Criteria and Significance of Dietary Protein Sources in Humans

# The Protein Digestibility–Corrected Amino Acid Score[1]

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ABSTRACT The protein digestibility–corrected amino acid score (PDCAAS) has been adopted by FAO/WHO as the preferred method for the measurement of the protein value in human nutrition. The method is based on comparison of the concentration of the first limiting essential amino acid in the test protein with the concentration of that amino acid in a reference (scoring) pattern. This scoring pattern is derived from the essential amino acid requirements of the preschool-age child. The chemical score obtained in this way is corrected for true fecal digestibility of the test protein. PDCAAS values higher than 100% are not accepted as such but are truncated to 100%. Although the principle of the PDCAAS method has been widely accepted, critical questions have been raised in the scientific community about a number of issues. These questions relate to *1*) the validity of the preschool-age child amino acid requirement values, *2*) the validity of correction for fecal instead of ileal digestibility and *3*) the truncation of PDCAAS values to 100%. At the time of the adoption of the PDCAAS method, only a few studies had been performed on the amino acid requirements of the preschool-age child, and there is still a need for validation of the scoring pattern. Also, the scoring pattern does not include conditionally indispensable amino acids. These amino acids also contribute to the nutrition value of a protein. There is strong evidence that ileal, and not fecal, digestibility is the right parameter for correction of the amino acid score. The use of fecal digestibility overestimates the nutritional value of a protein, because amino acid nitrogen entering the colon is lost for protein synthesis in the body and is, at least in part, excreted in urine as ammonia. The truncation of PDCAAS values to 100% can be defended only for the limited number of situations in which the protein is to be used as the sole source of protein in the diet. For evaluation of the nutritional significance of proteins as part of mixed diets, the truncated value should not be used. In those cases, a more detailed evaluation of the contribution of the protein to the amino acid composition of the mixed diet is required. From such an evaluation, it appears that milk proteins are superior to plant proteins in cereal-based diets. J. Nutr. 130: 1865S—1867S, 2000.

KEY WORDS: • *protein quality* • *amino acid score* • *scoring pattern* • *digestibility* • *critical evaluation*

It is well accepted that the nutritional value of proteins may differ substantially depending on their (essential) amino acid composition and digestibility. For many years, bioassays, mainly with rats, were the methods of choice to assess the nutritional value of proteins. This value was expressed in parameters such as protein efficiency ratio, net protein utilization and biological value. In 1989, a joint FAO/WHO Expert Consultation on Protein Quality Evaluation (FAO/WHO 1990) concluded that protein quality could be assessed adequately 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 in a reference pattern of essential amino acids. This reference pattern was based on the essential amino acid requirements of the preschool-age child as published in 1985 (FAO/WHO/UNU 1985) (**Table 1**). Subsequently, this percentage is corrected for the true fecal digestibility of the test protein, as measured in a rat assay. This scoring method, known as the protein digestibility–corrected amino acid score (PDCAAS),[2] was adopted as the preferred method for measurement of the protein value in human nutrition. Proteins with PDCAAS values exceeding 100% were not considered to contribute additional benefit in humans and were truncated to 100%. The PDCAAS formula is shown later.

$$\text{PDCAAS}(\%) = \frac{\text{mg of limiting amino acid in 1 g of test protein}}{\text{mg of same amino acid in 1 g of reference protein}} \times \text{fecal true digestibility}(\%) \times 100$$

**Table 2** shows values for protein efficiency ratio, true fecal

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[2] Abbreviation used: PDCAAS, protein digestibility–corrected amino acid score.

**TABLE 1**

*FAO/WHO/UNU amino acid requirement pattern based on amino acid requirements of preschool-age child*[1]

| Amino acid | Requirement |
|---|---|
| | *mg/g crude protein* |
| Isoleucine | 28 |
| Leucine | 66 |
| Lysine | 58 |
| Total sulfur amino acids | 25 |
| Total aromatic amino acids | 63 |
| Threonine | 34 |
| Tryptophan | 11 |
| Valine | 35 |
| Total | 320 |

[1] From FAO/WHO/UNU Expert Consultation 1985.

digestibility, amino acid score and nontruncated PDCAAS for some selected proteins.

Now, after ~10 y of experience with the PDCAAS method, it can be concluded that the method has been adopted widely. On the other hand, critical questions have been raised in the scientific community (Dutch Dairy Foundation on Nutrition and Health 1995, Darragh et al. 1998) about the following three PDCAAS issues: *1*) the validity of the preschool-age child amino acid scoring pattern, *2*) the validity of the true fecal digestibility correction and *3*) the truncation of PDCAAS values to 100%.

