Meal frequency and energy balance

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Several epidemiological studies have observed an inverse relationship between people's habitual frequency of eating and body weight, leading to the suggestion that a 'nibbling' meal pattern may help in the avoidance of obesity. A review of all pertinent studies shows that, although many fail to find any significant relationship, the relationship is consistently inverse in those that do observe a relationship. However, this finding is highly vulnerable to the probable confounding effects of *post hoc* changes in dietary patterns as a consequence of weight gain and to dietary under-reporting which undoubtedly invalidates some of the studies. We conclude that the epidemiological evidence is at best very weak, and almost certainly represents an artefact. A detailed review of the possible mechanistic explanations for a metabolic advantage of nibbling meal patterns failed to reveal significant benefits in respect of energy expenditure. Although some short-term studies suggest that the thermic effect of feeding is higher when an isoenergetic test load is divided into multiple small meals, other studies refute this, and most are neutral. More importantly, studies using whole-body calorimetry and doubly-labelled water to assess total 24h energy expenditure find no difference between nibbling and gorging. Finally, with the exception of a single study, there is no evidence that weight loss on hypoenergetic regimens is altered by meal frequency. We conclude that any effects of meal pattern on the regulation of body weight are likely to be mediated through effects on the food intake side of the energy balance equation.

Meal frequency: Nibbling: Gorging: Energy balance

The present paper reviews the epidemiological studies relating meal frequency to body weight, and attempts to integrate these with the results of physiological investigations on meal frequency and energy metabolism. The paper will focus exclusively on human subjects because, although there is a considerable literature describing the metabolic effects of differing meal patterns in experimental animals (Fabry & Tepperman, 1970; Adams & Morgan, 1981; Bellisle, 1995), there are important ecological differences between the natural feeding patterns of species, and because the human experimental data are adequate to answer the key questions relating to the efficiency of energy utilization in this context.

EPIDEMIOLOGICAL ASSOCIATIONS BETWEEN HABITUAL MEAL FREQUENCY AND BODY WEIGHT

The extensive work of Fabry and co-workers (Fabry *et al.* 1964, 1966; Hejda & Fabry, 1964) was the first to demonstrate strong and reproducible inverse relationships between habitual meal frequency and body weight in human subjects. Results from their first large sample study involving 379 Czechoslovakian men aged 60–64 years (Fabry *et al.* 1964) are illustrated in Fig. 1. Both the proportion of overweight subjects and mean skinfold thicknesses were significantly inversely related to meal frequency. Similar trends were observed in a smaller sample of eighty-nine men aged 30–50 years (Hejda & Fabry, 1964).

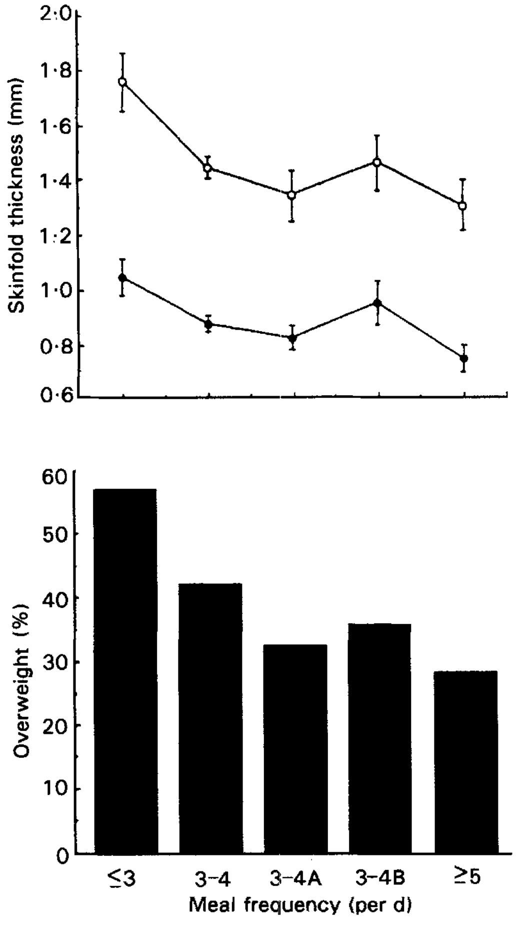

Fig. 1. Relationship between habitual meal frequency and body fatness in 379 Czechoslovakian men aged 60–64 years. (●), Triceps skinfold thickness; (○), subscapular skinfold thickness; A, additional snacks between meals; B, additional snacks at bedtime. Values are means with their standard errors represented by vertical bars. (Data from Fabry *et al.* 1964.)

