

Review article

International Society of Sports Nutrition Symposium, June 18-19, 2005, Las Vegas NV, USA - Symposium - Macronutrient Utilization During Exercise: Implications For Performance And Supplementation

PROTEIN – WHICH IS BEST?

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Received: 26 May 2004 / Accepted: 28 June 2004 / Published (online): 01 September 2004

ABSTRACT

Protein intake that exceeds the recommended daily allowance is widely accepted for both endurance and power athletes. However, considering the variety of proteins that are available much less is known concerning the benefits of consuming one protein versus another. The purpose of this paper is to identify and analyze key factors in order to make responsible recommendations to both the general and athletic populations. Evaluation of a protein is fundamental in determining its appropriateness in the human diet. Proteins that are of inferior content and digestibility are important to recognize and restrict or limit in the diet. Similarly, such knowledge will provide an ability to identify proteins that provide the greatest benefit and should be consumed. The various techniques utilized to rate protein will be discussed. Traditionally, sources of dietary protein are seen as either being of animal or vegetable origin. Animal sources provide a complete source of protein (i.e. containing all essential amino acids), whereas vegetable sources generally lack one or more of the essential amino acids. Animal sources of dietary protein, despite providing a complete protein and numerous vitamins and minerals, have some health professionals concerned about the amount of saturated fat common in these foods compared to vegetable sources. The advent of processing techniques has shifted some of this attention and ignited the sports supplement marketplace with derivative products such as whey, [casein](#) and soy. Individually, these products vary in quality and applicability to certain populations. The benefits that these particular proteins possess are discussed. In addition, the impact that elevated protein consumption has on health and safety issues (i.e. bone health, renal function) are also reviewed.

KEY WORDS: Sport supplementation, ergogenic aid, animal protein, vegetable protein.

INTRODUCTION

The protein requirements for athletic populations have been the subject of much scientific debate. Only recently has the notion that both strength/power and endurance athletes require a greater protein consumption than the general population become generally accepted. In addition, high protein diets have also become quite popular in the general population as part of many weight reduction programs. Despite the prevalence of high protein diets in athletic and sedentary populations,

information available concerning the type of protein (e.g. animal or vegetable) to consume is limited. The purpose of this paper is to examine and analyze key factors responsible for making appropriate choices on the type of protein to consume in both athletic and general populations.

Role of Protein

Proteins are nitrogen-containing substances that are formed by amino acids. They serve as the major structural component of muscle and other tissues in

the body. In addition, they are used to produce hormones, enzymes and hemoglobin. Proteins can also be used as energy; however, they are not the primary choice as an energy source. For proteins to be used by the body they need to be metabolized into their simplest form, amino acids. There have been 20 amino acids identified that are needed for human growth and metabolism. Twelve of these amino acids (eleven in children) are termed nonessential, meaning that they can be synthesized by our body and do not need to be consumed in the diet. The remaining amino acids cannot be synthesized in the body and are described as essential meaning that they need to be consumed in our diets. The absence of any of these amino acids will compromise the ability of tissue to grow, be repaired or be maintained.

Protein and Athletic Performance

The primary role of dietary proteins is for use in the various anabolic processes of the body. As a result, many athletes and coaches are under the belief that high intensity training creates a greater protein requirement. This stems from the notion that if more protein or amino acids were available to the exercising muscle it would enhance protein synthesis. Research has tended to support this hypothesis. Within four weeks of protein supplementation (3.3 versus 1.3 g·kg⁻¹·day⁻¹) in subjects' resistance training, significantly greater gains were seen in protein synthesis and body mass in the group of subjects with the greater protein intake (Fern et al., 1991). Similarly, Lemon et al. (1992) also reported a greater protein synthesis in novice resistance trained individuals with protein intakes of 2.62 versus 0.99 g·kg⁻¹·day⁻¹. In studies examining strength-trained individuals, higher protein intakes have generally been shown to have a positive effect on muscle protein synthesis and size gains (Lemon, 1995; Walberg et al., 1988). Tarnapolsky and colleagues (1992) have shown that for strength trained individuals to maintain a positive nitrogen balance they need to consume a protein intake equivalent to 1.8 g·kg⁻¹·day⁻¹. This is consistent with other studies showing that protein intakes between 1.4 – 2.4 g·kg⁻¹·day⁻¹ will maintain a positive nitrogen balance in resistance trained athletes (Lemon, 1995). As a result, recommendations for strength/power athletes' protein intake are generally suggested to be between 1.4 - 1.8 g·kg⁻¹·day⁻¹.

Similarly, to prevent significant losses in lean tissue endurance athletes also appear to require a greater protein consumption (Lemon, 1995). Although the goal for endurance athletes is not necessarily to maximize muscle size and strength,

loss of lean tissue can have a significant detrimental effect on endurance performance. Therefore, these athletes need to maintain muscle mass to ensure adequate performance. Several studies have determined that protein intake for endurance athletes should be between 1.2 – 1.4 g·kg⁻¹·day⁻¹ to ensure a positive nitrogen balance (Freidman and Lemon, 1989; Lemon, 1995; Meredith et al., 1989; Tarnopolsky et al., 1988). Evidence is clear that athletes do benefit from increased protein intake. The focus then becomes on what type of protein to take.

Protein Assessment

The composition of various proteins may be so unique that their influence on physiological function in the human body could be quite different. The quality of a protein is vital when considering the nutritional benefits that it can provide. Determining the quality of a protein is determined by assessing its essential amino acid composition, digestibility and bioavailability of amino acids (FAO/WHO, 1990). There are several measurement scales and techniques that are used to evaluate the quality of protein.

Protein Rating Scales

Numerous methods exist to determine protein quality. These methods have been identified as protein efficiency ratio, biological value, net protein utilization, and protein digestibility corrected amino acid score.

Protein Efficiency Ratio

The protein efficiency ratio (PER) determines the effectiveness of a protein through the measurement of animal growth. This technique requires feeding rats a test protein and then measuring the weight gain in grams per gram of protein consumed. The computed value is then compared to a standard value of 2.7, which is the standard value of [casein](#) protein. Any value that exceeds 2.7 is considered to be an excellent protein source. However, this calculation provides a measure of growth in rats and does not provide a strong correlation to the growth needs of humans.

Biological Value

Biological value measures protein quality by calculating the nitrogen used for tissue formation divided by the nitrogen absorbed from food. This product is multiplied by 100 and expressed as a percentage of nitrogen utilized. The biological value provides a measurement of how efficient the body utilizes protein consumed in the diet. A food with a high value correlates to a high supply of the essential

Table 1. Protein quality rankings.

