AMERICAN JOURNAL OF PHYSIOLOGY
Vol. 221, No. 3, September 1971. *Printed in U.S.A.*

Energy metabolism of proteins and amino acids

LEROY VORIS
National Academy of Sciences, Washington, D. C. 20418

VORIS, LEROY. *Energy metabolism of proteins and amino acids.* Am. J. Physiol. 221 (3): 952–954. 1971.—Some of the thermochemical constants and metabolizable energy factors involved in the metabolism of three proteins and eight amino acids have been compiled, and data are presented to show that protein added to maintenance diets for rats will spare the energy derived from carbohydrate and fat.

nutrition; metabolizable energy; heat production; thermochemical factors

---

SPECIFIC PROTEINS have specific characteristics with respect to their energy properties as well as with respect to their amino acid composition. The basic principles of thermochemistry apply likewise to the energy metabolism of specific amino acids.

Some of the thermochemical constants and metabolizable energy factors involved in the metabolism of three proteins and eight amino acids have been compiled from the published data of Max Kriss and collaborators (3–9) and are summarized herewith.

Some hitherto unpublished data from measurements conducted at the Pennsylvania State College in 1935 and 1937 are also presented to demonstrate that prtoein added to maintenance diets for rats will spare the metabolism of carbohydrate and fat for energy in the same way that carbohydrate and fat are credited with the sparing of protein.

Energy exchange factors. The heats of combustion and metabolizable energy values, as determined in rats for casein, gelatin and muscle protein, are presented in Table 1, and those for amino acids in Table 2. The factors involved in the O_2/CO_2 exchange and heat production are presented in Table 3. The general procedure of experimentation and methodology for calculation of the factors was described by Kriss and Voris in 1937 (9).

In general, the respiration and energy factors for protein and amino acids are correlated with the ratios of carbon to nitrogen contained therein (4). Kriss (7) found very close agreement between the determined as compared with theoretical factors for the O_2/CO_2 exchange and heat production of the amino acids when calculated on the basis of the nitrogen of the amino acid metabolized.

In 1958 an extensive compilation of data on energy values of protein and amino acids was reported by Levy, Bernstein, and Grossman from the United States Army Medical Research and Nutrition Laboratory (10). The primary objective was to ascertain the calorie content of urine of human beings for estimation of the metabolizable energy of foodstuffs. They derived a factor of 6.28 kcal/g of urinary nitrogen or 1.0 kcal/g of absorbed protein. The corresponding values in rats for casein, gelatin, and muscle protein (*column 9* of Table 3) are 0.98, 1.17 and 1.08 kcal/g of absorbed protein (9).

Effects of protein supplements on heat production. The results of adding protein supplements to basal diets approximating maintenance energy equilibrium in rats are presented in Table 4. The daily heat produced is that derived from 7-hr measurements in a Haldane respiration chamber in which the activity was controlled (1, 2). One-half of the daily quota of feed was fed twice daily for at least 5 days prior to measurement of heat production in order to stabilize the rate of metabolism as being representative of the dietary regimen.

TABLE 1. *Heats of combustion and metabolizable energy of proteins (summary of determinations by Kriss et al. (3, 8))*

Material	Ref	Heat of Combustion		Metabolizable Energy			
		As fed	Pure[a]	As fed	%	Pure[a]	%
Casein	(8)	5.096	5.757	4.118	80.8	4.592	79.8
	(9)	5.240	5.941	4.264[b]	81.4	4.737[b]	79.7
		5.240	5.941	4.345[c]	82.9	4.714[c]	79.3
	(3)	5.175	5.760	4.213[b]	81.4	4.710[b]	81.7
		5.175	5.760	4.290[c]	82.9	4.800[c]	83.3
Gelatin	(9)	4.523	5.223	3.692[b]	81.6	4.105[b]	78.6
		4.523	5.223	3.641[c]	80.5	3.937[c]	75.4
	(3)	4.573	5.300	3.732[b]	81.6	4.240[b]	80.0
		4.573	5.300	3.681[c]	80.1	4.170[c]	78.7
Muscle	(9)	5.593	5.631	4.944[b]	88.4	4.402[b]	78.2
		5.593	5.631	4.745[c]	84.8	4.120[c]	73.2
	(3)	5.559	5.640	4.915[b]	88.4	4.500[b]	79.8
		5.559	5.640	4.720[c]	84.9	4.400[c]	78.0

Values are given in kilocalories per gram. [a]Water-, fat-, ash-free. [b]1.5 g/day fed. [c]3.0 g/day fed.

The increase in daily kilocalories attributable to the added protein (Table 4) is greater than the net increase in daily heat produced because of the concomitant decrease in kilocalories derived from carbohydrate or fat in the basal diet.

