Fatty acid chain length, postprandial satiety and food intake in lean men

S.D. Poppitt [a,b,*], C.M. Strik [a], A.K.H. MacGibbon [e], B.H. McArdle [d], S.C. Budgett [d], A.-T. McGill [a,c]

[a] Human Nutrition Unit, University of Auckland, Auckland, New Zealand
[b] School of Biological Sciences, University of Auckland, Auckland, New Zealand
[c] School of Public Health, University of Auckland, Auckland, New Zealand
[d] Department of Statistics, University of Auckland, Auckland, New Zealand
[e] Fonterra Research Centre, Palmerston North, New Zealand

ARTICLE INFO

ABSTRACT

High-fat diets are associated with obesity, and the weak satiety response elicited in response to dietary lipids is likely to play a role. Preliminary evidence from studies of medium (MCT) and long chain triglycerides (LCT) supports greater appetite suppression on high-MCT diets, possibly a consequence of direct portal access, more rapid oxidation and muted lipaemia. No data is as yet available on high-SCT diets which also have direct hepatic access. In this study SCT- (dairy fats), MCT- (coconut oil) and LCT-enriched (beef tallow) test breakfasts (3.3 MJ) containing 52 g lipid (58 en% fat) were investigated in a randomized, cross-over study in 18 lean men. All participants were required to complete the 3 study days in randomised order. Participants rated appetite sensations using visual analogue scales (VAS), and energy intake (EI) was measured by covert weighing of an *ad libitum* lunch meal 3.5 h postprandially. Blood samples were collected by venous cannulation. There were no detectable differences between breakfasts in perceived pleasantness, visual appearance, smell, taste, aftertaste and palatability ($P>0.05$). There was no significant effect of fatty acid chain length on ratings of hunger, fullness, satisfaction or current thoughts of food, nor did energy (mean, sem: SCT: 4406, 366 kJ; MCT: 4422, 306 kJ; LCT: 4490, 324 kJ; $P>0.05$) or macronutrient intake at lunch differ between diets. The maximum difference in EI between diets was less than 2%. Postprandial lipaemia also did not differ significantly. We conclude that there was no evidence that fatty acid chain length has an effect on measures of appetite and food intake when assessed following a single high-fat test meal in lean participants.

1. Introduction

Whilst lipids are commonly associated with poor satiety and weight gain, there is some evidence of a hierarchy within the group. Physicochemical properties such as fatty acid saturation [1], chain length [2], and lipid emulsification [3–5] may all contribute although there is little consensus as to the relative role each may play in controlling intake [6–8].

Medium (MCT) and short chain triglycerides (SCT) are relatively minor components of the typical western diet but substitution for abundant long chain triglycerides (LCT) would be warranted if preliminary findings of enhanced satiety were confirmed. MCTs are commonly used in clinical nutrition since rapid hydrolysis, ready absorption and muted lipaemia [9,10] makes them ideal for enteral therapies. It has long been hypothesised that MCTs may be more satiating than LCTs due to increased oxidative capacity [2,11]. MCTs

undergo nearly complete hydrolysis to free fatty acids (FFA), are absorbed directly into the portal vein and transported rapidly to the liver for β-oxidation, in contrast to LCTs which are more slowly absorbed via the intestinal lymphatic ducts and transported by chylomicrons into the systemic circulation prior to oxidation or storage [12,13]. The proposal that altering fat oxidation can in turn alter food intake arose from early rodent studies where inhibition of oxidation through blockade of the enzyme which transfers fatty acids from cytoplasm to mitochondria, carnitine palmitoyltransferase I (CPT-I), caused an increase in energy intake (EI) [11]. *Ex vivo* studies of medium chain fatty acids (MCFA) have shown the rate of degradation to CO_2 to be 10 fold faster than LCFA [14], and animal studies have also shown food intake to decrease on a high-MCT diet [15]. Results from the few clinical studies to date however remain inconclusive. Studies in lean men have shown EI to be lower when MCTs are covertly increased in both short postprandial [16,17] and longer term manipulations [2] whilst other studies have failed to show an effect on intake of either single meal [18] or longer term [19] MCT supplementation. Interestingly more recent studies have shown enhanced weight and adipose loss on high-MCT [13,20,21] and high structured-MCT/LCT (transesterified) diets [22,23], although whether

* Corresponding author. SD Poppitt, University of Auckland Human Nutrition Unit, 18 Carrick Place, Mount Eden, Auckland 1024, New Zealand. Tel.: +64 96305160; fax: +64 96305764.
E-mail address: s.poppitt@auckland.ac.nz (S.D. Poppitt).

this is a consequence of restricted intake or increased expenditure is uncertain [19,24]. Certainly there is growing evidence for heightened fat oxidation and energy expenditure as a driver of weight loss when the MCT content of the diet is increased [25].

SCT are present in the diet at lower levels than either LCT or MCT. They are found mainly in bovine dairy, in foods such as butter fat for which much of the characteristic 'buttery' taste is attributed to the release of SCFA from the triglyceride (TAG) moiety. Importantly, SCT are also absorbed directly into the portal vein, transported rapidly to the liver for β-oxidation and this enhanced oxidative capacity may in turn suppress food intake. To our knowledge, no studies to date have investigated the effect of rapidly oxidized SCT on satiety and energy intake.

