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Opinion paper

Factors contributing to the selection of dietary protein food sources

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SUMMARY

Protein is the only dietary macronutrient required for life. As such, it is reasonable to consider dietary protein as the centerpiece of a healthy eating pattern. To do so requires consideration of what type of protein should be eaten. Account should be taken of the quality of the protein, the density of the protein in the protein food source, and the non-protein components of protein food source. The quality of protein can be quantified based on the amount and profile of essential amino acids (EAAs), as well as the true ileal digestibility of the EAAs in the protein. The density of protein in a food source can be quantified on the basis of the amount of total calories ingested to achieve intake of the daily requirement of all EAAs. Non-protein components of protein food sources can be considered in terms of the amount and nature of fat, carbohydrate and fiber, as well as the content of micronutrients. Potential beneficial effects of high-quality protein food sources should be balanced against any possible adverse effects. When all of these factors are considered we conclude that animal-based protein foods (e.g., eggs, dairy, meat, fish, poultry) occupy an important place in a healthy eating pattern.

1. Introduction

Over the past decade or more there has been increasing focus on defining the optimal amount of dietary protein consumption needed for improved health outcomes during weight loss [2–4], in the elderly [5–7], and also in circumstances such as exercise [8–11] and serious illness [12]. The belief by the public of the benefits related to higher levels of protein intake is reflected in any grocery or convenience store in the United States, as the shelves are now packed with high protein foods and protein-rich dietary supplements. Protein supplements have turned into a multi-billion dollar industry, and even commodities such as breakfast cereals commonly boast of added protein. However, over the same time, the USDA Dietary Guidelines for Americans (DGA), reflected at various times as “My Pyramid” and ‘My Plate”, have remained basically unchanged with regard to the recommended level of dietary protein to consume each day [13–15]. While the amount of recommended protein intake has remained relatively constant in the DGA, the generally recommended protein food sources have gradually evolved from reliance on animal-based sources of protein, such as red meat and cow's milk, towards an emphasis on plant sources of protein.

In this review, we will address the various factors that contribute to the quality of a dietary protein, including the amount and profile of essential amino acids (EAAs) in the protein and the true ileal digestibility of the individual amino acids in the protein. We will also address other aspects of dietary protein quality, including the caloric intake relative to the protein content of different food sources, and the nature of the non-protein component of protein food sources. We will discuss additional nutritional issues related to food sources of dietary protein, such as the type of carbohydrate and/or fat, the amount of other key nutrients, and potential adverse pathophysiological responses to particular foods. Finally, we will discuss these factors in the context of overall dietary patterns.

2. The role of dietary essential and non-essential amino acids in protein synthesis

Amino acids can be classified as dietary essential (EAA) or dietary non-essential (NEAA). EAA either cannot be produced in the

Abbreviations: AMDR, acceptable macronutrient distribution range; DGA, dietary guidelines for americans; DRI, dietary reference intake; DIAAS, digestible indispensable amino acid score; EAA, essential amino acids; EAR, estimated average requirement; NEAA, nonessential amino acids; RDA, recommended dietary allowance.

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body at all or at a rate sufficient to meet nutritional requirements [16]. The EAAs include histidine (His), isoleucine (Ile), leucine (Leu), valine (Val), lysine (Lys), threonine (Thr), phenylalanine (Phe), methionine (Met), and tryptophan (Trp). For nearly 100 years it has been known that the requirements for individual EAAs depend on a person's physiological status, such as growth and development as opposed to maintenance [16]. More recent data indicate that circumstances such as aging, athletic performance and serious illness may also influence both the amount and profile of the optimally required EAAs (e.g., Refs. [5,8,9,12,16]).

The basis for a dietary requirement for the EAAs in adults stems from their role in the maintenance of the body protein mass. Body protein is in a constant state of turnover. All proteins in the body are continually degraded to their component amino acids over time, with some being broken down more rapidly than others. Also, protein is lost from the body via the digestive tract, skin, and hair and, to a small extent, in the urine. Protein mass can only be maintained if proteins that are degraded or lost from the body are replaced by newly synthesized proteins. Many of the amino acids released in the process of breakdown can be reutilized to synthesize new proteins. However, a certain amount of both the EAAs and NEAAs released by protein breakdown are metabolized and excreted as CO_2, ammonia and urea, and these must be replaced if body mass is to be retained. New NEAAs can be produced in the body from other amino acids or from simple precursors (e.g. NH_3), and therefore are generally not limiting. In contrast, for the rate of protein synthesis to equal or exceed the rate of protein breakdown the metabolized EAAs and EAAs lost directly from the body must be replenished by dietary intake. Furthermore, the individual EAAs must be replenished in proportion to their requirement for protein synthesis.