Fabry *et al.* (1966) also performed an intervention study in which two schools for 6–16-year-old children were selected for comparison of a three meal *v.* seven meal daily regimen, whilst a third school remained on its normal five meals daily pattern (total n 226 children). Average energy intakes did not differ significantly between schools. The results of this 1-year intervention were assessed using an 'index of proportionality' which summarized changes in weight relative to height growth (high index of proportionality represents greater relative weight gain). For older children (10–16 years) there was a higher proportion of subjects with an elevated index of proportionality in the school with three meals daily compared with the other two schools ($P < 0{\cdot}05$ for boys and $P < 0{\cdot}001$ for girls). Changes in triceps, subscapular and abdominal skinfolds mirrored the changes in proportionality index. For younger children there were no significant differences.

Subsequent studies by other workers are summarized in Table 1. Some report non-significant effects, but where significant effects are reported they all support the Fabry *et al.*

Table 1. *Summary of epidemiological studies investigating the relationship between meal frequency and measures of body mass or body fatness*

Reference	Sample size	Subjects		Meal frequency (daily)	Outcome measures	Statistical significance
		Sex	Age (years)			
Fabry *et al.* (1964)	379	M	60–64	≤ 3–≥ 5	Overweight*	–, $P \leq 0.01$
					SFT	–, $P \leq 0.05$
Fabry *et al.* (1966)	226	M+F	6–16	3, 5+7	Body wt	–, Significant†
					SFT	–, Significant†
Metzner *et al.* (1977)	2028	M+F	35–69	1– ≥ 8	Adiposity Index‡	–, $P \leq 0.01$
Charzewska *et al.* (1981)	886	M	40–59	2, 3–4, 5–7	Percentage body fat§	–, $P < 0.05$
					BMI	–, $P < 0.05$
Dreon *et al.* (1988)	155	M	39–50	1–7	Percentage body fat§	NS‖
					BMI	NS
Edelstein *et al.* (1992)	2034	M+F	50–89	1–2, 3, ≥ 4	BMI	NS
					Waist:hip	–, $P \leq 0.01$
Kant (1995)	7147	M+F	25–74	Baseline ≤ 2–≥ 7	Wt change	–, $P \leq 0.05$
					Baseline BMI	–, $P \leq 0.05$
					TSF	–, $P \leq 0.05$
					SSF	–, $P \leq 0.05$
		M+F	35–84	Follow-up¶ ≤ 2–≥ 7	Wt change	NS
					Baseline BMI	NS
					TSF	NS
					SSF	NS
Summerbell *et al.* (1996)	220	M+F	Elderly	1–3, 4–6	BMI	NS
			Working age		BMI	NS
			Middle-aged		BMI	NS
			Adolescents		BMI	–, $P \leq 0.05$

SFT, skinfold thickness; TSF, triceps skinfold; SSF, subscapular skinfold; –, negative relationship; M, male; F, female.
* $\geq 10\%$ overweight.
† Actual level of significance not given.
‡ Adiposity index combines four different skinfold measures and BMI.
§ Measured from underwater weighing.
‖ Narrow range of subject type, all obese sedentary males.
¶ Follow-up study 10 years later used different methodologies of meal frequency estimation (see pp. S60–S61).

(1964) initial demonstration of lower body weight and adiposity in nibblers compared with gorgers. (In common with other authors we have adopted the terms ‘nibbling’ and ‘gorging’ to describe the two ends of whatever spectrum of meal patterns is covered in each study.) Fig. 2 illustrates the adiposity index for 948 men and 1080 women in the Tecumseh Community Health Study (Metzner *et al.* 1977). Apart from the very small number of subjects consuming only one meal daily (two men and four women; combined in the category $\leq$ two meals in Fig. 2) there was a highly significant inverse trend for both sexes ($P < 0.008$ for men and $P < 0.001$ for women).

