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The Nutrition of the Young Ayrshire Calf

6. The Utilization of the Energy of Whole Milk

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Two series of experiments with calves to determine the net energy value of whole milk have been published, one in Austria (Soxhlet, 1878) and one in Russia (Tomme & Taranenko, 1939). Soxhlet determined carbon and nitrogen balances in three experiments at a high nutritional plane and, from the results he obtained Armsby, (1917) calculated the net availability of the metabolizable energy of whole milk. To accomplish this Armsby assumed that the maintenance requirement of the calf, per unit of surface area, was 10 % higher than that of the adult steer. He commented that the value he obtained was much lower than would be expected on the basis of the application of Rubner's factors of 69 % for protein, 87 % for fat and 94 % for carbohydrate to the proximate principles present in whole milk. Kellner's (1926) computation of the net energy value of whole milk was, however, considerably lower than Armsby's value, and so indeed was Hansson's (1926). These estimates were made by the application of factors, determined by Kellner on mature cattle, to the proximate principles digested by the calf.

Russian workers (Urmaliat, Reinbot & Elitchiev, 1937; Lebehdiev, 1937) realized these large discrepancies between estimates of the nutritive value of cow's milk, and in 1939 Tomme & Taranenko made six determinations of energy balance with young calves given 7-8 l. of whole milk as the sole diet. They calculated that the starch equivalent of whole milk containing 4 % fat was 21.7, a value higher than Kellner's value of 14.7 and lower than Armsby's value of 27.1. It is uncertain from Tomme & Taranenko's paper what method was used to calculate the maintenance requirement upon which the calculation of net energy ultimately depends. It would appear, however, that fasting heat production determined 12-18 h after the last meal was the basis. Blaxter & Wood (1951*a*), however, have shown that the heat production of the calf determined at this time is markedly affected by the previous plane of nutrition. There is therefore some uncertainty regarding the nutritive value of the gross energy

of whole milk, largely owing to the difficulties involved in determining the basal demand for maintenance energy. For this reason an attempt was made to determine the net energy value of milk by the classical method of measuring the increase in heat production and energy balance that occurs following an increase in food intake.

EXPERIMENTAL

Plan of experiment. An Ayrshire bull calf aged 3 days was used. He was given whole milk only for the 1st week, during which time he became accustomed to the experimental procedure. Unfortunately, after 6 days he had diarrhoea, which was treated by replacing his milk allowance with water for 1 day and by subsequent gradual realimentation. This necessitated a delay in the onset of the experiment which commenced 2 days after the calf was again receiving his whole ration.

The calf was confined in a metabolism cage and harnessed for separate collection of faeces and urine. The technique has already been described by Blaxter & Wood (1951*a*). Two 14-day periods were employed. In the first period the calf was given 4 l. whole milk daily in two feeds. In the second 8 l. were given in three feeds. Four days were taken to effect the change-over, and collection of urine and faeces was not commenced until a further 2 days had elapsed.

Carbon-dioxide determination. The carbon-dioxide production of the calf was determined in a respiration chamber of the open-circuit type. This instrument has been illustrated (Anonymous, 1950) and will be described elsewhere. Briefly, it consists of a metabolism cage (permitting separate collection of excreta) through which a measured stream of outdoor air is drawn. Samples of the air leaving the chamber were taken automatically, and in these samples carbon dioxide and water vapour were determined gravimetrically. The respiratory quotient was not determined accurately. Single samples of outgoing air were taken at hourly, or in some experiments at 2-hourly, intervals, and the oxygen and carbon-dioxide content determined by analysis in a Haldane type apparatus. These were not, of course, true samples, but have been used as rough checks of the heat production determined by carbon- and nitrogen-balance methods. The temperature of the chamber was thermostatically controlled at 20° in the first series of experiments when the calf was given 4 l. milk. In the second series a period of warm weather made it impossible to maintain the temperature at 20° and it rose to 27°. All respiration experiments lasted 24 h. Milk and urine were preserved with mercuric chloride and potassium dichromate.

Analytical methods. The analytical methods for urine and faeces were those previously described (Blaxter & Wood, 1951*b*). Milk fat was determined by the Gerber method. Carbon in urine was determined by wet combustion in a stream of carbon-dioxide-free air, using a solution of silver dichromate in concentrated sulphuric acid to oxidize organic matter. Carbon in the dried faeces, and in the milk previously dried at 70°, was determined by combustion in a tube furnace packed with copper oxide and lead chromate. In either case the carbon dioxide was absorbed by soda lime and weighed. All analyses were made at intervals of 2 days. Three balances of carbon and nitrogen were made when 4 l. milk were given and two when 8 l. were given.