Protein Type	Protein Efficiency Ratio	Biological Value	Net Protein Utilization	Protein Digestibility Corrected Amino Acid Score
Beef	2.9	80	73	0.92
Black Beans	0		0	0.75
Casein	2.5	77	76	1.00
Egg	3.9	100	94	1.00
Milk	2.5	91	82	1.00
Peanuts	1.8			0.52
Soy protein	2.2	74	61	1.00
Wheat gluten	0.8	64	67	0.25
Whey protein	3.2	104	92	1.00

Adapted from: U.S Dairy Export Council, Reference Manual for U.S. Whey Products 2nd Edition, 1999 and Sarwar, 1997.

amino acids. Animal sources typically possess a higher biological value than vegetable sources due to the vegetable source's lack of one or more of the essential amino acids. There are, however, some inherent problems with this rating system. The biological value does not take into consideration several key factors that influence the digestion of protein and interaction with other foods before absorption. The biological value also measures a protein's maximal potential quality and not its estimate at requirement levels.

Net Protein Utilization

Net protein utilization is similar to the biological value except that it involves a direct measure of retention of absorbed nitrogen. Net protein utilization and biological value both measure the same parameter of nitrogen retention, however, the difference lies in that the biological value is calculated from nitrogen absorbed whereas net protein utilization is from nitrogen ingested.

Protein Digestibility Corrected Amino Acid Score

In 1989, the Food & Agriculture Organization and World Health Organization (FAO/WHO) in a joint position stand stated that protein quality could be determined by expressing the content of the first limiting essential amino acid of the test protein as a percentage of the content of the same amino acid content in a reference pattern of essential amino acids (FAO/WHO, 1990). The reference values used were based upon the essential amino acids requirements of preschool-age children. The recommendation of the joint FAO/WHO statement was to take this reference value and correct it for true fecal digestibility of the test protein. The value obtained was referred to as the protein digestibility corrected amino acid score (PDCAAS). This method has been adopted as the preferred method for measurement of the protein value in human nutrition (Schaafsma, 2000). Table 1 provides a measure of

the quantity of various proteins using these protein rating scales.

Although the PDCAAS is currently the most accepted and widely used method, limitations still exist relating to overestimation in the elderly (likely related to reference values based on young individuals), influence of ileal digestibility, and antinutritional factors (Sarwar, 1997).

Amino acids that move past the terminal ileum may be an important route for bacterial consumption of amino acids, and any amino acids that reach the colon would not likely be utilized for protein synthesis, even though they do not appear in the feces (Schaafsma, 2000). Thus, to get truly valid measure of fecal digestibility the location at which protein synthesis is determined is important in making a more accurate determination. Thus, ileal digestibility would provide a more accurate measure of digestibility. PDCAAS, however, does not factor ileal digestibility into its equation. This is considered to be one of the shortcomings of the PDCAAS (Schaafsma 2000).

Antinutritional factors such as trypsin inhibitors, lectins, and tannins present in certain protein sources such as soybean meal, peas and fava beans have been reported to increase losses of endogenous proteins at the terminal ileum (Salgado et al., 2002). These antinutritional factors may cause reduced protein hydrolysis and amino acid absorption. This may also be more effected by age, as the ability of the gut to adapt to dietary nutritional insults may be reduced as part of the aging process (Sarwar, 1997).

Protein Sources

Protein is available in a variety of dietary sources. These include foods of animal and plant origins as well as the highly marketed sport supplement industry. In the following section proteins from both vegetable and animal sources, including whey,

[casein](#), and soy will be explored. Determining the effectiveness of a protein is accomplished by determining its quality and digestibility. Quality refers to the availability of amino acids that it supplies, and digestibility considers how the protein is best utilized. Typically, all dietary animal protein sources are considered to be complete proteins. That is, a protein that contains all of the essential amino acids. Proteins from vegetable sources are incomplete in that they are generally lacking one or two essential amino acids. Thus, someone who desires to get their protein from vegetable sources (i.e. vegetarian) will need to consume a variety of vegetables, fruits, grains, and legumes to ensure consumption of all essential amino acids. As such, individuals are able to achieve necessary protein requirements without consuming beef, poultry, or dairy. Protein digestibility ratings usually involve measuring how the body can efficiently utilize dietary sources of protein. Typically, vegetable protein sources do not score as high in ratings of biological value, net protein utilization, PDCAAS, and protein efficiency ratio as animal proteins.

Animal Protein

Proteins from animal sources (i.e. eggs, milk, meat, fish and poultry) provide the highest quality rating of food sources. This is primarily due to the 'completeness' of proteins from these sources. Although protein from these sources are also associated with high intakes of saturated fats and cholesterol, there have been a number of studies that have demonstrated positive benefits of animal proteins in various population groups (Campbell et al., 1999; Godfrey et al., 1996; Pannemans et al., 1998).

Protein from animal sources during late pregnancy is believed to have an important role in infants born with normal body weights. Godfrey et al. (1996) examined the nutrition behavior of more than 500 pregnant women to determine the effect of nutritional intake on placental and fetal growth. They reported that a low intake of protein from dairy and meat sources during late pregnancy was associated with low birth weights.

In addition to the benefits from total protein consumption, elderly subjects have also benefited from consuming animal sources of protein. Diets consisting of meat resulted in greater gains in lean body mass compared to subjects on a lactoovo-vegetarian diet (Campbell et al., 1999). High animal protein diets have also been shown to cause a significantly greater net protein synthesis than a high vegetable protein diet (Pannemans et al., 1998). This was suggested to be a function of reduced protein breakdown occurring during the high animal protein diet.

There have been a number of health concerns raised concerning the risks associated with protein emanating primarily from animal sources. Primarily, these health risks have focused on cardiovascular disease (due to the high saturated fat and cholesterol consumption), bone health (from bone resorption due to sulfur-containing amino acids associated with animal protein) and other physiological system disease that will be addressed in the section on high protein diets.

Whey

Whey is a general term that typically denotes the translucent liquid part of milk that remains following the process (coagulation and curd removal) of cheese manufacturing. From this liquid, whey proteins are separated and purified using various techniques yielding different concentrations of whey proteins. Whey is one of the two major protein groups of bovine milk, accounting for 20% of the milk while [casein](#) accounts for the remainder. All of the constituents of whey protein provide high levels of the essential and branched chain amino acids. The bioactivities of these proteins possess many beneficial properties as well. Additionally, whey is also rich in vitamins and minerals. Whey protein is most recognized for its applicability in sports nutrition. Additionally, whey products are also evident in baked goods, salad dressings, emulsifiers, infant formulas, and medical nutritional formulas.

Varieties of Whey Protein

There are three main forms of whey protein that result from various processing techniques used to separate whey protein. They are whey powder, whey concentrate, and whey isolate. Table 2 provides the composition of Whey Proteins.

