Magnesium and the Athlete

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Abstract
Magnesium is the fourth most abundant mineral and the second most abundant intracellular divalent cation in the body. It is a required mineral that is involved in more than 300 metabolic reactions in the body. Magnesium helps maintain normal nerve and muscle function, heart rhythm (cardiac excitability), vasomotor tone, blood pressure, immune system, bone integrity, and blood glucose levels and promotes calcium absorption. Because of magnesium's role in energy production and storage, normal muscle function, and maintenance of blood glucose levels, it has been studied as an ergogenic aid for athletes. This article will cover the general roles of magnesium, magnesium requirements, and assessment of magnesium status as well as the dietary intake of magnesium and its effects on exercise performance. The research articles cited were limited from those published in 2003 through 2014.

Introduction

Magnesium is the fourth most abundant mineral and the second most abundant intracellular divalent cation in the body. Approximately 50% of magnesium can be found in the bone and approximately 50% is inside body tissue cells and organs, while less than 1% is in the blood. It is a required mineral that is involved in more than 300 metabolic reactions in the body, including, but not limited to, protein synthesis, cellular energy production and storage, cell growth and reproduction, and deoxyribonucleic acid and ribonucleic acid synthesis (20,22). Magnesium helps maintain normal nerve and muscle function, heart rhythm (cardiac excitability), vasomotor tone, blood pressure, immune system, bone integrity, and blood glucose levels and promotes calcium absorption (20,22).

Because of magnesium's role in energy production and storage, normal muscle function, and maintenance of blood glucose levels, it has been studied as an ergogenic aid for athletes. Prior to discussing magnesium's possible role in athletic performance, magnesium requirements, assessment of magnesium status, and magnesium intake in athletes will be discussed.

Magnesium Requirements

The Recommended Dietary Allowance (RDA) for magnesium ranges from 400 to 420 $mg\cdot d^{-1}$ for males 14 to over 70 years of age. The RDA for women 14 to over 70 years of age ranges from 310 to 320 $mg\cdot d^{-1}$ (4). Good food sources of magnesium are listed in the Table.

Approximately 60% of adults in the United States do not consume the RDA for magnesium. Although increased diseases attributed to magnesium deficiency have not been reported, low dietary intake of magnesium and low magnesium status have been associated with chronic inflammatory stress conditions (11,12). In humans, deficient magnesium intakes are mostly marginal to moderate (approximately 50% to 90% of RDA). Marginal-to-moderate magnesium deficiency through exacerbating chronic inflammatory stress may be contributing significantly to the occurrence of atherosclerosis, hypertension, osteoporosis, diabetes mellitus, and cancer (11). Athletes who do not consume proper amounts of magnesium are not immune to a chronic inflammatory response and need to be aware of the potential consequences this could have to their short- and long-term health and athletic performance.

Assessment of Magnesium Status

The most common method used to assess magnesium status is via serum magnesium; however, this is the least sensitive marker of magnesium status because there is a lag time between serum changes in magnesium and subclinical deficiency.

The best marker for magnesium status is the magnesium loading test. With the magnesium loading test, individuals are infused with a certain amount of magnesium and then urine is collected over a period of 4 to 24 h. In the magnesium loading test, percent retention of magnesium is evaluated. If 80% or more of magnesium is retained in the body, the person is considered magnesium deficient.

Although the magnesium loading test is the gold standard to assess magnesium status, it is not practical and can be expensive. Thus, ionized magnesium can be used to evaluate magnesium status and is a good marker of magnesium status.

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Table.
Food sources of magnesium.

Food	Magnesium per Serving (mg)
1/4 cup of sunflower seeds without shell	119
1 ounce of dry roasted almonds	80
1/2 cup of boiled spinach	78
2 tablespoons of yeast extract spread (Marmite or Vegemite)	66
2 tablespoons of sesame seeds	56 to 68
3/4 cup of beans (black, lima, Navy, adzuki, white kidney, pinto, Great Northern, cranberry, chick peas)	60 to 89
1 cup of plain or vanilla soy milk	61
1/2 cup of cooked black beans	60
1/2 cup of cooked and shelled edamame	50
2 tablespoons of peanut butter	49
2 slices of whole wheat bread	46
1 cup of cubed avocado	44
3.5 ounces of baked potato with skin	43
1/2 cup of cooked brown rice	42
8 ounces of plain low-fat yogurt	42
1/2 cup of canned kidney beans	35
1 medium banana	32
3 ounces of farmed and cooked salmon	26
1 cup of milk	24 to 27
2 ounces of cooked halibut	24
1/2 cup of raisins	23
3 ounces of roasted chicken breast	22
3 ounces of 90% lean, pan-broiled ground beef	22
1/2 cup of chopped and cooked broccoli	12
1/2 cup of cooked white rice	10
1 medium apple	9
1 medium carrot	7

Adapted from: The United States Department of Agriculture (USDA) Nutrient Database Web site. Available from: http://www.ars.usda.gov/main/site_main.htm?modecode=80-40-05-25.