In light of the effects of MCT on body weight, the conflicting data on appetite suppression and the absence of any studies of SCT in either clinical or animal models we wanted to determine whether a meal supplemented with SCT and MCT altered postprandial satiety and subsequent food intake when compared with an isoenergetic high-LCT meal. We hypothesized that differences in uptake and metabolism of SCT, MCT and LCT may be reflected by muted peripheral lipaemia and enhanced postprandial satiety following the SCT and MCT supplemented meals.

2. Participants and methods

2.1. Participants

The participants were young, lean men with a mean age of 27.2 (9.3 sd) years and mean BMI of 22.8 (1.8 sd) kg/m^2 (Table 1). They were recruited into this trial through poster, newspaper and electronic advertisement and were from the local community including local tertiary institutions. Exclusion criteria were current (BMI>25 kg/m^2) or self-reported previous history of overweight or obesity, current energy restriction program (dieting), eating disorders, smoking, hypertension, cardiovascular disease, diabetes mellitus (type I or II) or history of any significant metabolic, endocrine or gastrointestinal disease. Lipid profile, hematology, liver function and blood glucose levels were measured during the screening procedures to ensure normal values. None of the participants were taking medications known to affect appetite or weight regulation. Written consent was obtained from each of the participants. Ethical approval for this study was obtained from the Northern Regional Ethics Committee, Auckland, New Zealand.

2.2. Study design

This was a repeat measures, cross-over study where the effects of 3 high-fat test breakfasts supplemented with LCT (tallow), MCT

Table 1
Participants' characteristics at baseline.

	Mean	SD
n	18	
Age (years)	27.2	9.3
Body weight (kg)	73.4	10.0
BMI (kg/m^2)	22.8	1.8
Waist circumference (cm)	77.2	5.4
Glucose (mmol/L)	4.7	0.4
TC (mmol/L)	4.1	0.7
HDL-C (mmol/L)	1.6	0.3
LDL-C (mmol/L)	2.1	0.6
TAG (mmol/L)	0.9	0.4
SBP (mm Hg)	117.1	10.0
DBP (mm Hg)	66.6	7.4

Mean (SD). BMI, body mass index; TC, total cholesterol; HDL-C, high density lipoprotein cholesterol; LDL-C, low density lipoprotein cholesterol; TAG, triglyceride; SBP, systolic blood pressure; DBP, diastolic blood pressure.
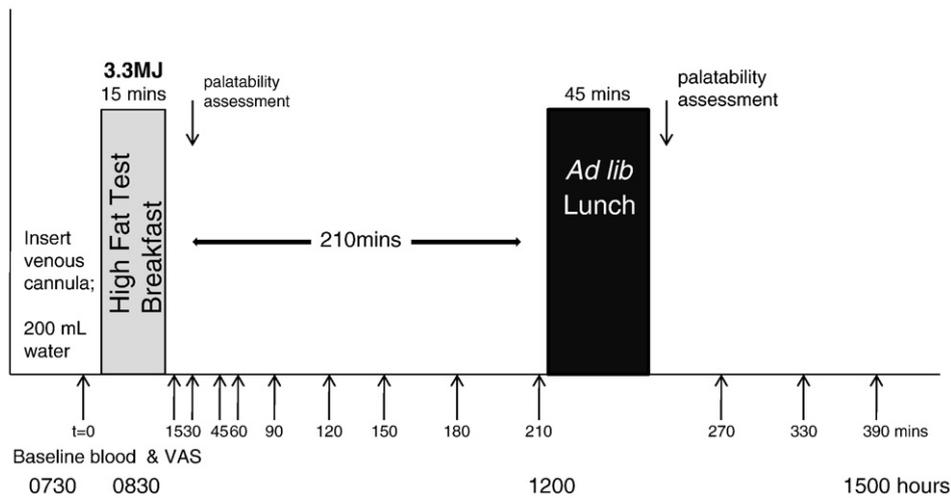
(coconut oil) or SCT (soft fraction milk fat) were assessed through subjective visual analogue scales (VAS) and *ad libitum* EI at a single lunch meal. The study was covert, hence the primary objective of measurement of food intake at the outcome lunch meal was not revealed to the participants prior to the study.

2.3. Procedures

All participants were required to attend the Human Nutrition Unit (HNU) at the University of Auckland on 3 separate occasions. Between study days, participants returned home for a washout period of at least 4 days during which they were asked to resume their habitual diet and exercise pattern, and also to abstain from alcohol and strenuous physical activity for 24 h prior to the clinic visit.

Participants arrived at HNU at 0730 h having fasted from 2000 h the previous evening. At each visit body weight (Seca, Model 708, Germany) and waist circumference (recorded to the nearest 0.1 cm midway between the last rib and the crest of the ileum at the natural point of waist narrowing using a non stretch tape measure) were measured whilst the participant was lightly clad. Any adverse events and/or changes in medications were recorded. Height was measured on a single occasion at the screening visit (Seca, Model 222, Germany). Participants were then given 200 ml of water to drink and an indwelling venous cannula was inserted. At 0800 baseline VAS rating subjective feelings of hunger, fullness, satisfaction and current thoughts of food [26] were completed and a baseline blood sample collected. Nausea was also assessed using VAS. The Protocol is shown in Fig. 1. The high-fat test breakfast was served at 0830 h which participants were asked to consume in full within 15 min. No further foods were allowed during the morning. A buffet-style lunch meal with a limited choice of both hot and cold items was served at 1200 h, 210 min after the breakfast, to assess *ad lib* energy and macronutrient intake. Lunch was served individually in a quiet dining room with minimal distractions. VAS ratings were measured and blood samples collected throughout the morning and for 2 h after completion of the *ad lib* lunch. All measurements of food intake were covert. Participants remained at the HNU throughout each study-day. Activities throughout the day were carefully controlled and monitored with the intent of ensuring a highly repeatable, sedentary day on each of the 3 occasions. Upon arrival at the Unit participants were settled on to a clinic bed in a private room and were required to remain either sitting or lying quietly on the bed until the *ad lib* lunch was served at 1200 h. During this period, other than for bathroom trips, they were required to remain sedentary and allowed to read, write, watch TV/DVDs or work quietly on a laptop computer. Participants were not allowed to sleep at any time during the study day.