Nitrogen balances were determined throughout but, for the purpose of computing the storage of fat and protein, the balances for the 48 h period, in which the balance of carbon was determined, were employed.

RESULTS

Table 1 shows the method of computation of the energy balances from the balances of carbon and nitrogen. To compute the heat production from these results it is necessary to know the energy intake and the calorific losses in urine and faeces. The

Table 1. *The storage of carbon and nitrogen by the calf during a period when 8 l. milk were given daily*

	Nitrogen (g/day)	Carbon (g/day)
Intake	44.8	535.8
Excretion:		
Faeces	Nil	Nil
Urine	12.8	23.8
Respiration	—	263.4
Storage in body	32.0	248.6
Carbon present in protein		100.9*
Storage of non-protein carbon		147.7
<i>Calorie equivalent of nitrogen and non-protein carbon stored</i>		
	g	Cal.†
Protein (N × 6.25) stored	200.1	1120
Fat stored	193.4‡	1798
Total	—	2918

* The carbon content of body protein (N × 6.25) was taken as 52.54 % (Kohler, 1901). (N × 3.152 = carbon in protein.)

† The calorific values of body protein (N × 6.25) and fat were taken as 5.6 and 9.3 Cal./g.

‡ The carbon content of body fat was taken as 76.4 % (Schulze & Reineke, 1867). (C × 1.31 = fat.)

energy value of the milk was calculated from the analytical values using the factors of 9.11 Cal./g for fat, 5.86 for protein and 3.95 for lactose (Andersen, 1926). The same factors were used to determine the calorific value of the faeces. The loss of energy in the urine was calculated from its carbon content using a factor of 36.5 Cal./g urinary carbon, a factor calculated from the results of simultaneous determinations of carbon and energy in calf urine by Tomme & Taranenko (1939).

In Table 2 the estimation of the heat production is shown. A further estimate of heat production may be made. This involves the computation of the non-protein respiratory quotient, and the use of the Zuntz-Schumburg (1901) tables. As previously stated, oxygen consumption was not as accurately determined as was carbon-dioxide production. Table 2 shows, however, that the agreement between estimates was very good. In the five experiments the maximum difference between the estimates was 118 Cal. in an experiment when 4 l. milk were given. In every case, however, the heat production calculated from the carbon and nitrogen balance was higher than that calculated from the respiratory quotient and oxygen consumption.

Table 2. *Estimation of heat production from the determined energy balance of the calf during a period when 8 l. milk were given daily*

	Cal./24 h
Milk ingested (calculated from analysis)	6135
Loss in faeces	Nil
Loss in urine (calculated from carbon content)	153
Energy of fat and protein stored	2918
Difference = heat production estimated from carbon and nitrogen balance	3064
Heat production estimated from oxygen consumption, carbon-dioxide production and urinary nitrogen excretion*	3129
Difference between estimates of heat production	65

* See text, p. 14.

Despite this excellent agreement for the individual balances the agreement between balances made at different times was not good. At the high level of nutrition, the balances were 2907 and 3147 Cal./24 h, whereas at the low level they were 742, 1126 and 322 Cal./24 h. This variation was due partly to daily variation in the fat content of the milk, and hence in the energy and carbon content of the milk. In the series at the low level of nutrition, a period in which milk with a low fat percentage of 3.8 and a carbon content of only 6.57 % was given resulted in the lowest balance. Milk with a fat content of 4.3 % and a carbon content of 7.29 % was associated with the highest balance. This, however, was clearly not the sole cause of the discrepancies. At the low plane of nutrition the heat production associated with the lowest balance and milk of the lowest calorific value was higher than any of the other determinations at this level of milk intake. This was related to much greater activity of the calf in the respiration chamber during the period concerned. A series of three 12 h determinations of heat production, lasting throughout the day-time, was then made. The heat production varied from 1400 Cal./12 h on a day when the calf tended to be lethargic, to 1690 Cal./12 h when the calf was jumping in his cage and very active. These results suggest that single determinations of heat production and energy balance in young animals are highly complicated by variation in their activity. This is in accordance with results obtained on human babies (Clements, 1949) in which the activity of crying doubles the heat production.

For the purpose of computation of net energy values, the mean values at each level of feeding have been used, for it was impossible to judge in which experiments activity was the most comparable. The results are given in Table 3.

