Thermic effect of a meal
2. Role in chronic undernutrition

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The thermic effect of a standard liquid meal (TEM; energy 2·5 MJ; containing (g/kg) protein 100, fat 150, carbohydrate 750; volume 350 ml) was measured in a chronically undernourished (UN; *n* 9) group of human subjects and was compared with results from two control groups, one normal weight (NW)-for-height (BMI > 20; *n* 10) and the other underweight (UW)-for-height (BMI < 18, *n* 10), using a ventilated-hood system over a period of 6 h after ingestion of the meal. Results indicated that the UN subjects had lower values for body-weight, height, percentage fat and fat-free mass (FFM) compared with those of either control group. Basal metabolic rates were lowest in the UN group in absolute terms; however, there were no significant differences among groups on an analysis of covariance (ANACOVA) with FFM as the covariate. TEM responses in the UN group were significantly higher when expressed either in absolute terms or as a percentage of the energy density of the meal. The post-meal total energy output was significantly lower ($P < 0·05$) in the UW and UN groups as compared with the NW group in absolute terms; however, on adjusting for differences in FFM (by ANACOVA) there were no significant differences among groups. This would suggest that in the chronically undernourished thermogenic responses to a meal are unlikely to contribute towards any energy saving and may not constitute a part of any adaptive response to the undernourished state.

Chronic undernutrition: Thermic effect: Substrate oxidation rates: Body composition

The energy cost of processing food depends on its metabolic fate, being lowest for fat and highest for protein as well as *de novo* lipogenesis from carbohydrate. After these metabolic costs have been subtracted from the thermic effect of the meal (TEM), the remaining increase in metabolic rate, which may be as much as 25–50% of the total response, is thought to be primarily due to sympathetic nervous system activation, although other, as yet unidentified, mechanisms may also be important (Horton, 1983). Earlier studies in this laboratory have shown that chronically undernourished subjects had a lower thermogenic response to noradrenaline infusions when compared with normal weight as well as underweight control subjects (Kurpad *et al.* 1989). With the likelihood of an adaptive role for TEM in the maintenance of energy balance in chronic undernutrition (James & Shetty, 1982) and the known interplay between the sympathetic nervous system (SNS) and TEM (Danforth 1989), it was decided to evaluate the thermic response of chronically undernourished subjects to a standard liquid test meal.

MATERIALS AND METHODS

Subjects

Thirty healthy male volunteers aged 18–30 years were investigated. They were classified on the basis of body mass indices (BMI; weight/height^2 (kg/m^2)) and socioeconomic status

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into an undernourished group (UN) and a control group. The undernourished group, drawn from the lower socioeconomic class (Kuppuswamy Class IV; Kuppuswamy, 1984) were unskilled manual labourers on a daily wage, resident in a neighbouring slum. The age-matched control subjects were medical students with access to *ad lib.* energy intakes. They were further subdivided into two groups (of ten subjects each) on the basis of their BMI into (*a*) normal weights (NW; BMI > 20) and (*b*) underweights (UW; BMI < 18).

All subjects underwent a complete clinical assessment before recruitment. Nutritional status was assessed by anthropometry, i.e. body-weight (kg) and height (m). Body fat was estimated from the sum of four skinfold thicknesses (biceps, triceps, subscapular and supra-iliac) measured with a Holtain skinfold calliper (Crymmych, UK) using the formula of Durnin & Womersley (1974). Fat-free mass (FFM) was calculated from the difference of body fat and body-weight.

Protocol

Protocol 2 described previously by Piers *et al.* (1992) was used for the measurement of the basal metabolic rate (BMR), TEM, post-meal total energy output (PMTEO) and substrate oxidation rates (SOR). It consisted of intermittent measurements of oxygen consumption over 6 h, following a standard liquid meal.

The test meal

The test meal consisted of tinned milk powder, rice cereal and sugar made up to 350 ml with water and served at room temperature. It provided 2·5 MJ energy with a nutrient composition (g/kg) of protein 100, fat 150 and carbohydrate 750. Energy and nutrient compositions were derived from the manufacturers' product information. All tinned products were purchased at the same time, belonged to the same batch of manufacture and were used well before their date of expiry.

