores, and the effect of exercise itself on the hypothalamic-pituitary-

ovarian axis in female athletes (76, 77). Amenorrheic athletes typically have low concentrations of estradiol and progesterone and have hormonal profiles similar to those of postmenopausal women. The reduced concentrations of endogenous estrogen associated with athletic amenorrhea may prevent the formation of adequate bone density (34, 76, 77).

Two reports (published as letters) suggested that a significant proportion of female athletes with amenorrhea were vegetarians (78, 79). However, these were descriptive studies that could not determine whether the cause was the vegetarian diet, heavy exercise training, lower energy intake, or other factors. There is increasing evidence that low energy intake, not diet quality, is a major cause of oligoamenorrhea in female athletes, and that when brought into positive energy balance, hormonal profiles return to normal and menstruation resumes (80). Hanne et al (24) observed that when vegetarian female athletes are properly nourished, their menstrual cycle function is normal compared with that of matched nonvegetarian control subjects.

CONCLUSION

A vegetarian diet per se is not associated with improved aerobic endurance performance; however, other benefits make this dietary regimen worthy of consideration by serious athletes. A plant-based diet facilitates high-carbohydrate intake, which is essential to support prolonged exercise. A well-planned vegetarian diet can provide athletes with adequate amounts of all known nutrients, although the potential for suboptimal iron, zinc, trace element, and protein intake exists if the diet is too restrictive. However, this concern exists for all athletes, vegetarian or non-vegetarian, who have poor dietary habits. Athletes who consume diets rich in fruit, vegetables, and whole grains receive high amounts of antioxidant nutrients that help reduce the oxidative stress associated with heavy exertion. Whereas athletes are most often concerned with performance, vegetarian diets also provide long-term health benefits and a reduction in risk of chronic disease. In 2 studies, a combination of regular physical activity and vegetarian dietary practices resulted in lower mortality rates did than a vegetarian diet or exercise alone (2, 81). 

REFERENCES

1. Thorogood M, Mann J, Appleby P, McPherson K. Risk of death from cancer and ischemic heart disease in meat and non-meat eaters. *BMJ* 1994;308:1667–70.
2. Fraser GE, Lindsted KD, Beeson WL. Effect of risk factor values on lifetime risk of and age at first coronary event. The Adventist Health Study. *Am J Epidemiol* 1995;142:746–58.
3. Burr ML, Sweetnam PM. Vegetarianism, dietary fiber, and mortality. *Am J Clin Nutr* 1982;36:873–7.
4. Snowdon DA, Phillips RL, Fraser GE. Meat consumption and fatal ischemic heart disease. *Prev Med* 1984;13:490–500.
5. Snowdon DA, Phillips RL. Does a vegetarian diet reduce the occurrence of diabetes? *Am J Public Health* 1985;75:507–12.
6. Giovannucci E, Rimm EB, Stampfer MJ, Colditz GA, Ascherio A, Willett WC. Intake of fat, meat, and fiber in relation to risk of colon cancer in men. *Cancer Res* 1994;54:2390–7.
7. Appleby PN, Thorogood M, McPherson K, Mann JI. Associations between plasma-lipid concentration and dietary, lifestyle and physical factors in the Oxford Vegetarian Study. *J Human Nutr Diet* 1995;8:305–14.
8. Melby CL, Toohey ML, Cebrick J. Blood pressure and blood lipids



