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The Amino-Acid Score and Physical Growth: Implications for the Assessment of Protein Quality

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***Abstract*—**The purpose of this study was to test the reliability of various standards that assess the quality of proteins via the "amino-acid score" and serve as a nutritional guideline for both children and adults. The height of young men in 42 European countries, Australia, New Zealand and USA was compared with the average consumption of food (after FAOSTAT, 2009) and a subsequent statistical analysis identified types of food with the most pronounced effect on physical growth. The results show that milk products and pork meat are by far the most significant nutritional factors in this regard. Cereals, vegetables and especially wheat played a strongly negative role. The results generally agreed best with the amino-acid score of proteins according to the standard of FAO 1985. In our opinion, the new standard of FAO 2007 underestimates the importance of tryptophan, which should provoke a debate about new modifications of the FAO guidelines.

***Keywords*—**Protein quality, amino-acid score, physical growth, male height.

I. Introduction

THE amino-acid score (AAS) was introduced as a substitute for older indicators for protein quality (e .g. the protein-efficiency ratio or biological value) in 1981 [1]. It is defined as the ratio between the content of the least represented (most limiting) amino acid and its content in an „ideal protein“. Requirements of essential amino acids for children of preschool age were established by a report of FAO/WHO/UNU in 1985. The most objective assessment of protein quality further requires the correction of AAS by protein digestibility and availability, which was recognized in the FAO/WHO Expert Consultation report (1991) that recommended the introduction of the PDCAAS score (Protein Digestibility-Corrected Amino Acid Score). In general, the digestibility of plant protein is routinely low, 80-90%, while this number in animal protein is higher, around 95%, and it can be as high as 100% in cooked meat [2]. The fact that PDCAAS can change in dependence on the food processing and culinary preparation is one of key problems of the assessment of protein quality. Nevertheless, despite certain imperfections, PDCAAS is still a very useful approach.

In 2007, a final report of a new FAO/WHO consultation recommended new scoring patterns for children and adults. The standards for 3-10 year old children and adults differ only slightly. It was also recognized that the truncation of the PDCAAS to 1.00 (in all foods with PDCAAS higher than 1.00) removes any additional differences in nutritional quality between high-quality protein sources. Another FAO Expert Consultation in 2011 proposed the introduction of a new approach, the Digestible Indispensable Amino Acid Score (DIAAS) that reflects differences in digestibility in individual amino acids.

Irrespectively of these theoretical assumptions and recommendations, the real demands of the amino-acid intake – especially in older children - are still uncertain and are a subject of an ongoing debate. The 2007 report explicitly stated that „there is a paucity of long-term prospective studies examining health outcomes [of proposed amino-acid scoring patterns]". Furthermore, while the FAO standard from 1985 was based on children recovering from malnutrition, the new standard of FAO from 2007 is defined as the minimum amount of amino acids necessary for maintaining nitrogen balance, which may not be an optimal for situations, where maximal anabolism is required [3]. Therefore, all these scoring patterns haven't undergone any long-term test of reliability.

In our opinion, one of such a long-term tests could be the relationship between physical growth and the consumption of various types of food, whose amino-acid scores would be computed according to different standards.

II. Methods

Actual height of young males (age range ~17-30 years) was collected from 42 European countries, Australia, New Zealand and USA. All these anthropometric studies were finished within the last 14 years (1999-2013). These data were compared with the annual consumption of 19 food items (including various subcategories) from the FAOSTAT database (for the year 2009) [4], in order to identify food items with the most significant impact on physical growth. The same comparison was made between male height and approximate protein consumption from these food items.

To test the reliability of current standards, with which the quality of proteins is evaluated, we computed amino acid scores in various types of food, based on data from the FAO.org database [5], according to four different standards of protein quality (FAO 1985, FAO 2007, body proteins, proteins in human milk). Nine essential amino-acids were included (see Table I). Subsequently, we chose 8 types of food with average protein consumption rates higher than 3 g/day per capita - milk products, pork meat, beef meat, poultry (or chicken meat,

Data on the body height of Czech men are based on results from the the project "Creating a research team for the purpose of determining the level of physical activity (inactivity) in selected age groups of the population of men and women in the Czech Republic" (CZ.1.07/2.3.00/20.0044), financed by the European Social Fund and the state budget of the Czech Republic.

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respectively), potatoes, fish, eggs, wheat - and compared their amino acid scores with r-ratios, which described their relationship with male stature. The amino acid score in milk products had to be computed rather arbitrarily, as an average value of amino acid scores of sterilized milk, cheese and curd.