Calculation of BMR, TEM, PMTEO, and SOR

BMR, TEM, PMTEO and SOR were calculated as described earlier (Piers *et al.* 1992). The TEM was considered to have ended when post-meal energy expenditures were not different from premeal basal values, on a paired *t* test for each group of subjects studied.

Statistical analysis

A paired *t* test was used to compare the mean postprandial energy expenditures each hour following the meal, with the premeal basal values (i.e. BMR) in each group. All results were analysed by means of a one-way analysis of variance (ANOVA); differences between groups were identified using least significant differences at the 5% significance level. The BMR and PMTEO were also analysed by an analysis of covariance (ANACOVA) with FFM as the covariate (Dowdy & Wearden, 1983). The *F* ratio was considered significant at the 5% level.

Ethical approval

Ethical approval was obtained for the study from a duly constituted Human Investigation Committee of the medical school and all subjects gave fully informed written consent.

RESULTS

Mean values with their standard errors for the anthropometric and metabolic variables studied, for each group, are given in Table 1 and ANOVA of these variables are given in Table 2(a). The UN group consisted of nine subjects, as one dropped out before completion of the TEM measurement. They were of significantly shorter stature and lower body-

Table 1. *Anthropometric and metabolic variables in chronic undernutrition*
(Mean values with their standard errors)

Group...	NW (*n* 10)		UW (*n* 10)		UN (*n* 9)	
	Mean	SE	Mean	SE	Mean	SE
Ht (m)	1·77	0·02	1·75	0·03	1·65*†	0·02
Wt (kg)	67·3	1·7	50·8*	1·5	43·3*†	1·1
FFM (kg)	55·3	0·9	44·4*	1·5	38·9*†	0·9
BMI (kg/m^2)	21·3	0·4	16·5*	0·4	16·0*	0·3
BMR (kJ/h)	283·8	9·5	232·1*	6·1	222·3*	8·5
TEM: kJ/6 h	174·8	12·9	193·7	15·0	227·0*	10·0
As % of energy in meal	7·0	0·5	7·7	0·6	9·1	0·4
PMTEO (kJ/6 h)	1875·4	51·8	1586·0*	27·6	1560·9*	53·3

NW, normal weight (BMI > 20); UW, underweight (BMI < 18); UN, undernourished; FFM, fat-free mass; BMI, body mass index (weight/height^2); BMR, basal metabolic rate; TEM, thermic effect of a meal; PMTEO, post-meal total energy output.

* Mean values for UW or UN group were significantly different from those for NW group (ANOVA, least significant difference procedure), $P < 0·05$.

† Mean values for UN group were significantly different from those for UW group (ANOVA, least significant difference procedure), $P < 0·05$.

weights ($P < 0·05$) than either control groups. The BMI, however, was comparable in the UN and UW groups, both of which were significantly lower than that of the NW group ($P < 0·05$). FFM was significantly lower in the UN group when compared with either of the controls groups ($P < 0·05$), while the UW group had a significantly lower FFM than that of the NW group ($P < 0·05$). Both the UW and UN groups had significantly lower BMR when compared with the NW group ($P < 0·05$); however, these differences disappeared on an ANACOVA with FFM as the covariate (Tables 1 and 2(b)).

The TEM lasted for 5 h in the NW, but the TEM responses were still evident 6 h postprandially in the UW and UN groups. We have, therefore, examined all responses among groups at 6 h following the meal in order to make a valid comparison (Matthews *et al.* 1990). When expressed in absolute terms, the TEM was highest in the UN and lowest in the NW; significant differences existed between the UN and NW groups ($P < 0·05$). These differences persisted even when the TEM was expressed as a percentage of the energy content of the meal (Tables 1 and 2(a)).

The PMTEO was significantly lower in absolute terms in the UW and UN groups compared with the NW controls ($P < 0·05$) on an ANOVA (Table 1); however, on an ANACOVA with FFM as the covariate there were no significant differences among any of the groups ($P > 0·05$; Table 2(b)).