In effect, some of the energy derived from carbohydrate and fat of the basal diet when it was fed alone was spared by preferential disposal of the extra energy provided by the protein supplement. The basic principle is that, within the

TABLE 2. *Heats of combustion and metabolizable energy of some amino acids (summary of determinations of Kriss et al. (4, 6))*

Amino Acid	Ref.	Heat of Combustion, kcal/g	Metabolizable Energy kcal/g	Metabolizable Energy %
DL-Alanine	(4)	4.354	2.544	58.4
Arginine	(6)	3.346	3.478	70.1
L-Asparagine	(7)	3.423	2.051	59.9
Aspartic Acid	(7)	2.889	2.060	71.3
D-Glutamic acid	(4)	3.651	2.818	77.2
Glycine	(4)	3.098	1.915[a]	61.8
Glycine	(4)	3.098	1.972[b]	63.7
L-Leucine	(6)	6.376	5.702	89.5
L-Tyrosine	(7)	5.841	3.422	58.6

[a] 2.4 g/day fed. [b] 1.8 g/day fed.

TABLE 3. *O_2/CO_2 exchange and heat production factors in energy metabolism of proteins and amino acids*

	Ref.	1	2	3	4	5	6	7	8	9
Proteins										
Caselin	(8)	0.82	6.67		5.47		30.59		4.586	6.36
	(9)	0.83	6.76		5.58		31.15		4.607	6.46
Gelatin	(9)	0.83	5.05		4.22		23.44		4.637	6.82
Muscle	(9)	0.80	5.96		4.75		26.71		4.483	6.75
Amino Acids										
Alanine	(4)	0.83	3.40	4.78	2.82	3.95	16.18	22.70[a]	4.751	10.45[a]
Arginine	(6)	0.77	2.21	2.21	1.70	1.70	11.8	11.8	5.35	4.77[b]
Asparagine	(7)	1.00	2.33	2.39	2.33	2.39	10.0	10.3	4.30	5.80
Aspartic acid	(7)	1.17	4.68	4.84	5.46	5.66	20.6	21.3	4.40	6.30
Glutamic acid	(4)	1.00	6.88	7.08	6.85	7.05	31.24	32.13	4.491	6.10
Glycine	(4)	0.99	2.25	2.42	2.23	2.40	10.26	11.18	4.592	6.20
Leucine	(6)	0.73	11.91	12.06	8.73	8.84	53.4	54.1	4.48	6.38
Tyrosine	(7)	0.89	9.68	14.82	8.64	13.24	45.7	70.0[c]	4.72	28.5[c]

Column nos: *1*, respiratory quotient; *2*, liters O_2 used/g urinary N. *3*, liters O_2 used/g N amino acid metabolized. *4*, liters CO_2 produced/g urinary N. *5*, liters CO_2 produced/g N amino acid metabolized. *6*, kcal metabolized/g urinary N. *7*, kcal metabolized/g N amino acid metabolized. *8*, kcal/liter O_2. *9*, urinary kcal/g urinary N. [a] 70% of alanine N metabolized. [b] 12% of urinary N as ammonia. [c] 65% of tyrosine N metabolized.

metabolic energy system, protein and carbohydrate, when in surplus, will be preferentially disposed of by oxidation or fat synthesis because the body has limited storage capacity for either one or the other.

The net heat increments as percent of the metabolizable energy of the supplements were 55 and 53% in *experiments 1* and *2* and 37 and 33% in *experiments 3* and *4*, although the amounts of added protein were the same. The difference in the size of the rats and the amounts of basal diet appeared to effect a difference in the energy utilization of the supplements. An interpretation of the data from Table 4 is presented in Table 5 to illustrate that these differences do not prevail when account is taken of the energy spared in relation to the actual source of heat produced.

The kilocalories spared from carbohydrate and fat of the basal diet by the added protein is assumed to become available to the animal as metabolizable energy in addition to that provided by the supplement itself. Therefore, the effective metabolizable energy of the supplement is taken to be the sum of the energy spared from the basal diet and the metabolizable energy of the protein added (*column 4*, Table 5).