Charzewska *et al.* (1981) studied the relationship between meal frequency and overweight in 886 Polish men aged 40–59 years. BMI averaged 27·8, 26·8 and 26·5 kg/m^2 in men consuming two, three to four and five to seven meals daily respectively ($P < 0.05$ for trend). A similar relationship existed when BMI was analysed according to the interval

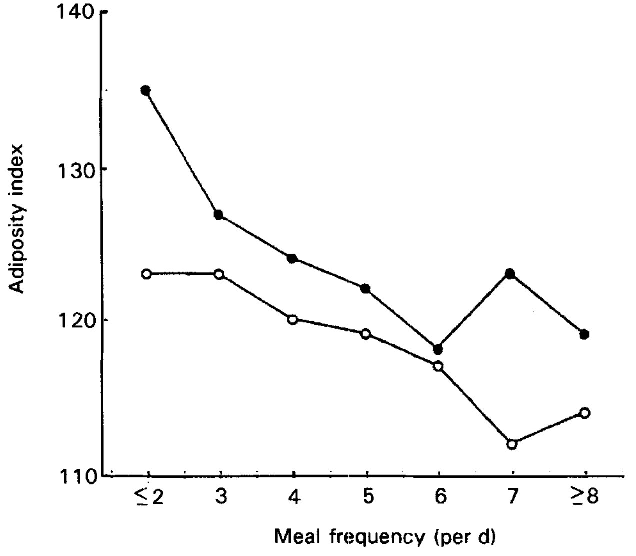

Fig. 2. Relationship between habitual meal frequency and body fatness in adult men and women in the Tecumseh Community Health Study. Adiposity index combines BMI and skinfolds and describes adiposity relative to the population median. Data from 948 men (○) and 1080 women (●). (Redrawn from Metzner *et al.* 1977.)

between meals. Another Polish study comparing dietary patterns in groups of 100 obese and fifty normal-weight women also found that the obese tended to consume fewer meals daily ($P < 0{\cdot}05$; Kulesza, 1980).

The NHANES I Epidemiologic Follow-Up Study is more difficult to interpret. It obtained measures of meal frequency at baseline (1971–5) and at follow-up (1982) and related these to BMI at each time period and to weight gain between baseline and follow-up (Kant, 1995). The estimates of frequency at baseline were obtained from 24 h recall of actual times of eating, and at follow-up from two questions concerning usual meal frequency and usual snacking patterns. At baseline, associations between eating frequency and BMI or skinfolds were weak and inconsistent for men, but strong for women and in the inverse direction, thus supporting the work of Fabry *et al.* (1964, 1966) and Hejda & Fabry (1964). Subsequent weight changes were also significantly related to eating frequency at baseline, but in an unpredictable manner. In women the highest gain was in those consuming two or fewer meals daily, but in men this category showed the lowest gain. In women there was a steady increase in weight gain over the other meal-frequency categories, and a similar tendency in men. However, all these relationships became non-significant when adjusted for possible confounders in multivariate regression analysis (physical activity, smoking status, alcohol intake and morbidity). The interpretation of this data-set is further complicated by the fact that meal frequency measured at follow-up was not significantly related to measures of fatness or weight gain in either sex.

Finally, a recent study of the eating habits of lean and obese Swedish men found a small difference in intake occasions (meals and snacks combined, 5·6 *v.* 5·3 daily; $P < 0{\cdot}02$), again in support of the contention of Fabry *et al.* (1964, 1966), but the significance disappeared after elimination of under-reporters (5·3 *v.* 5·9 daily; NS; Anderson & Rossner, 1996).

Although the relationships between feeding frequency and body weight look quite persuasive in Figs. 1 and 2, in many of the epidemiological studies there has been an absence of critical assessment of some key factors which hamper interpretation. The first of these relates to the reliability of classification of subjects' meal frequency. Kant (1995) found a very low reproducibility of the frequency estimates between baseline and follow-up (Kendall's coefficient of concordance 0·1). This is likely to be particularly critical in studies such as that of Kant (1995) which use only a single day to estimate habitual frequency, but to some extent is the least of the methodological problems since it will tend to obscure actual relationships (Type II error) rather than generate spurious relationships.