SOR and non-protein respiratory quotients (NPRQ) are given in Table 3. Owing to the loss of some urine samples collected following the BMR measurements, SOR could not be computed for all subjects studied; therefore, the number of subjects studied do not tally in Tables 1 and 3. During the BMR (df 2,21) significantly lower amounts of carbohydrate (F 3·7, $P < 0·05$) and higher amounts of fat (F 15·6, $P < 0·05$) were oxidized by the NW group compared with the UN group. There were no differences in protein oxidation rate among any of the groups (F 0·5, $P > 0·05$) during this period. In the 6 h postprandial period (df 2,26), protein oxidation rates were significantly different in the NW and UN groups (F 11·6, $P < 0·05$), being highest in the NW group and lowest in the UN group. Fat oxidation

Table 2. *One-way ANOVA of the anthropometric and metabolic variables and analysis of covariance of basal metabolic rate (BMR) and post-meal total energy output (PMTEO) for normal weight, underweight and undernourished subjects*

Source	df	SS	MS	*F*	*P*
		(*a*) One-way ANOVA			
Ht					
Between groups	2	0·0877	0·0438	9·4	0·0009
Within groups	26	0·1217	0·0047		
Wt					
Between groups	2	2904·4	1452·2	71·5	0·0000
Within groups	26	527·7	20·3		
FFM					
Between groups	2	1346·3	673·2	54·2	0·0000
Within groups	26	322·8	12·4		
BMI					
Between groups	2	165·0	82·5	60·8	0·0000
Within groups	26	35·3	1·4		
BMR					
Between groups	2	20982·4	10491·2	16·4	0·0000
Within groups	26	16650·4	640·4		
TEM					
Between groups	2	13114·8	6557·4	4·0	0·0298
Within groups	26	42273·9	1625·9		
TEM as % of energy in meal					
Between groups	2	21·0	10·5	4·0	0·0298
Within groups	26	67·6	2·6		
PMTEO					
Between groups	2	597519·4	298759·7	15·1	0·0000
Within groups	26	514812·2	19800·5		
		(*b*) Analysis of covariance of BMR and PMTEO			
BMR					
Covariate FFM	1	20842·5	20842·5	34·2	0·0000
Between groups	2	1560·7	780·4	1·3	0·2950
Residual	25	15229·6	609·2		
PMTEO					
Covariate FFM	1	570042·0	570042·0	29·8	0·0000
Between groups	2	64738·5	32369·2	1·7	0·2040
Residual	25	477551·2	19102·0		

FFM, fat-free mass; BMI, body mass index (weight/height^2); TEM, thermic effect of a meal; SS, sum of squares; MS, mean square.

followed the same trend (F 11·0, $P < 0·05$). Carbohydrate oxidation rates were highest in the UN and lowest in the NW group, but the differences were not statistically significant ($P > 0·05$). SOR and test meal energy intakes expressed per kg body-weight are given in Table 4. These show a similar trend to the absolute amount of each substrate oxidized.

NPRQ (Table 3) obtained during the BMR and the postprandial measurements were significantly lower in the NW subjects compared with either the UW or the UN subjects (BMR: df 2,21, F 9·3; postprandial: df 2,26, F 8·6; $P < 0·05$). There were, however, no significant differences between the UW and UN groups, although values for the UN group were higher.

Table 3. *Non-protein respiratory quotients (NPRQ) and substrate oxidation rates for normal weight (NW), underweight (UW) and undernourished (UN) subjects*†

(Mean values with their standard errors)

	BMR‡		Postprandial‡	
	Mean	SE	Mean	SE
NPRQ				
NW	0·806	0·01	0·881	0·01
UW	0·890*	0·02	0·949*	0·02
UN	0·925*	0·03	0·969*	0·01
Carbohydrate (g)				
NW	5·03	0·74	56·37	4·66
UW	7·54	0·89	64·18	4·56
UN	8·06*	0·99	68·64*	2·73
Fat (g)				
NW	3·80	0·33	14·42	1·40
UW	1·75*	0·40	5·57*	2·14
UN	1·09*	0·39	0·34*	1·66
Protein (g)				
NW	2·88	0·48	21·08	1·57
UW	2·41	0·32	15·85*	1·41
UN	2·41	0·31	12·08*	0·60

* Mean values were significantly different from those for NW group (ANOVA, least significant difference procedure), $P < 0·05$.