- among vegetarian, semivegetarian, and nonvegetarian African Americans. *Am J Clin Nutr* 1994;59:103–9.
9. Thorogood M, Carter R, Benfield L, McPherson K, Mann JI. Plasma lipids and lipoprotein cholesterol concentrations in people with different diets in Britain. *BMJ* 1987;295:351–3.
 10. Levin N, Rattan J, Gilat T. Energy intake and body weight in ovo-lacto vegetarians. *J Clin Gastroenterol* 1986;8:451–3.
 11. Nieman DC, Underwood BC, Sherman KM, et al. Dietary status of Seventh-Day Adventist vegetarian and non-vegetarian elderly women. *J Am Diet Assoc* 1989;89:1763–9.
 12. Millet P, Guillaud JC, Fuchs F, Klepping J. Nutrient intake and vitamin status of healthy French vegetarians and nonvegetarians. *Am J Clin Nutr* 1989;50:718–27.
 13. Krajcovicova-Kudlackova M, Simoncic R, Babinska K, et al. Selected vitamins and trace elements in blood of vegetarians. *Ann Nutr Metab* 1995;39:334–9.
 14. American Dietetic Association. Position of the American Dietetic Association: vegetarian diets. *J Am Diet Assoc* 1993;93:1317–9.
 15. Key TJA, Thorogood M, Appleby PN, Burr ML. Dietary habits and mortality in 11,000 vegetarians and health conscious people: results of a 17 year follow up. *BMJ* 1996;313:775–9.
 16. Pietinen P, Rimm EB, Korhonen P, et al. Intake of dietary fiber and risk of coronary heart disease in a cohort of Finnish men. The Alpha-Tocopherol, Beta-Carotene Cancer Prevention Study. *Circulation* 1996;94:2720–7.
 17. Rimm EB, Ascherio A, Giovannucci E, Spiegelman D, Stampfer MJ, Willett WC. Vegetable, fruit, and cereal fiber intake and risk of coronary heart disease among men. *JAMA* 1996;275:447–51.
 18. American Dietetic Association. Position of the American Dietetic Association: phytochemicals and functional foods. *J Am Diet Assoc* 1995;95:493–6.
 19. Steinmetz KA, Potter JD. Vegetables, fruit, and cancer prevention: a review. *J Am Diet Assoc* 1996;96:1027–39.
 20. White R, Frank E. Health effects and prevalence of vegetarianism. *West J Med* 1994;160:465–71.
 21. Nieman DC. Vegetarian dietary practices and endurance performance. *Am J Clin Nutr* 1988;48:754–61.
 22. Cotes JE, Dabbs JM, Hall AM, et al. Possible effect of a vegan diet upon lung function and the cardiorespiratory response to submaximal exercise in healthy women. *J Physiol* 1970;209:30P–2P.
 23. Williams MH. Nutritional aspects of human physical and athletic performance. Springfield, IL: Charles C Thomas Publisher, 1985:415–6.
 24. Hanne N, Dlin R, Rotstein A. Physical fitness, anthropometric and metabolic parameters in vegetarian athletes. *J Sports Med Phys Fitness* 1986;26:180–5.
 25. Nieman DC, Haig JL, De Guia ED, Dizon GP, Register UD. Reducing diet and exercise training effects on resting metabolic rates in mildly obese women. *J Sports Med Phys Fitness* 1988;28:79–88.
 26. Snyder AC, Dvorak LL, Roepke JB. Influence of dietary iron source on measures of iron status among female runners. *Med Sci Sports Exerc* 1989;21:7–10.
 27. Nagel D, Seller D, Franz H, Leitzmann C, Jung K. Effects of an ultra-long (1000 km) race on lipid metabolism. *Eur J Appl Physiol* 1989;59:16–20.
 28. Seiler D, Nagel D, Franz H, Hellstern P, Leitzmann C, Jung K. Effects of long-distance running on iron metabolism and hematological parameters. *Int J Sports Med* 1989;10:357–62.
 29. Eisinger M. Nutrient intake of endurance runners with lacto-ovo vegetarian diet and regular Western diet. *Z Ernährungswiss* 1994;33:217–29.
 30. Nieman DC, Sherman KM, Arabatzis K, et al. Hematological, anthropometric, and metabolic comparisons between vegetarian and nonvegetarian elderly women. *Int J Sports Med* 1989;10:243–50.
 31. Richter EA, Kiens B, Raben A, Tvede N, Pedersen BK. Immune parameters in male athletes after a lacto-ovo-vegetarian diet and a mixed Western diet. *Med Sci Sports Exerc* 1991;23:517–21.