The more important potential errors relate first to the issue of dietary under-reporting by overweight people, and second to the possibility of reverse causality. Dietary under-reporting by obese, post-obese, overweight and diet-restrained subjects has now been shown to be one of the most robust biopsychological phenomena ever described (Prentice *et al.* 1986; Lichtman *et al.* 1992; Black *et al.* 1993), and there is evidence that snacks are especially prone to under-reporting, which would impinge strongly on the validity of meal-frequency estimates (Livingstone *et al.* 1990; Heitmann & Lissner 1995; Poppitt *et al.* 1995). The importance of this phenomenon is illustrated in Fig. 3 using the Kant (1995) data for women. Fig. 3(a) shows the apparent strong inverse relationship between meal frequency and mean BMI and skinfold thicknesses. Fig. 3(b) shows the reported energy intakes and compares them with the population predicted minimal energy requirements using the Goldberg *et al.* (1991) cut-offs derived from physiological first principles. It is apparent that most of the estimates of energy intake are impossibly low, indicating massive under-reporting, especially in view of the fact that the cut-offs are set at a very conservative value of only $1{\cdot}4 \times$ BMR. The strong inverse relationship between apparent energy intake and BMI is also quite impossible and cannot be resolved (as implied by the original authors) by invoking differences in the thermic effect of feeding between nibblers and gorgers (see p. S66). Unreliable dietary data, in which low recorded feed frequencies are highly suggestive of non-reporting of certain eating occasions, are therefore the only possible explanation of the apparent paradox and represent a major issue when trying to detect possible effects of meal frequency on body weight.

The issue of reverse causality is equally important. This refers to the likelihood that people omit meals (particularly breakfast) when they become overweight in an attempt to lose weight or to prevent further gain (Summerbell *et al.* 1996). Clearly these *post hoc* alterations in diet pattern would greatly confound data interpretation and would tend to create the inverse relationships observed in some of the studies in Table 1 without implying any causal linkage between meal frequency and changes in body weight.

Summerbell *et al.* (1996) have addressed these potential errors both in criticising the literature and in a fresh analysis of 7 d weighed-diet records from 220 subjects covering a range of age-groups. They observed that the inverse relationship between meal frequency and BMI which existed in first-pass analysis disappeared after exclusion of dietary under-reporters. This was true for all age-groups except adolescents where it remained marginally significant. However, subsequent analysis has shown that the removal of dieting boys and weight-conscious girls eliminates any association between BMI and meal frequency even in adolescents (H. Crawley and C. Summerbell, personal communication).

Summerbell *et al.* (1996) have concluded that the combination of under-reporting and missing meals by overweight people help to resolve the contradictory results of previous studies, and the apparent contradiction between epidemiological data and the experimental data described later (p. S66). We support these cautionary conclusions. These comments, however, refer to cross-sectional epidemiological studies and do not necessarily invalidate

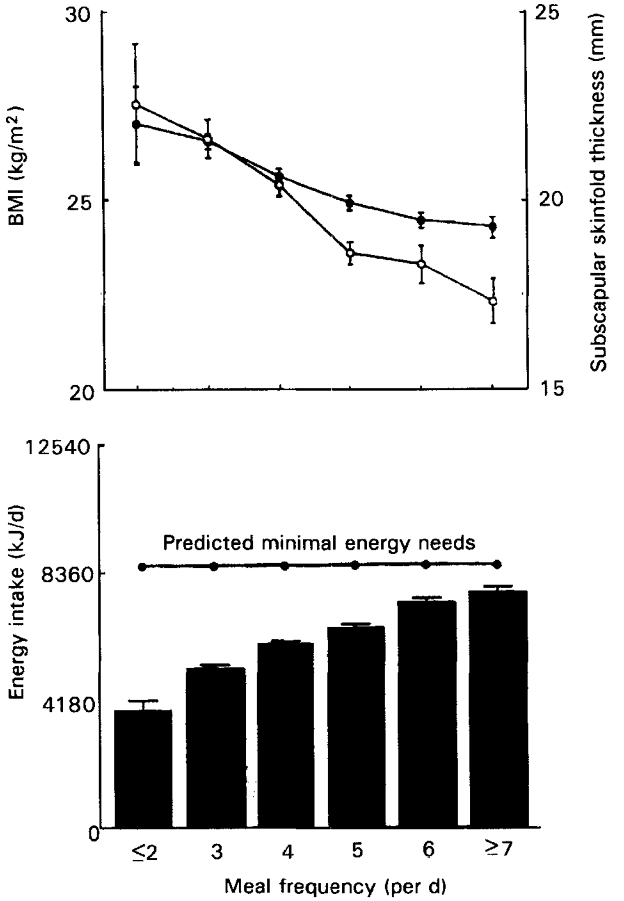

Fig. 3. Measures of adiposity and reported energy intake in the NHANES I Epidemiologic Follow-Up Study. (●), BMI; (○), subscapular skinfold thickness. Data for women only (*n* 4567). Values are means with their standard errors represented by vertical bars. Predicted minimal energy needs estimated as 1·4 × predicted BMR (Goldberg *et al.* 1991). (Data from Kant, 1995.)

the Fabry *et al.* (1966) intervention studies in schoolchildren. There may be quite different effects of meal frequency in growing and adult animals. This would be consonant with animal literature indicating greater feed conversion efficiency with increased frequency of feeding.