Adapted from: Dietitians of Canada. *Food Sources of Magnesium.*

Red blood cell magnesium is another way to measure magnesium status; however, it has not been established as a reliable maker at present.

Magnesium Intake in Athletes

Nutrient intake in athletes has been observed by a number of researchers; however, longer-term assessments need to be conducted for a more definitive evaluation. Furthermore, most of the research on dietary intake in athletes that has been conducted were cross-sectional. De Sousa et al. (3) examined the nutrient and water intake of adolescents from sports federations in the Federal District of Brazil. They collected 2- and 4-d nonconsecutive diet records from 326 adolescent athletes 11 to 14 years of age. They reported a lower magnesium intake among all athletes, but this was even lower for females compared with that for males. They stated that better nutrition guidelines are needed for adolescents, especially females, to meet adequate nutrition requirements.

Juzwiak et al. (8) also evaluated adolescent athletes' dietary intake. They collected 4-d non-consecutive food records and reported lower than required intake of magnesium. These observed deficiencies signify an additional hurdle for adolescents involved in competitive sports to achieve an optimum nutrition to maintain growth, health, and performance.

More individuals have been competing in various types of events, such as adventure racing or expedition racing, which is a combination of two or more endurance sports including orienteering, mountain biking, cross-country running, paddling, and climbing. Adventure racing can last from several hours to 10 d. Zalcman et al. (24) examined the energy intake in relation to the current recommendations for ultra-endurance athletes. They studied 24 adventure race athletes 24 to 42 years of age (18 men and 6 women). They assessed food intake using a 3-d diet record. Although the men and women athletes had adequate intake for most micronutrients, their magnesium intake was below requirements.

Wierniuk and Włodarek (23) evaluated the nutritional intake of 25 male athletes 19 to 25 years of age who were students at two universities in Poland and were aerobically trained. They analyzed 3-d diet records, using two weekdays and one weekend day. They reported that these athletes consumed significantly lower amounts of magnesium than recommended (60% below recommendations). They concluded that there is a need for sports nutrition counseling for health and exercise performance.

More recently, Silva and Paiva (16) assessed the dietary intake of 67 elite rhythmic gymnasts prior to a competition. They reported low intake of magnesium. Heaney et al. (6) also reported low magnesium intake (19% below requirements) in 72 elite female athletes from a variety of sports.

There is paucity of data on the dietary intake of collegiate athletes. Clark et al. (1) evaluated the pre- and postseason dietary intake of National Collegiate Athletic Association Division I female soccer players using 3-d diet records. They reported that pre- and postseason intake of magnesium were marginal (defined as <75% of the dietary reference intake).

Noda et al. (13) examined the nutrient intake of male collegiate soccer players, with the main goal of advising these student-athletes about healthy nutrition practices that also could optimize performance. They used food frequency questionnaires to assess dietary intake in 31 soccer players and 15 controls. Noda et al. (13) found that the mean magnesium intake was lower than the RDA for Japan. Imamura et al. (7) also researched collegiate athletes. They evaluated the dietary intake, from food frequency questionnaires, of collegiate rugby players (18 forwards and 16 backs) compared with that of 26 sedentary individuals. Imamura et al. (7) reported that magnesium intake was lower than the recommended intake in the rugby players compared with that in the sedentary controls. Thus, international female and male collegiate soccer players, as well as male rugby players, do not consume the proper amount of magnesium in their diets, and this is likely the case for other collegiate athletes.

In a study to determine whether athletes required magnesium supplementation, Czaja et al. (2) evaluated the magnesium intake of 62 elite Polish runners from their daily food rations. Compared with the previously mentioned research studies, these researchers measured the magnesium content in the food using flame atomic absorptiometry. Czaja et al. (2) reported that the female runners' analyzed diets provided 256 + 111 mg of magnesium, while the male runners' analyzed diets provided 284 + 58 mg of magnesium. Conversely, computer analyses of the diets were 159% to 181% higher than the analyzed food rations, indicating a significant discrepancy between the two. This also suggests that those researchers, who only analyze diet records, may be significantly overestimating magnesium intake in athletes. Czaja et al. (2) stated that these results indicate justification of magnesium supplementation in these elite Polish runners. Although just one study in a select group of athletes, these results are noteworthy because they indicate the need for more food analyses to definitively determine true magnesium intake.

