

PAPER

Decreased thermic effect of food after an irregular compared with a regular meal pattern in healthy lean women

HR Farshchi^{1*}, MA Taylor¹ and IA Macdonald¹

¹Centre for Integrated Systems Biology and Medicine, Institute of Clinical Research and School of Biomedical Sciences, Queen's Medical Centre, University of Nottingham, Nottingham, UK

OBJECTIVES: To investigate the impact of irregular meal frequency on body weight, energy intake, appetite and resting energy expenditure in healthy lean women.

DESIGN: Nine healthy lean women aged 18–42 y participated in a randomised crossover trial consisting of three phases over a total of 43 days. Subjects attended the laboratory at the start and end of phases 1 and 3. In Phase 1 (14 days), subjects were asked to consume similar things as normal, but either on 6 occasions per day (regular meal pattern) or follow a variable predetermined meal frequency (between 3 and 9 meals/day) with the same total number of meals over the week. In Phase 2 (14 days), subjects continued their normal diet as a wash-out period. In Phase 3 (14 days), subjects followed the alternative meal pattern to that followed in Phase 1. Subjects recorded their food intake for three predetermined days during the irregular period when they were eating 9, 3 and 6 meals/day. They also recorded their food intake on the corresponding days during the regular meal pattern period. Subjects fasted overnight prior to each laboratory visit, at which fasting resting metabolic rate (RMR) was measured by open-circuit indirect calorimetry. Postprandial metabolic rate was then measured for 3 h after the consumption of a milkshake test meal (50% CHO, 15% protein and 35% fat of energy content). Subjects rated appetite before and after the test meal.

RESULTS: There were no significant differences in body weight and 3-day mean energy intake between the regular and irregular meal pattern. In the irregular period, the mean energy intake on the day when 9 meals were eaten was significantly greater than when 6 or 3 meals were consumed ($P=0.0001$). There was no significant difference between the 3 days of the regular meal pattern. Subjective appetite measurement showed no significant differences before and after the test meal in all visits. Fasting RMR showed no significant differences over the experiment. The overall thermic effect of food (TEF) over the 3 h after the test meal was significantly lower after the irregular meal pattern ($P=0.003$).

CONCLUSION: Irregular meal frequency led to a lower postprandial energy expenditure compared with the regular meal frequency, while the mean energy intake was not significantly different between the two. The reduced TEF with the irregular meal frequency may lead to weight gain in the long term.

International Journal of Obesity (2004) 28, 653–660. doi:10.1038/sj.ijo.0802616

Published online 16 March 2004

Keywords: irregular meal frequency; energy expenditure; energy intake; thermic effects of food; regular meal pattern; appetite; hunger and satiety

Introduction

The prevalence of obesity continues to increase around the world, in spite of a widespread desire to control body weight. Body weight, or more precisely body energy content, can only increase when energy intake exceeds energy expendi-

ture for a prolonged period. Meal pattern has been identified as a factor influencing body weight.^{1,2} Fabry *et al*¹ suggested a negative relationship between meal frequency and body weight in the 1960s. Many investigators have attempted to evaluate further the effect of meal frequency on body weight.^{3–17} An effect could be mediated either by changed intakes (perhaps secondary to modified appetite) or changed energy expenditure.

A few studies have evaluated the effect of meal frequency on energy intake with inconclusive results.^{3,6,18–23} Studies considering appetite ratings derived from visual analogue

*Correspondence: HR Farshchi, E 72, School of Biomedical Sciences, Queen's Medical Centre, Clifton Boulevard, Nottingham NG7 2UH, UK.
E-mail: mbxhfr@nottingham.ac.uk

Received 8 July 2003; revised 9 December 2003; accepted 28 December 2003

scales (VAS) have been undertaken in lean²⁴ and obese.²⁵ In both cases, subjects were given a large breakfast on one occasion or 5 smaller meals at hourly intervals on the other. The total food intake through the morning was the same. Subjects were then offered an *ad libitum* meal at lunchtime. In spite of similar appetite ratings before the *ad libitum* meal in both eating patterns, subjects consumed more food in the *ad libitum* meal when eaten after the large breakfast rather than the five snacks. However, the reported sensations of satiety were the same in both conditions.

Many studies have evaluated the effect of meal frequency on energy expenditure as a major influencing factor on body weight. Studies assessing the effect of meal frequency on total energy expenditure report no statistical association between these two factors.^{15,26–28} Studies evaluating the effect of meal frequency on thermic effect of foods (TEF) have suggested contradictory results.^{29–32}

It seems that Western populations are increasingly moving away from regular meals towards marked interdaily variation in frequency and time of consumption of food. The wide availability of food, including the availability of 'ready meals' that can be stored and rapidly regenerated, and the consumption of more meals outside the home are likely contributors to the variability in eating patterns. Recent studies^{33,34} report that the prevalence of an irregular meal pattern has increased in adolescents compared with previous decades. Furthermore, Japanese studies reported that irregular snacking had become more common in children, which may contribute to the increasing prevalence of obesity seen in children.^{35–37} To our knowledge, no previous study has evaluated the effect of an irregular meal pattern on energy metabolism in adults. The purpose of the present study was to examine the effect of irregular meal frequency on energy expenditure and energy intake in healthy normal weight women.

