Micronutrient Requirements for Athletes

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Vitamins and minerals are necessary for many metabolic processes in the body and are important in supporting growth and development [1]. Vitamins and minerals also are required in numerous reactions involved with exercise and physical activity, including energy, carbohydrate, fat and protein metabolism, oxygen transfer and delivery, and tissue repair [1]. The vitamin and mineral needs of athletes have always been a topic of discussion. Some researchers state that athletes require more vitamins and minerals than their sedentary counterparts, whereas other researchers do not report greater micronutrient requirements. The intensity, duration, and frequency of the sport/workout and the overall energy and nutrient intakes of the individual all have an impact on whether or not micronutrients are required in greater amounts [1–3]. This article evaluates the vitamin and mineral needs of athletes.

DIETARY REFERENCE INTAKES
The Dietary Reference Intakes (DRI) for all known vitamins and essential minerals for healthy individuals living in the United States were updated between 1997 and 2005 [4–8]. Adequate Intake (AI), Recommended Dietary Allowance (RDA), Estimated Average Requirement (EAR), and Tolerable Upper Intake Level (UL) all are under the DRI heading. The RDA is the dietary intake level that is sufficient for approximately 98% of healthy individuals living in the United States. The AI is a projected value that is used when the RDA cannot be established. The EAR is a value used to estimate the nutrient requirements of half of the healthy individuals in a group [8]. The UL is the maximum quantity of a nutrient most individuals can consume without resulting in adverse side effects [8]. The DRIs for all nutrients may be found at the following website: http://www.iom.edu/Object.File/Master/21/372/0.pdf.

In most cases, if energy intakes are sufficient, the micronutrient requirements of athletes are similar to healthy, fairly active individuals; using the DRI for evaluating nutrient needs would be suitable. Some athletes may have greater requirements, however, as a result of disproportionate losses of nutrients in...
sweat and urine. For these athletes, supplementation may need to be considered on an individual basis. Many athletes supplement with vitamins, minerals, and ergogenic aids on their own. The UL provides guidelines to athletes who supplement, which should prevent negative effects from occurring owing to oversupplementation.

**IMPORTANCE OF ACCURATE DIETARY INTAKE ASSESSMENT**

Although this article focuses on micronutrients, a total evaluation of an athlete’s energy intake is necessary because even if an athlete is consuming the correct amount of micronutrients (especially if he or she is supplementing with a vitamin-mineral supplement), if energy requirements are not being met, athletic performance still would be suboptimal. Clark and colleagues [9] examined the preseason and postseason intakes of macronutrients and micronutrients in division I female soccer players. They reported that despite meeting total energy requirements (carbohydrate needs were not met), vitamin E, folate, copper, and magnesium intakes were suboptimal (<75% of the DRI).

The evaluation of an athlete’s diet must be conducted properly to ensure accuracy [10]. It is common for athletes (and nonathletes) to underreport their dietary intake. Consequently, it is imperative that athletes are taught how to estimate accurately portion sizes and fluid intake, the amount and frequency of snacking, any weight management practices they may perform, and changes in their food patterns during seasons and off-seasons [10].

**MICRONUTRIENT INTAKE AND NUTRITION STATUS AMONG ATHLETES**

**Dietary Intake Assessment and Nutritional Status in Male Athletes**

Assessing dietary intake among any individual is difficult and is often criticized because of the inherent lack of accuracy. Nonetheless, dietary records are still the best method presently available to estimate dietary intake. Although dietary records often provide information about intake at a particular point in time, longer term studies can help to provide a more accurate assessment of dietary intake, even if one point in time is assessed per year. Leblanc and coworkers [11] analyzed the diets of French male athletes training at the National Training Centre in Clairefontaine. There were 180 athletes, 13 to 16 years old, who participated in this 3-year dietary survey. Despite the long-term nature of this study, calcium and iron were the only micronutrients evaluated. Each year, a 5-day food record was collected from these athletes. Leblanc and coworkers [11] reported insufficient energy intake for all athletes. They also reported that calcium intake was below recommendations during the first year, whereas iron intake was sufficient; however, calcium and iron intakes significantly improved ($P<.05$) over the 3-year period [11]. The researchers stated that the increase in calcium and iron intake may have been a result of a physiologic adjustment to growth or to the positive effects of the nutrition courses provided during their stay at the Centre [11]. Rico-Sanz and colleagues [12] also reported lower than recommended intakes of calcium in eight male soccer players (average age 17
years) who were part of the Puerto Rican Olympic soccer team, despite an adequate energy intake.