These issues are discussed later; it is concluded that it is timely to evaluate the PDCAAS method in its current form.

### *Validity of preschool-age child amino acid scoring pattern*

This reference scoring pattern (Table 1) is based on amino acid balance studies performed ~20 y ago by Torun et al. (1981) and Pineda et al., 1981) in a limited number of 2-y-old children. These children were recovering from malnutrition and thus not representing normal healthy preschool-age children. The results of these studies, which so far have not yet been published in peer-reviewed international journals, were expressed in mg/kg of body weight/d and were assumed to include a safety margin of the same magnitude as that of the FAO/WHO safe level of high quality protein (meat, fish, egg, milk) intake for this particular group of children. The reference pattern was obtained by computing the ratios between the essential amino acid requirement values (mg/kg body weight/d) and this safe level of high quality protein intake (g/kg body weight/d), thus resulting in values of mg/g of protein for each essential amino acid.

Although there is no evidence to reject the assumption that both numerator and denominator of these ratios include similar margins of safety, this has not been validated. A difference in safety margins of nominator and denominator would result in an incorrect reference pattern with underestimated or overestimated values.

Another issue is that the current reference pattern is restricted to the indispensable amino acids and does not include amino acids that become indispensable under specific physiological or pathological conditions, such as cystine, tyrosine, taurine, glycine, arginine, glutamine and proline. This implies that these latter amino acids should also contribute to the nutritional value of a protein (van Hooydonk 1994).

These considerations plead for a critical contemplation of the current scoring pattern.

### *Validity of true fecal digestibility correction*

As recognized by the FAO/WHO Expert Consultation on protein quality evaluation (1990), the intestinal flow of amino acids beyond the terminal ileum is an important route for bacterial metabolic consumption of amino acids. Amino acids that appear in the colon are most probably lost for body protein synthesis. Therefore, ileal rather than fecal digestibility is the critical biologically relevant parameter for amino acid or protein digestibility. The Expert Consultation recognized the shortcomings of the true fecal digestibility correction and recommended methodological studies to resolve uncertainties about the contribution and variation of endogenous amino acid losses at the terminal ileum before the determination of ileal digestibility could be recommended to replace fecal digestibility. Since then, several studies in this field were published (e.g., Caine et al. 1997a and 1997b, Huisman et al. 1993, Rowan et al. 1994, Van Leeuwen et al. 1996) indicating that antinutritional factors associated with dietary proteins may enhance substantially endogenous losses of amino acids and therefore decrease the nutritional value of the protein. Only true ileal digestibility of amino acids will take these losses into account (Darragh et al. 1998), and it is therefore timely to consider the use of ileal instead of fecal digestibility values.

### *Truncation of PDCAAS values to 100%*

According to the current PDCAAS method, values that are higher than 100% are truncated to 100%, arguing that digestible essential amino acid concentrations in a protein in excess of those in the preschool-age child reference pattern do not provide additional nutritional benefit. This statement is correct when the protein in question is the sole source of protein in the human diet, as occurs in infant feeding practices and under special conditions, like enteral feeding. However, under all other conditions, humans consume mixed diets with proteins from a variety of sources. Under such conditions, the power of high quality proteins to balance the amino acid pattern of the mixed diet is extremely relevant. A classic and widely accepted example in this regard is the combination of milk and wheat, in which the relatively high lysine concentration of milk proteins compensates for the low concentration of this essential amino acid in wheat. So it can easily be computed that 1.2 g of casein can balance 1 g of wheat protein, whereas 6.2 g of soy protein would be needed to do so (**Table 3**). The truncation of PDCAAS values thus largely eliminates

**TABLE 2**

*True fecal digestibility, amino acid score and PDCAAS for selected proteins*[1]

| Protein | PER | Digestibility | AAS | PDCAAS |
|---|---|---|---|---|
| | | | % | |
| Egg | 3.8 | 98 | 121 | 118 |
| Cow's milk | 3.1 | 95 | 127 | 121 |
| Beef | 2.9 | 98 | 94 | 92 |
| Soy | 2.1 | 95 | 96 | 91 |
| Wheat | 1.5 | 91 | 47 | 42 |

[1] Data from FAO/WHO Expert Consultation 1990, European Dairy Association 1997, and Renner 1983.

