KEY POINTS

1. For the strength-trained athlete attempting to increase muscle mass, probably the most important nutritional considerations are to obtain sufficient energy and protein. Adequate amounts of both may be obtained simply by increasing the amount of complex carbohydrates and healthful protein sources in the daily diet.

2. Most of the commercial nutritional products marketed for strength-trained athletes are promoted as a dietary means to influence metabolic processes that stimulate muscle growth and/or facilitate the loss of body fat, primarily by inducing the endogenous production or release of testosterone or human growth hormone (HGH).

3. There is little or no scientific evidence supporting positive effects on muscle growth, body fat reduction, or strength enhancement in strength-trained athletes for the following nutritional supplements: arginine, lysine, and ornithine (amino acids); ornithine alpha-ketoglutarate (OKG); inosine; choline; yohimbine; "glandulars;" vitamin B12; carnitine; chromium; boron; magnesium; medium chain triglycerides; omega-3 fatty acids; gamma oryzanol; Smilax. Additional research is needed to support or refute claims made for some of these products, as well as others that may be of interest to strength-trained athletes, e.g., creatine and antioxidant vitamins.

4. Given the fraudulent claims made for most nutritional supplements marketed for strength-trained athletes, and because many are relatively expensive, let the buyer beware!

INTRODUCTION

Muscular strength represents the capacity to generate power or force and is thus an essential requisite for all athletes. The general belief is that increased strength will enhance performance and prevent injuries, so specific strength resistance training programs have been developed and applied to almost all sports. Strength training may also confer some health benefits by favorably modifying risk factors associated with the development of several chronic diseases (Stone et al., 1991) or by improving psychological well-being via an enhanced body image due to body composition changes (Tucker, 1987). Furthermore, strength training is recommended as part of a comprehensive fitness program (American College of Sports Medicine, 1990).

Although strength training may be an adjunct to training programs for all sports, it is particularly important for athletes involved in sports where increased lean body mass (LBM), particularly muscle mass, is a critical determinant of success. Increased muscle mass is important for enhancing strength and power production (e.g., for weightlifters), improving stability (e.g., for interior linemen in football) or enhancing one's aesthetic appearance (e.g., for bodybuilders).

The most obvious effect of strength training is muscular hypertrophy. To help compensate for genetic limitations in hormonal status, particularly testosterone, many strength-trained athletes have used exogenous anabolic/androgenic steroids (AAS) effectively to maximize muscle growth and strength, and many athletes view AAS as an essential component for success (Smith & Perry, 1992). However, the use of AAS has been banned by most athletic governing bodies and has also been associated with a variety of health problems (Williams, 1994; in press). Thus, although AAS continue to be used by athletes, as well as by noncompetitive recreational athletes (Perry et al., 1992), there is increasing focus on nutrient supplementation as an alternative ergogenic means to enhance muscular mass and strength (Cowart, 1992; Kleiner, 1991).

Several recent surveys (Barron & Vanscoy, 1993; Grunewald & Bailey, 1993; Philen, et al., 1992) of commercially marketed nutritional supplements published in health and bodybuilding magazines (e.g., Flex, Ironman, Muscle and Fitness) have identified hundreds of products with advertised claims of performance benefits, the most frequently mentioned being enhanced muscle growth. The table in the accompanying handout provides a listing of the most commonly marketed nutritional supplements that claim to stimulate muscle growth, their additional hypothetical roles, and a summary of the available research with human subjects. The focus of this review will be on those nutritional supplements advertised to enhance body composition or strength development, although in many cases scientific data are very limited or nonexistent.
effect of arginine and lysine supplementation on body composition or strength (Mitchell et al., 1993), and no effect of a supplement containing all 20 amino acids on lifting performance (Fry et al., 1993). Ornithine a-ketoglutarate (one or two molecules of ornithine bound to a molecule of a-ketoglutarate) is a recent addition to the list of “anabolics” available to strength athletes. This compound, known as OKG, purportedly increases insulin output and action (Cynober et al., 1984), thereby attenuating protein degradation in skeletal muscle (Gelland et al., 1987). There is also a preliminary report of a large OKG-induced increase in insulin-like growth factor I (IGF-I) and stature in six prepubertal children afflicted with bowel disorders (Moukarzel et al., 1993). The IGF-I is a peptide responsible for many of the growth promoting effects of growth hormone. There are apparently no complete peer-reviewed reports of well-controlled experiments on OKG effects on resistance-trained subjects as of this writing.