TABLE I
ESSENTIAL AMINO ACIDS IN DIFFERENT STANDARDS OF PROTEIN QUALITY

	Ile	Leu	Lys	Met + Cys	Phe + Tyr	Thr	Trp	Val	His
Human milk	55	96	69	33	94	44	17	55	21
FAO 1985	28	66	58	25	63	34	11	35	19
FAO 2007	30	61	48	23	41	25	6,6	40	16
Body proteins	35	75	73	35	73	42	12	49	27

Comparison of the composition of essential amino acids ($mg.g^{-1}$ of protein) in different standards of protein quality (Ile - Isoleucine; Leu – Leucine; Lys – Lysine; Met - Methionine; Cys – Cysteine; Tyr - tyrosine; Phe – Phenylalanine; Thr – Threonine; Trp – Tryptophan; Val – Valine; His - Histidine)

Statistical correlations between amino-acid scores and nutritional standards were investigated via Pearson linear coefficients in the program Statistica 10.

III. RESULTS

The comparison between the height of young males and FAOSTAT data showed quite uniquevocally that milk products (including cheese) and pork meat were food items with the most significant impact on physical growth (Table IIA). This applied even for protein consumption (Table IIB). Out of all other eatables, only total consumption of meat and protein from meat reached a moderate statistical significance, as well as total consumption of protein from fish. In contrast, cereals, vegetables and especially wheat had a strongly negative effect. The ratio between the consumption of high quality proteins (milk products, pork meat) and low quality products (cereals, vegetables) correlated even more significantly with male stature ($r=0.69$; $p<0.000001$) (Fig. 1), and after the exclusion of former Yugoslavia (the biggest outlier), the r-value further increased to $r=0.77$. This finding indicates that the proportion of the best and worst proteins in a particular diet is the best indicator of its overall value.

Amino-acid scores computed from various standards in 26 foodstuffs (Table III) generally agree with each other, although there are marked differences in some individual cases. Methionine+cysteine emerged most frequently as limiting amino acids determining the amino-acid score (36-times), followed by tryptophan (26x), lysine (15x), leucine (11x), fenylalanine+cysteine and histidine (4x), valine (3x), threonine (2x) and isoleucine (1x). Amino-acid scores based on the standards of FAO 1985 and proteins from human milk mutually correlate best ($r=0.963$). In contrast, relationships in FAO 2007 vs. human milk proteins (0.879), and in body proteins vs. human milk proteins ($r=0.849$) have the lowest r-value (Table IV).

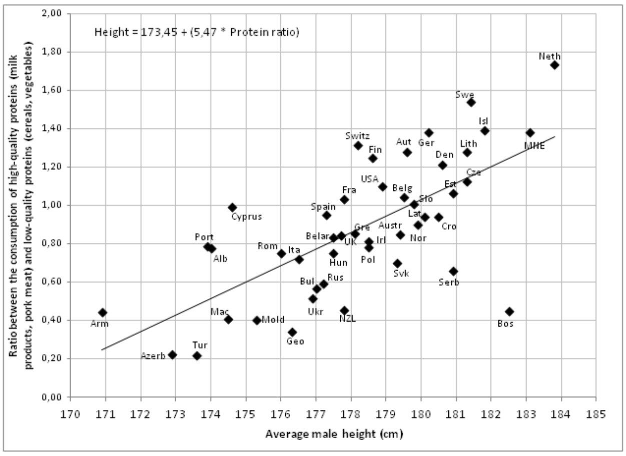

Fig. 1 Ratio between the consumption of high-quality and low-quality proteins Ratio between the consumption of high-quality proteins (milk products, pork meat) and low-quality proteins (cereals, vegetables) in 2009 (according to FAOSTAT [4]), and its relationship with average male height ($r=0.69$; $p<0.000001$)

The standard of FAO 1985 shows the best fit with all three remaining standards, while there exists a polarity between human milk proteins vs. FAO 2007 and body proteins. If we summed up the ranking of food items in Table III, spinage proteins appear as one of the very best in all four comparisons (10), and are distantly followed by eggs (18), fresh milk (19), curd and mutton meat (24), cheese and pork meat (25), molluscs and sterilized milk (27). Proteins of the worst quality are contained in cereals (mainly wheat and maize), fruits and hazelnuts.