STUDIES ON THE EFFECT OF MEAL FREQUENCY ON WEIGHT LOSS DURING ENERGY RESTRICTION

Most studies relating to the energetic effects of differing meal frequencies cite the work of Debry *et al.* (1973) who observed a much better weight loss in dieting subjects on a seven meals daily regimen compared with three meals daily (142 *v.* 78 g/d). However, as shown in Table 2, six other published studies which have addressed the same issue found no significant effect of meal frequency, and even the small non-significant trends are in

Table 2. *Summary of studies comparing weight loss on energy restricted nibbling* v. *gorging regimens*

Reference	Subjects	Weight-loss regimen	Meal pattern (no. of meals daily)	Results	Statistical significance
Bortz *et al.* (1966)	Six women: 19–56 years Obese	2·5 MJ/d for 60 d (20 d on each meal pattern)	Three One Nine	Not listed* − 0·23 kg/d − 0·24 kg/d	NS
Finkelstein & Fryer (1971)	Eight women†: 20–22 years BMI 27 kg/m^2	7·1 MJ/d for 30 d followed by 5·9 MJ/d for 30 d	Three Six	− 6·1 kg − 5·5 kg	NS
Young *et al.* (1971)	Eleven men: 20–25 years BMI 34 kg/m^2	7·5 MJ/d for 14 weeks‡	One, three and six	Frequency effect (greater *v.* lesser) − 0·32 kg BW − 0·12 kg FM	 NS NS
Debry *et al.* (1973)	Eight men, twenty-four women: 16–65 years 120–220 % IBW	5·0–7·5 MJ/d§ 42 % energy from carbohydrate	Three Seven	− 78 g/d	$P < 0.025$ N > G
Debry *et al.* (1973)	Eight men, twenty-eight women: 16–65 years 120–220 % IBW	5·0–7·5 MJ/d§ 16 % energy from carbohydrate	Three ‖ Seven Seven Three	Rp 0·238 Rp 0·220 Rp 0·461 Rp 0·188	NS $P < 0.025$ N > G
Garrow *et al.* (1981)	Fourteen women: 18–56 years BMI 38 kg/m^2	3·4 MJ/d for 3 weeks¶	One Five	− 255 (SE 29) g/d − 224 (SE 20) g/d	NS
Verboeket-van de Venne & Westerterp (1993)	Fourteen women**: 20–58 years BMI 30 kg/m^2	4·2 MJ/d for 4 weeks	Two†† Three to five Two Three to five Two Three to five	− 4·1 kg BW − 4·7 kg BW − 2·3 kg FM − 2·7 kg FM − 1·8 kg FFM − 2·0 kg FFM	 NS NS NS

N, nibbling; G, gorging; BW, body weight; FM, fat mass; FFM, fat-free mass; IBW, ideal body weight; Rp, change in BW expressed as % IBW.

* Graphical summaries of each subject's weight curve shows no difference.

† Four subjects followed each meal pattern.

‡ After 14 d run-in on three meals daily subjects were randomly assigned to one, three or six meals daily for 5 weeks then randomly reassigned to these meal patterns for a further 5 weeks.

§ Adjusted to each subject's 'needs'. Three meal schedule was used for first month of diet, followed by seven-meal schedule for second month.

‖ Seventeen subjects had 1 month with three meals followed by 1 month with seven meals; nineteen subjects had order reversed.

¶ Meal frequency effects were tested for 7 d each during weeks 2 and 3 in randomized order.

** Seven subjects assigned to each meal pattern.

†† Two meals, 1·7 MJ lunch, 2·5 MJ supper; three to five meals, 1·25 MJ breakfast, 1·25 MJ lunch, 1·7 MJ supper with flexibility to use some lunch or supper as snacks.

differing directions. A number of other studies provide additional, although less direct, evidence of non-significant effects (Cohn & Allweiss, 1963; Nunes & Canham, 1963; Swindells *et al.* 1968; Thomas & Call, 1973). It seems unlikely that this failure to observe an effect can be ascribed to poor study design since, although the sample sizes are smaller than in the initial Debry *et al.* (1973) study, the protocols are quite robust and the range of feeding frequencies is large (one to nine meals daily).