Whey Protein Powder

Whey protein powder has many applications throughout the food industry. As an additive it is seen in food products for beef, dairy, bakery, confectionery, and snack products. Whey powder itself has several different varieties including sweet whey, acid whey (seen in salad dressings), demineralized (seen primarily as a food additive including infant formulas), and reduced forms. The demineralized and reduced forms are used in products other than sports supplements.

Whey Protein Concentrate

The processing of whey concentrate removes the water, lactose, ash, and some minerals. In addition, compared to whey isolates whey concentrate typically contains more biologically active components and proteins that make them a very attractive supplement for the athlete.

Whey Protein Isolate (WPI)

Isolates are the purest protein source available. Whey protein isolates contain protein concentrations of 90% or higher. During the processing of whey protein isolate there is a significant removal of fat and lactose. As a result, individuals who are lactose-intolerant can often safely take these products (Geiser, 2003). Although the concentration of protein in this form of whey protein is the highest, it often contains proteins that have become denatured due to the manufacturing process. The denaturation of proteins involves breaking down their structure and losing peptide bonds and reducing the effectiveness of the protein.

Table 2. Composition (%) of whey protein forms.

Component	Whey Powder	Whey Concentrate	Whey Isolate
Protein	11 – 14.5	25 – 89	90 +
Lactose	63 – 75	10 – 55	0.5
Milk Fat	1 – 1.5	2 – 10	0.5

Adapted from Geiser, 2003.

Whey is a complete protein whose biologically active components provide additional benefits to enhance human function. Whey protein contains an ample supply of the amino acid cysteine. Cysteine appears to enhance glutathione levels, which has been shown to have strong antioxidant properties that can assist the body in combating various diseases (Counous, 2000). In addition, whey protein contains a number of other proteins that positively effect immune function such as antimicrobial activity (Ha and Zemel, 2003). Whey protein also contains a high concentration of branched chain amino acids (BCAA) that are important for their role in the maintenance of tissue and prevention of catabolic actions during exercise. (MacLean et al., 1994).

Casein

Casein is the major component of protein found in bovine milk accounting for nearly 70-80% of its total protein and is responsible for the white color of milk. It is the most commonly used milk protein in the industry today. Milk proteins are of significant physiological importance to the body for functions relating to the uptake of nutrients and vitamins and they are a source of biologically active peptides. Similar to whey, casein is a complete protein and also contains the minerals calcium and phosphorous. Casein has a PDCAAS rating of 1.23 (generally reported as a truncated value of 1.0) (Deutz et al. 1998).

Casein exists in milk in the form of a micelle, which is a large colloidal particle. An attractive property of the casein micelle is its ability to form a gel or clot in the stomach. The ability to form this

clot makes it very efficient in nutrient supply. The clot is able to provide a sustained slow release of amino acids into the blood stream, sometimes lasting for several hours (Boirie et al. 1997). This provides better nitrogen retention and utilization by the body.

Bovine Colostrum

Bovine colostrum is the “pre” milk liquid secreted by female mammals the first few days following birth. This nutrient-dense fluid is important for the newborn for its ability to provide immunities and assist in the growth of developing tissues in the initial stages of life. Evidence exists that bovine colostrum contains growth factors that stimulate cellular growth and DNA synthesis (Kishikawa et al., 1996), and as might be expected with such properties, it makes for interesting choice as a potential sports supplement.

Although bovine colostrum is not typically thought of as a food supplement, the use by strength/power athletes of this protein supplement as an ergogenic aid has become common. Oral supplementation of bovine colostrum has been demonstrated to significantly elevate insulin-like-growth factor 1 (IGF-1) (Mero et al., 1997) and enhance lean tissue accretion (Antonio et al., 2001; Brinkworth et al., 2004). However, the results on athletic performance improvement are less conclusive. Mero and colleagues (1997) reported no changes in vertical jump performance following 2-weeks of supplementation, and Brinkworth and colleagues (2004) saw no significant differences in strength following 8-weeks of training and supplementation in both trained and untrained subjects. In contrast, following 8-weeks of supplementation significant improvements in sprint performance were seen in elite hockey players (Hofman et al., 2002). Further research concerning bovine colostrum supplementation is still warranted.

Vegetable Protein

Vegetable proteins, when combined to provide for all of the essential amino acids, provide an excellent source for protein considering that they will likely result in a reduction in the intake of saturated fat and cholesterol. Popular sources include legumes, nuts and soy. Aside from these products, vegetable protein can also be found in a fibrous form called textured vegetable protein (TVP). TVP is produced from soy flour in which proteins are isolated. TVP is mainly a meat alternative and functions as a meat analog in vegetarian hot dogs, hamburgers, chicken patties, etc. It is also a low-calorie and low-fat source of vegetable protein. Vegetable sources of protein also provide numerous other nutrients such as phytochemicals and fiber that are also highly regarded in the diet.

Soy

Soy is the most widely used vegetable protein source. The soybean, from the legume family, was first chronicled in China in the year 2838 B.C. and was considered to be as valuable as wheat, barley, and rice as a nutritional staple. Soy's popularity spanned several other countries, but did not gain notoriety for its nutritional value in The United States until the 1920s. The American population consumes a relatively low intake of soy protein (5g · day⁻¹) compared to Asian countries (Hasler, 2002). Although cultural differences may be partly responsible, the low protein quality rating from the PER scale may also have influenced protein consumption tendencies. However, when the more accurate PDCAAS scale is used, soy protein was reported to be equivalent to animal protein with a score of 1.0, the highest possible rating (Hasler, 2002). Soy's quality makes it a very attractive alternative for those seeking non-animal sources of protein in their diet and those who are lactose intolerant. Soy is a complete protein with a high concentration of BCAA's. There have been many reported benefits related to soy proteins relating to health and performance (including reducing plasma lipid profiles, increasing LDL-cholesterol oxidation and reducing blood pressure), however further research still needs to be performed on these claims.

Soy Protein Types

The soybean can be separated into three distinct categories; flour, concentrates, and isolates. Soy flour can be further divided into natural or full-fat (contains natural oils), defatted (oils removed), and lecithinated (lecithin added) forms (Hasler, 2002). Of the three different categories of soy protein products, soy flour is the least refined form. It is commonly found in baked goods. Another product of soy flour is called *textured soy flour*. This is primarily used for processing as a meat extender. See Table 3 for protein composition of soy flour, concentrates, and isolates.

Table 3. Protein composition of soy protein forms.

Soy Protein Form	Protein Composition
Soy Flour	50%
Soy Concentrate	70%
Soy Isolate	90%

Soy concentrate was developed in the late 1960s and early 1970s and is made from defatted soybeans. While retaining most of the bean's protein content, concentrates do not contain as much soluble carbohydrates as flour, making it more palatable. Soy concentrate has a high digestibility and is found in nutrition bars, cereals, and yogurts.