Methods

Subjects

Nine healthy, lean women aged 18–42 y (mean 23.7, standard deviation (s.d.): 7.4 y) with regular menstruation or on the oral contraceptive pills, neither pregnant nor lactating and with no self-reported history of hypercholesterolaemia, hyperglycaemia or any serious medical conditions were recruited from the students and staff of the Queen's Medical Centre in Nottingham. No self-reported dieting (a score of less than 10 on The Eating Inventory³⁸) and no cognitive indicator of depression (score of less than 30 on the Beck Depression Inventory³⁹) were also inclusion criteria. The mean body mass index (BMI) was 22.4 kg/m² (s.d.: 2.4 kg/m²). Ethical permission for the study was obtained from The University of Nottingham Medical School Research Ethics Committee.

Design

The randomised crossover trial consisted of three phases over a total of 43 days for each subject. Subjects attended a

screening session and then four laboratory visits at the start and end of phases 1 and 3. Each laboratory visit lasted a maximum of 4 h. In Phase 1 (14 days), subjects were asked to eat and drink similar things to their normal diet, but to either consume them on 6 occasions per day (regular meal pattern) with regular intervals between meals or follow a chaotic eating plan (ie irregular meal pattern). To achieve the irregular meal pattern, subjects were asked to have their usual foods and drinks but follow a predetermined meal frequency with between 3 and 9 meals/day for 14 days. Each number of meals per day was repeated twice (ie 7, 4, 9, 3, 5, 8, 6, 5, 9, 8, 3, 4, 7 and 6 occasions/day, respectively) with an average of 6 meals/day. The number of meals on the last 2 days of the regular and irregular meal patterns were similar (ie 6 and 6 vs 7 and 6). In Phase 2 (14 days), subjects continued their normal diet and eating pattern as a wash-out period. In Phase 3 (14 days), subjects were finally asked to follow the alternative meal pattern to that which they followed in Phase 1. A 'meal' was defined as any food or snack (solid or liquid) containing energy, with an interval between two eating occasions of more than 1 h. The participants remained free living during the study and the diet content was self-selected.

Protocol for laboratory visits

Subjects were asked to fast overnight for at least 10 h and take no exercise other than walking required for the activities of daily living for 48 h prior to the laboratory visit. On arrival, weight, height, waist and hip circumferences were measured. Subjects then rested supine and an intravenous cannula was inserted for blood sampling. The results of the analysis of the blood samples have been published recently.⁴⁰ Resting metabolic rate (RMR) was measured in the fasting state and then for 3 h after the consumption of the milkshake test meal. Subjects also completed VAS for the following factors: satiety, hunger, fullness and urge to eat. All visits were undertaken in the morning.

Laboratory procedures

Anthropometric measurements. Weight, waist and hip circumference measurements were carried out at each laboratory visit. Weight was measured on a balance scale (Avery, UK) to the nearest 0.1 kg when subjects were fasting, had an empty bladder, were wearing light clothing with empty pockets and with no shoes. Height was measured using a stadiometer attached to the weighing scale to the nearest 0.1 cm during the screening visit. Waist circumference was measured to the nearest 0.1 cm in a horizontal plane at the level of the midpoint between the lower margin of the last rib and the crest of ileum when the subject stood with feet 25–30 cm apart.⁴¹ Hip circumference was also measured to the nearest 0.1 cm in a horizontal plane at the maximum point over the buttock at the level of femoral greater trochanter by a flexible nonstretch nylon tape.⁴¹

Body composition was measured by bioelectrical impedance (using a QuadScan 4000, Bodystat Ltd, Douglas, UK) with the subject lying on a nonconductive couch with arms and legs abducted.

Test meal consumption. The milkshake test meal was given as a breakfast. Subjects were given a volume of the test meal on the basis of their weight at the start of the experiment (10 kcal (41.8 kJ), per kg body weight). The percentages of total energy from the macronutrients were 50% carbohydrate, 35% fat and 15% protein. The test meal contained semiskimmed milk, Build up (Nestlé SA, Switzerland), double cream (Sainsbury's, UK, containing 1831 kJ energy and 47.5 g fat, of which 29.7 g saturated per 100 ml) and polycal (Nutricia Clinical Care, UK) with either strawberry or vanilla flavour. It was served at a temperature of 18–20°C from an open glass. Subjects were asked to consume the drink over 10 min.

Visual analogue scales. Each subject completed VAS questionnaires to assess subjective hunger, satiety, fullness and desire to eat. Subjects completed these questionnaires just before the test meal and every 30 min after the test meal for 3 h. Ratings were made on 100-mm VAS with words at each end that expressed the most extreme rating.⁴²

Energy expenditure and substrate oxidation. RMR was measured after a 10 h fast, at 0800–0900, by an open-circuit indirect calorimeter (V max, Sensor Medics Corporation, Yorba Linda, USA). After a warm-up period of 30 min, a reference gas (4% CO₂, 16% O₂, balance N₂ and 26% O₂ and balance N₂) used to calibrate the oxygen and carbon dioxide analysers. The gas analysers were calibrated before every run with the two calibration gases and atmospheric air was then measured. Ingoing and outgoing air were analysed for O₂ and CO₂ every minute during each period of measurement. Readings were collected every minute with a personal computer.