The details of the Debry *et al.* (1973) study are not precisely described in the publications, and it is unclear whether the same subjects appear in different papers. The meal frequencies were applied in non-random order, and it is not clear how the overall ration was decided, and whether or not this was altered during the trial. Each of these features suggests that the result should be interpreted with caution.

The study by Garrow *et al.* (1981) was conducted entirely within a strictly controlled metabolic ward in which compliance was probably close to perfect. The results, therefore, directly reflect any possible differences in energy expenditure due to altered meal frequency. The other studies were conducted in a free-living setting and, therefore, provide additional insight into possible differences in compliance to the restricted diets since this would affect weight loss. Clearly there was no detectable advantage in terms of the hard end-points of weight or fat loss. Subjective comments reported by Young *et al.* (1971) favoured three meals daily. Verboeket-van de Venne & Westerterp (1993) made actual measurements of compliance through dietary records. Although these are notoriously unreliable in obese subjects, especially when given a prescribed diet, they revealed no apparent difference between energy intake on the nibbling and gorging patterns (4·30 *v.* 4·28 MJ/d). Garrow *et al.* (1981) reported that in their experience patients who are kept rigidly to a low-energy diet (3·4 MJ/d) find it more tolerable if it is distributed in many short meals.

Three of the weight-loss studies also investigated the influence of meal frequency on the composition of tissue loss. Young *et al.* (1971) reported no effect on fat loss. Garrow *et al.* (1981) reported a significantly lower N loss on the nibbling diet (1·3 g/d) than on the gorging diet (2·1 g/d; $P < 0{\cdot}001$), although the analysis had to be adjusted for powerful order effects since the different feeding patterns were imposed in the second and third weeks of dieting in different subjects. Verboeket-van de Venne & Westerterp (1993) reported no differential loss of lean or fat tissue.

We conclude that, in spite of the seemingly impressive results favouring a nibbling regimen recorded by Debry *et al.* (1973), most studies find that meal pattern has no significant impact on weight loss during intentional energy restriction.

SHORT-TERM STUDIES OF DIET-INDUCED THERMOGENESIS

It is reasonable to suppose that any differences in energy expenditure between nibbling and gorging meal patterns will be most apparent during the period of postprandial nutrient handling when energy is being used for the absorption, transport, interconversion and storage of substrates. The rate of ingestion and absorption of nutrients might influence their short-term metabolic fate with energetic consequences. For instance, a very large bolus meal with a high carbohydrate content might saturate the maximal rate of glycogen synthesis and force additional disposal via *de novo* lipogenesis; there is much evidence to support a hyperlipogenic effect of gorging in animal studies (Fabry & Tepperman, 1970). The 'inefficiency' of glycogen synthesis (approximately 2 %) is much lower than the inefficiency of lipogenesis (approximately 25 %; Flatt, 1985) and, hence, a larger meal might be expected to be associated with a greater heat production. Similarly, a large meal might stimulate a greater proportion of 'facultative' thermogenesis, the component which is mediated (especially by carbohydrate) through activation of the sympathetic nervous system (Jéquier, 1992).

For these reasons, and because most investigators do not possess whole-body calorimeters, there have been a number of short-term studies of the thermic effect of feeding (TEF), alternatively referred to as diet-induced thermogenesis. The results of these studies, employing intermittent postprandial measures of energy expenditure by ventilated hood or Douglas bag methods, are summarized in Table 3.

A central problem with short-term studies is the question of whether the postprandial measurements capture the entire area under the thermogenic peak. Many studies of TEF restrict their measurements to about 3 h duration because it is difficult for subjects to remain completely still for longer periods. However, the thermogenic peak may take much longer to subside, particularly after a very large meal. This may be especially pertinent in studies of nibbling *v.* gorging, and it is noteworthy that the two shortest studies in Table 3, by Tai *et al.* (1991) and LeBlanc *et al.* (1993), have yielded almost exactly opposite findings despite their rather similar investigative protocols. In a slightly longer study, Molnar (1992) corroborates the findings of Tai *et al.* (1991) (TEF is greater on the gorging regimen), but the difference amounts to only 3·4 % of the ingested energy. The other longer studies recorded no significant differences in TEF (Belko & Barbieri, 1987; Kinabo & Durnin, 1990).