Iglesias-Gutierrez and associates [13] evaluated the dietary intake and nutritional status of adolescent Spanish soccer players of similar age to those studied by Leblanc and coworkers [11] (14–16 years old; n = 33). The soccer players consumed an adequate amount of iron; however, 48% of these athletes were iron deficient (without anemia). These results suggest that even with adequate intakes of micronutrients, the impact of training may require greater amounts of certain micronutrients. A nutrition intervention, including education and monitoring transient and long-term micronutrient changes (intake and blood values), is required to make definitive recommendations, however [13,14]. It has been suggested that nutrition education be provided to athletes at an early age and continued throughout adolescence, not only to optimize athletic performance, but also to promote healthy dietary practices throughout the life span [14].

In a more recent study, Paschoal and Amancio [15] examined the dietary intake and nutritional status of eight Brazilian elite male swimmers, 18 to 21 years old. Four-day dietary records indicated adequate energy and micronutrient intake, with the exception of calcium, for which only four of the athletes consumed the recommended amount. The biochemical indices of nutritional status all were within normal limits for the micronutrients. These researchers also reported that 62.5% and 25% of the swimmers consumed amino acid and antioxidant supplements. Similar to other researchers, Paschoal and Amancio [15] strongly recommended nutrition education for balanced dietary intake and education about supplementation.

Rankinen and associates [16] also evaluated the dietary intake and nutritional status of athletes (Finnish elite male ski jumpers) (n = 21), but compared them with age-matched controls (n = 20). Dietary intake was assessed via 4-day dietary records. There were no differences between groups in age and height, although the ski jumpers had a lower mean body weight and percent body fat (assessed via dual-energy x-ray absorptiometry). Energy intake was significantly lower (P = .001) in the ski jumpers compared with the control participants. Despite this difference in energy intake, thiamine, riboflavin, folate, vitamin C, calcium, and iron intakes were similar between groups; however, vitamins D and E, zinc, and magnesium were significantly lower in the ski jumpers compared with the controls. Although the ski jumpers had significantly lower intakes of these micronutrients, their biochemical markers of nutritional status were within normal limits. Although nutritional status was within normal limits, the cross-sectional nature of this and many other studies to determine nutritional status among athletes may not accurately capture deficiencies that could be occurring over time. Blood (plasma or serum) concentrations of micronutrients are not always the best measure of status.

Dietary Intake Assessment and Nutritional Status in Female Athletes

There seems to be more research on the dietary intake of female athletes than male athletes, probably because of a higher prevalence of disordered eating.
among women, especially in sports that require a specific body weight to compete or in sports that also highly value aesthetics. Ziegler and colleagues [17] evaluated 18 female competitive figure skaters, 14 to 16 years old, during pre-season, the competitive season, and off-season using 3-day dietary records. Energy intake was below energy needs, although energy intake did not differ significantly over the three seasons. Nonetheless, throughout the competitive season, 78%, 50%, and 44% of the skaters had intakes less than 67% of the RDA for folate, iron, and calcium. The biochemical indicators of nutritional status were within normal limits, although long-term assessments are required to evaluate the impact of the less-than-adequate intake of the aforementioned nutrients. Ziegler and colleagues [17] emphasized the need for nutrition education among these athletes, especially throughout their competitive season.