 32. Raben A, Kiens B, Richter EA, et al. Serum sex hormones and endurance performance after a lacto-ovo-vegetarian and a mixed diet. *Med Sci Sports Exerc* 1992;24:1290–7.
 33. Nieman DC, Butterworth DE, Nehlsen-Cannarella SL, Henson DA, Fagoaga OR. Animal product intake and immune function. *Veg Nutr Int J* 1997;1:5–11.
 34. Nieman DC. *Fitness and sports medicine: a health-related approach*. Mountain View, CA: Mayfield Publishing Company, 1999.
 35. Coyle EF. Substrate utilization during exercise in active people. *Am J Clin Nutr* 1995;61(suppl):968S–79S.
 36. Rauch LHG, Rodger I, Wilson GR, et al. The effects of carbohydrate loading on muscle glycogen content and cycling performance. *Int J Sports Nutr* 1995;5:25–36.
 37. Nieman DC, Butler JV, Pollett LM, Dietrich SJ, Lutz RD. Nutrient intake of marathon runners. *J Am Diet Assoc* 1989;89:1273–8.
 38. Cerqueira MT, Fry MM, Conner WE. The food and nutrient intakes of the Tarahumara Indians of Mexico. *Am J Clin Nutr* 1979;32:905–15.
 39. Ruud JS. *Vegetarianism: implications for athletes*. Omaha: International Center for Sports Nutrition, 1990.
 40. Kleiner SM. The role of meat in an athlete's diet: its effect on key macro- and micronutrients. *Sports Sci Exch* 1995;8:1–6.
 41. American Dietetic Association. Timely statement of the American Dietetic Association: nutrition guidance for adolescent athletes in organized sports. *J Am Diet Assoc* 1996;96:611–2.
 42. Gibson RS. Content and bioavailability of trace elements in vegetarian diets. *Am J Clin Nutr* 1994;59(suppl):1223S–32S.
 43. Craig WJ. Iron status of vegetarians. *Am J Clin Nutr* 1994;59(suppl):1233S–7S.
 44. Alexander D, Ball MJ, Mann J. Nutrient intake and hematological status of vegetarians and age-sex matched omnivores. *Eur J Clin Nutr* 1994;48:538–46.
 45. Nathan I, Hackett AF, Kirby S. The dietary intake of a group of vegetarian children aged 7–11 years compared with matched omnivores. *Br J Nutr* 1996;75:533–44.
 46. Lowik MR, Schrijver J, Odink J, Van Den Berg H, Wedel M. Long-term effects of a vegetarian diet on the nutritional status of elderly people (Dutch Nutrition Surveillance System). *J Am Coll Nutr* 1990;9:600–9.
 47. Brants HA, Lowik MR, Westenbrink S, Hulshof KF, Kistemaker C. Adequacy of a vegetarian diet at old age (Dutch Nutrition Surveillance System). *J Am Coll Nutr* 1990;9:292–302.
 48. Donovan UM, Gibson RS. Iron and zinc status of young women aged 14 to 19 years consuming vegetarian and omnivorous diets. *J Am Coll Nutr* 1995;14:463–72.
 49. Janelle KC, Barr SI. Nutrient intakes and eating behavior scores of vegetarian and nonvegetarian women. *J Am Diet Assoc* 1995;95:180–6, 189.
 50. Salonen JT, Nyyssönen K, Korpella H, et al. High stored iron levels are associated with excess risk of myocardial infarction in eastern Finnish men. *Circulation* 1992;86:803–11.
 51. Lakka TA, Nyyssönen K, Salonen JT. Higher levels of conditioning leisure time physical activity are associated with reduced levels of stored iron in Finnish men. *Am J Epidemiol* 1994;140:148–60.
 52. Stevens RG, Jones Y, Micozzi MS, Taylor PR. Body iron stores and the risk of cancer. *N Engl J Med* 1988;319:1047–52.
 53. Selby GB, Eichner ER. Hematocrit and performance: the effect of endurance training on blood volume. *Semin Hematol* 1994;31:122–7.
 54. Nachtigall D, Nielsen P, Fischer R, Engelhardt R, Gabbe EE. Iron deficiency in distance runners: a reinvestigation using ⁵⁹Fe-labelling and non-invasive liver iron quantification. *Int J Sports Med* 1996;17:473–9.
 55. Balke B, Snow C. Anthropological and physiological observations on Tarahumara endurance runners. *Am J Phys Anthropol* 1965;23:293–301.