2.4. High-fat test breakfasts

The 3 high-fat breakfasts were matched for total fat content (52 g, 58 en% fat) and were isoenergetic (3.3 MJ). They comprised two savoury muffins which were served with 300 ml water on each occasion. The diets differed in fatty acid composition and were (i) high-LCT (from tallow), (ii) high-MCT (from coconut oil) and (iii) high-SCT (from soft fraction milk fat). The energy and macronutrient composition of each of the 3 test breakfasts were calculated using the dietary program FoodWorks™ (Professional Edition, Version 2.10.136, 1998–2000; Xyris Software) and are shown in Table 2.

2.5. Visual Analogue Scales (VAS)

Ratings were recorded by placing a vertical line on to 100 mm scales, anchored at either end by statements; "I am not hungry/I am not full at all/I am completely empty/nothing at all" on the left and "I am as hungry I have ever been/I am totally full/I cannot eat another bite/a large amount" on the right. VAS ratings of nausea were also

Fig. 1. Daily protocol for the study.

measured as an outcome. How thirsty, energetic and relaxed the participants felt were also included as a distraction from the main outcomes. VAS were completed prior to the test meal and 15, 30, 45, 60, 90, 120, 150, 180, 210, [ad lib lunch], 270, 330 and 390 min after the subject began consumption of the test breakfast. Blood samples were collected immediately prior to the VAS measurements at intervals throughout the morning. Immediately after the breakfast test meal on each occasion, the participants also rated the pleasantness, visual appeal, smell, taste, aftertaste and overall palatability of the high-fat meal on separate 100-mm VAS. Each question was anchored on the left hand side with not at all pleasant/poor visual appeal/bad smell/bad taste/high aftertaste/bad palatability.

2.6. Ad libitum lunch

The *ad libitum* lunch consisted of a buffet-style meal with a limited choice of both hot and cold items, served in excess. In an attempt to avoid over-consumption the variation of meal items offered was restricted. Participants were advised that they could eat as much or as little as they chose and that they were to remain in the room for a period of 45 min. The items presented at the *ad lib* buffet meal, along with their serving weight, energy and macronutrient contents are shown in Table 3. Each item was served in excess. Covert weighing of each meal item was carried out before and after lunch to allow calculation of energy and macronutrient intake. Energy and macro-

nutrient content of foods consumed at the *ad lib* lunch were calculated using the dietary program FoodWorks (Professional Edition Version 2.10.136 1998–2000; Xyris Software).

2.7. Serum parameters

Blood samples were collected by venous cannulation throughout the morning at baseline (0), and at 30, 60, 120 and 180 min after the test breakfast. Samples were analysed for total TAG, glucose and insulin concentrations using standard laboratory methods.

2.8. Statistical analysis

Energy (MJ), macronutrient intake (g) and the weight (g) of the food consumed at the *ad libitum* lunch were analysed using the dietary program FoodWorks (Professional Edition Version 2.10.136 1998–2000; Xyris Software). Single factor ANOVA (Microsoft Office Excel, 2003) was also used to identify whether there were changes in body weight, BMI or waist circumference over the duration of the study. VAS data were analysed using a repeated measures Linear Mixed Model ANOVA (SAS: PROC MIXED, SAS version 8.0, SAS

Table 2
Energy and macronutrient composition of the 3 high-fat breakfast test meals.

	SCT	MCT	LCT
Weight (g)	234	234	234
Energy (kJ)	3315	3315	3315
Fat (% of energy)	58	58	58
Fat (g)	52	52	52
SCT (g)	3	0	0
MCT (g)	7	10	0.1
SCT + MCT (g)	10	10	0.1
LCT (g)	42	42	52
SCT (% of total fat)	6	0	0
MCT (% of total fat)	14	20	0.2
LCT (% of total fat)	80	80	100
Protein (% of energy)	10	10	10
Protein (g)	19	19	19
Carbohydrate (% of energy)	33	33	33
Carbohydrate (g)	64	64	64

SCT, short chain triglyceride; MCT, medium chain triglyceride; LCT, long chain triglyceride.