† n 9, 7 and 8 for groups NW, UW and UN respectively; for details of groups, see pp. 177–178.

‡ Measurements made over 1 and 6 h for BMR and postprandial respectively.

DISCUSSION

A reduced thermic response to food has long been postulated as a possible contributory factor to the development of obesity (Shetty, 1980; Shetty *et al.* 1981, Schutz *et al.* 1984). Similarly a blunting of the TEM may contribute, in part, towards the adaptive changes taking place to help maintain energy balance during chronic energy deficiency (James & Shetty, 1982). The reduced thermic response to noradrenaline infusions in chronically undernourished subjects (Kurpad *et al.* 1989) indicates a reduced activity of the SNS in the UN. This reduction could conceivably affect the thermic response to a meal, as the SNS is thought to be responsible for 25–50% of the TEM (Horton, 1983; Sims & Danforth, 1987).

In the present study, we present findings on the thermic response to a standard test meal in a group of UN subjects. It is well established that the magnitude of the TEM is strongly related to the size of the energy load (Miller *et al.* 1967; Hill *et al.* 1984; Belko *et al.* 1986; Owen *et al.* 1987). Thus, when meals are given relative to body-weight or FFM, lean individuals would receive smaller loads, which may bias the comparison with normal-weight subjects. Therefore, the results of studies in which variable energy loads are used are difficult to interpret and potentially misleading owing to the confounding effect of varied meal sizes (Segal *et al.* 1990). It therefore seems preferable to use a standard test meal and express the TEM as a percentage of the energy content of the meal as suggested by Schutz (1984).

The TEM responses in the UN group were compared with those of two control groups, one having appropriate weight-for-height, and the other underweight-for-height and hence similar BMI to the UN group. The UN group had the lowest absolute BMR, which were significantly different from those of the NW group ($P < 0·05$) but similar ($P > 0·05$) to

Table 4. *Energy intakes, preprandial and postprandial nutrient utilization rates (per kg body-weight) for normal weight (NW), underweight (UW) and undernourished (UN) subjects*‡

(Mean values with their standard errors)

	Preprandial		Postprandial							
	Oxidized (kJ/h)		Intake (kJ)		Oxidized (kJ/6 h)		% of intake oxidized		Stored§ (kJ/6 h)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Carbohydrate										
NW	1·3	0·21	28·0	0·68	14·2	1·40	50·3	4·17	13·8	1·11
UW	2·5*	0·30	37·2*	1·13	21·5*	1·84	57·3	4·07	15·8	1·42
UN	3·1*	0·37	43·5*†	1·13	26·6*†	1·21	61·3*	2·44	16·9	1·18
Fat										
NW	2·1	0·21	5·6	0·14	8·1	0·84	144·8	14·01	−2·5	0·83
UW	1·3	0·29	7·4*	0·23	4·2*	1·60	55·9*	21·47	3·3*	1·60
UN	0·9*	0·33	8·7*†	0·23	2·9*	1·40	33·6*	16·66	5·8*	1·41
Protein										
NW	0·7	0·13	3·7	0·09	5·3	0·45	141·1	10·53	−1·6	0·41
UW	0·8	0·12	5·0*	0·15	5·2	0·40	106·1*	9·48	−0·2*	0·47
UN	0·9	0·12	5·8*†	0·15	4·7	0·27	80·9*	4·63	1·1*†	0·26

* Mean values were significantly different from those for NW group (ANOVA, least significant difference procedure), $P < 0·05$.
† Mean values for UN group were significantly different from those for UW group (ANOVA, least significant difference procedure), $P < 0·05$.
‡ *n* 9, 7 and 8 for groups NW, UW and UN respectively; for details of groups, see pp. 177–178.
§ Energy intake – oxidized.