We conclude that there is no strong evidence in support of a biologically-significant difference in TEF according to meal patterns. The 24 h studies discussed later (p. S66) entirely corroborate this summary. Further subsidiary support for this conclusion can be drawn from the observation that extraordinarily large doses of carbohydrate (500 g per meal) can be disposed of without recourse to any net lipogenesis (Acheson *et al.* 1982),

Table 3. *Summary of studies comparing thermic effect of feeding on nibbling* v. *gorging regimens*

Reference	Subjects	Outcome measures	Meal pattern	Results: Mean	Results: SE	Significance
Belko & Barbieri (1987)	Twelve men: 18–34 years, BMI 22 kg/m^2	TEF for 10 h	Two meals (50 % need)	43·3*	4·71	
			Four meals (25 % need)	43·4*	5·0	NS
Kinabo & Durnin (1990)	Eighteen women: 18–34 years, BMI 21 kg/m^2	TEF for 6 h	High-fat:			
			One meal (5040 kJ)	356 kJ†	23	
			Two meals (2520 kJ)	340 kJ†	16	NS
			Low-fat:			
			One meal (5040 kJ)	377 kJ†	30	
			Two meals (2520 kJ)	381 kJ†	27	NS
Molnar (1992)	Six boys, five girls: 12(SD 1) years, Obese	TEF for 6 h	One meal (30 % REE)	11·9 %‡	1·3	$P < 0·02$
			Three meals (10 % REE)	8·5 %‡	0·7	G > N
Tai *et al.* (1991)	Seven women: 23–30 years, Lean	TEF for 5 h	One meal (3138 kJ)	241 kJ†	34	$P < 0·05$
			Six meals (523 kJ)	174 kJ†	25	G > N
LeBlanc *et al.* (1993)	Three men, three women: 21–28 years, BMI 23 kg/m^2	TEF for 4 h	One meal (2732 kJ)	180 kJ†	16	$P < 0·05$
			Four meals (683 kJ)	259 kJ†	29	N > G

N, nibbling; G, gorging; TEF, thermic effect of food; REE, 24 h resting energy expenditure.
* Litres O_2 above resting levels.
† kJ above resting levels.
‡ % Energy in meals.

thus undermining one of the initial arguments in favour of the hypothesis that TEF might differ according to meal pattern.

STUDIES OF TOTAL ENERGY EXPENDITURE

Irrespective of any possible effects of meal pattern on TEF the key determinant of any ultimate effect on energy balance will be whether nibbling or gorging habits have any impact on total 24 h energy expenditure. Five studies using 24–48 h whole-body calorimetry are listed in Table 4; one of these made additional measurements of free-living energy expenditure over 7 d periods by doubly-labelled water. In addition to the over-riding advantage of covering the whole 24 h period, these studies also benefit from generally superior protocols, including dietary adaptation periods before the calorimetry (6–14 d in all except one study) and good discrimination between the nibbling and gorging meal patterns.

Table 4. *Summary of studies comparing total daily energy expenditure on nibbling* v. *gorging regimens*

Reference	Subjects	Outcome measures	Meal pattern	Results		Statistical significance
				Mean	SE	
Dallosso *et al.* (1982)	Eight men: 18–23 years BMI 22 kg/m^2	24 h EE* 7–14 d adaptation	Two meals (88 kJ/kg per d) Six meals (29 kJ/kg per d)	9759 9639	408 kJ/d 314	NS
Wolfram *et al.* (1987)	Two men, six women: 20–23 years BMI 23 kg/m^2	48 h EE 14 d adaptation	One meal (9·3 MJ) Five meals (1·9 MJ)	8·42 8·37	1·15 MJ/d 1·32	NS
Verboeket-van de Venne & Westerterp (1991)	Two men, eleven women: 18–23 years BMI 21 kg/m^2	24 h EE† No adaptation	Two meals (0·7 × SMR)‡ Seven meals (0·2 × SMR)	7282 7834	230 kJ/d 259	NS
Verboeket-van de Venne & Westerterp (1993)	Fourteen women: 20–58 years BMI 30 kg/m^2	24 h EE After 4 weeks on 4·2 MJ/d diet	Two meals§ Three to five meals§	7838 7867	416 kJ/d 202	NS
Verboeket-van de Venne *et al.* (1993)	Ten men: 25–61 years BMI 25 kg/m^2	24 h EE 6 d adaptation	Two meals ‖ Seven meals ‖	9·4 9·4	0·2 MJ/d 0·2	NS
		ADMR by DLW[7]	Two meals Seven meals	11·8 12·3	0·3 MJ/d 0·5	NS

SMR, sleeping metabolic rate; EE, energy expenditure; ADMR by DLW[7], average daily metabolic rate measured over 7 d by doubly-labelled-water method.