Isolates are the most refined soy protein product containing the greatest concentration of

protein, but unlike flour and concentrates, contain no dietary fiber. Isolates originated around the 1950s in The United States. They are very digestible and easily introduced into foods such as sports drinks and health beverages as well as infant formulas.

Nutritional Benefits

For centuries, soy has been part of a human diet. Epidemiologists were most likely the first to recognize soy's benefits to overall health when considering populations with a high intake of soy. These populations shared lower incidences in certain cancers, decreased cardiac conditions, and improvements in menopausal symptoms and osteoporosis in women (Hasler, 2002). Based upon a multitude of studies examining the health benefits of soy protein the American Heart Association issued a statement that recommended soy protein foods in a diet low in saturated fat and cholesterol to promote heart health (Erdman, 2000). The health benefits associated with soy protein are related to the physiologically active components that are part of soy, such as protease inhibitors, phytosterols, saponins, and isoflavones (Potter, 2000). These components have been noted to demonstrate lipid-lowering effects, increase LDL-cholesterol oxidation, and have beneficial effects on lowering blood pressure.

Isoflavones

Of the many active components in soy products, isoflavones have been given considerably more attention than others. Isoflavones are thought to be beneficial for cardiovascular health, possibly by lowering LDL concentrations (Crouse et al., 1999) increasing LDL oxidation (Tikkanen et al., 1998) and improving vessel elasticity (Nestel et al., 1999). However, these studies have not met without conflicting results and further research is still warranted concerning the benefits of isoflavones.

Soy Benefits for Women

An additional focus of studies investigating soy supplementation has been on women's health issues. It has been hypothesized that considering that isoflavones are considered phytoestrogens (exhibit estrogen-like effects and bind to estrogen receptors) they compete for estrogen receptor sites in breast tissue with endogenous estrogen, potentially reducing the risk for breast cancer risk (Wu et al. 1998). Still, the association between soy intake and breast cancer risk remains inconclusive. However, other studies have demonstrated positive effects of soy protein supplementation on maintaining bone mineral content (Ho et al., 2003) and reducing the severity of menopausal symptoms (Murkies et al., 1995).

High Protein Diets

Increased protein intakes and supplementation have generally been focused on athletic populations. However, over the past few years high protein diets have become a method used by the general population to enhance weight reduction. The low-carbohydrate, high protein, high fat diet promoted by Atkins may be the most popular diet used today for weight loss in the United States (Johnston et al., 2004). The basis behind this diet is that protein is associated with feelings of satiety and voluntary reductions in caloric consumption (Araya et al., 2000; Eisenstein et al., 2002). A recent study has shown that the Atkins diet can produce greater weight reduction at 3 and 6 months than a low-fat, high carbohydrate diet based upon U.S. dietary guidelines (Foster et al., 2003). However, potential health concerns have arisen concerning the safety of high protein diets. In 2001, the American Heart Association published a statement on dietary protein and weight reduction and suggested that individuals following such a diet may be at potential risk for metabolic, cardiac, renal, bone and liver diseases (St. Jeor et al., 2001).

Protein Intake and Metabolic Disease Risk

One of the major concerns for individuals on high protein, low carbohydrate diets is the potential for the development of metabolic ketosis. As carbohydrate stores are reduced the body relies more upon fat as its primary energy source. The greater amount of free fatty acids that are utilized by the liver for energy will result in a greater production and release of ketone bodies in the circulation. This will increase the risk for metabolic acidosis and can potentially lead to a coma and death. A recent multi-site clinical study (Foster et al., 2003) examined the effects of low-carbohydrate, high protein diets and reported significant elevation in ketone bodies during the first three months of the study. However, as the study duration continued the percentage of subjects with positive urinary ketone concentrations became reduced, and by six months urinary ketones were not present in any of the subjects.

Dietary Protein and Cardiovascular Disease Risk

High protein diets have also been suggested to have negative effects on blood lipid profiles and blood pressure, causing an increase risk for cardiovascular disease. This is primarily due to the higher fat intakes associated with these diets. However, this has not been proven in any scientifically controlled studies. Hu et al., (1999) have reported an inverse relationship between dietary protein (animal and vegetable) and risk of cardiovascular disease in women, and Jenkins and colleagues (2001) reported a decrease in lipid profiles in individuals consuming

a high protein diet. Furthermore, protein intake has been shown to often have a negative relationship with blood pressure (Obarzanek et al., 1996). Thus, the concern for elevated risk for cardiovascular disease from high protein diets appears to be without merit. Likely, the reduced body weight associated with this type of diet is facilitating these changes.

In strength/power athletes who consume high protein diets, a major concern was the amount of food being consumed that was high in saturated fats. However, through better awareness and nutritional education many of these athletes are able to obtain their protein from sources that minimizes the amount of fat consumed. For instance, removing the skin from chicken breast, consuming fish and lean beef, and egg whites. In addition, many protein supplements are available that contain little to no fat. It should be acknowledged though that if elevated protein does come primarily from meats, dairy products and eggs, without regard to fat intake, there likely would be an increase in the consumption of saturated fat and cholesterol.

Dietary Protein and Renal Function

The major concern associated with renal function was the role that the kidneys have in nitrogen excretion and the potential for a high protein diet to over-stress the kidneys. In healthy individuals there does not appear to be any adverse effects of a high protein diet. In a study on bodybuilders consuming a high protein ($2.8 \text{ g}\cdot\text{kg}^{-1}$) diet no negative changes were seen in any kidney function tests (Poortsman and Dellalieux, 2000). However, in individuals with existing kidney disease it is recommended that they limit their protein intake to approximately half of the normal RDA level for daily protein intake ($0.8 \text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$). Lowering protein intake is thought to reduce the progression of renal disease by decreasing hyperfiltration (Brenner et al., 1996).

Dietary Protein and Bone

High protein diets are associated with an increase in calcium excretion. This is apparently due to a consumption of animal protein, which is higher in sulfur-based amino acids than vegetable proteins (Remer and Manz, 1994; Barzel and Massey, 1998). Sulfur-based amino acids are thought to be the primary cause of calciuria (calcium loss). The mechanism behind this is likely related to the increase in acid secretion due to the elevated protein consumption. If the kidneys are unable to buffer the high endogenous acid levels, other physiological systems will need to compensate, such as bone. Bone acts as a reservoir of alkali, and as a result calcium is liberated from bone to buffer high acidic levels and restore acid-base balance. The calcium released by bone is accomplished through

osteoclast-mediated bone resorption (Arnett and Spowage, 1996). Bone resorption (loss or removal of bone) will cause a decline in bone mineral content and bone mass (Barzel, 1976), increasing the risk for bone fracture and osteoporosis.