those of the UW group. However, these differences were not apparent on an ANACOVA with the FFM as the covariate (Table 2(b)). The significantly higher basal NPRQ in the UN group were due to utilization of carbohydrate (from glycogen stores) as a fuel in the fasted state with little fat or protein being oxidized (Tables 3 and 4). These results are likely to be due to the differences in the composition of the antecedent diets among the three groups, since fasting RQ are known to follow food quotients (Flatt, 1985). This use of carbohydrate as a fuel in the fasting state is possibly beneficial to these UN individuals, since carbohydrate (glycogen) oxidation results in more ATP than isoenergetic amounts of fat or protein (McGilvery & Goldstein, 1979; Waterlow, 1988).

The TEM responses in the UN were the largest both in absolute terms and when expressed as a percentage of the energy content of the meal (Tables 1 and 2(a)). The higher thermic response to a protein meal compared with that of an isoenergetic carbohydrate meal given as glucose, both in lean and obese subjects (Nair *et al.* 1983), has been attributed to a stimulation of protein synthesis by the dietary protein rather than by glucose intake (Woo *et al.* 1985). Although recent evidence suggests a stimulation of protein synthesis by sustained carbohydrate overfeeding (Welle *et al.* 1989), we are not aware of similar changes with day-to-day variation in carbohydrate intake. Since the UN subjects showed a lower protein oxidation per kg body-weight, it is likely that the increased TEM was due, in part, to an increased protein synthesis. Since protein oxidation rates were not corrected for changes in the plasma urea pool from the fasted to the fed state, we are not in a position to comment on these results. It has been demonstrated that, for isoenergetic amounts, carbohydrate produces a higher TEM response than fat (Schwartz *et al.* 1985; Swaminathan *et al.* 1985). The observation that PMTEO, corrected for body size (Table 2(b)), were similar among groups would indicate that all groups had similar thermogenic capacities. A higher TEM response could then be expected in those who oxidized the largest amount of carbohydrate. The UN group in the present study not only oxidized the largest amount of carbohydrate but also the least amount of fat (Tables 3 and 4). This could account for their higher TEM responses. In contrast, the NW controls, while oxidizing smaller amounts of carbohydrate (50 % in NW group *v.* 61 % in UN group, $P < 0{\cdot}05$), mobilized both fat and protein during the 6 h of measurement. The importance of this higher TEM response in the UN group may be of limited significance in the light of the lack of significant differences in the PMTEO among groups after correction for body size. From a similar analysis, Garrow (1984) has suggested that a lower TEM in the obese cannot account for their obesity, since at every stage of measurement the obese have higher total energy outputs following a meal.

Recent findings on TEM measured over 15 h in Gambian subjects suggest the opposite, namely that TEM responses are blunted during the lean season compared with European subjects (Minghelli *et al.* 1990). Before such results are accepted as evidence for an efficiency of energy utilization in 'undernourished' subjects, it is important to note the following points. First, the Gambians (in the 'hungry' season) are not comparable to the UN group in the present study either in terms of anthropometry or body composition. Second, their dietary intakes compared with Europeans were different in energy and composition, both factors that influence the TEM response. The higher RQ of Gambians compared with Europeans (0·90 (SE 0·007) *v.* 0·84 (SE 0·006)) would indicate a higher proportion of dietary carbohydrate utilization and hence should have resulted in a higher TEM response. Paradoxically, a lower TEM response was obtained. Perhaps these results reflect an acute metabolic response to seasonal cycling of energy balance in this Gambian population.

In conclusion, UN individuals demonstrate a greater utilization of carbohydrate as a fuel, both in the basal and the fed state. The lower postprandial fat oxidation rates suggest a tendency to store this nutrient. The TEM responses to the standard test meal are highest

in the UN, even when corrected for the energy content of the meal. The absence of a significant difference in the PMTEO among groups, once corrections were made for body size (by an ANACOVA), would suggest similar thermogenic capacities in all groups of subjects in response to the standard meal. These results tend to indicate that modulations in the TEM in the chronically undernourished are unlikely to contribute towards any energy saving and may not constitute a part of their adaptive response to the undernourished state.

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