Because magnesium deficiency has been linked with lower bone mineral density, Matias et al. (10) examined whether magnesium intake mediates the association between bone mineral density and lean soft tissue in elite male (n = 8) and elite female (n = 9) swimmers.

They measured bone mineral density, bone mineral content, lean soft tissue, and fat mass using dual-energy x-ray absorptiometry. Dietary intake was analyzed using a 7-d food record. Matias et al. (10) reported a significantly lower than recommended intake of magnesium among the athletes. In addition, they reported a significant association between bone mineral density and lean soft tissue; however, when magnesium intake was included, they reported it to be a strong and significant predictor of bone mineral density, even after adjusting for energy, vitamin D, calcium, and phosphorus intake. They concluded that "young athletes engaged in low-impact sports, should pay special attention to magnesium intake, given its potential role in bone mineral mass acquisition during growth" (10).

Magnesium Status and Athletic Performance

While assessing magnesium intake is important, assessing magnesium status on exercise performance is equally important. Tong et al. (18) evaluated the serum oxidant and antioxidant status in male runners (n = 12), cyclists (n = 12), and untrained adolescents (n = 12). They measured serum thiobarbituric acid-reactive substances, xanthine oxidase, catalase, reduced glutathione, superoxide dismutase, and total antioxidant capacity. Dietary intake was evaluated using 7-d diet records. Tong et al. (18) reported significant correlations between dietary magnesium intake and catalase and reduced glutathione concentrations. Although magnesium does not play a major role in antioxidant production in the body, the association with catalase and reduce glutathione concentrations in this study indicate its importance with these enzymes.

Although Tong et al. (18) evaluated the effects of magnesium intake on antioxidant status, Soria et al. (17) examined the effect of exercise intensity on magnesium concentration. They studied 27 well-trained euhydrated endurance athletes (average age, 15 years) on incremental exercise on cycle ergometer with an increased workload of 0.5 $W \cdot kg^{-1}$ of body weight every 10 min until exhaustion. They measured plasma magnesium concentrations at baseline, the end of each 10-min state, and at 3, 5, and 7 min after exercise. They did not report any changes in plasma magnesium concentrations during any time point of the study. Soria et al. (17) stated that plasma volume plays an essential role in magnesium homeostasis during exercise. This is true of most minerals; however, because when plasma volume decreases, there may be a hemoconcentration of that mineral, plasma volume should be measured. Nonetheless, this study emphasizes the importance of being properly hydrated for both exercise performance and magnesium status.

Magnesium Supplementation and Athletic Performance

Magnesium intake and status are both important for overall health and athletic performance; however, can magnesium supplementation improve athletic performance? Setaro et al. (15) examined whether magnesium supplementation acts as an ergogenic aid in the athletic performance of volleyball players. They studied 25 professional male volleyball players, who were randomly assigned to take either 350 $mg \cdot d^{-1}$ of magnesium or a control group (500 mg of maltodextrin) for 4 wk. They evaluated the following at baseline and after 4 wk of supplementation: erythrocyte, plasma and urinary magnesium levels, plasma creatine kinase activity, lactate production, maximal oxygen uptake ($\dot{V}O_{2max}$) and plyometric performance (squat jump, counter-movement jump, counter-movement jump with arm swing) and isokinetic performance (peak torque, potency, and total work). Setaro et al. (15) reported that erythrocyte and urinary magnesium concentrations as well as creatine kinase activity and $\dot{V}O_{2max}$ stayed within average ranges in both the supplemented and control groups. Nonetheless, plasma magnesium concentrations decreased significantly within the supplemented group, which is not an expected response. They also reported significant decreases in lactate production and significant increases (of up to 3 cm) in counter-movement jump and counter-movement jump with arm swing in the magnesium-supplemented group, with no changes reported in the control group.

While some positive changes occurred with supplementation, the results of this study do not provide a clear indication that magnesium supplementation is warranted as an ergogenic aid.

Supplement manufacturers have claimed that supplements containing magnesium lactate dehydrate and calcium lactate monohydrate will improve athletic performance because the lactate will be used for energy (14). Nonetheless, there is paucity of data suggesting that these supplements will enhance the use of the lactate shuttle system for increased energy production during exercise. Peveler et al. (14) evaluated whether magnesium lactate dehydrate and calcium lactate monohydrate supplementation would act as ergogenic aids. They studied nine competitive cyclists (seven men and two women) who rode in three simulated 20-km time trials on a Velotron. The researchers used a Velotron to increase control over the time trials and to simulate road cycling. Peveler et al. (14) did not report significant differences between the placebo and magnesium lactate dehydrate or calcium lactate monohydrate with respect to time, mean power, or heart rate. Although not significant, times during the placebo trials were faster in relation to the magnesium lactate dehydrate or calcium lactate monohydrate trials, although not significantly faster. Based on these results, it appears that supplementing with either magnesium lactate dihydrate or calcium lactate monohydrate does not improve times during a simulated 20-km cycling time trial.