The effect of the type of protein consumed on bone resorption has been examined in a number of studies. Sellmeyer and colleagues (2001) examined the effects of various animal-to-vegetable protein ratio intakes in elderly women (> 65 y). They showed that the women consuming the highest animal to vegetable protein ratio had nearly a 4-fold greater risk of hip fractures compared with women consuming a lower animal to vegetable protein ratio. Interestingly, they did not report any significant association between the animal to vegetable protein ratio and bone mineral density. Similar results were shown by Feskanich et al (1996), but in a younger female population (age range = 35 – 59 mean 46). In contrast, other studies examining older female populations have shown that elevated animal protein will increase bone mineral density, while increases in vegetable protein will have a lowering effect on bone mineral density (Munger et al., 1999; Promislow et al., 2002). Munger and colleagues (1999) also reported a 69% lower risk of hip fracture as animal protein intake increased in a large (32,000) postmenopausal population. Other large epidemiological studies have also confirmed elevated bone density following high protein diets in both elderly men and women (Dawson-Hughes et al., 2002; Hannan et al., 2000). Hannan and colleagues (2000) demonstrated that animal protein intake in an older population, several times greater than the RDA requirement, results in a bone density accrual and significant decrease in fracture risk. Dawson-Hughes et al (2002), not only showed that animal protein will not increase urinary calcium excretion, but was also associated with higher levels of IGF-I and lower concentrations of the bone resorption marker N-telopeptide.

These conflicting results have contributed to the confusion regarding protein intake and bone. It is likely that other factors play an important role in further understanding the influence that dietary proteins have on bone loss or gain. For instance, the intake of calcium may have an essential function in maintaining bone. A higher calcium intake results in more absorbed calcium and may offset the losses induced by dietary protein and reduce the adverse effect of the endogenous acidosis on bone resorption (Dawson-Hughes, 2003). Furthermore, it is commonly assumed that animal proteins have a higher content of sulfur-containing amino acids per g of protein. However, examination of Table 4 shows that this may not entirely be correct. If protein came from wheat sources it would have a mEq of 0.69 per g of protein, while protein from milk

contains 0.55 mEq per g of protein. Thus, some plant proteins may have a greater potential to produce more mEq of sulfuric acid per g of protein than some animal proteins (Massey, 2003). Finally, bone resorption may be related to the presence or absence of a vitamin D receptor allele. In subjects that had this specific allele a significant elevation in bone resorption markers were present in the urine following 4-weeks of protein supplementation, while in subjects without this specific allele had no increase in N-telopeptide (Harrington et al., 2004). The effect of protein on bone health is still unclear, but it does appear to be prudent to monitor the amount of animal protein in the diet for susceptible individuals. This may be more pronounced in individuals that may have a genetic endowment for this. However, if animal protein consumption is modified by other nutrients (e.g. calcium) the effects on bone health may be lessened.

Table 4. Potential acid as sulfate from sulfur-containing amino acids.

Food	mEq per g of protein
Oatmeal	.82
Egg	.80
Walnuts	.74
Pork	.73
Wheat (whole)	.69
White Rice	.68
Barley	.68
Tuna	.65
Chicken	.65
Corn	.61
Beef	.59
Milk	.55
Cheddar	.46
Soy	.40
Peanuts	.40
Millet	.31
Almonds	.23
Potato	.23

Adapted from Massey, 2003.

Protein Intake and Liver Disease Risk

The American Heart Association has suggested that high protein diets may have detrimental effects on liver function (St. Jeor et al., 2001). This is primarily the result of a concern that the liver will be stressed through metabolizing the greater protein intakes. However, there is no scientific evidence to support this contention. Jorda and colleagues (1988) did show that high protein intakes in rats produce morphological changes in liver mitochondria. However, they also suggested that these changes were not pathological, but represented a positive hepatocyte adaptation to a metabolic stress.

Protein is important for the liver not only in promoting tissue repair, but to provide lipotropic

agents such as methionine and choline for the conversion of fats to lipoprotein for removal from the liver (Navder and Leiber, 2003a). The importance of high protein diets has also been acknowledged for individuals with liver disease and who are alcoholics. High protein diets may offset the elevated protein catabolism seen with liver disease (Navder and Leiber, 2003b), while a high protein diet has been shown to improve hepatic function in individuals suffering from alcoholic liver disease (Mendellhall et al., 1993).

Comparisons between Different Protein Sources on Human Performance

Earlier discussions on protein supplementation and athletic performance have shown positive effects from proteins of various sources. However, only limited research is available on comparisons between various protein sources and changes in human performance. Recently, there have been a number of comparisons between bovine colostrum and whey protein. The primary reason for this comparison is the use by these investigators of whey protein as the placebo group in many of the studies examining bovine colostrum (Antonio et al., 2001; Brinkworth et al., 2004; Brinkworth and Buckley, 2004; Coombes et al., 2002; Hofman et al., 2002). The reason being that whey protein is similar in taste and texture as bovine colostrum protein.

Studies performed in non-elite athletes have been inconclusive concerning the benefits of bovine colostrum compared to whey protein. Several studies have demonstrated greater gains in lean body mass in individuals supplementing with bovine colostrum than whey, but no changes in endurance or strength performance (Antonio et al., 2001; Brinkworth et al., 2004). However, when performance was measured following prolonged exercise (time to complete 2.8 kJ·kg⁻¹ of work following a 2-hour ride) supplement dosages of 20 g·day⁻¹ and 60 g·day⁻¹ were shown to significantly improve time trial performance in competitive cyclists (Coombes et al., 2002). These results may be related to an improved buffering capacity following colostrum supplementation. Brinkworth and colleagues (2002) reported that although no performance changes were seen in rowing performance, the elite rowers that were studied did demonstrate an improved buffering capacity following 9-weeks of supplementation with 60 g·day⁻¹ of bovine colostrum when compared to supplementing with whey protein. The improved buffering capacity subsequent to colostrum supplementation may have also influenced the results reported by Hofman et al., (2002). In that study elite field hockey players supplemented with either 60 g·day⁻¹ of either colostrum or whey protein

for 8-weeks. A significantly greater improvement was seen in repeated sprint performance in the group supplementing with colostrum compared to the group supplementing with whey protein. However, a recent study has suggested that the improved buffering system seen following colostrum supplementation is not related to an improved plasma buffering system, and that any improved buffering capacity occurs within the tissue (Brinkworth et al., 2004).