Subjects rested on a bed in a room maintained at 18–20°C and relaxed for about 20 min. Fasting RMR was then measured for 30 min with the subject lying in the supine position. A transparent ventilated hood was positioned over the subject's head with Collins tubing connecting the hood to the monitor and expired gases were continuously collected. Subjects then drank the milkshake test meal over a period of 10 min. Then, postprandial metabolic rate (PPMR) was measured for periods of 15 min starting immediately after the test meal consumption. Two 15-min measurements were made per hour for 3 h. Subjects rested on the bed but were not allowed to sleep during the energy expenditure measurements. In the interval between the two consecutive measurements, subjects were also on the bed but they were permitted to read.

The TEF was measured by the trapezoidal method measuring the area under the curve of PPMR above the baseline RMR for all of the visits. Respiratory quotient (RQ) and

substrate oxidation were calculated using oxygen consumption and carbon dioxide production in each visit, ignoring any protein contribution.⁴³

Free-living procedures

Food intake measurement. The participants were given training in recording their food intake in a diary using a semiquantitative method based on household measurements. An instruction booklet with a day menu example was also given to each subject before each recording.

Before the start of Phase 1, subjects were asked to record their habitual dietary intake for 3 days (1 weekend and 2 weekdays) by completing a food diary according to the instructions given. In the regular meal pattern period, subjects were asked to provide a food record for 3 of the 14 days (the 3rd, 11th and 14th days). Subjects also recorded their food intake on the 3rd (9 meals/day), 11th (3 meals/day) and 14th (6 meals/day) days of the irregular meal pattern periods. Food diary records for the subjects' habitual, regular and irregular meal patterns were analysed using the 'Microdiet' Package (Downlee Systems Limited, The University of Salford, UK, 2000, Edition 1.2).

Statistical analysis. The statistical package SPSS version 10 (SPSS, Chicago, USA) was used for data entry and analysis. All data are reported as means ± s.d. Data were tested for normality (Kolmogorov–Smirnov statistic with Lilliefors correction). Comparisons of the anthropometric measurements and fasting RMR before and after the intervention periods were performed using Student's paired *t*-test (two-tailed). To investigate the interactions between the factors, repeated measures analysis of variance (ANOVA) was carried out either two way (ie two within-subjects factors; pre- and postdietary intervention, meal pattern) or three way (ie with three within-subjects factors; time course after the test meal, meal pattern, pre- and postdietary intervention) as appropriate. When ANOVA indicated a significant main effect (including interaction), the level of significance for pairwise comparisons of each was obtained using paired *t*-test. Statistical significance was set at $P < 0.05$ for all statistical tests.

Results

There were no statistical differences in body weight by meal pattern either at the premeal pattern period visits (visits 1 and 3) or the postmeal pattern visits (visits 2 and 4). Body weight did not change across the regular and irregular meal patterns (Table 1).

Waist circumference, waist to hip ratio and body fat percentage showed no significant differences by meal pattern either at the premeal pattern period visits (visits 1 and 3) or the postmeal pattern visits (visits 2 and 4). Furthermore, these values did not change significantly across

the two intervention periods (Table 1). Comparing the two meal patterns, there were no significant differences in body fat percentage at the start of both interventions. There were also no significant differences in these values after the regular and irregular meal patterns (Table 1).

Energy intake

The preexperiment food diary records showed a significant difference between weekdays and weekend ($P=0.0001$), with lower energy intake on weekdays compared with the weekend. The mean energy intake on two weekdays and one weekend was 7.86 ± 1.17 , 7.70 ± 1.04 and 9.61 ± 1.29 MJ/day, respectively. However, there were no significant differences in the food macronutrient composition between weekdays and weekends.

All subjects reported having adhered to the appropriate meal patterns during the two interventions. The mean energy intake recorded over 3 days during the regular and irregular meal pattern was 8.01 ± 0.50 and 8.42 ± 0.49 MJ/day, respectively. The comparison of the mean energy intake over the two interventions revealed a trend of lower energy intake during the regular meal pattern ($P=0.075$). On the other hand, there was no significant difference in the percentage of total energy from protein, fat and carbohydrate between the two meal patterns.

Table 1 Physical characteristics of the subjects over the experiment^a

	Regular meal pattern		Irregular meal pattern	
	Preperiod	Postperiod	Preperiod	Postperiod
Body weight (kg)	63.6 ± 8.0	63.2 ± 7.2	62.7 ± 7.7	63.0 ± 7.9
BMI (kg/m ²)	22.4 ± 2.0	22.3 ± 1.7	22.1 ± 2.1	22.2 ± 2.0
Waist (cm)	78.0 ± 6.1	77.0 ± 5.6	80.0 ± 7.5	77.0 ± 5.4
Waist/hip	0.82 ± 0.05	0.82 ± 0.05	0.83 ± 0.05	0.82 ± 0.04
Body fat (%)	26.0 ± 3.1	27.1 ± 2.8	25.6 ± 2.9	26.9 ± 3.2

^aMean \pm s.d.