Although not a supplementation study, Gulick et al. (5) examined whether the topical cream MagPro™ would improve muscle flexibility or muscular endurance. Twelve physically active men and 26 physically active women (phase 1) as well as nine physically active men and nine physically active women (phase 2) participated in this double-blind, randomized controlled trial. In phase 1, individuals applied MagPro™ cream to the gastrocnemius-soleus muscle (on one leg) then applied the placebo cream to the gastrocnemius-soleus muscle (on the other leg). They then conducted a stretching protocol and compared ankle dorsiflexion before and after the cream application.

In phase 2, one cream was applied to both quadriceps muscles, after which the participants exercised on a cycle ergometer. One week later, the opposite cream was applied to both quadriceps muscles, after which the participants exercised on a cycle ergometer.

Gulick et al. (5) reported no significant differences in flexibility between the MagPro™ cream and the placebo cream. In addition, there were no significant differences between the MagPro™ cream and the placebo cream in cycling endurance performance. Thus, applying a cream containing magnesium will not act as an ergogenic aid with respect to flexibility and endurance performance.

In a pilot study, Kass et al. (9) had a twofold purpose to their study. First, they wanted to study the effects of magnesium supplementation on systolic blood pressure at rest and during recovery from aerobic and resistance exercises as well as study magnesium's effects on exercise performance. Secondly, they examined whether a habitually low or high dietary intake of magnesium affected the results. They studied 16 physically active men, about 21 years of age, who were randomly assigned to 300 $mg{\cdot}d^{-1}$ of magnesium oxide supplementation or a control group for 14 d. At baseline and after 14 d, resting blood pressure and heart rate were assessed prior to a 30-min maximal cycling test, which was followed by a 3-by-5-second isometric bench press. Participants also were asked to keep a 3-d food record.

Kass et al. (9) reported a significant decrease in resting systolic blood pressure (8.9 mm Hg reduction) and postexercise (13 mm Hg reduction) in the magnesium-supplemented group. In addition, recovery blood pressure was significantly lower in the magnesium-supplemented group compared with that in the control group. Nonetheless, there were no differences in exercise performance between the groups. In addition, the group who consumed higher magnesium in their diets had additive positive effects on blood pressure compared with those with a lower magnesium intake. Although there were no direct effects on exercise performance, these results indicate that both supplementation and high dietary intake of magnesium can significantly improve postexercise blood pressure.

The research presented thus far has been conducted in relatively young, active men and women; however, little research has been conducted on the effects of magnesium supplementation in older individuals. Veronese et al. (21) researched the effects of 12 wk of magnesium supplementation (300 mg of magnesium oxide per day) in 53 women compared with a control group ($n = 71$). These women were 71.5 + 5.2 years of age. The major outcome measure was a change in the short physical performance battery; the secondary outcome measures were changes in peak torque, isometric and isokinetic strength of the lower limbs, as well as handgrip strength. After 12 wk, the magnesium-supplemented group had a significantly better total short physical performance battery score compared with that of the control group. Similar to Kass et al. (9), Veronese et al. (21) reported worse scores in those individuals whose magnesium intake was below the RDA. No differences were observed in the secondary outcome measures. Veronese et al. (21) stated that "These findings suggest a role for magnesium supplementation in preventing or delaying the age-related decline in physical performance."

It should be noted that in the aforementioned studies, magnesium status was either not evaluated or assessed via plasma or serum magnesium concentrations, which are less sensitive to change. Using the magnesium loading test, as previously mentioned, is expensive and not practical to use in the field; however, more researchers should consider using both plasma or serum magnesium and ionized magnesium to more definitively assess magnesium status.

Summary

Magnesium is an important mineral with respect to energy metabolism, and thus would seem important with respect to exercise performance. Based on the research presented in this review, it appears that most athletes do not consume adequate amounts of magnesium in their diets. In addition, the computer analyses of diets may overestimate true dietary intake. Although there is some evidence that magnesium supplementation may enhance athletic performance in individuals of all ages, more research is required for longer periods to definitively make the case that magnesium can act as a true ergogenic aid.

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