In a comparison between [casein](#) and whey protein supplementation, Boirie and colleagues (1997) showed that a 30-g feeding of [casein](#) versus whey had significantly different effects on postprandial protein gain. They showed that following whey protein ingestion the plasma appearance of amino acids is fast, high and transient. In contrast, [casein](#) is absorbed more slowly producing a much less dramatic rise in plasma amino acid concentrations. Whey protein ingestion stimulated protein synthesis by 68%, while [casein](#) ingestion stimulated protein synthesis by 31%. When the investigators compared postprandial leucine balance after 7-hours post ingestion, [casein](#) consumption resulted in a significantly higher leucine balance, whereas no change from baseline was seen 7-hours following whey consumption. These results suggest that whey protein stimulates a rapid synthesis of protein, but a large part of this protein is oxidized (used as fuel), while [casein](#) may result in a greater protein accretion over a longer duration of time. A subsequent study showed that repeated ingestions of whey protein (an equal amount of protein but consumed over a prolonged period of time [4 hours] compared to a single ingestion) produced a greater net leucine oxidation than either a single meal of [casein](#) or whey (Dangin et al., 2001). Interestingly, both [casein](#) and whey are complete proteins but their amino acid composition is different. Glutamine and leucine have important roles in muscle protein metabolism, yet [casein](#) contains 11.6 and 8.9 g of these amino acids, respectively while whey contains 21.9 and 11.1 g of these amino acids, respectively. Thus, the digestion rate of the protein may be more important than the amino acid composition of the protein.

In a study examining the effects of [casein](#) and whey on body composition and strength measures, 12 weeks of supplementation on overweight police officers showed significantly greater strength and lean tissue accrual in the subjects ingesting [casein](#) compared to whey (Demling and DeSanti, 2000). Protein supplementation provided a relative protein consumption of 1.5 g·kg·day⁻¹. Subjects supplemented twice per day approximately 8–10 hours apart.

Only one study known has compared colostrum, whey and [casein](#) supplementation (Fry et

al., 2003). Following 12-weeks of supplementation the authors reported no significant differences in lean body mass, strength or power performances between the groups. However, the results of this study should be examined with care. The subjects were comprised of both males and females who were resistance training for recreational purposes. In addition, the subject number for each group ranged from 4–6 subjects per group. With a heterogeneous subject population and a low subject number, the statistical power of this study was quite low. However, the authors did analyze effect sizes to account for the low statistical power. This analysis though did not change any of the observations. Clearly, further research is needed in comparisons of various types of protein on performance improvements. However, it is likely that a combination of different proteins from various sources may provide optimal benefits for performance.

CONCLUSIONS

It does appear that protein from animal sources is an important source of protein for humans from infancy until mature adulthood. However, the potential health concerns associated with a diet of protein consumed primarily from animal sources should be acknowledged. With a proper combination of sources, vegetable proteins may provide similar benefits as protein from animal sources. Maintenance of lean body mass though may become a concern. However, interesting data does exist concerning health benefits associated with soy protein consumption.

In athletes supplementing their diets with additional protein, [casein](#) has been shown to provide the greatest benefit for increases in protein synthesis for a prolonged duration. However, whey protein has a greater initial benefit for protein synthesis. These differences are related to their rates of absorption. It is likely a combination of the two could be beneficial, or smaller but more frequent ingestion of whey protein could prove to be of more value. Considering the paucity of research examining various sources of protein in sport supplementation studies, further research appears warranted on examining the benefits of these various protein sources.

REFERENCES

- Antonio, J., Sanders, M., and Van Gammeren, D. (2001) The effects of bovine colostrums supplementation on body composition and exercise performance in active men and women. *Nutrition* **17**, 243-247.
- Araya, H., Hills, J., Alvina, M. and Vera, G. (2000) Short-term satiety in preschool children: A comparison between high protein meal and a high complex carbohydrate meal. *International Journal of Food Sciences and Nutrition* **51**, 119-124.
- Arnett, T.R. and Spowage, M. (1996) Modulation of the resorptive activity of rat osteoclasts by small changes in extracellular pH near the physiological range. *Bone* **18**, 277-279.
- Barzel, U.S. (1976) Acid-base balance in disorders of calcium metabolism. *NY State Journal of Medicine* **76**, 234-237.
- Barzel, U.S. and Massey, L.K. (1998) Excess dietary protein can adversely affect bone. *Journal of Nutrition* **128**, 1051-1053.
- Boirie, Y., Dangin, M., Gachon, P., Vasson, M.P., Maubois, J.L. and Beaufrere, B. (1997) Slow and fast dietary proteins differently modulate postprandial protein accretion. *Proclamations of National Academy of Sciences* **94**, 14930-14935.
- Brenner, B.M., Lawler, E.V. and Mackenzie, H.S. (1996) The hyperfiltration theory: a paradigm shift in nephrology. *Kidney International* **49**, 1774-1777.
- Brinkworth, G.D. and Buckley J.D. (2004) Bovine colostrums supplementation does not affect plasma buffer capacity or haemoglobin content in elite female rowers. *European Journal of Applied Physiology* **91**, 353-356.
- Brinkworth, G., Buckley, J., Bourdon, P., Bulbin, J. and David, A. (2002) Oral bovine colostrum supplementation enhances buffer capacity, but not rowing performance in elite female rowers. *International Journal of Sports Nutrition and Exercise Metabolism* **12**, 349-363.
- Brinkworth, G.D., Buckley, J.D., Slavotinek, J.P. and Kurmis, A.P. (2004) Effect of bovine colostrum supplementation on the composition of resistance trained and untrained limbs in healthy young men. *European Journal of Applied Physiology* **91**, 53-60.
- Buckley J.D., Brinkworth, G.D. and Abbott, M.J. (2004) Effect of bovine colostrums on anaerobic exercise performance and plasma insulin-like growth factor I. *Journal of Sport Sciences* **21**, 577-588.
- Campbell, W.W., Barton Jr., M.L., Cyr-Campbell, D., Davey, S.L., Beard, J.L., Parise, G. and Evans, W.J. (1999) Effects of an omnivorous diet compared with a lactoovovegetarian diet on resistance-training-induced changes in body composition and skeletal muscle in older men. *American Journal of Clinical Nutrition* **70**, 1032-1039.
- Coombes, J.S., Conacher, M., Austen, S.K. and Marshall, P.A. (2002) Does effects of oral bovine colostrums on physical work capacity in cyclists. *Medicine and Science in Sports and Exercise*. **34**, 1184-1187.
- Counous, G. (2000) Whey protein concentrate (WPC) and glutathione modulation in cancer treatment. *Anticancer Research* **20**, 4785-4792.
- Crouse, J.R., Morgan, T., Terry, J.G., Ellis, J., Vintolins, M. and Burke, G.L. (1999) A randomized trial comparing the effect of casein with that of soy protein containing varying amounts of isoflavones on plasma concentrations of lipids and lipoproteins. *Archives of Internal Medicine* **159**, 2070-2076.