56. Clarkson PM, Haymes EM. Trace mineral requirements for athletes. *Int J Sport Nutr* 1994;4:104–19.
57. Fogelholm M. Indicators of vitamin and mineral status in athletes' blood: a review. *Int J Sports Nutr* 1995;5:267–84.
58. Mares-Perlman JA, Subar AF, Block G, Greger JL, Luby MH. Zinc intake and sources in the US adult population: 1976–1980. *J Am Coll Nutr* 1995;14:349–57.
59. American Dietetic Association. Position of the American Dietetic Association: vitamin and mineral supplementation. *J Am Diet Assoc* 1996;96:73–7.
60. Clarkson PM. Antioxidants and physical performance. *Crit Rev Food Sci Nutr* 1995;35:131–41.
61. Sen CK. Oxidants and antioxidants in exercise. *J Appl Physiol* 1995;79:675–86.
62. Ji LL. Exercise and oxidative stress: role of the cellular antioxidant systems. *Exerc Sport Sci Rev* 1995;23:135–66.
63. Kanter M. Free radicals and exercise: effects of nutritional antioxidant supplementation. *Exerc Sport Sci Rev* 1995;23:375–97.
64. Young VR, Pellett PL. Plant proteins in relation to human protein and amino acid nutrition. *Am J Clin Nutr* 1994;59(suppl):1203S–12S.
65. Lemon PWR. Do athletes need more dietary protein and amino acids? *Int J Sport Nutr* 1995;5:S39–61.
66. Greenhaff PL. Creatine and its application as an ergogenic aid. *Int J Sport Nutr* 1995;5:S100–10.
67. Maughan RJ. Creatine supplementation and exercise performance. *Int J Sport Nutr* 1995;5:94–101.
68. Hultman E, Söderlund K, Timmons JA, Cederblad G, Greenhaff PL. Muscle creatine loading in men. *J Appl Physiol* 1996;81:232–7.
69. Clarys PM, Zinzen EM, Hebbelinck M, Verlinden M. The effect of oral creatine supplementation on torque production in a vegetarian and a non-vegetarian population: a double blind study. *Veg Nutr Int J* 1997;1:100–5.
70. Burke LM, Pyne DB, Telford RD. Effect of oral creatine supplementation on single-effort sprint performance in elite swimmers. *Int J Sport Nutr* 1996;6:222–33.
71. Williams MH, Branch JD. Creatine supplementation and exercise performance: an update. *J Am Coll Nutr* 1998;17:216–34.
72. Bagga D. Effects of a very low-fat, high-fiber diet on serum hormones and menstrual function—implications for breast cancer prevention. *Cancer* 1995;76:2491–6.
73. Pedersen AB, Bartholomew MJ, Dolence LA, Aljadir LP, Netteburg KL, Lloyd T. Menstrual differences due to vegetarian and nonvegetarian diets. *Am J Clin Nutr* 1991;53:879–85.
74. Barbosa JC, Shultz TD, Filley SJ, Nieman DC. The relationship among adiposity, diet, and hormone concentrations in vegetarian and nonvegetarian postmenopausal women. *Am J Clin Nutr* 1990;51:798–803.
75. Goldin BR, Adlercreutz H, Gorbach SL, et al. Estrogen excretion patterns and plasma levels in vegetarian and omnivorous women. *N Engl J Med* 1982;307:1542–7.
76. Yeager KK, Agostini R, Nattiv A, Drinkwater B. The female athlete triad: disordered eating, amenorrhea, osteoporosis. *Med Sci Sports Exerc* 1993;25:775–7.
77. Loucks AB, Vaitukaitis J, Cameron JL, et al. The reproductive system and exercise in women. *Med Sci Sports Exerc* 1992;24(suppl):S288–92.
78. Brooks SM, Sanborn CF, Albrecht BH, Wagner WW. Diet in athletic amenorrhea. *Lancet* 1984;1:559–60 (letter).
79. Slavin J, Lutter J, Cushman S. Amenorrhea in vegetarian athletes. *Lancet* 1984;1:1474–5 (letter).
80. Dueck CA, Matt KS, Manore MM, Skinner JS. Treatment of athletic amenorrhea with a diet and training intervention program. *Int J Sport Nutr* 1996;6:24–40.
81. Chang-Claude J, Frentzel-Beyme R. Dietary and lifestyle determinants of mortality among German vegetarians. *Int J Epidemiol* 1993;22:228–36.