The comparison of r-ratios from Table IIB with amino acid scores computed in the selected 8 food items showed that the standard that correlated best with our results was the standard of FAO from 1985 ($r=0.78$; $p=0.021$). The composition of body proteins ($r=0.74$; $p=0.034$) and the standard of FAO from 2007 ($r=0.72$; $p=0.042$) correlated slightly less, and the composition of amino acids in human milk approached statistical significance ($r=0.67$; $p=0.067$). In all these comparisons, eggs were the most striking outlier, and after their exclusion, the correlation values were even higher: The best agreement was found with amino acids from human milk ($r=0.94$; $p=0.002$) and the standard of FAO from 1985 ($r=0.92$; $p=0.003$). The standard of FAO from 2007 ($r=0.84$; $p=0.019$) and the composition of body proteins ($r=0.81$; $p=0.028$) were clearly less reliable. Remarkably, the r-ratios of 8 selected food items from Table IIB didn't correlate well with the total content of essential amino acids in 1 gram of protein ($r=0.56$; $p=0.15$).

TABLE II (A)
PEARSON LINEAR CORRELATIONS BETWEEN MALE HEIGHT AND FOOD CONSUMPTION IN 45 COUNTRIES

Whole food	r	r^2	p	kg/year per capita
Wheat	-0.62	0.39	0.000004	105.1
Cereals total	-0.52	0.27	0.0003	130.4
Vegetables total[a]	-0.50	0.25	0.0005	129.4
Milk products total	0.45	0.20	0.002	215.9
Pork meat	0.44	0.20	0.002	30.3
Cheese	0.42	0.18	0.004	11.3
Meat total	0.33	0.11	0.025	70.9
Crustaceans	0.29	0.08	0.053	2.1
Fish total[b]	0.28	0.08	0.06	10.3
Oilcrops	-0.24	0.06	0.11	4.7
Fruits	0.22	0.05	0.14	99.4
Fish & seafood total	0.21	0.04	0.16	20.1
Potatoes	0.11	0.01	0.48	71.9
Mutton & goat meat	-0.09	0.01	0.57	3.2
Legumes	-0.07	0.01	0.64	2.9
Beef meat	0.07	0.00	0.65	15.1
Nuts	0.06	0.00	0.70	3.8
Poultry meat	0.04	0.00	0.80	20.5
Eggs	0.00	0.00	0.98	10.7

Pearson linear correlations between male height and food consumption in 45 countries, in order of statistical significance. Statistically significant correlations ($p<0.05$) are above the horizontal line. Subcategories are in italics. *Note:* [a] Vegetables don't include potatoes. [b] Includes freshwater fish, pelagic marine fish and other (unspecified) species of marine fish. *Source:* [4].

TABLE II (B)
PEARSON LINEAR CORRELATIONS BETWEEN MALE HEIGHT AND FOOD CONSUMPTION IN 45 COUNTRIES

Protein	r	r^2	p	g/day per capita
Wheat	-0.62	0.38	0.000007	24.5
Cereals total	-0.55	0.30	0.0001	29.3
Cheese	0.46	0.21	0.001	7.8
Pork meat	0.46	0.20	0.002	8.2
Milk products total	0.45	0.20	0.002	19.2
Vegetables total[a]	-0.42	0.18	0.004	3.9
Fish total[b]	0.32	0.10	0.034	3.5
Meat total	0.31	0.10	0.037	23.7
Crustaceans	0.25	0.06	0.10	0.5
Fish & seafood total	0.25	0.06	0.10	5.9
Mutton & goat meat	-0.10	0.01	0.52	1.1
Potatoes	0.09	0.01	0.56	3.0
Nuts	0.07	0.01	0.64	0.7
Poultry meat	0.05	0.00	0.73	7.7
Legumes	-0.05	0.00	0.76	1.7
Beef meat	0.05	0.00	0.77	5.8
Oilcrops	0.04	0.00	0.79	1.0
Fruits	-0.01	0.00	0.90	1.3
Eggs	0.01	0.00	0.97	3.2

Pearson linear correlations between male height and food consumption in 45 countries, in order of statistical significance. Statistically significant correlations ($p<0.05$) are above the horizontal line. Subcategories are in italics. *Note:* [a] Vegetables don't include potatoes. [b] Includes freshwater fish, pelagic marine fish and other (unspecified) species of marine fish. *Source:* [4].