Table 2 Daily nutrient intake during the regular and irregular meal pattern

	Regular meal pattern				Irregular meal pattern			
	Day 1	Day 2	Day 3	Mean	Day 1 ^a	Day 2 ^a	Day 3 ^a	Mean
Energy (MJ)	8.18 ^b	7.88	8.04	7.96	9.81 ^{b,c}	8.14 ^c	7.36 ^c	8.44
s.d.	0.98	0.47	0.92	0.79	0.77	0.74	0.57	0.69
Protein (%)	15.0	14.2	13.6	14.3	14.7	14.1	15.5	14.8
s.d.	5.6	4.0	2.1	3.9	3.8	3.7	3.0	3.5
Fat (%)	42.4	37.6	37.3	39.1	38.0	40.3	36.1	38.1
s.d.	7.1	7.5	5.7	6.8	5.5	9.5	6.3	7.1
CHO (%)	42.6	45.5	44.2	44.1	45.3	40.9	46.4	44.2
s.d.	8.3	7.4	8.7	8.1	5.0	8.2	8.3	7.2

^aDay 1: 9 meals/day, day 2: 6 meals/day and day 3: 3 meals/day. ^bSignificantly higher energy intake on 9 meals compared with the corresponding day of the regular meal pattern ($P=0.002$). ^cA significant higher energy intake in the 9 meals/day compared with 3 ($P=0.0001$) and 6 ($P=0.001$) meals/day, also higher energy intake on 6 meals compared with 3 meals/day ($P=0.001$). CHO = carbohydrate.

The mean daily energy intake showed no significant differences between the 3 days of the regular meal pattern period. However, the mean daily energy intake in the irregular meal pattern period was significantly different between the days (ANOVA, $P=0.0001$, Table 2), with energy intake being significantly higher with 9 meals/day compared with 3 ($P=0.0001$) and 6 ($P=0.001$) meals/day (Table 2). There was also a higher energy intake on the day with 6 meals compared with the day with 3 meals ($P=0.001$) during the irregular meal pattern. There was a trend for a higher percentage of total energy from carbohydrate with 9 meals ($P=0.065$) and 3 meals ($P=0.058$) compared with 6 meals/day during the irregular meal pattern. However, there was no significant difference in the percentage of protein and fat during that period.

Energy intake of the day with 9 meals in the irregular meal pattern period was significantly higher than the energy intake on the corresponding day of the regular meal pattern ($P=0.002$). On the day with 3 meals/day of the irregular meal pattern, there was also a trend for lower energy intake compared with the similar day of the regular meal pattern ($P=0.1$). On the other hand, there were no significant differences between the energy intake of the days with 6 meals/day in the regular and irregular meal pattern (Table 2).

Appetite measurement

The response curves for the four appetite sensations (hunger, satiety, fullness and desire to eat) are shown in Figure 1. Fasting values for all variables and the profiles after the test meal were not significantly different over the experiment.

Energy expenditure and substrate oxidation

RMR of the subjects was measured at each laboratory visit after an overnight fast (10 h). There was no significant difference between the fasting RMR values before and after the dietary interventions and no significant changes across

