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Energy cost of measles infection

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SUMMARY A model predicting the nutritional cost of measles has been based on data from a study of energy balance in Kenyan children during and after measles. The energy shortfall, consequent upon a reduction in energy intake and a sustained level of energy expenditure, is met by tissue catabolism. The magnitude of resulting weight loss will be greater in lean than in plump children. During recovery, the intake of gross dietary energy to regain lost weight must take account of obligatory energy losses in stool and urine and also of the energy cost of biosynthesis. The speed of recovery is influenced both by the energy density of the available food and its palatability. The nutritional cost of infection and other illnesses causing negative energy balance will be greater to lean people whose diet is of low energy density.

Nutritional disadvantage and infection are synergistically involved in the development of childhood malnutrition in poor countries.[1 2] Concern about the cost effectiveness of aid programmes fuels the debate about the relative values of public health or nutritional intervention. The considerable contribution of community education to the overall benefits of many Third World projects increases the difficulty of quantifying the effect of the main intervention.[3 4] The observer effect seems to be particularly important in deprived communities. An unfortunate result is the paucity of sound evidence incriminating infections as a primary cause of malnutrition,[5] despite much circumstantial evidence suggesting an association.[6 7]

The hypothesis that infections are of major importance in the genesis of malnutrition was therefore tested experimentally. The impact of a simple infection upon the existing nutritional state of children eating traditional diets was investigated by means of an energy balance study. Twenty black Kenyan children were studied during and after recovery from acute measles,[8] an infection that has been linked in Kenya[9] and elsewhere in Africa[10] with the development of childhood malnutrition. The experimental data were then used to construct a model predicting the nutritional cost of measles infection to well and malnourished children eating diets of different energy density.

Subjects and methods

A 24 hour energy balance study was carried out on 20 children admitted with measles to the Infectious Diseases Hospital, Nairobi. All the children were readmitted for a control study after full recovery. Convalescence was monitored at home visits. Nineteen of the children were boys, selected to facilitate urine collection. Eight malnourished children were included in the study.

A 24 hour weighed collection of food, faeces, and urine was made. The energy content of food and faeces was determined by bomb calorimetry, and the energy content of urine was calculated from its nitrogen content. Energy expenditure was measured by indirect calorimetry. The methodology of the study has already been described in detail.[8 11] Results of the measurements of gross energy intake and of energy losses in faeces and urine were used to estimate the metabolisable energy intake.

The metabolic rate was measured by indirect calorimetry on all children.[8] The results of all measurements of the resting metabolic rate—that is, from observations made at least four hours after a meal of at least 25kJ—were used to derive a mean value for each subject. Data on the mean resting metabolic rate were available on 18 children during measles and on 18 children after recovery. The mean resting metabolic rate was used to estimate the energy expenditure during resting metabolism. The apparent energy balance[12] was calculated from data on the metabolisable energy intake and the energy expenditure in each subject, thus apparent energy balance=metabolisable energy intake −energy expenditure kJ/kg/24h.

Measurements of weight and of supine length were expressed in terms of their deviation from the reference mean recommended by the World Health

Organisation.[13 14] A negative deviation of 2SD from the reference mean weight for length was used as the cut off point for the diagnosis of malnutrition. Informed verbal consent was obtained from all parents, and the study protocol was passed by the medical research ethical committee of Kenyatta National Teaching Hospital, Nairobi.

Results

The grave and significant ($p<0.01$) reduction in the mean level of intake of gross energy during acute measles is illustrated in Table 1. The mean (SE) energy density of food tolerated by ill children was also significantly lower than during the control study (2·6 (0·1) and 3·9 (0·3) kJ/g, respectively; $p<0.01$).

Neither the level of gross energy intake nor the energy density of the diet eaten in either study was significantly influenced by the child's nutritional state during measles. Faecal energy losses in both studies represented a similar percentage reduction in gross energy (Table 1),[8] whereas energy loss in urine during measles represented a significantly greater percentage reduction in energy intake. The magnitude of the energy losses in faeces and urine was not influenced by the child's initial nutritional state. The mean (SE) energy available after faecal and urinary energy losses for metabolism was equivalent to 75·6 (5·6)% and 83·7 (3·2)% of the gross intake during the infection and control studies, respectively ($p<0.02$, Wilcoxon's paired rank sum test). The mean (SE) level of the metabolisable energy intake was 81·5 (17·5) kJ/kg/24h during measles and 309·4 (32·8) kJ/kg/24h after recovery.