From the results in Table 3 the net availability of the metabolizable energy may be computed using the equation:

$$\text{energy balance} = a \times \text{metabolizable energy} - b \times \text{metabolic body size},$$

where a represents net availability, and $b \times$ metabolic body size represents maintenance requirements. Metabolic body size is the interspecies unit of basal metabolism represented by body-weight raised to the power 0.73 (Brody, 1945). Using simultaneous equations, the value of a was found to be 0.845, and of b 121.6. The net availability of the metabolizable energy of whole milk was thus 85 %, and the maintenance requirement about 120 Cal. of net energy or 140 Cal. of metabolizable

Table 3. *Mean body-weight, daily gain of weight, metabolizable energy ingested and energy balance of the calf at two planes of nutrition*

	Milk intake	
	4 l./day (mean of three experiments)	8 l./day (mean of two experiments)
Mean body-weight (kg)	35.1	46.7
Mean daily gain of body-weight (g)	390	950
Metabolizable energy* (Cal.)	2801	5969
Energy balance† (Cal.)	730	3031
Metabolic body size‡ (kg)	13.44	16.54

* Gross energy ingested less energy of the excreta.

† Determined from carbon and nitrogen balances.

‡ From Brody's (1945) formula: metabolic body size = $W^{0.73}$, where W = body-weight in kg.

energy/kg body-weight raised to the power 0.73. For a calf weighing 35 kg ($35^{0.73}$ kg = 13.4 kg) this would be equivalent to 1608 Cal. of net energy or 1876 Cal. of metabolizable energy per day. These estimates may be compared with previous estimates made by regression analysis of body-weight changes in calves where the maintenance requirement of the 30–35 kg calf was found to be 1771 ± 97 Cal. digested energy/day and in other trials 1921 ± 129 Cal. (Blaxter & Wood, 1951c, 1952). Digested energy, less the small amount of energy in the urinary solids, is the metabolizable energy. These three estimates do not differ markedly from one another. All are very much higher than either the interspecies normal basal metabolism of adult animals of 70.4 Cal. of net energy/kg body-weight raised to the power 0.73 (Brody, 1945) or the minimum base value of heat production of mature cattle and sheep, which is approximately 50 Cal. net energy/kg metabolic body size (Forbes, Braman, Kriss & Swift, 1931; Forbes & Kriss, 1932; Marston, 1948). This emphasizes both the intensity of metabolism in the young, active, growing animal, and the errors inherent in Armsby's assumption that the maintenance requirement of the young is but slightly greater per unit of surface than that of the adult.

The total energy ingested was metabolized to the extent of 94 % at the lower level of feeding and of 97 % at the higher, the loss of energy in the faeces being the main determinant. A figure of 95 % has been taken as representative of the normal animal.

DISCUSSION

It is of interest to compare the present results with those of Soxhlet (1878) and of Tomme & Taranenko (1939). This is done graphically in Fig. 1, where the metabolizable energy and the energy balance have been expressed on the basis of metabolic body size ($W^{0.73}$) following the method of Marston (1948). It will be seen that the spread of the values about the mean line is considerable. Part of this is due to individual differences between the calves, but from the results obtained in the present study a large part is thought to be due to variation in heat loss caused by the activity of the calf in the confines of its cage. The line passing through the distribution is one obtained using the maintenance value of 144 Cal. metabolizable energy and a slope of

0.85, as obtained in the present study. It will be noted that whereas Soxhlet's results agree admirably, the Russian results mostly fall below the line, suggesting that these calves had greater maintenance requirements than either the Austrian or British calves. This may be a breed difference or an activity difference or an effect of body size, for the Russian calves were much larger than the others. In any case, indiscriminate pooling of the data is not warranted, and despite the large variation in conditions the results are in good agreement.

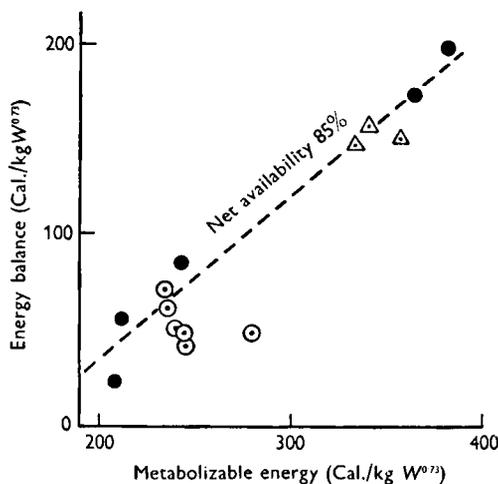


Fig. 1. The relationship between the intake of metabolizable energy and the balance of energy both expressed as Cal./kg body-weight raised to the power 0.73 in Soxhlet's (1878), Tomme & Taranenko's (1939) and the present experiments with calves. ●, present results (1951); △, results of Soxhlet (1878); ○, results of Tomme & Taranenko (1939).