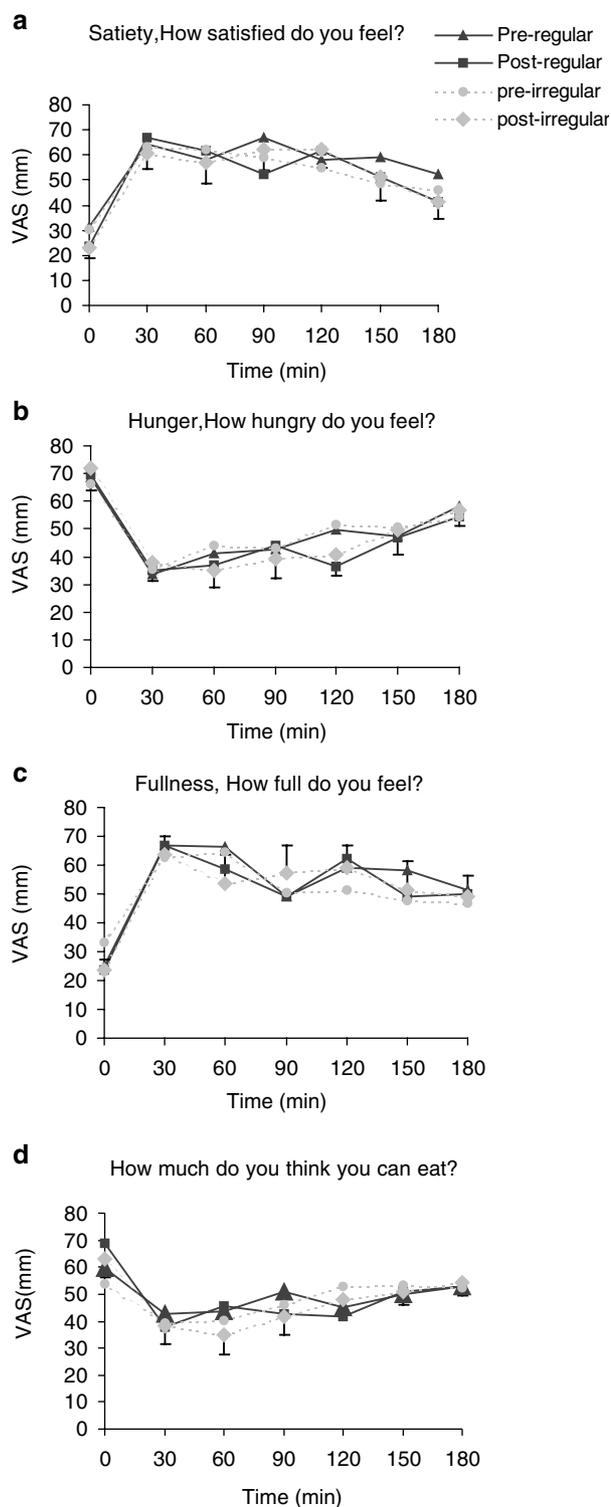


Figure 1 Mean (\pm s.e.m.) subjective appetite scores (satiety, a; hunger, b; fullness, c; and prospective food consumption, d) in nine healthy women before and after the test meal in the pre- and postregular and irregular meal patterns. For clarity only a few s.e.m. values are shown. No significant differences were observed (ANOVA).

either phase (ANOVA, Figure 2). The metabolic rate increased significantly above basal values after the test meal in all visits and there was a significant interaction in the PPMR responses (three-way ANOVA, $P=0.03$). PPMR showed no significant difference between the preintervention visits (Figure 2). However, PPMR was lower after the irregular meal pattern than before it, whereas after the regular meal pattern PPMR was higher than before it (Figure 2). Comparison of the TEF values obtained showed a significant interaction in the two-way ANOVA ($P=0.003$, Figure 3). There was no significant difference in the TEF values for the visits before the two intervention periods. However, TEF fell significantly after the irregular meal pattern ($P=0.02$) compared with a slight rise after the regular meal pattern. TEF was also significantly lower after the irregular meal pattern compared with after the regular ($P=0.04$).

Fasting RQ showed no significant differences over the experiment. RQ, however, increased significantly after the test meal in all visits.

No significant differences were observed in the postprandial RQ profiles over the study. Substrate oxidation also showed no significant differences over the two interventions (Table 3).

Discussion

The purpose of this study was to examine the effect of regular and irregular meal frequency on anthropometric measurements, food intake, energy expenditure and appetite ratings. No studies, to our knowledge, have considered this area especially in adults.

The present study does not show any significant differences either in body weight or in anthropometric measurements between the regular and irregular meal patterns. Thus, as one would have predicted, a 2-week intervention with relatively modest changes in energy intake and/or expenditure is not enough for any significant change in body weight and anthropometric measurements.

The present study shows no significant differences in total energy intake and in the macronutrient composition of the subjects' food between the regular and the irregular meal patterns. Subjects were asked to have 6 meals/day during the regular meal pattern period according to the dietary instructions. They were also asked to have the predetermined irregular meal frequency, 3–9 meals/day, with the average of 6 meals/day in the irregular meal pattern period. In this study, we clearly defined a meal as providing some energy, and the interval between the two consecutive meals was to be more than 1 h. Cyclic fluctuations have been reported in women's food intake across the menstrual cycle.^{44,45} To overcome this possible factor, the start of each interventional period was identical in terms of menstrual period. There was a trend of higher mean energy intake during the irregular meal pattern compared with the regular one. This indicates that these women on self-selected diets may have found it

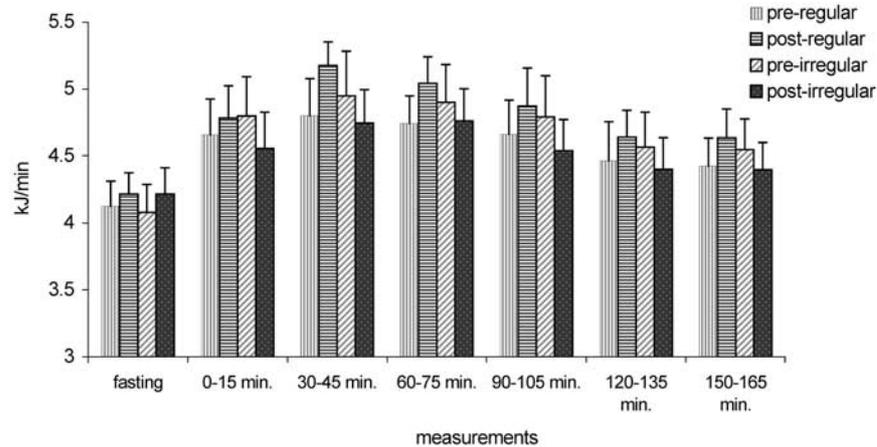


Figure 2 Mean energy expenditure in nine healthy women before and after the test meal in the pre- and postregular and irregular meal patterns. Subjects drank the milkshake test meal over 10 min. Time '0' refers to the end of the test meal consumption. Energy expenditure profiles were significantly different between the regular and irregular meal patterns ($P=0.03$). The premeal patterns profiles were similar, while the profile after the irregular meal pattern was flatter compared with after the regular meal pattern.