In summary, there is no consistent evidence supporting an anabolic or ergogenic effect of amino acid supplement-mentation in the diets of strength-trained athletes. Creatine. Creatine is a nitrogen-containing substance found naturally in meat. In the body it combines rapidly with phosphate to form creatine phosphate, a high energy compound stored in the muscle. Recent studies have shown that oral supplements of creatine monohydrate, approximately 20-25 g/d, could lead to increased creatine content in the muscle (Harris et al., 1992), increased muscle torque in repeated bouts of maximal isokinetic exercise (Greenhafl et al., 1993), and improved performance in repeated 6 s bouts of high-intensity cycling exercise (Balsom et al., 1993). Additionally, Balsom and others (1993) reported a significant increase in body mass (1.1 kg) following 6 d of supplementation with 25 g creatine monohydrate/d; they speculated that the increase could be due to synthesis of contractile proteins or to greater retention of water. These initial data are impressive, but additional research is needed for confirmation.

Inosine. Inosine is not an amino acid, but a nucleoside involved in the formation of purines such as adenine. Advertisements have suggested that inosine supplementation may enhance adenosine triphosphate (ATP) formation in the muscle and thus be of value to strength athletes. However, there are no research data to support these claims.

Choline. Choline is an amine, a constituent of phospholipids found in plant and animal foods. Choline is a precursor for the development of acetylcholine, a neurotransmitter secreted at the myoneural junction, and phosphatidyl-choline (lecithin), a component of lipoproteins involved in lipid transport. Based on these roles, choline supplementation may be hypothesized to either increase strength or facilitate the loss of body fat, but no research has been uncovered to support these hypotheses (Grunewald & Bailey, 1993; Williams, 1992)

Yohimbine. Yohimbine is a nitrogen-containing alkaloid extracted from the bark of the yohimbe tree. It functions as an alpha2-adrenoreceptor blocker, increasing serum levels of norepinephrine (Grossman et al., 1991). Yohimbine has been used as an adjunct in the treatment of obesity (Kucio et al., 1991) and for the treatment of impotence (Grunewald & Bailey, 1993). Comparable to Smilax, yohimbe and yohimbe bark are advertised to increase testosterone levels, but no scientific data have been disclosed supportive of any anabolic effects.

Glandulars. Glandulars are extracts from various animal tissues or glands, such as the pituitary, thymus, adrenal, and testes. Their use is based on the premise that they will enhance function of the glands in the body from which they are derived, e.g., orchic extract from the testes purportedly facilitates testosterone production. However, these glandular extracts are degraded during the digestive process and are inactive when absorbed as the digested components (Newsom, 1989).

VITAMINS AND MINERALS

One of the most popular products marketed for all athletes is the multivitamin/mineral supplement. Most contemporary research studies report that long-term supplementation with multivitamin/mineral compounds does not enhance sport performance, including strength performance (Singh, et al., 1992; Telford et al., 1992). However, several individual vitamins and minerals have been marketed specifically for strength athletes.

Vitamin B12. Vitamin B 12 is essential in the synthesis of DNA, the enhanced production of which may be hypothesized to stimulate muscle growth. A coenzyme form of B 12, known as Dibencobal, has been advertised for bodybuilders to increase muscle growth and strength, but these claims are based on erroneous data. No studies have been uncovered documenting a growth promoting or strength enhancing effect of Dibencobal, nor has supplementation with cyanocobalamin, a form of B 12, been found to improve performance in various tests of strength (Williams, 1992). Antioxidant Vitamins. High-intensity exercise, particularly intense eccentric muscle contractions during the early stages of a strength training program, may cause muscle tissue damage (Evans, 1991). A possible cause of this muscle damage following intense exercise is an increased production of free radicals, leading to lipid peroxidation. Singh (1992) has suggested that the antioxidant vitamins (C, E, and beta-carotene) may protect against such damage. Numerous supplementation studies have been conducted with antioxidant vitamin supplement-entation, as well as other antioxidants such as selenium and coenzyme Q10, to evaluate their potential protective effect. Some early studies produced promising results, but Goldfarb (1993) recently summarized the literature and noted that although trained individuals may have a greater need for antioxidants, more research is needed to justify supplementation with antioxidants to protect against exercise-induced muscle damage.