Table 3
Energy content and macronutrient composition of foods offered at the *ad libitum* lunch meal.

| Menu items	Portion size (g)	Energy (kJ)	Protein (g)	Fat (g)	CHO (g)
Fried rice	1600	4621	39	30	167
Bread, light rye, 1/4 slices	168	1781	13	3	62
Bread, white sliced, 1/4 slices	168	1814	14	3	84
Chicken breast, roasted, shredded	190	1170	48	10	0
Ham, smoked, slices	190	888	30	4	13
Capsicum, red and green, slices	68	72	1	1	3
Tomato, raw, slices	127	86	1	0.3	3
Spiced apple and fruit loaf	400	5620	20	45	212
Peaches, tinned in fruit juice, slices, drained	820	1476	4	1	78
Butter	250	6457	3	175	4
Mayonnaise	250	3675	2	77	45
Soy sauce	300	297	3	0	15
Milk, full fat	1000	2550	31	33	47
Bottled water	1500	0	0	0	0
Boiled water for decaff tea/coffee	1000	0	0	0	0

CHO, carbohydrate.
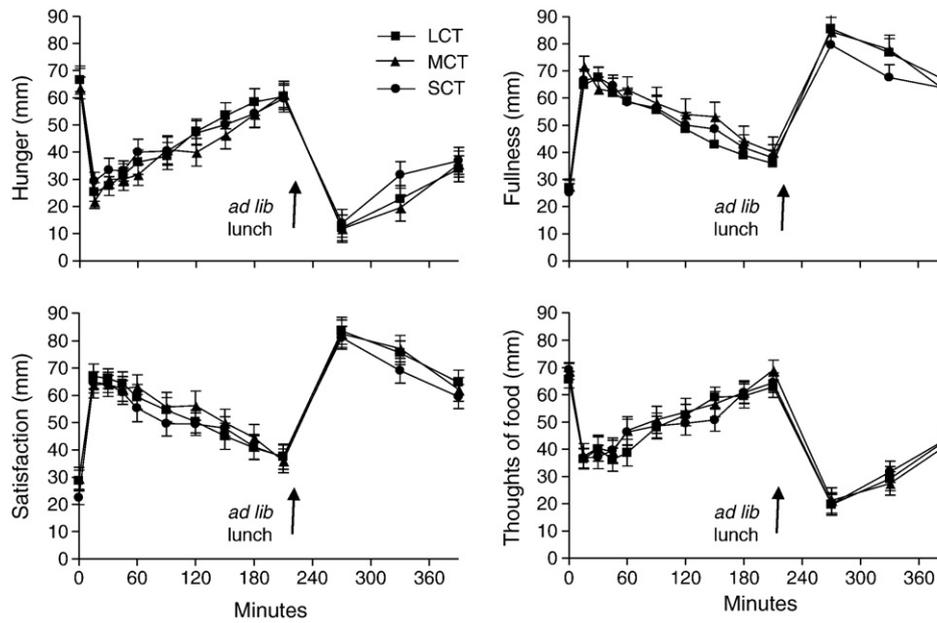
Fig. 2. Mean (sem) visual analogue scale (VAS) scores for hunger, fullness, satisfaction and current thoughts of food following the 3 high-fat test breakfasts. The *ad libitum* lunch was served 210 min after the test breakfast. LCT, long chain triglyceride; MCT, medium chain triglyceride; SCT, short chain triglyceride.

Institute Inc, Cary, NC, 2001). The subject, the test meal (condition), the study period (time), and the study day (visit number) were included in the procedure, as was the diet/time interaction which addressed whether the trajectory over time following the test meal

differed between diets (diet*time). Repeat measures analyses of VAS were performed over the 3.5 h ($VAS_{0-3.5 h}$) and 6 h ($VAS_{0-6 h}$) period following the test breakfast, as were the blood parameters. *Ad libitum* lunch data was analysed using univariate ANOVA (SAS: PROC MIXED,
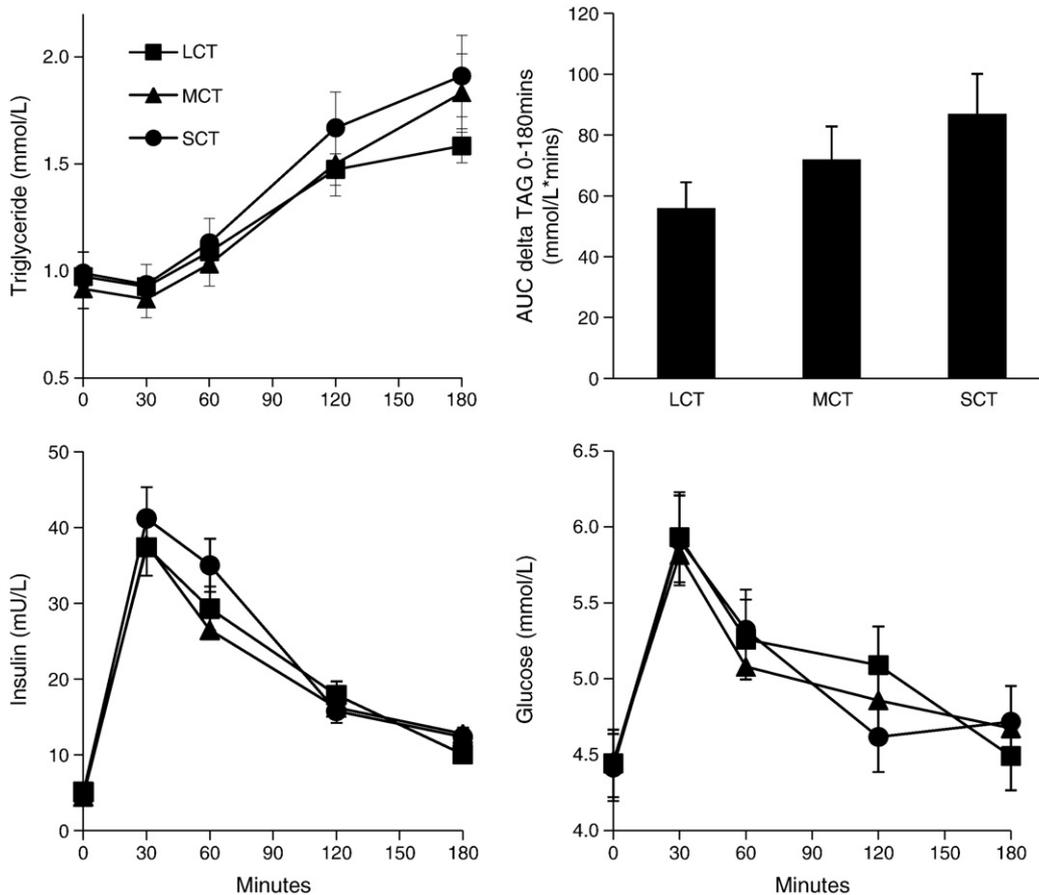