**TABLE 3**

*Amount of protein needed to upgrade 1 g of wheat protein to obtain the preschool-age child's lysine requirement level of 58 mg/g mixed crude protein*

| Protein | Protein supplement needed |
|---|---|
| | *g* |
| Beef | 1.0 |
| Cow's milk | 1.6 |
| Egg | 2.6 |
| Soy | 6.2 |

the differences in the power of high quality proteins to balance the amino acid composition of inferior proteins. This is highly relevant, not only for the low lysine content of cereals but also for the low content of S-containing amino acids and threonine of many plant protein sources. Thus, truncated PDCAAS values do not provide information about the potency of a protein to balance inferior proteins, and a solution for this problem should be found.

The questions about the validity of the amino acid scoring pattern and the application of the true fecal rather than the true ileal digestibility correction as well as the truncation of PDCAAS values warrant a critical evaluation of PDCAAS in its current form as a measure of protein quality in human diets.

## LITERATURE CITED

Caine, W. R., Sauer, W. C., Tamminga, S., Verstegen, M.W.A. & Schulze, H. (1997a) Apparent ileal digestibilities of amino acids in newly weaned piglets and fed diets with protease-treated soybean meal. J. Anim. Sci. 75: 2962–2969.

Caine, W. R., Tamminga, S., Verstegen, M.W.A., Sauer, W. C. & Schulze H. (1997b) Endogenous recoveries of true ileal digestibilities of amino acids in newly weaned piglets fed diets with protease-treated soybean meal. J. Anim. Sci. 75: 2970–2979.

Darragh, A. J., Schaafsma, G. and Moughan, P. J. (1998) Impact of amino acid availability on the protein digestibility corrected amino acid score. Proceedings of the Nutrition Week of the International Dairy Federation, Wellington, New Zealand, March 9–11, 1998.

Dutch Dairy Foundation on Nutrition and Health (1995) Proceedings of the International Workshop on Nutritional Aspects of Milk Proteins in Comparison with Other Proteins, organized by the Dutch Foundation on Nutrition and Health, Utrecht, the Netherlands, March 13–14, 1995.

European Dairy Association (1997) Nutritional Quality of Proteins. European Dairy Association, Brussels, Belgium.

FAO/WHO Expert Consultation (1990) Protein Quality Evaluation. Food and Agricultural Organization of the United Nations, FAO Food and Nutrition Paper 51, Rome.

FAO/WHO/ÚNU Expert Consultation (1985) Energy and Protein Requirements. Technical Report Series 724. World Health Organization, Geneva.

Huisman, J., Verstegen, M.W.A., Van Leeuwen, P. & Tamminga, S. (1993) Reduction of N pollution by decrease of the excretion of endogenous N in pigs. In: Nitrogen Flow in Pig Production and Environmental Consequences, pp. 55–61. Pudoc Scientific Publishers, Wageningen, the Netherlands.

Pineda, O., Torun, B., Viteri, F. E. & Arroyave, G. (1981) Protein quality in relation to estimates of essential amino acid requirements. In: Protein Quality in Humans (Bodwell, C. E., Adkins, J. S. & Hopkins, D. T., eds.), pp. 29–42. AVI Publishing Company, Westport, CT.

Renner, E. (1983) Milk and Dairy Products in Human Nutrition. W-Gmbh Volkswirtschaftlicher Verlag, München, pp. 90–130.

Rowan, A. M., Moughan, P. J., Wilson, P. J., Maher, K. & Tasman-Jones, C. (1994) Comparison of ileal and fecal digestibilities of dietary amino acids in adult humans and evaluation of the pig as a model for animal digestion studies in man. Br. J. Nutr. 71: 29–42.

Torun, B., Pineda, O., Viteri, F. E. & Arroyave, G. (1981) Use of amino acid composition data to predict protein nutritive value for children with specific reference to new estimates of their essential amino acid requirements. In: Protein Quality in Humans (Bodwell, C. E., Adkins, J. S. & Hopkins, D. T., eds.), pp. 374–393. AVI Publishing Company, Westport, CT.

Van Hooydonk, A.C.M. (1994) Definition of the nutritional value of dietary proteins. In: Protein Definition. Proceedings of the 1st IDF Symposium, Minneapolis, MN, October 1993. International Dairy Federation, Brussels.

Van Leeuwen, P., Veldman, A., Boisen, S., Deuring, K., Kempen, G.J.M., Derksen, G. B., Verstegen, M.W.A. & Schaafsma, G. (1996) Apparent ileal dry matter and crude protein digestibilty of rations fed to pigs and determined with the use of chromium oxide (Cr2O3) and acid-insoluble ash as digestive markers. Br. J. Nutr. 76: 551–562.