Carnitine. Carnitine is a vitamin-like compound, found naturally in food, particularly in meats, but it is also synthesized in the body. Carnitine facilitates the transfer of long-chain fatty acids into the mitochondria and has been theorized to be ergogenic for aerobic endurance athletes. However, recent well-controlled research suggests otherwise (Decombaz et al., 1993). Carnitine has been advertised to strength athletes as a means to facilitate loss of body fat, but no supportive data have documented such an effect.

Chromium. Chromium is considered to be an essential component of the glucose-tolerance factor, which potentiates the effect of insulin (Lefavi et al., 1992), and is currently being marketed as an anabolic aid for strength athletes, primarily in the form of chromium picolinate (Grunewald & Bailey, 1993). Two studies conducted by Evans (1989) demonstrated that daily chromium picolinate supplementation (200 g) for approximately 7 wk to either male volunteers in a weight training class or college football players in training, significantly increased LBM and decreased body fat in comparison to the placebo groups. However, these studies have been criticized for poor experimental control (Lefavi et al., 1992); furthermore, there were no tests of strength conducted in either study. Two more recent reports, with research designs similar to those reported by Evans but with
NUTRITIONAL SUPPORT FOR MUSCLE GROWTH

The diet provides six general classes of nutrients (carbohydrate, fat, protein, vitamins, minerals, and water) indispensable to human physiology because they function in one or more ways to (1) provide energy, (2) support growth and development, or (3) regulate metabolic processes. All of these functions are important for strength-trained athletes attempting to increase muscle mass and strength.

NUTRIENTS FOR ENERGY AND SUPPORT OF MUSCLE GROWTH

Although muscle tissue contains numerous nutrients, protein is the major constituent of muscle other than water. However, the other energy nutrients are essential for synthesis of contractile proteins and other regulatory proteins in the cell. Adequate dietary energy and protein are thus two key elements underlying muscle growth.

Energy. According to Lemon (1991), perhaps the most important single factor determining protein needs of the strength athlete is the adequacy of energy intake. For athletes who are maintaining body weight, daily energy intake must equal daily energy expenditure. However, for athletes attempting to stimulate muscle development, it is not known exactly how many additional megajoules (MJ) of energy are necessary to form one kilogram (kg) of muscle tissue, nor is it known in what form this energy should be consumed (1MJ=238 kcals). Estimates range from about 21 to 33.6 MJ/kg of muscle (equivalent to 2,270 to 3,630 kcals per pound of muscle).

Therefore an additional intake of approximately 2.2 MJ (500 kcal) daily by an athlete attempting to gain 1 lb of muscle mass per week is a reasonable goal (Williams, 1992) that has been supported by research (Bartels et al., 1989).

Protein. The recommended dietary allowance (RDA) for protein is 0.8 g/kg body weight per day for individuals age 19 and above, 0.9 g/kg for age 15-18, and 1.0 g/kg for age 11-14; the RDA will support normal growth and development in the average individual. However, athletes involved in intense strength training programs, particularly novices, may have significantly higher protein requirements than do sedentary individuals, as documented in several recent studies (Lemon, 1991; Lemon et al., 1992; Tamopolsky et al., 1992). To maintain or possibly increase muscle mass while strength training, these investigators have recommended a protein RDA of 1.5-2.0 g/kg, or about twice the current American and Canadian RDA.

These additional energy and protein needs may be obtained easily from a balanced, healthful diet. Complex carbohydrates, such as breads, cereals, rice and pasta, provide healthful sources of energy and serve to spare the use of protein as an energy source (Lemon & Mullin, 1980). Depending on energy intake, a diet containing 12-15 % of the total energy intake as protein could provide about 1.5-2.0 g/kg. Healthful protein sources include lean meat, fish, and poultry, skim milk, and legumes complemented with grains. Protein supplements targeted to strength-trained athletes have been marketed for years as either powdered protein, canned liquid meals high in protein, or special concoctions high in protein content. However, the protein content in these products is usually derived from other food sources, such as milk, egg, or soy protein, and provides no advantages over natural sources. There are no reliable research data supporting a beneficial effect of such protein supplements when compared to comparable amounts of natural protein sources.

Nevertheless, such commercial supplements may be a convenient means for some busy athletes to secure additional protein in the diet. Still, it is imperative to emphasize the point that such supplements should be used to complement a balanced, healthful diet, not to serve as a substitute for wholesome, natural foods (Williams, 1992).