IV. DISCUSSION

In contrast with the standards of FAO that are based on short-term nutritional analyses, our study approaches the problem from a different angle and investigates long-term „results of the real world“ – the effect of protein consumption on physical growth. The findings show quite clearly that proteins from milk products and pork meat are superior to any other food item from the FAOSTAT database, which agrees with their position among the best proteins according to all four standards. In contrast, proteins from other kids of meat like beef and poultry don't show any effect on male stature, even at relatively high consumption rates. The fact that the standard of FAO 2007 places pork meat on a par with beef and chicken meat indicates that the amino-acid composition in this standard may not accurately reflect nutritional demands in humans. More concretely, this standard probably underestimates the necessary intake of tryptophan, which otherwise appears as the limiting amino acid in both beef and chicken meat according to all three remaining standards. For a change, the composition of body proteins probably underestimates the biological value of milk (relatively to beef), due to the combination of higher demands on methionine+cysteine and relaxed demands on tryptophan.

The results in other types of food should be taken with bigger caution, due to low consumption rates. Although the amino-acid score in fish protein is above-average, it is remarkable that the average amino-acid composition of fish protein (according to FAO.org [5]) is almost identical to beef protein. On the other hand, this is complicated by the fact that amino-acid scores in various types of fish vary widely – from very high in flatfish (1.25 according to FAO 1985) and *Gadiformes* (e.g. cod, mackerel – 1.08) to rather low in eels (0.92) and *Cypriniformes* (e.g. carp, catfish – 0.93). The only essential amino acid, whose content is substantially higher in fish protein than in beef protein is valine. Interestingly, out of all standards, the content of valine is the highest in human milk. However, increasing requirements on valine would also decrease AAS in pork meat, which suggests that valine content is not the factor that could explain the difference between the biological quality of beef and fish. Rather, it is the consumption of some marine fish with very high amino-acid scores.

The most surprising result of our comparison was the lack of any correlation between male stature and the consumption of eggs. In fact, eggs had the lowest r-ratios out of all investigated food items, and their relationship with height was strikingly curvilinear, similar like in beef and poultry (data not showed). This may be caused by too low a consumption rate in egg protein (3.2 g/day per capita). Nevertheless, fish protein still showed significant correlation with height, despite similar daily intake (3.5 g per capita). In this context, we should mention the study of Evenepoel et al. [8], who found that digestibility of raw egg protein in the small intestine was only 65%, in comparison with 94% in cooked eggs. In other words, the consumption of raw or insufficiently cooked eggs would decrease the amino-acid score of egg protein almost on the level of legumes and potatoes.

TABLE III (A)
AMINO – ACID SCORES IN VARIOUS TYPES OF FOOD, ACCORDING TO DIFFERENT STANDARDS

Proteins in human milk (after [1])		FAO, age 2-5 years (1985) (after [7])	
Spinage	0.876	Fresh milk	1.247
Eggs	0.873	Spinage	1.246
Sterilized milk	0.857	Eggs	1.200
Soybeans	0.824	Molluscs	1.171
Fresh milk	0.807	Sterilized milk	1.166
Pork meat	0.785	Mutton meat	1.154
Molluscs	0.765	Pork meat	1.142
Mutton meat	0.747	Soybeans	1.134
Cheese (average)	0.709	Cheese (average)	1.096
Curd	0.706	Curd	1.091
Crustaceans	0.676	Fish (all types)	1.020
Champignons	0.668	Beef meat	1.017
Fish (all types)	0.660	Brewer's yeast	0.999
Beef meat	0.658	Crustaceans	0.987
Brewer's yeast	0.650	Chicken meat	0.932
Chicken meat	0.603	Champignons	0.882
Beans	0.579	Pea	0.812
Potatoes	0.576	Beans	0.764
Rice	0.578	Potatoes	0.760
Pea	0.528	Rice	0.687
Lentils	0.520	Lentils	0.686
Hazelnuts	0.456	Apples	0.635
Wheat	0.444	Hazelnuts	0.602
Apples	0.426	Wheat	0.529
Maize	0.387	Maize	0.461
Oranges	0.286	Oranges	0.417

Amino-acid scores in various types of food, according to different standards (computed by the authors). *Source:* [5] (amino-acid composition in food).