Hassapidou and Manstrantoni [18] compared the dietary intake of elite Greek female athletes in four different sports (volleyball, middle distance running, ballet dancing, and swimming) with a nonathletic control group. They evaluated dietary intake using 7-day weighed dietary records over two seasons, the training season and the competitive season. The investigators reported a lower than recommended intake of iron in the athletic and nonathletic groups, but a higher than recommended intake of vitamin C in all participants, which they stated was “characteristic of the population of the Mediterranean countries” [18]. Although micronutrient intakes did not differ between athletes and nonathletes, biochemical indices to assess status were not conducted. An additional study on dietary intake conducted in female Greek athletes (volleyball players) found that these adolescent athletes did not consume recommended intakes for calcium, iron, folate, magnesium, zinc, vitamin A, and the B vitamins [19]. Neither of these groups of researchers evaluated nutritional status; nevertheless, the lower than recommended intake could lead to less than optimal performance and growth (in the adolescent athletes).

Beals [20] conducted a more complete study on 23 nationally ranked female adolescent volleyball players. Nutrient intake was assessed using 3-day weighed food records. Iron, vitamins C and B₁₂, and folate status were determined through blood samples. Beals [20] found that these athletes consumed fewer calories than they expended (energy intake = 2248 ± 414 kcal/d, energy expenditure = 2815 kcal/d). They also consumed less than the recommended intakes for folate, B-complex vitamins, vitamin C, iron, calcium, magnesium, and zinc. With respect to their nutritional status, three of the athletes had iron deficiency anemia, one athlete had a marginal vitamin B₁₂ status, and four athletes had marginal vitamin C status. Beals [20] also reported a high percentage of athletes who had past or present menstrual disorders (amenorrhea, oligomenorrhea, or irregular menstrual cycles). The combination of low energy and micronutrient intake and menstrual irregularities shows the need for long-term studies evaluating dietary intake and nutritional status among athletes of all levels and ages.

In another comprehensive study, Kim and coworkers [21] compared the nutritional intake, iron status, and immunologic patterns of Korean female Judo athletes to control participants. Three-day dietary records were used to
evaluate intake. In general, vitamin and mineral intakes were within recommendations; however, calcium and iron intakes were less than 100% of the recommendations, whereas intakes of phosphorus, thiamine, and riboflavin were greater in athletes compared with controls. None of the participants were iron deficient; however, iron, thiamine, and niacin intakes were positively associated with the immunologic variables measured. Although more research is required on the dietary intake and nutritional status of all athletes, further investigation is needed in the area of specific vitamins and minerals with immunologic function in athletes, especially endurance athletes [21].

Athletes of all levels of competition can be negatively affected by poor dietary intake. Heptathletes are so varied in their training and competition, by the mere nature of their sport, that they may be at greater risk for nutritional deficiencies. Mullins and coworkers [22] assessed the dietary intake (using 4-day dietary records) and nutritional status of 19 female heptathletes, 26 ± 3 years of age, during their training season. These athletes consumed more than 67% of the recommended intakes for all nutrients, with the exception of vitamin E, despite the fact that more than 50% of this group took vitamin supplements. Biochemical markers indicated normal iron status. The cross-sectional nature of this study, similar to some of the previously discussed studies, may not accurately reflect dietary intake and nutritional status.