NUTRIENTS FOR METABOLIC REGULATION OF MUSCLE GROWTH

Resistance training is a potent stimulus for muscle growth, and its anabolic effect may be influenced by adequate levels of serum testosterone, human growth hormone (HGH), and insulin, all anabolic hormones. Exogenous testosterone administration may increase LBM, particularly when normal serum levels are low as in constitutionally delayed puberty (Gregory et al., 1992). Further, exogenous HGH supplementation may increase LBM in aged males with HGH deficiency (Binnerts et al., 1992); however, two recent, well-controlled studies have not shown any significant anabolic effect when HGH was administered to healthy young males involved in strength training programs (Deyssig et al., 1993; Yarasheski et al., 1992). Therefore, it appears likely that nutritional supplements could be effective if they remedied a deficiency and corrected some hormonal imbalance, but might not be effective if the body’s hormone receptors are sensitive to naturally occurring testosterone, growth hormone, and/or insulin.

Insulin has antiproteolytic effects on skeletal muscle protein under certain conditions (Gelland et al., 1987). In other words, insulin tends to spare muscle protein from being degraded. However, there is no systematic evidence that chronic increases in circulating insulin enhance muscle mass in resistance-trained human beings. On the negative side, chronic hyperinsulinemia could result in serious disorders of carbohydrate and fat metabolism.

AMINO ACIDS AND OTHER NITROGEN CONTAINING SUBSTANCES

The infusion or ingestion of various individual amino acids has been used clinically to regulate the secretion of HGH, somatomedins (insulin-like growth factors), and insulin (Jacobson, 1990; Kreider, 1993). This clinical research provides the rationale underlying the fact that amino acid mixtures are the largest category of supplements marketed to bodybuilders (Grunewald & Bailey, 1993). However, although some studies have shown that high oral doses of ornithine may increase HGH secretion (Bucci et al., 1990), more recent research revealed no significant effect of arginine, lysine, ornithine, and tyrosine, either separately or in various combinations, on either HGH (Fogelholm et al., 1993; Lambert et al., 1993; Suminski et al., 1993) or insulin secretion (Bucci et al., 1992; Fogelholm et al., 1993). Nevertheless, two recent, well-controlled studies using experimentally-induced HGH deficiency (Binnerts et al., 1992; Elam et al., 1989) revealed that 2 g/d of arginine and ornithine (1 g each), in conjunction with a strength training program, reduced body fat, increased LBM, and increased strength over a 5 wk period. In a review of food supplements marketed for athletes, Barron and Vanscoy (1993) cited this research as scientific support for claims that arginine/ornithine could stimulate HGH and increase LBM. However, these studies have been criticized for questionable statistical analysis (Williams, 1992). Moreover, several studies using experienced weightlifters and more appropriate experimental designs have not shown any significant effect of oral arginine supplementation on peak muscle torque or muscular endurance (Hawkins et al., 1991), no effect of arginine and lysine supplementation on body composition or strength...
improved experimental control, revealed no significant effect of chromium picolinate supplementation (200 g/d) on LBM, body fat, or strength in either males involved in a weight training program (Hallmark et al., 1993) or college football players involved in resistance training (Clancy et al., 1993). Although the research data are limited, there is no firm scientific support for the contention that chromium picolinate supplementation exerts an ergogenic effect on strength athletes.

Boron. Boron is not currently considered an essential mineral, but it is an essential component of plant foods. Nielsen (1992) noted that boron may help prevent osteoporosis, and in a related study he reported that boron supplements given to postmenopausal women for 48 d (after they had been deprived of boron for four months) doubled their serum testosterone levels. Shortly thereafter, advertisements in muscle magazines indicated that boron could increase serum testosterone levels. However, Nielsen later commented that his results were completely misinterpreted: for example, continued boron supplementation to the postmenopausal women did not increase testosterone levels any higher, and boron supplementation with males did not increase serum testos-terone levels at all. Moreover, Ferrando and Green (1993) provided boron supplements to bodybuilders in training, and although serum boron levels increased, there were no significant increases in serum testosterone, LBM, or strength.

