Digestibility issues of vegetable versus animal proteins: Protein and amino acid requirements—functional aspects

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Protein digestibility predicts the proportion of ingested nitrogen or amino acid made available to the organism after digestion and absorption. It is determined from the proportion that is not absorbed in the intestine following protein consumption in either human subjects or animal models (mainly growing rats or pigs). This is a complex process due to the continuous movements and exchange of protein, amino acids, and urea between the gut lumen and the systemic pools. For determination of true digestibility, additional discrimination is made between exogenous (food) and endogenous (secretions, desquamations) nitrogen losses. Individual amino acid digestibility is usually related to whole protein digestibility, but individual amino acid digestibility can be determined.

The digestibility of protein has largely been determined from fecal digestibility, the difference between nitrogen ingested and excreted in the feces, which does not take into account colonic metabolism. As unabsorbed amino acids are mostly metabolized by colonic bacteria and then converted to ammonia and other compounds that can be absorbed, fecal digestibility can be overestimated. Ileal digestibility, measured at the terminal ileum, is considered more accurate for determination of dietary amino acid digestibility. From these measurements, a high (> 95%) digestibility is usually observed with animal proteins (egg, milk, meat) as well as concentrated or purified plant protein once plant cell wall constituents are removed (wheat gluten, wheat flour, soy protein isolate). A lower digestibility (around 80% to 90%) is observed with some less purified plant products (cereals, peas, soybean flour), and a digestibility of 50% to 80% can be associated with higher levels of plant cell walls, the presence of antinutritional factors, or food processing and heat treatment. **Table 1** shows the effect of processing on the digestibility of protein from wheat. Differences between fecal and ileal digestibility are particularly important for plant protein sources, which are poorly digested in the upper intestine and increase the quantity of protein-derived nitrogen to be fermented in the colon. **Table 2** compares fecal and ileal digestibility of animal and vegetable protein sources in humans. This is also complicated by the hypothesized recycling of bacterial-derived amino acids to the host and the potential for colonic nitrogen metabolism to either remove or add amino acids to the dietary supply.

TABLE 1. Digestibility of wheat protein according to processing method

Protein source	True fecal digestibility (%)
Wheat gluten	99
Wheat, refined	96
Wheat flour, white	96
Wheat, whole	86
Wheat, cereal	77

The recent (and still unpublished) Food and Agriculture Organization (FAO) expert consultation on protein quality evaluation in human nutrition concluded that proteins should first be described on the basis of their digestible amino acid contents, with each amino acid being treated as an individual nutrient, and that the protein digestibility corrected amino acid score (PDCAAS) should be replaced by a new score, the digestible indispensable amino acid score (DIAAS), where DIAAS % = 100 × [(mg of digestible indispensable amino acid in 1 g of dietary protein)/(mg of the same indispensable amino acid in 1 g of reference protein)] [1].

Ileal protein digestibility values are most often lower than those derived from fecal data. This is the case for individual amino acids as well, with the exception of methionine, which had an ileal digestibility 10 percentage points higher than the fecal value [2]. Differences in amino acid ileal digestibility were found between milk

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TABLE 2. Fecal versus ileal digestibility (%) of proteins in humans

	Fecal	Ileal		
Protein	True	Apparent	True	Reference
Milk protein	96.6	91	95	Mahé et al., 1994 [4]; Bos et al., 2003 [5]; Gaudichon et al., 2002 [3]
Fermented milk	—	90	—	Mahé et al., 1994 [4]
Casein	—	—	94.1	Deglaire et al., 2009 [6]
Soy protein	95	—	91.5	Bos et al., 2003 [5]; Gaudichon et al., 2002 [3]
Pea protein	—	—	91.5	Gausserès et al., 1997 [7]
			89.4	Gausserès et al., 1996 [8]
			90	Mariotti et al., 2001 [9]
Wheat gluten	99	—	90.3	Bos et al., 2005 [10]
			85.0	Juillet et al., 2008 [11]
Lupin protein	—	—	90.0	Mariotti et al., 2002 [12]
Rapeseed protein	—	—	84	Bos et al., 2007 [13]

and soy for proline, alanine, tyrosine, threonine, valine, and histidine, as well as overall nitrogen digestibility, with the milk values being higher in all cases [3].