Fig. 3. Change in blood parameters during the 180 min following the 3 high-fat test breakfasts. LCT, long chain triglyceride; MCT, medium chain triglyceride; SCT, short chain triglyceride.

SAS version 8.0, SAS Institute Inc, Cary, NC, 2001). Statistical significance was based on 95% limits ($P<0.05$).

3. Results

Eighteen healthy male participants were randomized into this study, all of whom completed each of the 3 preload study days.

3.1. Visual Analogue Scales

There were no significant differences in VAS ratings of pleasantness, visual appearance, smell, taste, aftertaste or palatability between the 3 high-fat test breakfasts when assessed immediately after each breakfast meal (diet, $P>0.05$). Pleasantness of the muffins was rated as moderate-high for all 3 diets (mean, sem, LCT: 59, 5 mm; MCT: 55, 5 mm; SCT: 57, 5 mm) and there was no evidence of nausea following any of these high-fat breakfasts when calculated as an increase above fasting baseline values 30 min postprandially (mean, sem; LCT: 0.1, 0.1; MCT: −6.3, 0.2; SCT: 0.4, 0.1 mm). Fig. 2 shows the mean ratings for VAS-rated hunger, fullness, satisfaction and current thoughts of food following the test breakfast for the high-LCT, high-MCT and high-SCT diets. Hunger significantly decreased (time, $P<0.05$) and fullness significantly increased (time, $P<0.05$) on all study days immediately following consumption of the high-fat breakfast. However, there was no significant difference in ratings of hunger, fullness, satisfaction or thoughts of food between any of the 3 lipids when compared over either 3.5 h (VAS$_{0–3.5 h}$; 0–210 min, diet*time, $P>0.05$), or 6 h (VAS$_{0–6 h}$; 0–390 min, diet*time, $P>0.05$).

3.2. Serum parameters

Fasting levels of circulating TAG were similar between each study day at baseline ($P>0.05$) and consumption of the high-fat breakfast lead to a gradual increase over 180 min for all diets (Fig. 3, top left panel, time, $P<0.01$). Appearance of TAG into venous circulation from the breakfast was gradual. There was no appearance of TAG of dietary origin at 30 min postprandially following any of the lipids, but by 60 min concentrations had begun to increase following all 3 high-fat breakfasts. Over 3 h both the high-SCT and high-MCT breakfasts tended to increase circulating TAG above that of the high-LCT meal (Fig. 3, top right panel) but the increase was not significant at any of the time points measured in this group of 18 lean individuals ($P>0.05$). There was no differential glucose or insulin response to any of the 3 diets. As expected the breakfast meal induced a rapid increase in both glucose and insulin following SCT, MCT and LCT meals (time, $P<0.01$), and levels had returned to close to baseline 180 min later (see Fig. 3, bottom panels).

3.3. Energy intake at ad libitum lunch

When all diets were combined, energy consumed at the ad lib lunch was significantly associated with VAS-assessed hunger and fullness measured 180 min after the breakfasts (Fig. 4). Increased hunger and decreased fullness were both associated with a higher ad lib intake. There was however no significant difference in EI between the lipids at the lunch meal (diet, $P>0.05$). Mean (sem) EI was 4490 (324) kJ, 4422 (306) kJ and 4406 (366) kJ following the LCT-, MCT- and SCT-rich breakfasts respectively. The maximum difference in EI between diets was less than 2%, and there was no evidence of a lower
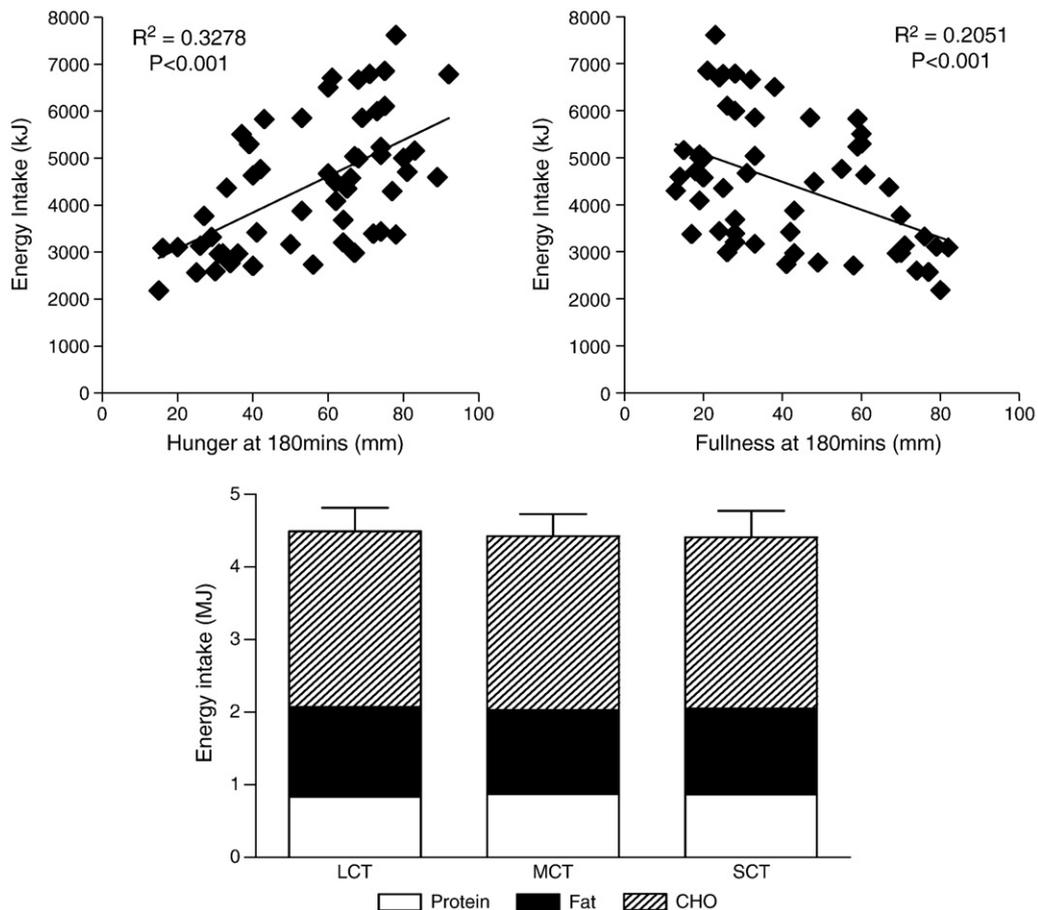