Given these findings, boron supplementation does not appear to exert anabolic effects in strength-trained athletes. Magnesium. Magnesium is an essential nutrient with multiple metabolic roles, including its involvement in protein synthesis and muscle contraction. In a 1988 review, McDonald and Keen did not find any data showing an ergogenic effect of magnesium supplementation in individuals who had normal body magnesium levels. These findings are supported by a more recent study by Terblanche and others (1992) who noted no effect of magnesium supplementation on quadriceps muscle strength and fatigue during 6 wk of recovery from a marathon. However, Brilla and Haley (1992) reported that magnesium supplementation to untrained males and females involved in 7 wk of weight training increased quadriceps muscle torque significantly more than in the placebo group. Currently, there are too few data to justify magnesium supplementation for strength athletes, but more research appears to be warranted.

LIPIDS

Although dietary lipids may be used as a source of energy for strength athletes attempting to gain weight, most of the lipid derivatives marketed for strength athletes are advertised to provide beneficial effects on metabolic processes. Plant sterols, or phytosterols, are marketed because of their structural resemblance to testosterone. Medium chain triglycerides. Medium chain triglycerides (MCT) are water soluble and can be absorbed and metabolized readily. Commercial brands are advertised to promote muscularity and to lower body fat, possibly because of their energy content (app. 7 kcal/gm) and their thermic effect upon ingestion. MCT supplementation has been studied in relation to aerobic endurance exercise, and found to be ineffective, but no studies have been uncovered revealing an ergogenic effect on muscularity or weight loss in strength-trained athletes.

Omega-3 fatty acids. Omega-3 fatty acids (O-3FA), polyunsaturates found primarily in fish oils, may be metabolized in the body to eicosanoids. Bucci (1993) noted that one specific eicosanoid, prostaglandin El (PGEl) may stimulate HGH. Bucci cited two studies in which a commercially available blend of fish and vegetable oils purported increased strength and speed when it was provided to university football teams. However, the only source cited by Bucci (1993) is the training manual for the commercial product used in the studies. As with MCT, O-3FA have not been shown to enhance aerobic endurance, and no peer-reviewed studies have been found supporting an ergogenic effect on strength-trained athletes.

Gamma oryzanol. Gamma oryzanol is a phytosterol, a ferulic acid ester derived from rice bran oil. Both gamma oryzanol and ferulic acid products are advertised as substances that increase serum testosterone and HGH. Although gamma oryzanol may influence lipid metabolism, there are no data supportive of an ergogenic effect in humans. Wheeler and Garleb (1991) reviewed research with animals and speculated that gamma oryzanol actually may reduce testosterone production.

Smilax. There are several hundred species of the genus Smilax. Tinctures that contain various phytosterols, such as sitosterol and stigmasterol, may be extracted from the roots, as can sarsaparilla, a flavoring agent, and many Smilax extracts have been used in folk medicine for years. Smilax is advertised as a means to stimulate testosterone production and to increase muscle gains and strength (Grunewald & Bailey, 1993), but there are no scientific data to support these claims.

SUMMARY

Vitamin and mineral products constitute about 80 percent of all dietary supplements marketed, and in appropriate doses they are most likely safe for the healthy individual. However, some herbal products lack safety data, and their use has caused various health problems, even fatalities (Huxtable, 1992). Pearl (1993) highlighted some of the medical complications associated with consumption of Smilax, yohimbine, and other components of popular nutritional supplements for bodybuilders. Additionally, some herbal products may contain substances whose use is banned for athletic competition. For example, Ma Huang contains the stimulant ephedrine.

Finding an effective nutritional alternative to AAS use by athletes is highly desired but, unfortunately, as documented in this review and via interpretation of studies evaluating the effect of nutritional supplements on physical performance surveyed in the medical literature from 1966-1992 (Barron & Vanscoy, 1993), there are few scientific data available supporting advertised claims of increased muscle mass, strength, or power for nutritional supplements targeted for strength-trained athletes. For products with preliminary supportive data, additional confirmatory studies are needed.

Fortunately, fraudulent advertising may be a thing of the past, because by July, 1994, the U.S. Food and Drug Administration has mandated that all health claims on dietary supplement labels must be supported by scientific agreement. By July, 1995, all nutrients in dietary supplements must be listed on the label. Most likely, however, dietary supplement manufacturers will use other marketing techniques, such as testimonials, pamphlets and other advertising media that are protected by the first amendment to the Constitution. Consumers have a right to expect nutritional supplements to be high quality products that are both safe and effective as advertised. Given the fact that some athletes may spend as much as $400 per month for such supplements (Short & Marquart, 1993), the phrase caveat emptor (let the buyer beware) is certainly advisable.