In two separate studies, Gropper and colleagues [23,24] evaluated the copper and iron intake and status of 70 female collegiate athletes (18–25 years old) from across different sports. Depending on the sport, copper intake ranged from 41% to 118% of the recommended intakes. Of the athletes, 41% did not consume two thirds of the RDA for copper. Serum copper and ceruloplasmin concentrations were within normal limits for all athletes. With respect to iron intake and status, 25% of the athletes did not consume two thirds of the RDA for iron, and these athletes displayed suboptimal serum ferritin, iron, or transferring saturation concentrations [24]. Athletes whose serum ferritin concentration was 15 µg/L or less also displayed serum iron concentrations of less than 60 µg/dL and transferrin saturation of less than 16% (both below normal). Despite the fact that these were athletes from different sports, and iron deficiency was not apparent, iron depletion was present in many of these athletes across different sports and different ages. Certain studies have suggested that iron-depleted women have decreased maximal oxygen consumption (VO₂max) as a result of decreased iron storage [25]. Some studies have observed alterations in metabolic rate, thyroid hormone status, and thermoregulation with iron depletion and iron deficiency anemia [26–29], although some researchers have not observed these alterations [30]. Mild iron deficiency anemia also has been shown to affect psychomotor development, intellectual performance, and immune function negatively [31,32]. The fact the iron deficiency anemia is one of the most common nutritional deficiencies throughout the world, especially in women, further emphasizes the need for proper nutrition education and intake among female athletes.

The previously discussed studies all have been cross-sectional in nature, which provides a snapshot of the athletes’ intake and status, but do not allow
for further interpretation. Petersen and associates [33] evaluated 18 female collegiate swimmers and 6 female collegiate divers preseason and after 16 weeks of training. There were no changes in energy intake over time; however, the athletes significantly improved their dietary quality as evidenced by increases in iron, vitamin C, and vitamin B6 intake. The investigators also reported improved iron status in these athletes, with increases in hemoglobin and hematocrit, with a subsequent decrease in serum transferrin receptors. Clark and coworkers [9] assessed dietary intake in female collegiate soccer players preseason to postseason and reported marginal intakes (<75% of the DRI) for vitamin E, folate, copper, and magnesium, with no improvements over the season as Petersen and associates [33] reported. Although these studies evaluated preseason to postseason dietary intake or nutritional status, research examining intake over a longer period is needed to assess fully any impact of poor dietary intake on nutritional status and performance.

Dietary Intake Assessment and Nutritional Status in Special Populations of Female Athletes

Female athletes may be more restrictive in their dietary intake than male athletes, placing them at greater risk for nutritional deficiencies and impaired performance and health. Beals and Manore [34] evaluated the diet and nutritional status of female athletes with subclinical eating disorders (n = 24), compared with those of controls (n = 24). The group with subclinical eating disorders had significantly lower energy intake than the control group (1989 kcal/d versus 2300 kcal/d; P = .004); however, energy expenditure did not differ between groups. Average micronutrient intake and iron, zinc, magnesium, vitamin B12, and folate status did not differ between groups (and were within normal limits). Athletes in both groups used vitamin-mineral supplements, which likely improved nutritional status.

Aside from disordered eating, many female athletes are vegetarians for various reasons, which also could affect nutritional intake and status. Janelle and Barr [35] compared the nutrient intakes of vegetarian (n = 23) and nonvegetarian (n = 22) athletes, 20 to 40 years old, using 3-day dietary records. The vegetarian athletes had lower intakes of riboflavin, niacin, vitamin B12, zinc, and sodium intakes, while consuming higher intakes of folate, vitamin C, and copper compared with the nonvegetarians. Within the subgroup of the vegetarians, vegans consumed lower calcium and vitamin B12 compared with lactovegetarians. Despite the health-conscious nature of many vegetarians, dietary intake still may be inadequate and is definitely not the same among subgroups of vegetarians. Vegetarian athletes may need more information on proper nutritional intake to ensure adequate energy and micronutrient intake for optimal performance and health.

Dietary Intake Assessment and Nutritional Status in Female and Male Athletes

Numerous researchers evaluated the dietary intake of female and male athletes from similar sports. These studies can help shed some light on gender
differences within the same sports. Although the total nutrient intake of athletes is important, evaluating the diversity of athletes’ meals and snacks in providing nutrients is also important. Ziegler and colleagues [36] evaluated the contribution of breakfast, lunch, dinner, and snacks on the macronutrient and micronutrient intake of 46 male and 48 female elite figure skaters who participated in the 1999 US National Figure Skating Championships. Three-day dietary records were used to assess dietary intake. With respect to micronutrient intake, they reported that breakfast was the main source of dietary folate (36%), whereas breakfast and dinner were the main sources of iron (29% and 27%) and calcium (32% and 29%). Ziegler and colleagues [36] concluded that these figure skaters needed to be educated about the benefits of consuming breakfast and about consuming a variety of foods throughout the day to maintain proper energy and micronutrient intake.