The true heat increment, then, is the actual increase in heat produced (*column 1*, Table 5) primarily from the added

TABLE 5. *Actual heat increment and effective metabolizable energy of protein supplements (interpretations of data from Table 4)*

Expt No.	1 Actual Heat Increase, kcal	2 Heat Spared by Added Protein, kcal	3 Metab Energy of Added Protein, kcal	4 Effective Metab Energy, col 2 + col 3 kcal	5 (Col 1/col 4) × 100
1	8.43	1.61	12.46	14.07	59.8
2	5.26	1.14	7.85	8.99	58.5
3	11.83	7.16	12.49	19.65	60.2
4	8.04	5.24	8.52	13.76	58.4

TABLE 4. *Effects of protein added to basal maintenance diets on sources of heat produced in rats*

Expt No.	Treatment	No.	Avg Wt, g	Metab Energy Intake, kcal	Daily Heat Produced, kcal	Non-Prot RQ	Sources of Daily Heat: Protein, kcal	Carbohy, kcal	Fat, kcal	Fat Synthesis, kcal
1	5 g Basal diet	8	100	18.65	14.15	0.96	1.64	10.91	1.60	0
	+ 3 g Muscle protein	6		31.11	20.97	1.05	9.95	10.90	0	0.12
	Increase over basal			12.46	6.82		8.31	−0.01	−1.60	0.12
2	7 g Basal diet	8	150	26.63	14.54	1.08	2.43	11.91	0	0.21
	+ 2 g Muscle protein	8		34.48	18.68	1.09	7.69	10.77	0	0.21
	Increase over basal			7.85	4.14		5.26	−1.14	0	0
3	8 g Basal diet	17	240	29.44	23.35	0.89	3.35	12.84	7.16	0
	+ 3 g Muscle protein	12		41.93	28.02	1.00	13.02	15.00	0	0
	Increase over basal			12.49	4.67		9.67	2.16	−7.16	0
4	11 g Basel diet	8	280	41.11	24.34	0.99	3.63	20.05	0.66	0
	+ 2 g Muscle protein	8		49.63	27.14	1.13	11.22	15.47	0	0.45
	Increase over basal			8.52	2.80		7.59	−4.58	−0.66	0.45

protein. In the case of *experiment 3* there was also an increase in heat produced from carbohydrate and complete sparing of heat produced from fat. When the true heat increment is related to the effective metabolizable energy, the percentage of heat produced from the added protein is similar in all four experiments (*column 5*, Table 5).

This interpretation is simply a method of accounting for the redistribution of the sources of heat production caused by the added protein. The same principles apply when added energy from carbohydrate or fat depresses the urinary nitrogen excretion or, in fact, the spare heat produced from protein. In a metabolic energy system, the source of heat produced will be related to the total quantity of metabolizable energy and the relative proportions of carbohydrate, fat, or protein, and will be unrelated to the rate of metabolism or the size of the animal.

The principles presented herein may have implications with respect to the differentiation of the biological values of specific proteins. The differential nutritional value of specific proteins for providing amino acids are maximally manifest when they are fed at levels low enough to minimize their involvement in energy metabolism. Observations that compound, or do not differentiate between the energy properties and the amino acid-providing properties of proteins are subject to spurious interpretation. Implications with respect to specific dynamic action were discussed by Kriss (5).

Received for publication 16 April 1971.

REFERENCES

1. Forbes, E. B., J. W. Bratzler, E. J. Thacker, and L. F. Marcy. Dynamic effects and net energy values of protein, carbohydrate and fat. *J. Nutr.* 18: 57–70, 1939.
2. Forbes, E. B., M. Kriss, and R. C. Miller. The energy metabolism of the albino rat in relation to the plane of nutrition. *J. Nutr.* 8: 535–552, 1934.
3. Kriss, M. The specific dynamic effects of proteins when added in different amounts to a maintenance ration. *J. Nutr.* 15: 565–581, 1938.
4. Kriss, M. A comparative study of the metabolism of certain amino acids, with special reference to respiratory exchange and heat production. *J. Nutr.* 17: 1–14, 1939.
5. Kriss, M. The specific dynamic effects of amino acids and their bearing on the causes of specific dynamic effects of proteins. *J. Nutr.* 21: 257–274, 1941.
6. Kriss, M., and R. S. Bowman. The metabolism of arginine and leucine with special reference to respiratory exchange and heat production. *J. Nutr.* 24: 547–555, 1942.
7. Kriss, M., and L. F. Marcy. The metabolism of tyrosine, aspartic acid and asparagine, with special reference to respiratory exchange and heat production. *J. Nutr.* 19: 297–309, 1940.
8. Kriss, M., and R. C. Miller. The derivation of factors for computing the gaseous exchange and the heat production in the metabolism of casein by the albino rat. *J. Nutr.* 8: 669–674, 1934.
9. Kriss, M., and L. Voris. A further contribution to the derivation of factors for computing the gaseous exchange and the heat production in the metabolism of proteins. *J. Nutr.* 14: 215–221, 1937.
10. Levy, L. M., L. M. Bernstein, and M. I. Grossman. The calorie content of urine of human beings and the estimation of metabolizable energy of foodstuffs. *U. S. Army Med. Res. Nutr. Lab.* Proj. 6-60-11-020, Rept. No. 226, 61 p.