TABLE III (B)
AMINO – ACID SCORES IN VARIOUS TYPES OF FOOD, ACCORDING TO DIFFERENT STANDARDS

FAO, age 3-10 years (2007) (after [1])		Body proteins (after [6])	
Curd	1.643	Pork meat	1.005
Spinage	1.506	Mutton meat	1.001
Cheese (average)	1.464	Curd	1.000
Eggs	1.442	Cheese (average)	0.959
Fresh milk	1.416	Spinage	0.943
Molluscs	1.267	Fish (all types)	0.935
Sterilized milk	1.267	Beef meat	0.932
Mutton meat	1.264	Fresh milk	0.931
Fish (all types)	1.260	Eggs	0.899
Beef meat	1.251	Molluscs	0.881
Pork meat	1.236	Chicken meat	0.854
Soybeans	1.232	Sterilized milk	0.833
Chicken meat	1.207	Soybeans	0.810
Crustaceans	1.172	Brewer's yeast	0.714
Brewer's yeast	1.086	Crustaceans	0.694
Champignons	0.959	Champignons	0.630
Pea	0.883	Pea	0.580
Apples	0.870	Apples	0.548
Beans	0.830	Beans	0.546
Potatoes	0.826	Rice	0.546
Rice	0.831	Potatoes	0.543
Lentils	0.746	Lentils	0.490
Hazelnuts	0.654	Hazelnuts	0.430
Wheat	0.639	Wheat	0.420
Maize	0.557	Maize	0.366
Oranges	0.451	Oranges	0.357

Amino-acid scores in various types of food, according to different standards (computed by the authors). *Source:* [5] (amino-acid composition in food).

It is understandable that due to the very low daily intake of protein from other potential high-quality sources – spinage, mutton meat, molluscs and soybeans – a significant correlation with height can't be expected. Nevertheless, these food items regularly appeared among those with the best protein quality (Table III) and their increased consumption should be taken into consideration. Another question is the content of possible anti-nutritional factors, especially in plant foods like spinage and soy.

TABLE IV
RELATIONSHIPS BETWEEN VARIOUS STANDARDS OF PROTEIN QUALITY

	Human milk	FAO 1985	FAO 2007	Body proteins
Human milk		,9629	,8786	,8494
FAO 1985	,9629		,9418	,9349
FAO 2007	,8786	,9418		,9544
Body proteins	,8494	,9349	,9544	

Relationships (r-values) between various standards of protein quality, based on the amino acid scores in Table III.

V. CONCLUSION

The findings of our analysis indicate that milk products and pork meat offer the biggest benefits for physical growth of children at normal, everyday's rates of protein consumption, while cereals and vegetables very markedly decrease the overall quality of human diet. These results agree with the ranking of food proteins according to the amino-acid score, which confirms the assumption that the content of the most limiting amino acid is a critical indicator of protein quality. The total content of essential amino acids seems to be much less important. The previous praxis of truncating amino-acid scores to 1.00 appears as clearly misleading, because there exist marked differences in quality even among proteins with amino-acid scores above 1.00. It seems that only proteins with AAS around ~1.10 or higher (according to FAO 1985) can maximize the genetic potential of physical stature. Total consumption of protein doesn't matter much, as indicated by the lack of correlation with male stature ($r=0.19$; $p=0.22$).

Before the introduction of a new, more accurate standard, the old scoring pattern of FAO 1985 should preferably be used, because it corresponds best with our results. Furthermore, the amino-acid scores in FAO 1985 also don't deviate much from all three remaining standards. Apart from the anomaly in the case of eggs, proteins in human milk appear as a comparably reliable indicator. In our opinion, the content of tryptophan in the new FAO standard from 2007 was reduced too much and the standard doesn't appear to be a good measure of protein quality for situations, where maximal anabolism is required. Something similar applies even for body proteins, due to the combination of high requirements on methionine+cysteine and histidine, and relatively low on tryptophan. Although it is not entirely certain, if the amino-acid score of FAO 1985 is also useable for adults, the clear superiority of milk products and pork meat for physical growth shows that these foodstuffs should be considered as the best choice even in sports nutrition. In contrast, the widespread dietary praxis in athletes based on beef and chicken meat appears as insufficient, unless unnaturally high amounts of protein are consumed.

Due to the apparent limitations of this study, our recommendations with regard to possible changes in amino acid standards must be taken only as indicative. Understandably, we can't also be responsible for possible inaccuracies in the data of the FAO.org database, which are sometimes based on too low a number of studies. Nevertheless, the basic message of this study is a suggestion that an ideal protein standard should again increase the requirements of tryptophan up to the level of FAO 1985. Among other things, this change would decrease AAS in beef and profoundly raise AAS in pork meat on the level of milk (1.24, if all other scoring patterns remain like in the standard of FAO 2007), which would agree better with our results.

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