A larger study of the National Figure Skating Championship competitors was conducted in which 4-day diet records and fasting blood samples and anthropometric variables were assessed 2 months after the National Championships [37]. Forty-one figure skaters 11 to 18 years old participated in this study. The researchers compared their intakes with the Third National Health and Nutrition Examination Survey (NHANES III) and recommended intakes. Ziegler and colleagues [37] reported that the mean intakes for vitamins were greater than required intakes except for vitamins D and E. In addition, compared with NHANES III, the figure skaters consumed lower amounts of vitamins B₁₂ and E, but greater amounts of vitamin C and thiamine (female skaters only). Male and female figure skaters consumed lower amounts of magnesium and zinc compared with recommended intakes. Male figure skaters also consumed lower amounts of iodine, whereas female figure skaters consumed lower amounts of magnesium, zinc, calcium, iron, and phosphorus compared with recommended intakes. Although biochemical indices of nutritional status were within the normal range, electrolyte concentrations indicated dehydration. Ziegler and colleagues [37] emphasized the need for dietary interventions and nutrition education for these athletes to lead to optimal performance and health.

In a more recent study from the same group of researchers, Jonnalagadda and colleagues [38] assessed the food preferences and nutrient intakes of elite male ($n = 23$) and female ($n = 26$) figure skaters using 3-day dietary records. They reported that male figure skaters had a higher preference for grains, meat, dairy, fats, fruit, and sweets, whereas female figure skaters had a higher preference for fruits and grains. Total energy intake and vitamins E and D, magnesium, and potassium intake were less than two thirds of the recommended intake for males and females. Female skaters also consumed less than two thirds of the recommended intakes for folate, pantothenic acid, calcium, and phosphorus. The researchers did not assess biochemical indices of these athletes; nutritional status could not be determined. Regardless, decreased intakes, combined with intense training, can lead to impaired performance and health.

Constantini and associates [39] assessed the iron status of Israeli male and female gymnasts 12 to 18 years old compared with summers, tennis players,
and table tennis players. They all trained for about 25 hours per week, lived in the same national center for gifted athletes, and ate in the same dining room. Hemoglobin concentrations were less than 14 g/dL in 45% of the male gymnasts compared with only 25% of the nongymnasts and less than 13 g/dL in 25% of premenarcheal female gymnasts compared with 15% of nongymnasts. Iron depletion (serum ferritin levels <20 ng/mL) was observed in 36% of the male gymnasts and 30% of the female gymnasts. The prevalence of iron deficiency and depletion in the gymnasts compared with the other athletes was much greater and may be due to the pressures of maintaining a low body weight, even in males. Dubnov and Constantini [40] reported similar high rates of iron depletion and iron deficiency, however, in 103 male and female national basketball players. They reported that 15% of males and 25% of females were iron depleted, whereas 18% of males and 38% of females were iron deficient. These researchers recommend iron screening and nutritional counseling for athletes.