Each protein in the body has a distinct amount and profile of amino acids. Collagen, for example, is the most abundant protein in the body and is composed largely of the NEAAs proline, glycine, arginine, and hydroxyproline. Since all of these NEAAs can be produced in the body, ingestion of them is not necessary for the rate of collagen synthesis to match the rate of breakdown. In contrast, skeletal muscle is composed of a high proportion (about 50%) of EAAs, in a specific profile. All of the EAAs need to be available in proportion to their respective contribution to the amino acid composition of muscle protein for protein synthesis to proceed.

Consumption of dietary EAAs is necessary due to the irreversible metabolism of some of the EAAs released as a consequence of protein breakdown and because of direct daily losses from the body due to body processes such as skin renewal, maintenance of mucosal tissue, etc. Thus, all EAAs are required in the diet, and the profile of requirements for EAAs will generally reflect their proportionate contribution to the synthesis of all the proteins in the body. In addition to the role of EAAs in protein synthesis, other specific metabolic roles of EAAs are becoming recognized and are gaining scientific substantiation, such as serving as precursors for the synthesis of compounds including neurotransmitters, purines and pyrimidines, and nitric oxide. Nonetheless, the principal metabolic role of dietary EAAs is as precursors for protein synthesis [17], and thus the amount and profile of dietary EAA requirements are based (indirectly) on the ability to stimulate protein synthesis (see below).

The designation “non-essential” amino acid implies that these amino acids that can be synthesized in the body need not be eaten. Consistent with this interpretation, ingestion of a single dose of only EAAs in the profile of beef protein acutely stimulated muscle protein synthesis to the same extent as ingestion of the same amount of EAAs plus all of the NEAAs in beef protein [18]. However, experiments in which growth rates were measured in livestock have given rise to the notion that consumption of some NEAAs are necessary for optimal protein nutrition since simple-stomached farm animals grow optimally if as much as 30–40% of total amino acid intake is in the form of NEAAs (as determined when expressing the amino groups as a ratio of essential amino acid nitrogen to total amino acid nitrogen) [19]. Further, it seems that at maintenance in animals, a higher ratio of NEAA to EAA may be needed to provide ideally balanced protein. In theory, the nitrogen from one NEAA can be transferred to other molecules to produce all of the NEAAs in adequate amounts. However, in practice it seems that at least 3 different NEAAs must be given to ensure adequate availability of all of the NEAAs [19]. The designation of “non-essential” amino acids is thus somewhat of a misnomer, as NEAAs are an important component of dietary protein intake. However, since the composition of high quality proteins includes at least 50% NEAAs, and the proportion of NEAAs in lower quality proteins is even higher, adequate intake of EAAs from dietary protein ensures adequate NEAA intake. For this reason it is therefore reasonable to base the assessment of protein quality on the amount and profile of EAAs, even though consumption of some NEAAs is also necessary for optimal protein nutrition.

3. EAA requirements

The quality of a dietary protein is determined to a large extent by its ability to deliver all of the EAAs in proportion to their individual requirements. It is therefore pertinent to examine the requirements for dietary EAAs.

The amounts and patterns of dietary EAAs required for the maintenance of lean body mass are primarily based on data derived from experiments using the general approach of deleting one EAA from an otherwise complete diet and then adding back progressively greater amounts of that amino acid until a selected end point indicates that a break point in response has been achieved (19). The original studies using this approach utilized the amount of each individual EAA at which zero N-balance was achieved (in the presence of an abundance of the other EAAs) as the end-point [20]. Subsequent to the studies using N-balance as an end point, isotope tracer studies have been utilized to determine EAA requirements. The underlying principle of all isotopic approaches to determining EAA requirements is that the fate of an essential amino acid tracer in the body is either oxidation or incorporation into protein. Thus, oxidation and incorporation into protein (ie, protein synthesis) are inversely related.

An extensive series of studies were performed in human subjects in which the rate of oxidation of the EAA was compared to the actual intake of that EAA in the circumstance of an abundance of the other dietary amino acids. The oxidation of the test EAA was measured at increasing rates of consumption. The rate of oxidation increased at a rate significantly less than the rate of intake increased until an inflection point was achieved, at which point the rate of oxidation progressively increased at to approximately the same rate as intake increased. Owing to the inverse relation between the rate of oxidation and incorporation into protein, it was assumed that the inflection point of the curve relating oxidation to intake corresponded to the amount of intake at which further incorporation into protein stopped. The inflection point was therefore taken to represent the minimum intake of the test EAA required to meet physiological needs [21].

More recently, a different indicator amino acid method has been used to estimate the requirement for an individual test amino acid. The method is based on the amount of the test EAAs required to maximize the rate of whole body protein synthesis in the context of an excess of the other dietary amino acids [21]. With this method the indicator EAA (usually phenylalanine) is distinct from the test EAA. The oxidation rate of phenylalanine is quantified at different