Fig. 4. Correlation between energy intake, hunger (top left panel) and fullness (top right panel) at 180 min postprandially for all diets, and mean (sem) energy and macronutrient intake at the ad libitum lunch meal (bottom panel). LCT, long chain triglyceride; MCT, medium chain triglyceride; SCT, short chain triglyceride.

intake following either SCT or MCT when compared with the LCT-rich breakfast. Based on a total energy expenditure of 1.4× predicted BMR, EI at the lunch meal represented approximately one third of daily energy intake. When macronutrient intake was compared between diets there was also no significant difference in carbohydrate, protein or fat intake at the free choice *ad lib* buffet meal. The weight of food eaten (1043 g, 1096 g, 1104 g) was also similar between diets.

4. Discussion

We hypothesized that differential treatment of lipids during digestion and absorption, and subsequent effects on β-oxidation shown in previous studies (25,27) would be reflected by a greater satiety response when SCT and MCT were included in a high-fat breakfast meal. There was however no evidence from our study that meals enriched with SCT or MCT had a greater appetite suppressing effect than LCT-enriched diets when the acute postprandial response to a high-fat meal was assessed in lean men.

During digestion of fats, the TAG component is hydrolysed in the mouth, stomach and upper small intestine by lingual, gastric and pancreatic lipases, typically in the case of LCT only partially to release two FFAs and an sn-2 monoglyceride [28–31] which later are resynthesised, form chylomicrons and circulate peripherally as TAG-rich lipoproteins (TRL). Higher enzyme activity for SCT and MCT leads to different metabolic pathways and, in contrast to LCT, shorter chain TAGs tend to be completely hydrolysed to FFAs, more rapidly absorbed and transported directly to the liver via the portal vein for rapid oxidation [12,28–31]. The direct hepatic access and increased oxidative capacity has been proposed as a mechanism which may drive heightened satiety and decreased food intake [11]. Whilst the ~3 MJ breakfast clearly caused changes in postprandial hunger and fullness following each of the 3 meals, and the trajectory of these changes was consistent and reproducible following each test breakfast, there was no evidence in support of the hypothesis that high-SCT and MCT meals induced greater feelings of satiety than an isoenergetic, fat-matched LCT meal. Nor that SCT or MCT- enriched breakfasts decreased either the weight of food or energy consumed at a subsequent *ad lib* buffet lunch meal when compared to the LCT-enriched breakfast. Energy intake was on average 4.5 MJ across each of the 3 test days, equivalent to ~35% of the total daily intake in these lean men, with no marked overconsumption in any of the participants at the lunch meal.

One issue for consideration may be whether the dose of SCT and MCT in this study was sufficient to induce changes in subjective satiety or eating behaviour. SCTs are present in a typical western diet in only small quantities, found in products such as dairy, and our current study was limited in the gram quantities of SCT that could be successfully incorporated into the test meal. SCFAs have characteristically unpleasant sensory properties which limit their intake, hence the relatively low 3 g dose administered. In both the high-SCT and high-MCT breakfasts 10 g of LCT was replaced with non-long chain fats. In the SCT breakfast this comprised 3 g SCT plus 7 g MCT, whilst in the MCT breakfast this comprised 10 g MCT only. Certainly these low doses of SCT and MCT did not drive significant suppression of postprandial lipaemia relative to the matched LCT diet, rather there was an unexpected trend towards an increase in the area under the curve (AUC) for serum TAG during the 3 h following the high-SCT and MCT breakfasts. Similar low dose studies have previously shown suppression in peripheral TAG levels over a 6 h postprandial period following 10 g MCT administration, although with greater effects in overweight compared with lean participants [10]. Low dose interventions of MCT have however been reported as successful in achieving weight loss. For example studies from the same laboratory of Aoyama et al. [13] showed significant reduction in body weight, body fat and abdominal subcutaneous fat in overweight individuals given a 10 g daily dose of MCT vs. LCT for a period of 12 weeks [13].