SUPPLEMENTATION AND ATHLETIC PERFORMANCE

Based on the aforementioned review, it seems that some athletes may need to supplement as a result of inadequate dietary intake or impaired nutritional status. Does supplementation improve performance, however? Tsalis and colleagues [41] evaluated whether the iron status of healthy adolescent swimmers was altered during a 6-month training season, and if increased daily iron intake (via supplement or food) would affect iron status or performance. Twenty-one male and 21 female Greek swimmers 12 to 17 years old were separated into three groups: (1) Group A received an iron supplement of 47 mg/d, (2) group B followed a diet high in iron (providing about 26 mg/d), and (3) group C served as the control group. Data were collected at baseline and at the end of three training phases. The investigators found significant variations in iron status during the training season; however, they did not find significant differences in iron status or performance among the three groups, which could have been due to the fact that these athletes were neither iron depleted nor iron deficient. Vasankari and associates [42] found no improvement in exercise-induced oxidative stress in Finnish runners who were supplemented with vitamin C. Although Bryant and colleagues [43] reported diminished membrane damage with 400 IU/d of vitamin E in trained cyclists (22.3 ± 2 years old, who participated in four separate supplementation trials—placebo, 1 g/d of vitamin C, 400 IU/d of vitamin E, or 1 g/d of vitamin C plus 200 IU/d of vitamin E), 1 g/d of vitamin C promoted cellular damage. Neither vitamin E nor vitamin C (alone or taken together) improved exercise performance.

Although these particular researchers did not find a positive effect on nutritional status or performance with supplementation, the nutritional status of the athletes is probably the key factor in why these trials were not as effective. It would seem that athletes who were deficient in particular micronutrients would benefit the most from supplementation, in terms of nutritional status and athletic performance. Conversely, with respect to vitamin C, Peake [44] stated,
“... it remains unclear if regular exercise increases the metabolism of vitamin C. However, the similar dietary intakes and responses to supplementation between athletes and non-athletes suggest that regular exercise does not increase the requirement for vitamin C in athletes.”

LIMITATIONS IN RESEARCH

Although a great deal of research has been conducted on vitamins and minerals and athletes, more research is required. In addition, the research that has been published has limitations, including, but not limited to, the following: (1) small sample sizes; (2) mostly conducted in female athletes; (3) variations in type of sport studied; (4) variations in levels of training and fitness of athletes studied; (5) deficient in solid longitudinal data; (6) variations in methodology or study design (many have been cross-sectional); (7) differences in the types and amounts of supplementation used; and (8) some studies use a combination of vitamin and mineral supplements, making it difficult to ascertain the effects of one particular vitamin or mineral.

GENERAL RECOMMENDATIONS

Based on this review, athletes seem to consume inadequate amounts of many micronutrients (and energy); however, not all athletes have impaired nutritional status, which could be a result of study design and not their true status. Maughan [45] stated it well in his review, “When talented, motivated and highly trained athletes meet for competition the margin between victory and defeat is usually small. When everything else is equal, nutrition can make the difference between winning and losing.” Economos and associates [46] published a review article in which they reviewed 22 research studies on the nutritional intake of athletes. Based on their review, they recommend an energy intake of greater than 50 kcal/kg/d for male athletes who train for more than 90 min/d and 45 to 50 kcal/kg/d for female athletes who train for more than 90 min/d. They also recommend that athletes who consume low-energy diets focus on adequate intakes of iron, calcium, magnesium, zinc, and vitamin B12. “There is no special food that will help elite athletes perform better; the most important aspect of the diet of elite athletes is that it follows the basic guidelines for healthy eating” [46]. Athletes should work with a registered dietitian with expertise in sports nutrition to establish his or her nutritional and performance goals—goals that will lead to consistent eating and training, leading to improved performance [45]. With respect to micronutrients, it seems that if energy intake is sufficient, balanced, and varied, and nutritional status is within normal limits, vitamin-mineral supplementation is not warranted [45,47]. Supplementation may be warranted for athletes who restrict energy intake, participate in sports with weight restrictions, or limit certain foods and food groups [47].

SUMMARY

The micronutrient intake and status of athletes has been assessed in numerous researcher studies; however, limitations exist in many of these studies, owing to
the cross-sectional nature of the study design. From the published data, however, it seems that athletes who consume adequate energy and micronutrients would not benefit from supplementation. Longitudinal research is required (including supplementation studies) to follow athletes over time and evaluate dietary intake, nutritional status, and effects of performance properly.

References