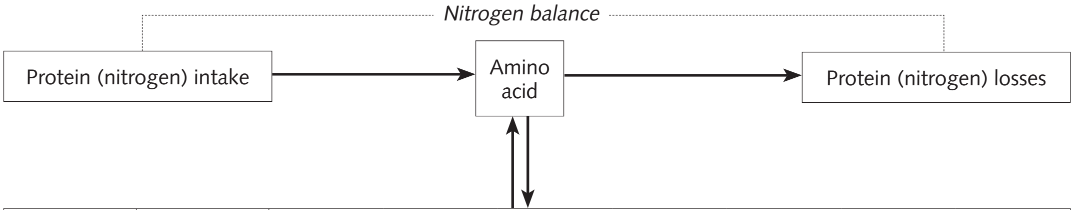
Protein and amino acid requirements: Functional aspects

Dietary proteins provide the body with nitrogen and amino acids as essential metabolic components, with numerous specific metabolic functions related to both proteogenic and nonproteogenic pathways. The current approach to determining protein requirements is related to the capacity of protein intake to allow nitrogen balance to be reached by providing nitrogen and indispensable amino acids. It is hypothesized that when nitrogen balance is reached, the protein and amino acid requirements for their different functions are satisfied, i.e., additional protein and amino acid intake above the requirement as derived from nitrogen balance does not further improve other markers or functional responses. This hypothesis can be discussed in reference to the influence of protein and amino acid supply on different markers and functions.

Protein nitrogen utilization can be related to the influence of protein and amino acid intake on the level and efficiency of dietary nitrogen retention in the body. Other approaches are related to protein turnover and protein synthesis in relation to maintenance and/or efficiency for deposition or development (growth) at the whole body level or for different and more specific target tissues such as muscle or bone. Protein and the branched-chain amino acid leucine improve muscle protein synthesis. However, there is no result showing that a dietary protein level and quality above the recommended requirement further modulate skeletal protein mass in nonexercising, young, healthy human subjects. In most epidemiological studies, bone mineral density is positively related to protein intake in infants, premenopausal women, and elderly people. Whether increasing protein intake and protein quality above the recommended intake further improves bone mineral density remains to be confirmed. In addition, protein quality can also be evaluated from different risk factors for metabolic dysfunction and disorders related, for instance, to insulin resistance, diabetes, obesity, and cardiovascular disease. But these markers do not indicate higher protein requirements than those defined by nitrogen balance.

According to different results, protein and amino acid requirements derived from nitrogen balance seem to represent a valuable approach, whereas other criteria related to nitrogen retention in different parts of the body, to the metabolic response of target tissues such as muscle and bone, or the influence on risk factors can be used additionally for more specific applications and specific situations (infants, exercise, older adults). Some of these approaches could be of help in the future to more precisely define protein and amino acid requirements adapted to specific sensitive populations and to the prevention of chronic and metabolic disease.

The hypothesis says that nitrogen balance is an adequate marker for protein requirement and that when it is satisfied other functions are also satisfied. If it is demonstrated one day that a protein biomarker (such as protein synthesis, muscle function, bone mass, adipose tissue, insulin, or disease risk) reaches an optimal plateau with a higher value than the nitrogen balance-derived requirement, protein recommendations will have to be revised (**fig. 1**). However, at this stage there are no data showing that nitrogen balance is not a good biomarker for the other functions.



Protein intake	Nitrogen balance	Amino acid utilization						
		Nitrogen utilization	Protein synthises	Muscle mass	Bone mass	Adipose tissue	Insulin	Disease risk
Deficient	Negative	Low	Low	Low	Low	↑	↑	↑
Requirement	0	Maximum	+	+	+	=	?	↓
↑	0		=+	=+	=+	↓	?	?
↑↑	0		=	=	=	↓	?	?

FIG. 1. Potential changes in protein and amino acid requirements based on functional aspects

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