Whilst there is growing evidence that high MCT diets may aid weight loss, the predominance of studies do appear to support a mechanism of increased expenditure rather than decreased intake [18,24,25], and certainly in our current acute study no differential postprandial effects on appetite were seen. This concurs with previous studies which also failed to show significant effects of MCT on acute postprandial satiety when given to lean subjects as a single test meal [18] and to overweight subjects as part of a longer 4 week study [19]. Conversely MCT has been shown to improve both satiety ratings and decrease food intake in both acute postprandial studies [16,17] and in a 3 day fully *ad lib* free feeding study which carefully matched high-MCT and LCT diets in a covert manipulation [2]. Increased weight and adipose loss reported in longer term studies giving a variety of MCT supplemented diets [13,20–23] continues the debate as to whether this may be a result of decreased intake or increased expenditure [19,24]. Evidence for enhanced expenditure comes from studies such as that by Kasai et al. [10] in a Japanese population which reported increased DIT when low dose MCT (5–10 g) was incorporated into common food items [23], and St Onge and Jones [25] in a high dose MCT supplementation study in an overweight Canadian population [25].

In light of the null outcome of our current trial it is important to review the methods employed. Certainly there are a wide range of published methodologies used to assess short-term appetite regulation. Whilst consensus on best practice is yet to be established a recent ILSI publication reviewed the assessment of appetite control and drafted guidance on good practice for appetite research [32]. Recommendations for single day preload studies to which our trial adhered included using a within-subject repeat measures design; presentation of subjects with precisely prepared foods matched for taste, appearance and other organoleptic properties established prior to the trial initiation through pre-testing; matching for energy content, macronutrient composition, energy density, physical state (solid vs. liquid), weight or volume; the use of real time experiments such that the foods offered are appropriate for the time of day at which they are presented; and the use of a covert (to assess physiological response to the preload) or overt (to assess both physiological and cognitive responses) study design depending on the hypothesis to be tested. Conversely the committee recommended trials to be double rather than single blind where possible, and the use of 'no energy' or other control arms in the trial. Issues critical to the design of the preload trial were stated to be antecedent levels of energy deprivation and physical activity, size and composition of the preload, time lapse between the preload and the outcome meal(s), and outcome meal composition [32]. It is also of note that our current trial assessed only lean males and hence conclusions should be restricted to this homogeneous study group.

The methodology in our current trial was based in part on published lipid emulsion studies [3–5] where small manipulations in lipids given as part of a test breakfast significant altered intake at a subsequent lunch meal. The relatively long (>3 h) time lapse between the preload and the outcome meal may make changes in eating behaviour more difficult to induce than trials employing a shorter timeframe. It is also possible that the buffet-style lunch, whilst restricted to only a few items, may have encouraged over-consumption, decreased sensitivity and masked differential effects, but again it is notable that a multi-item buffet lunch has previously been shown to be sensitive to effects of acute lipid manipulations [3–5]. A prior study conducted in our laboratory has also shown it to be sensitive to changes in energy content at a breakfast meal [33].

We hypothesized in this study that the rapid hydrolysis and absorption of a lipid meal enriched with SCT and/or MCT may lead to greater satiety. Whilst perhaps surprisingly there was a trend towards higher levels of circulating TAG from the SCT and MCT enriched breakfasts, effects on blood lipids were small and there was no effect on satiety ratings or food consumption at the subsequent meal when compared with an isoenergetic high-LCT breakfast. Whether

MCTs or SCTs induce clinically relevant changes in macronutrient oxidation and energy expenditure and hence may provide an aid to weight loss is an area of research that remains of some considerable interest.

Acknowledgements

References

[1] Lawton CL, Delargy HJ, Brockman J, Smith FC, Blundell JE. The degree of saturation of fatty acids influences post-ingestive satiety. Br J Nutr 2000;83:473–82.

[2] Stubbs RJ, Harbron CG. Covert manipulation of the ratio of medium to long-chain triglycerides in isoenergetically dense diets: effect on food intake in ad libitum feeding men. Int J Obes Relat Metab Disord 1996;20:435–44.

[3] Burns AA, Livingstone MB, Welch RW, Dunne A, Reid CA, Rowland IR. The effects of yoghurt containing a novel fat emulsion on energy and macronutrient intakes in non-overweight, overweight and obese subjects. J Obes Relat Metab Disord 2001;25:1487–96.

[4] Burns AA, Livingstone MB, Welch RW, et al. Short-term effects of yoghurt containing a novel fat emulsion on energy and macronutrient intakes in non-obese subjects. Int J Obes Relat Metab Disord 2000;24:1419–25.

[5] Burns AA, Livingstone MB, Welch RW, Dunne A, Rowland IR. Dose–response effects of a novel fat emulsion (Olibra) on energy and macronutrient intakes up to 36 h post-consumption. Eur J Clin Nutr 2002;56:368–77.

[6] Alfenas RC, Mattes RD. Effect of fat sources on satiety. Obes Res 2003;11:183–7.

[7] Strik CM, Lithander FE, McGill A-T, MacGibbon AK, McArdle BH, Poppitt SD. No evidence of differential effects of SFA, MUFA or PUFA on post-ingestive satiety and energy intake: a randomised trial of fatty acid saturation. Nutr J 2010;9:24.