The mean level of the resting metabolic rate was similar during measles and after recovery in the 18 children in whom data were complete, representing a mean (SE) resting energy expenditure of 257 (9·1) and 272 (8·8) kJ/kg/24h in the infection and control studies. The apparent energy balance was negative in 17 out of the 18 children during measles, but 12 out of the 18 were in positive balance during the control study. The mean level of the apparent energy balance was equivalent to −169 (22) kJ/kg/24h during measles and 67 (30) kJ/kg/24h after recovery. The energy required (expended) to maintain constant body energy is defined as the maintenance energy requirement, which is equal to metabolisable energy intake at zero energy balance.[15] In calculating apparent energy balance for children, studied at very different levels of metabolisable energy intake, the maintenance energy requirement had been approximated by the resting metabolic rate. A better estimate of the maintenance energy requirement is obtained by regression of energy balance on metabolisable energy intake when the maintenance energy requirement is equivalent to metabolisable energy intake at zero energy balance. When energy balance=0·95× metabolisable energy intake −255·3 kJ/kg/24h ($r=0.973$, $n=36$) then maintenance energy requirement is equivalent to 266 kJ/kg/24h. It is evident that an intake of metabolisable energy intake greater than 266 kJ/kg/24h will result in a positive value for energy balance; the value being negative at lower intakes of metabolisable energy intake. Using the mean value for the metabolisable energy intake during measles, and the improved estimate of the maintenance energy requirement, the magnitude of the energy shortfall is given by: energy balance=81·5 −266=−184·5 kJ/kg/24h.

Table 1 *The intake of gross, digestible, and metabolisable energy by 20 Kenyan children during and after acute measles, and the energy density of that dietary intake.*

Energy density by 20 children	*Measles*		*Control*	
Mean (SE) gross energy:				
kJ/kg/day	94	(18·5)	374	(29·6)
kCal/kg/day	22	(4·4)	89	(7·1)
Digestible as % gross*	92		87	
Metabolisable as % gross†	76		83	
Mean (SE) energy density:				
kJ/g	2·6	(0·1)	3·9	(0·29)
kCal/g	0·6	(0·02)	0·9	(0·07)

*Not significant by Wilcoxon paired rank sum test.
†$p<0.02$ by Wilcoxon paired rank sum test.

Discussion

Weight loss is the inevitable consequence of a 24 hour period of negative energy balance during measles, the energy shortfall, here estimated as −184 kJ/kg/24h, being made good by tissue catabolism. In practical terms, however, short term weight changes in an ill child are influenced more by changes in water balance than by changes in energy storage. The experimental data have, therefore, been used to construct a model predicting the theoretical weight of tissue lost during 24 hours and the cost of recovery of this weight by a 10 kg 'plump reference' child or alternatively by a 10 kg 'lean reference' child with measles (Table 2).

The model is dependent on a series of assumptions. Firstly, it is assumed that the composition of the tissue mixture to be catabolised can be estimated from body composition data.[16 17] Secondly, it is assumed that glycogen stores have been exhausted[18 19] and that there is non-preferential catabolism of fat and protein energy stores. Thirdly, it is assumed that catabolism proceeds with 100% efficiency, releasing all the stored energy into the metabolic pool.

After 24 hours of measles, when the energy balance is −184 kJ/kg/24h, the energy shortfall will

Table 2 *Magnitude of weight loss during one day of measles and energy requirements for recovery predicted for a 10 kg lean and 10 kg plump reference child*

Term	*Unit*	*Lean child*	*Plump child*
Measles			
Tissue composition:*			
Fat	g/g	0·15	0·25
Protein	g/g	0·17	0·15
Water	g/g	0·68	0·6
Energy	kJ/g	8·4	11·8
Energy shortfall in one day of measles	kJ	1840	1840
Obligatory catabolic weight loss	g	219	156
Recovery			
Maintenance requirement of metabolisable energy at new weight	kJ	2601	2618
Energy cost tissue weight gain†	kJ/g	18·4	18·4
Extra requirement of metabolisable energy to regain lost weight	kJ	4029	2870
Extra requirement of gross energy assuming 20% energy lost in faeces and urine	kJ	5036	3588
Weight of extra food when energy density diet is			
(i) 2·6 kJ/g		1·94	1·38
(ii) 3·9 kJ/g	kJ	1·29	0·92