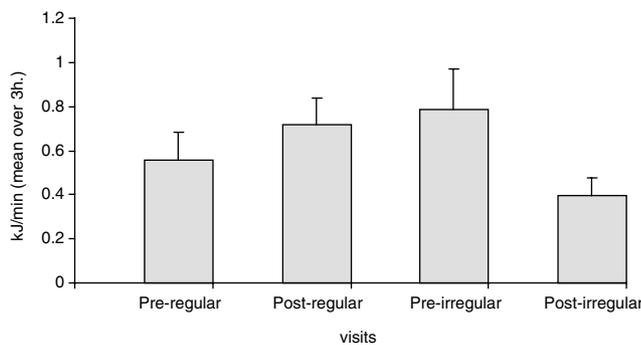


Figure 3 TEF in nine healthy women in the pre- and postregular and irregular meal patterns. There were significant differences between the two interventions ($P=0.003$, ANOVA).

more difficult to adjust to having an irregular meal frequency while maintaining their normal intake of food. There may also be some inaccuracy in extrapolating the energy intake record for 3 days to represent the entire 14-day intervention period. There was no significant difference in the mean energy intake of the 3 days of the regular meal pattern. However, a positive relationship between meal frequency and energy intake was observed during the irregular meal pattern period. This result could be in agreement with a previous study,¹⁸ but in contrast to others.^{19–22} A recent study²³ also reported no association between meal frequency and energy intake. The present study also shows no significant differences between the two meal patterns in the appetite ratings after the test meal. There is no study evaluating the effect of an irregular meal pattern on appetite rating in response to a test meal. A few experiments altered meal frequency during the experimental

day and showed a greater appetite control with a higher meal frequency in lean²⁴ and obese men.²⁵ However, these are not directly comparable to the present study.

We did not find any significant difference in fasting RMR across the four visits. As expected, a significant increase in the metabolic rate after the test meal was observed in all visits. However, there was a significant difference in the TEF after the two different eating patterns, with a lower response after the irregular meal pattern compared with the regular one. There was no significant difference in fasting and postprandial RQ and substrate oxidation. One might have expected reduced fat and/or carbohydrate oxidation in association with the reduced thermogenesis. However, interindividual variation in substrate utilisation and ignoring protein oxidation in producing these estimations may have contributed to the lack of difference. It is worth noting that numerically smaller postprandial values were observed after the irregular meal pattern.

In the present experiment, blood samples were also taken for the measurement of circulating glucose, lipids, insulin and uric acid concentrations before and for 3 h after the consumption of the test meal.⁴⁰ In summary, the results indicate that the irregular meal pattern for 14 days produced a significantly lower fasting insulin sensitivity (higher HOMA-IR) and greater insulin response to a test meal compared with the regular meal pattern. The irregular meal pattern also caused serum total and LDL cholesterol to be higher than the regular meal pattern.

It has previously been reported that impaired thermogenesis is associated with insulin resistance in obesity^{46,47} A further study⁴⁸ demonstrated an independent effect of insulin resistance and obesity in producing blunted TEFs. In the present study, the irregular meal pattern failed to produce any significant differences in body weight in spite of

Table 3 RQ and substrate oxidation (fasting and postprandial)

	Regular meal pattern				Irregular meal pattern			
	Preperiod visit		Postperiod visit		Preperiod visit		Postperiod visit	
	BL	Postprandial	BL	Postprandial	BL	Postprandial	BL	Postprandial
RQ	0.788	0.904	0.796	0.907	0.792	0.905	0.797	0.914
s.d.	0.023	0.017	0.017	0.025	0.022	0.019	0.018	0.031
CHO ^a	4.86	12.12	5.40	12.66	5.16	12.48	5.28	12.54
s.d.	0.48	0.90	0.54	1.80	0.42	1.08	0.72	1.86
Fat ^a	4.50	2.16	4.32	2.04	4.32	2.10	4.38	1.86
s.d.	0.54	0.36	0.48	0.54	0.72	0.42	0.78	0.72

^aUnit: g/h. BL = basal fasting, CHO = carbohydrate.

reduced dietary thermogenesis, but this was expected due to the short term of the intervention. However, insulin insensitivity and the reduced TEF resulting from the irregular meal pattern are in the agreement with the previous studies reporting the association between insulin resistance and blunted thermogenesis.

Many studies have evaluated the effect of stable meal frequency on energy expenditure. Evaluating the effect of meal frequency on the TEF has tended to produce contradictory results.^{29–32} The two longer studies (TEF for 10 h²⁹ and 6 h³⁰) reported no significant association between TEF and meal frequency. However, the other two more recent but shorter studies (TEF for 5 h³¹ and 4 h³²) found a significant effect of meal frequency on TEF. Tai *et al*³¹ recorded a greater TEF in lower meal frequency, while LeBlanc *et al*³² found the opposite results. Studies assessing the effect of meal frequency on total energy expenditure report no statistical association between these two factors.^{15,26–28} However, poor definition of the key variables hampers the interpretation and comparison of these previous studies.

The prevalence of obesity has increased in industrial countries in the last decades. At the same time, the opportunity to consume food irregularly has also increased due to accessibility of ready prepared foods, fast food outlets and differences in work patterns. It is believed that people appear to be moving away from a regular meal pattern to irregular meals,^{34,48,49} and recent Japanese studies reported that irregular snacking was more common in obese children compared with normal weight children.^{35–37} The results of the present study indicate a potential mechanism by which irregular meal pattern might impact on energy expenditure which could lead to weight gain in the longer term.