* Measured twice (after 7 d and 14 d) on nibbling and gorging regimen; average results presented. Also analysed by five shorter intervals.

† Also analysed by 3 h intervals.

‡ Total daily need assessed as 1·4 × SMR measured previously.

§ Two meals, 1·7 MJ lunch, 2·5 MJ supper; three to five meals, 1·25 MJ breakfast, 1·25 MJ lunch, 1·77 MJ supper with flexibility to use some lunch or supper as snacks.

‖ Energy intake (EI) based on 7 d record. Two meals, 40 % EI lunch, 60 % EI supper; seven meals, 100 % EI divided between seven small meals and snacks between 07.30–20.30 hours.

These studies provide a very strong consensus that there is no effect of meal pattern on total energy expenditure. In most of the studies the group mean values for 24 h energy expenditure are almost identical on the different treatments. The single doubly-labelled-water study corroborates the calorimetry results.

Within the 24 h period several studies observed shifts in the diurnal pattern of energy expenditure in a predictable direction. For instance, Dallosso *et al.* (1982) reported significantly raised night-time expenditure on the gorging regimen. This was caused by ingestion of the second large meal at 19.00 hours, at the same time as the last of the much smaller nibbling meals when on the alternative treatment. The significantly raised night-time expenditure was compensated for by a lower daytime expenditure. Similar results were reported by Verboeket-van de Venne *et al.* (1993) who observed the anticipated increase in energy expenditure immediately after the larger meals.

Whole-body calorimetry can also be used to obtain an integrated estimate of total TEF over a 24 h period. This is achieved by calculating the slope of the relationship between activity counts (measured by Doppler) and energy expenditure. The zero intercept of this line represents energy expenditure at a state of total rest. It is then assumed that the difference between this value and BMR represents TEF. In two separate studies Verboeket-van de Venne & Westerterp (1993) and Verboeket-van de Venne *et al.* (1993) have performed this calculation and demonstrated that there was no significant influence of meal frequency on TEF after adjustment for the relevant time intervals.

CONCLUSIONS AND PRIORITIES FOR FUTURE RESEARCH

We conclude that there is robust evidence from several independent laboratories to refute the hypothesis that feeding frequency is a significant determinant of energetic efficiency in human subjects when assessed over 24 h or longer. Consequently, feeding frequency has no significant impact on the rate of weight loss during energy restriction. We further conclude that the epidemiological studies which have suggested that nibbling is associated with leanness are extremely vulnerable to methodological errors which may generate spurious relationships due to dietary under-reporting and *post hoc* alterations in eating patterns in response to weight gain. Although these may not totally invalidate the cross-sectional studies, they highlight the need for considerable caution in interpreting the results and point to the need for a more critical analysis in the future.

Since we conclude that feeding frequency has no discernible effect on 24 h energy expenditure, then any putative effects on regulation of body weight must be mediated through effects on the intake side of the energy balance equation. Aspects of this question are reviewed elsewhere in this workshop (de Castro, 1997; Gatenby, 1997), but may also require fresh experimental approaches. Future research might usefully investigate the effects of meal frequency on spontaneous food selection and on the regulation of energy intake. This should address both the immediate effects of high and low meal frequencies, and the downstream effects on later meals. One prospective study in hyperlipidaemic patients already suggests that recommendations to increase or decrease meal frequency are accompanied by concomitant changes in overall energy intake and in body weight (King & Gibney, 1997). Interactions between meal frequency and habitual levels of physical activity might also be important. The difficulties of such research with respect to the confounding effects of under-reporting should not be underestimated.

In the field of eating disorders there is emerging interest in the potential interaction between eating frequency and the development and treatment of eating disorders.

Cognitive behavioural therapies for bulimia stress the importance of establishing regular meal patterns, and some practitioners are recommending high snack frequencies as a means of inhibiting bingeing. There is a need for a formal appraisal of the evidence base for such interventions.

Any decisions regarding dietary advice in favour of the adoption of nibbling or gorging meal patterns should be dominated by a consideration of the effects on carbohydrate and lipid metabolism (Jenkins, 1997; Mann, 1997), rather than on energy expenditure, where a prudent analyst would probably conclude that the metabolic effects are neutral.

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