[8] Logan C, McCaffrey T, Wallace J, et al. Investigation of the medium term effects of Olibra fat emulsion on food intake on nonobese subjects. Eur J Clin Nutr 2006;60:1081–91.

[9] Swift LL, Hill JO, Peters JC, Green H. Medium-chain fatty acids: evidence for incorporation into chylomicron triglycerides in humans. Am J Clin Nutr 1990;52:834–6.

[10] Kasai M, Maki H, Nosaka N, et al. Effect of medium-chain triglycerides on postprandial triglyceride concentrations in healthy men. Biosci Biotechnol Biochem 2003;67:46–53.

[11] Friedman M, Harris R, Ji H, Ramirez I, Tordoff M. Fatty acid oxidation affects food intake by altering hepatic energy status. Am J Physiol 1999;276:R1046–53.

[12] You Y-QN, Ling PR, Qu JZ, Bistrian BR. Effects of medium-chain triglycerides, long-chain triglycerides, or 2-monododecanoin on fatty acid composition in the portal vein, intestinal lymph, and systemic circulation in rats. JPEN 2008;32:169–75.

[13] Aoyama T, Nosaka N, Kasai M. Research on the nutritional characteristics of medium-chain fatty acids. J Med Invest 2007;54:2007.

[14] Scheig R, Klatskin G. Hepatic metabolism of 1–14C octanoic and 1–14C palmitic acids. J Am Oil Chem Soc 1968;45:31–3.

[15] Friedman MI, Edens NK, Ramirez I. Differential effects of medium- and long-chain triglycerides on food intake of normal and diabetic rats. Physiol Behav 1983;31:851–5.

[16] Van Wymelbeke V, Himaya A, Louis-Sylvestre J, Fantino M. Influence of medium-chain and long-chain triacylglycerols on the control of food intake in men. Am J Clin Nutr 1998;68:226–34.

[17] Van Wymelbeke V, Louis-Sylvestre J. M MF. Substrate oxidation and control of food intake in men after a fat-substitute meal compared with meals supplemented with an isoenergetic load of carbohydrate, long-chain triacylglycerols, or medium-chain triacylglycerols. Am J Clin Nutr 2001;74:620–30.

[18] Bendixen H, Flint A, Raben A, et al. Effect of 3 modified fats and a conventional fat on appetite, energy intake, energy expenditure, and substrate oxidation in healthy men. Am J Clin Nutr 2002;75:47–56.

[19] St-Onge M, Ross R, Parsons W, Jones P. Medium-chain triglycerides increase energy expenditure and decrease adiposity in overweight men. Obes Res 2003;11:395–402.

[20] Takeuchi H, Sekine S, Kojima K, Aoyama T. The application of medium-chain fatty acids: edible oil with a suppressing effect on body fat accumulation. Asia Pac J Clin Nutr 2008;17:320–3.

[21] Tsuji H, Kasai M, Takeuchi H, Nakamura M, Okazaki M, Kondo K. Dietary medium-chain triacylglycerols suppress accumulation of body fat in a double-blind, controlled trial in healthy men and women. J Nutr 2001;131:2853–9.

[22] Matsuo T, Matsuo M, Kasai M, Takeuchi H. Effects of a liquid diet supplement containing structured medium- and long-chain triacylglycerols on body fat accumulation in healthy young subjects. Asia Pac J Clin Nutr 2001;10:46–50.

[23] Kasai M, Nosaka N, Maki H, et al. Effect of dietary medium- and long-chain triacylglycerols (MLCT) on accumulation of body fat in healthy humans. Asia Pac J Clin Nutr 2003;12:151–60.

[24] Matsuo T, Matsuo M, Taguchi N, Takeuchi H. The thermic effect is greater for structured medium- and long-chain triacylglycerols versus long-chain triacylgly-cerols in healthy young women. Metabolism 2001;50:125–30.

[25] St-Onge M, Jones P. Greater rise in fat oxidation with medium-chain triglyceride consumption relative to long-chain triglyceride is associated with lower initial body weight and greater loss of subcutaneous adipose tissue. Int J Obes Relat Metab Disord 2003;27:1565–71.

[26] Flint A, Raben A, Blundell JE, 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.

[27] Mu H, Porsgaard T. The metabolism of structured triacylglycerols. Prog Lipid Res 2005;44:430–48.

[28] Bloom B, Chaikoff IL, Reinhardt WO. Intestinal lymph as a pathway for transport of absorbed fatty acids of different chain lengths. J Physiol 1951;166:451–5.

[29] Bach AC, Babayan VK. Medium-chain triglycerides: an update. Am J Clin Nutr 1982;36:950–62.

[30] Carey MC, Small DM, Bliss CM. Lipid digestion and absorption. Ann Rev Physiol 1983;45:651–77.

[31] Mattson FH, Volpenhein RA. The digestion and absorption of triglycerides. J Biol Chem 1964;239:2772–7.

[32] Blundell J, deGraaf C, Hulshof T, et al. Appetite control: methodological aspects of the evaluation of foods. Obes Rev 2010 advanced e-pub, Jan.

[33] Lithander FE, Strik CM, McGill AT, MacGibbon AK, McArdle BH, Poppitt, SD. No effect of an oleoylethanolamide-related phospholipid on satiety and energy intake: a randomised controlled trial of phosphatidylethanolamine. Lipids Health Dis 2008;29(41) e-pub.