- Dangin, M., Boirie, Y., Guillet, C. and Beaufrere B. (2002) Influence of the protein digestion rate on protein turnover in young and elderly subjects. *Journal of Nutrition* **132**, 3228S-3233S.
- Dawson-Hughes, B. (2003) Calcium and protein in bone health. *Proclamations of the Nutrition Society* **62**, 505-509.
- Dawson-Hughes, B. and Harris, S.S. (2002) Calcium intake influences the association of protein intake with rates of bone loss in elderly men and women. *American Journal of Clinical Nutrition* **75**, 773-779.
- Demling, R.H. and DeSanti, L. (2000) Effect of a hypocaloric diet, increased protein intake and resistance training on lean mass gains and fat mass loss in overweight police officers. *Annals of Nutrition Metabolism* **44**, 21-29.
- Deutz, N.E.P., Bruins, M.J. and Soeters, P.B. (1998) Infusion of soy and casein protein meals affects interorgan amino acid metabolism and urea kinetics differently in pigs. *Journal of Nutrition* **128**, 2435-2445.
- Eisenstein J, Roberts SB, Dallal G, and Saltzman E. (2002) High-protein weight-loss diets: are they safe and do they work? A review of the experimental and epidemiologic data. *Nutrition Reviews* **60**, 189-200.
- Erdman, J.W. Jr. (2000) Soy protein and cardiovascular disease. A statement for healthcare professionals from the Nutrition Committee of the AHA. *Circulation* **102**, 2555-2559.
- Fern, E.B., Bielinski, R.N. and Schutz, Y. (1991) Effects of exaggerated amino acid and protein supply in man. *Experientia* **47**, 168-172.
- Feskanich, D., Willett, W.C., Stampfer, M.J. and Colditz, G.A. (1996) Protein consumption and bone fractures in women. *American Journal of Epidemiology* **143** 472-479.
- Food and Agriculture Organization/World Health Organization. (1990) Protein quality evaluation; report of the joint FAO/WHO expert consultation. *FAO Food and Nutrition Paper* **52**, Rome, Italy.
- Foster, G.D., Wyatt, H.R., Hill, J.O., McGuckin B.G., Brill C., Mohammed B.S., Szapary P.O., Rader D.J., Edman J.S. and Klein S. (2003) A randomized trial of a low-carbohydrate diet for obesity. *The New England Journal of Medicine* **348**, 2082-2090.
- Friedman, J.E. and Lemon, P.W.R. (1989) Effect of chronic endurance exercise on the retention of dietary protein. *International Journal of Sports Medicine* **10**, 118-123.
- Fry, A.C., Schilling, B.K., Chiu, L.Z.F., Weiss, L.W., Kreider, R.B. and Rasmussen, C.J. (2003) Muscle fiber and performance adaptations to resistance exercise with MyoVive, colostrum or casein and whey supplementation. *Research in Sports Medicine* **11**, 109-127.
- Geiser, M. (2003) The wonders of whey protein. *NSCA's Performance Training Journal* **2**, 13-15.
- Godfrey, K., Robinson, S., Barker, D.J.P., Osmond, C. and Cox, V. (1996) Maternal nutrition in early and late pregnancy in relation to placental and fetal growth. *British Medical Journal* **312**, 410-414.
- Ha, E. and Zemel, M.B. (2003) Functional properties of whey, whey components, and essential amino acids: mechanisms underlying health benefits for active people. *Journal of Nutritional Biochemistry* **14**, 251-258.
- Hannan, M.T., Tucker, K.L., Dawson-Hughes, B., Cupples, L.A., Felson, D.T. and Kiel, D.P. (2000) Effect of dietary protein on bone loss in elderly men and women: The Framingham Osteoporosis Study. *Journal of Bone Mineral Research* **15**, 2504-2512.
- Harrington, M., Bennett, T., Jakobsen, J., Ovesen, L., Brot, C., Flynn, A. and Cashman, K.D. (2004) The effect of a high-protein, high-sodium diet on calcium and bone metabolism in postmenopausal women and its interaction with vitamin D receptor genotype. *British Journal of Nutrition* **91**, 41-51.
- Hasler, C.M. (2002) The cardiovascular effects of soy products. *Journal of Cardiovascular Nursing* **16**, 50-63.
- Ho, S.C., Woods, J., Lam, S., Chen, Y., Sham, A. and Lau, J. (2003) Soy protein consumption and bone mass in early postmenopausal Chinese women. *Osteoporosis International* **14**, 835-842.
- Hofman, A., Smeets, R., Verlaan, G., v.d. Lugt, R. and Verstappen, P.A. (2002) The effect of bovine colostrums supplementation on exercise performance in elite field hockey players. *International Journal of Sport Nutrition and Exercise Metabolism* **12**, 461-469.
- Hu, F.B., Stampfer, M.J., Manson, J.E., Rimm, E., Colditz, G.A., Speizer, F.E., Hennekens, C.H. and Willett, W.C. (1999) Dietary protein and risk of ischemic heart disease in women. *American Journal of Clinical Nutrition* **70**, 221-227.
- Jenkins D.J.A., Kendall C.W.C., Vidgen E., Augustin L.S.A., van Erk M., Geelen A., Parker T., Faulkner D., Vuksan V., Josse R.G., Leiter L.A. and Connelly P.W. (2001) High protein diets in hyperlipidemia: effect of wheat gluten on serum lipids, uric acid and renal function. *American Journal of Clinical Nutrition* **74**, 57-63.
- Johnston, C.S., Tjonn, S.L. and Swan, P.D. (2004) High-protein, low-fat diets are effective for weight loss and favorably alter biomarkers in healthy adults. *Journal of Nutrition* **134**, 586-591.
- Jorda, A., Zaragoza, R., Portoles M, Baguena-Cervellera R. and Renau-Piqueras J. (1988) Long-term high-protein diet induces biochemical and ultrastructural changes in rat liver mitochondria. *Archives of Biochemistry and Biophysics* **265**, 241-248.
- Kishikawa, Y., Wantanabe, D.S. Watanabe T, and Kubo S. (1996) Purification and characterization of cell growth factor in bovine colostrums. *Journal of Veterinary Medicine and Science* **58**, 47-53.
- Lemon, P.W.R., Tarnopulosky, M.A., McDougall, J.D. and Atkinson, S.A. (1992) Protein requirements and muscle mass/strength changes during intensive training in novice bodybuilders. *Journal of Applied Physiology* **73**, 767-775.
- Lemon, P.W.R. (1995) Do athletes need more dietary protein and amino acids? *International Journal of Sports Nutrition* **5**, S39-S61.