References

- Fabry P, Fodor J, Hejl Z, Braun T, Zvolankova K. The frequency of meals: its relation to overweight, hypercholesterolaemia, and decreased glucose tolerance. *Lancet* 1964; ii: 614–615.
- Fabry P, Fodor J, Hejl Z, Geizerova H, Balcarova O. Meal frequency and ischaemic heart-disease. *Lancet* 1968; 27: 190–191.
- Edelstein S, Barrett-Connor E, Wingard D, Cohn B. Increased meal frequency associated with decreased cholesterol concentrations; Rancho Bernardo, CA, 1984–1987. *Am J Clin Nutr* 1992; 55: 664–669.
- Kant A, Schatzkin A, Graubard B, Ballard-Barbash R. Frequency of eating occasions and weight change in the NHANES I Epidemiologic Follow-up Study. *Int J Obes Relat Metab Disord* 1995; 19: 468–474.
- Whybrow S, Kirk T. Nutrient intakes and snacking frequency in female students. *J Hum Nutr Diet* 1997; 10: 237–244.
- Drummond S, Crombie N, Cursiter M, Kirk T. Evidence that eating frequency is inversely related to body weight status in male, but not female, non-obese adults reporting valid dietary intakes. *Int J Obes Relat Metab Disord* 1998; 22: 105–112.
- Dreon D, Frey-Hewitt B, Ellsworth N, Williams P, Terry R, Wood P. Dietary fat: carbohydrate ratio and obesity in middle-aged men. *Am J Clin Nutr* 1988; 47: 995–1000.
- Bellisle F, Rolland-Cachera M, Deheeger M, Guillaud-Bataille M. Obesity and food intake in children: evidence for a role of metabolic and/or behavioral daily rhythms. *Appetite* 1988; 11: 111–118.
- Ruxton C, Kirk T, Belton N. The contribution of specific dietary patterns to energy and nutrient intakes in 7–8-year-old Scottish schoolchildren. 2. Weekday lunches. *J Hum Nutr Diet* 1996; 9: 15–22.
- Anderson I, Rossner S. Meal patterns in obese and normal weight men: the 'Gustaf' Study. *Eur J Clin Nutr* 1996; 50: 639–646.
- Summerbell C, Moody R, Shanks J, Stock M, Geissler C. Relationship between feeding pattern and body mass index in 220 free-living people in four age groups. *Eur J Clin Nutr* 1996; 50: 513–519.
- Crawley H, Summerbell C. Feeding frequency and BMI among teenagers aged 16–17 years. *Int J Obes Relat Metab Disord* 1997; 21: 159–161.
- Fábry P, Hejda S, Cerný K, Osancová K, Pechar J. Effect of meal frequency in schoolchildren. Changes in weight-height proportion and skinfold thickness. *Am J Clin Nutr* 1966; 18: 358–361.
- Wadhwa P, Young E, Schmidt K, Elson C, Pringle D. Metabolic consequences of feeding frequency in man. *Am J Clin Nutr* 1973; 26: 823–830.
- Dallosso H, Murgatroyd P, James W. Feeding frequency and energy balance in adult males. *Hum Nutr Clin Nutr* 1982; 36C: 25–39.
- Jenkins D, Wolever T, Vuksan V, Brighenti F, Cunnane S, Rao A, Jenkins A, Buckley G, Patten R, Singer W, Corey P, Josse RG. Nibbling versus gorging: metabolic advantages of increased meal frequency. *N Engl J Med* 1989; 5: 929–934.
- Arnold L, Ball M, Duncan A, Mann J. Effect of isoenergetic intake of three or nine meals on plasma lipoproteins and glucose metabolism. *Am J Clin Nutr* 1993; 57: 446–451.