*Values based on Fomon's data on body composition[16] and adapted to agree with experimental estimates of body fat.
†Spady *et al.*[20]

be 1840 kJ for both the plump and the lean 10 kg reference child. The energy stored per gram by the lean child is less than that stored by the plump child, so that the weight loss in catabolism by a lean child, necessary to make good the energy shortfall, will be greater than that by a plump child (219 g compared with 156 g, Table 2). Although this magnitude of weight loss might pass unremarked over a 24 hour period, the estimated cumulative weight loss during a week of measles accords with clinical reports of loss of up to 15% of body weight.[10]

To regain the weight lost the gross intake of dietary energy must be sufficient to cover not only obligatory faecal and urinary energy losses but also to meet the energy cost of tissue synthesis. The energy cost of 'catch up' weight gain has been calculated by Spady *et al* to be 18·4 kJ/g of tissue growth.[20] This estimate, which is based on a study of children gaining weight rapidly on a high fat synthetic formula, may be unusually low. The theoretical cost of tissue synthesis may also be calculated in terms of the energy cost of protein and fat synthesis.[21] It is then possible to estimate the cost of synthesis of 'lean' and 'fatty' tissue. If the new tissue were identical in composition to the catabolised 'lean' or 'fat' tissue the total cost of its synthesis would be 13·4 kJ/g or 18·8 kJ/g, respectively. As available evidence, however, suggests that there is a relatively high contribution of fat to catch up weight gain[20 22] the calculations in this model are made using the experimental estimate of the energy cost of tissue synthesis due to Spady *et al.*[20] Therefore, when the energy cost of 'catch up' tissue synthesis is 18·4 kJ/g the intake of metabolisable energy necessary to regain 156 g of lost tissue will be 2870 kJ. For the leaner child who has lost 219 g, the required extra intake of metabolisable energy will be 4029 kJ. Furthermore, as an estimated 20% of gross energy is likely to be lost in faeces and urine the required intake of gross energy will be 3550 kJ and 5037 kJ, respectively. The weight of this extra intake will depend on the energy density of the diet available to, or tolerated by, an ill child. Using values for energy density from our study, the weight of the required extra food intake can be predicted to lie between 0·92 kg and 1·94 kg and to be influenced both by the child's previous nutritional state and his present appetite. This weight of food will of necessity be additional to the 0·67–1·01 kg of daily intake necessary to meet the maintenance energy requirements.

It is likely that the nutritional cost of measles and other infections has been underestimated by this model. The energy yield from tissue catabolism will certainly be less than the total stored energy, while the protein contribution to tissue catabolism during infection is likely to be greater than predicted here. The high prevalence of post-measles infection, including gastroenteritis with malabsorption, will also prolong the illness and hinder convalescence.

The energy balance model is not restricted in its application. The energy cost of any illness will be immediately increased by a period of negative energy balance. For every 100 kJ of negative energy balance, it may be calculated from these data that at least 195 kJ of gross energy intake will be required to restore balance. The calculation is simple: energy deficit−energy storage/g=weight lost; weight loss×energy cost of growth×factor for energy losses=gross energy intake. Using values based on this study, the equation becomes $(100-11{\cdot}8)\times 18{\cdot}4\times 1{\cdot}25=195$ kJ.

Thus the nutritional goal must be, in every case, to supply ill children with at least sufficient intake of dietary energy to meet the maintenance energy requirement. The estimate of the maintenance energy requirement for an individual will be improved by knowledge both of energy losses in the faeces and urine and of the level of energy expenditure. By the same token, when considering the nutritional health of communities prevention should be directed at those infections that, either by virtue of their severity or because of iatrogenic starvation therapy—for example, diarrhoea treated with oral rehydration—are most likely to result in periods of negative energy balance in growing children.

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