- MacLean, D.A., Graham, T.E. and Saltin, B. (1994) Branched-chain amino acids augment ammonia metabolism while attenuating protein breakdown during exercise. *American Journal of Physiology* **267**, E1010-1022.
- Massey, L.K. (2003) Dietary animal and plant protein and human bone health: a whole foods approach. *Journal of Nutrition* **133**, 862S-865S.
- Mendenhall, C.L., Moritz, T.E., Roselle, G.A., Morgan, T.R., Nemchausk, B.A., Tamburro, C.H., Schiff, E.R., McClain, C.J., Marsano, L.S. and Allen, J.I. (1993) A study of oral nutrition support with oxadrolone in malnourished patients with alcoholic hepatitis: results of a Department of Veterans Affairs Cooperative Study. *Hepatology* **17**, 564-575.
- Meredith, C.N., Zackin, M.J., Frontera, W.R. and Evans, W.J. (1989) Dietary protein requirements and protein metabolism in endurance-trained men. *Journal of Applied Physiology* **66**, 2850-2856.
- Mero, A., Miiikkulaninen, H., Riski, J., Pakkanen, R., Aalto, J. and Takala, T. (1997) Effects of bovine colostrums supplementation on serum IGF-1, IgG, hormone and saliva IgA during training. *Journal of Applied Physiology* **93**, 732-739.
- Munger, R.G., Cerhan, J.R. and Chiu, B.C.H. (1999) Prospective study of dietary protein intake and risk of hip fracture in postmenopausal women. *American Journal of Clinical Nutrition* **69**, 147-52.
- Murkies, A.L., Lombard, C., Strauss, B.J.G., Wilcox, G., Burger, H.G. and Morton, M.S. (1995) Dietary flour supplementation decreases post-menopausal hot flushes: Effect of soy and wheat. *Journal of the Climacteric & Postmenopause* **21**, 189-195.
- Navder, K.P. and Lieber, C.S. (2003a) Nutritional support in chronic disease of the gastrointestinal tract and the liver. In: *Nutritional Aspects and Clinical Management of Chronic Disorders and Diseases*. Ed: Bronner, F. Boca Raton, FL: CRC Press. 45-68.
- Navder, K.P. and Lieber, C.S. (2003b) Nutrition and alcoholism. In: *Nutritional Aspects and Clinical Management of Chronic Disorders and Diseases*. Ed: Bronner, F. Boca Raton, FL: CRC Press. 307-320.
- Nestel, P.J., Pomeroy, S., Kay, S., Komesaroff, P., Behrsing, J., Cameron, J.D. and West, L. (1999) Isoflavones from red clover improve systemic arterial compliance but not plasma lipids in menopausal women. *Journal of Clinical Endocrinology Metabolism* **84**, 895-898.
- Obarzanek, E., Velletri, P.A. and Cutler, J.A. (1996) Dietary protein and blood pressure. *Journal of the American Medical Association* **275**, 1598-1603.
- Pannemans, D.L.E., Wagenmakers, A.J.M., Westerterp, K.R., Schaafsma, G. and Halliday, D. (1998) Effect of protein source and quantity on protein metabolism in elderly women. *American Journal of Clinical Nutrition* **68**, 1228-1235.
- Poortmans, J.R. and Dellalieux O. (2000) Do regular high protein diets have potential health risks on kidney function in athletes? *International Journal of Sport Nutrition & Exercise Metabolism* **10**, 28-38.
- Potter, S.M. (2000) Soy—new health benefits associated with an ancient food. *Nutrition Today* **35**, 53-60.
- Promislow, J.H.E., Goodman-Gruen, D., Slymen, D.J. and Barrett-Connor, E. (2002) Protein consumption and bone mineral density in the elderly. *American Journal of Epidemiology* **155**, 636-644.
- Remer, T. and Manz, F. (1994) Estimation of the renal net acid excretion by adults consuming diets containing variable amounts of protein. *American Journal of Clinical Nutrition* **59**, 1356-1361.
- Salgado, P., Montagne, L., Freire, J.P.B., Ferreira, R.B., Teixeira, A., Bento, O., Abreu, M.C., Toullec, R. and Lalles, J.P. (2002) Legume grain enhances ileal losses of specific endogenous serine-protease proteins in weaned pigs. *Journal of Nutrition* **132**, 1913-1920.
- Sarwar, G. (1997) The protein digestibility-corrected amino acid score method overestimates quality of proteins containing antinutritional factors and of poorly digestible proteins supplemented with limiting amino acids in rats. *Journal of Nutrition* **127**, 758-764.
- Schaafsma, G. (2000) The protein digestibility-corrected amino acid score. *Journal of Nutrition* **130**, 1865S-1867S.
- Sellmeyer, D.E., Stone, K.L., Sebastian, A. and Cummings, S.R. (2001) A high ratio of dietary animal to vegetable protein increases the rate of bone loss and risk of fracture in postmenopausal women. *American Journal of Clinical Nutrition* **73**, 118-122.
- St. Jeor, S.T., Howard, B.V., Prewitt, E., Bovee, V., Bazzarre, T. and Eckel, R.H. (2001) A statement for healthcare professionals from the nutrition committee of the council on nutrition, physical activity, and metabolism of the American Heart Association. *Circulation* **104**, 1869-1874.
- Tarnopolsky, M.A., Atkinson, S.A., MacDougall, J.D., Chesley, A., Phillips, S.M. and Swartz, H. (1992) Evaluation of protein requirements for trained strength athletes. *Journal of Applied Physiology* **73**, 1986-1995.
- Tarnopolsky, M.A., MacDougall, J.D. and Atkinson, S.A. (1988) Influence of protein intake and training status on nitrogen balance and lean body mass. *Journal of Applied Physiology* **64**, 187-193.
- Tikkanen, M.J., Wahala, K., Ojala, S., Vihma, V., and Adlecrantz, H. (1998) Effect of soybean phytoestrogen intake on low density lipoprotein oxidation resistance. *Proclamations of the National Academy of Science* **95**, P3106-P3110.
- United States Dairy Export Council (1999) *Reference Manual for U.S. Whey Products* 2nd Edition.
- Walberg, J.L., Leidy, M.K., Sturgill, D.J., Hinkle, D.E., Ritchey, S.J. and Sebolt, D.R. (1988) Macronutrient content of hypoenergy diet affects nitrogen retention and muscle function in weight lifters. *International Journal of Sports Medicine* **9**, 261-266.
- Wu, A.H., Ziegler, R.G., Nomura, A.M., West, D.W., Kolonel, L.N., Horn-Ross, P.L., Hoover, R.N. and Pike, M.C. (1998) Soy intake and risk of breast cancer in Asians and Asian Americans. *American*

Journal of Clinical Nutrition **68** (suppl),1437S-1443S.

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KEY POINTS

- Higher protein needs are seen in athletic populations.
- Animal proteins is an important source of protein, however potential health concerns do exist from a diet of protein consumed from primarily animal sources.
- With a proper combination of sources, vegetable proteins may provide similar benefits as protein from animal sources.
- Casein protein supplementation may provide the greatest benefit for increases in protein synthesis for a prolonged duration.

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