Previous estimates of the metabolizable energy value or starch equivalent of milk may now be examined. Table 4 summarizes the calculations. The estimates are of two types: those based on direct experimentation with calves in which energy balances have actually been determined and those based on the application of factors to the digested components of the diet. Of the former group, both Armsby's and Tomme &

Table 4. *The net energy value of whole milk containing 4% fat and 753 gross Cal./kg*

Method of calculation	Gross energy metabolized (%)	Net availability of metabolizable energy (%)	Net energy/kg. (Cal.)
Armsby's calculations from Soxhlet's (1878) results	95.0	73.8	528
Tomme & Taranenko's (1939) experimental results	92.2	74.2	512
Present experimental results	95.0	85.0	608
Using Kellner's factors for ruminants*	95.0	56.6	405
Using Hansson's factors for ruminants*	95.0	62.3	446
Using Rubner's factors for simple-stomached animals†	95.0	84.3	603

* These are given in full by Blaxter (1949-50).

† See text, p. 12.

Taranenko's results involve the assumption of a maintenance base-line. The present estimates are free from such assumption, and, as shown in Fig. 1, the energy balances observed by Soxhlet and, to a lesser extent, those of the Russian workers, agree quite well with the present calculation. The estimates based on factors, however, show very large discrepancies. Both Kellner's (1926) and Hansson's (1926) factors were based on values for the energy exchanges of mature steers. In these animals the heat increment due to food is very large and the net availability of metabolizable energy consequently small. The intermediary metabolism of the lower steam-volatile fatty acids which are produced in large amounts by microbial activity in the rumen and caecum is thought by most workers to be the main reason for this high heat increment (Phillipson, 1947-8). It would be expected, therefore, that these factors would considerably underestimate the net energy value of food in an animal in which extensive fermentation does not take place. The low net energy values given by both Kellner's and Hansson's factors can thus be attributed to the assumption that the assimilation of food materials in the non-ruminant calf involves the same energy loss as in the ruminant adult. Rubner's factors, however, were determined by calorimetric experiments with dogs and men and not with ruminating animals. The estimate they provide of the net energy value of milk is in close agreement with the experimental results for calves. It may be concluded therefore that their application to diets given to the calf before rumen development occurs is justified.

SUMMARY

1. Five carbon and nitrogen balances have been determined with a calf given cow's whole milk as its sole diet at two planes of nutrition.
2. It was found that activity of the calf within the confines of its cage was an important variable in determination of energy storage.
3. The energy balances were used to compute the net availability of the metabolizable energy of cow's whole milk, and gave a value of 84.5 %.
4. The maintenance requirement of the calf per unit of metabolic body size was 122 Cal. of net energy or 144 Cal. of metabolizable energy. This value was in agreement with estimates made by another method.
5. The results show that Rubner's factors may be used to compute the net energy value or starch equivalent of calf foods for calves that have not started ruminating.

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The Assessment of the Growth of Schoolchildren with Special Reference to Secular Changes*

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An interesting phenomenon, prominent in the present century, is a secular change in the pattern of growth of schoolchildren. It is usually regarded simply as an increase in the average height and weight of children of school age. This aspect, however, may be misleading and is not altogether satisfactory for comparative purposes. The change was therefore investigated, first in terms of age of attaining a given height or a given weight, and then in terms of rate of growth. This approach leads to the view that the secular change in the pattern of growth is essentially an acceleration.

METHODS AND RESULTS

Data surveyed

The figures dealt with here have been confined to the measurements of boys in Glasgow and London and two sets of data for England as a whole. In 1905-6 a very extensive survey was made of the heights and weights of Glasgow schoolchildren, the occupation of their parents, the number of rooms occupied and other similar information. The schools from which the children came were divided into four groups.

Group A comprised schools in the poorest districts of the city, group B in poor districts of the city, group C in better-class districts and group D in districts of a still higher class, including four out of five Higher Grade Schools.

* An abridged version of this paper was read at the sixty-third scientific meeting of The Nutrition Society on 14 October 1950, the topic under discussion being *Growth*.