- 18 Basdevant A, Craplet C, Guy-Grand B. Snacking patterns in obese French women. *Appetite* 1993; **21**: 17–23.
- 19 Yates H, Crombie N, Kirk T. Energy intake compensation during snacking intervention—a pilot study. *Nutr Food Sci* 1998; **98**: 267–271.
- 20 Westerterp-Plantenga MS, Wijckmans-Duysens NA, Hoor FT. Food intake in the daily environment after energy-reduced lunch, related to habitual meal frequency. *Appetite* 1994; **22**: 173–182.
- 21 Westerterp-Plantenga M, Kovacs EM, Melanson KJ. Habitual meal frequency and energy intake regulation in partially temporally isolated men. *Int J Obes Relat Metab Disord* 2002; **26**: 102–110.
- 22 Johnstone A, Shannon E, Whybrow S, Reid C, Stubbs R. Altering the temporal distribution of energy intake with isoenergetically dense foods given as snacks does not affect total daily energy intake in normal-weight men. *Br J Nutr* 2000; **83**: 7–14.
- 23 Taylor M, Garrow J. Compared with nibbling, neither gorging nor a morning fast affect short-term energy balance in obese patients in a chamber calorimeter. *Int J Obes Relat Metab Disord* 2001; **25**: 519–528.
- 24 Speechly D, Buffenstein R. Greater appetite control associated with an increased frequency of eating in lean males. *Appetite* 1999; **33**: 285–297.
- 25 Speechly D, Rogers G, Buffenstein R. Acute appetite reduction associated with an increased frequency of eating in obese males. *Int J Obes Relat Metab Disord* 1999; **23**: 1151–1159.
- 26 Wolfram G, Kirchgessner M, Muller H, Hollomey S. Thermogenesis in humans after varying meal time frequency. *Ann Nutr Metab* 1987; **31**: 88–97.
- 27 Verboeket-van de Venne W, Westerterp K. Influence of the feeding frequency on nutrient utilization in man: consequences for energy metabolism. *Eur J Clin Nutr* 1991; **45**: 161–169.
- 28 Verboeket-van de Venne W, Westerterp K, Kester A. Effect of the pattern of food intake on human energy metabolism. *Br J Nutr* 1993; **70**: 103–115.
- 29 Belko A, Barbieri T. Effect of meal size and frequency on the thermic effect of food. *Nutr Res* 1987; **7**: 237–242.
- 30 Kinabo J, Durnin J. Effect of meal frequency on the thermic effect of food in women. *Eur J Clin Nutr* 1990; **44**: 389–395.
- 31 Tai M, Castillo P, Pi-Sunyer F. Meal size and frequency: effect on the thermic effect of food. *Am J Clin Nutr* 1991; **54**: 783–787.
- 32 LeBlanc J, Mercier I, Nadeau A. Components of postprandial thermogenesis in relation to meal frequency in humans. *Can J Physiol Pharmacol* 1993; **71**: 879–883.
- 33 Høglund D, Samuelson G, Mark A. Food habits in Swedish adolescents in relation to socioeconomic conditions. *Eur J Clin Nutr* 1998; **52**: 784–789.
- 34 Samuelson G. Dietary habits and nutritional status in adolescents over Europe. An overview of current studies in the Nordic countries. *Eur J Clin Nutr* 2000; **54**: S21–S28.
- 35 Kagamimori S, Yamagami T, Sokejima S, Numata N, Handa K, Nanri S, Saito T, Tokui N, Yoshimura T, Yoshida K. The relationship between lifestyle, social characteristics and obesity in 3-year-old Japanese children. *Child Care Health Dev* 1999; **25**: 235–247.
- 36 Takahashi E, Yoshida K, Sugimori H, Miyakawa M, Izuno T, Yamagami T, Kagamimori S. Influence factors on the development of obesity in 3-year-old children based on the Toyama study. *Prev Med* 1999; **28**: 293–296.
- 37 Murata M. Secular trends in growth and changes in eating patterns of Japanese children. *Am J Clin Nutr* 2000; **72**: 1379S–1383S.
- 38 Garner D, Garfinkel P. The Eating Attitudes Test: an index of the symptoms of anorexia nervosa. *Psychol Med* 1979; **9**: 273–279.
- 39 Beck A. *Depression Inventory—Clinical, Experimental, and Theoretical Aspects*. Staples Press: London; 1969. pp 333–335.
- 40 Farshchi H, Taylor M, Macdonald I. Regular meal frequency creates more appropriate insulin sensitivity and lipid profiles compared with irregular meal frequency in healthy lean women. *Eur J Clin Nutr* 2004. (in press).
- 41 Garrow J. *Human Nutrition and Dietetics*, 10 edn. Churchill Livingstone: London; 2000.
- 42 Flint A, Raben A, Blundell J, Astrup A. Reproducibility, power and validity of visual analogue scales in assessment of appetite sensations in single test meal studies. *Int J Obes Relat Metab Disord* 2000; **24**: 38–48.
- 43 Frayn K. Calculation of substrate oxidation rates *in vivo* from gaseous exchange. *J Appl Physiol* 1983; **55**: 628–634.
- 44 Bowen D, Grunberg N. Variations in food preference and consumption across the menstrual cycle. *Physiol Behav* 1990; **47**: 287–291.
- 45 Buffenstein R, Poppitt S, McDevitt R, Prentice A. Food intake and the menstrual cycle: a retrospective analysis, with implications for appetite research. *Physiol Behav* 1995; **58**: 1067–1077.
- 46 Ravussin E, Bogardus C, Schwartz RS, Robbins DC, Wolfe RR, Horton ES, Danforth Jr E, Sims EA. Thermic effect of infused glucose and insulin in man. Decreased response with increased insulin resistance in obesity and noninsulin-dependent diabetes mellitus. *J Clin Invest* 1983; **72**: 893–902.
- 47 Ravussin E, Acheson K, Vernet O, Danforth E, Jequier E. Evidence that insulin resistance is responsible for the decreased thermic effect of glucose in human obesity. *J Clin Invest* 1985; **76**: 1268–1273.
- 48 Segal K, Albu J, Chun A, Edano A, Legaspi B, Pi-Sunyer F. Independent effects of obesity and insulin resistance on postprandial thermogenesis in men. *J Clin Invest* 1992; **89**: 824–833.
- 49 Lennernas M, Andersson I. Food-based classification of eating episodes (FBCE). *Appetite* 1999; **32**: 53–65.