Medium-chain triglycerides and conjugated linoleic acids in beverage form increase satiety and reduce food intake in humans

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List of abbreviations

CLA - conjugated linoleic acid

MCT - medium chain triglycerides

VAS - visual analogue scales

Abstract

Both developed and developing countries are seeing increasing trends of obesity in people young and old. It is thought satiety may play a role in the prevention of obesity by increasing satiety and reducing energy intake. We hypothesized that medium chain triglycerides **(**MCT) would increase satiety and decrease food intake compared to conjugated linoleic acid (CLA) and a control oil. 19 healthy participants were tested on three separate occasions, where they consumed a beverage test breakfast containing either (1) vegetable oil (control) (2) CLA or (3) MCT. Participants self-requested an *ad libitum* sandwich buffet lunch. Time between meals, satiety from visual analogue scales (VAS), energy intake at lunch, and intake for the rest of the day using weighed food diaries were measured. The results indicated that the time until a meal request was significantly different between the three meals ($p=0.016$), however there were no differences in intakes at the *ad libitum* lunch ($p>0.05$). The CLA breakfast generated the greatest delay in meal time request. There was a difference between the control lipid compared to both the CLA and MCT for energy intake over the remainder of the test day and for total energy intake on the test day ($p<0.001$ for both), with the CLA and MCT resulting in a lower intake than the control throughout the day. There were no significant differences in satiety from VAS scores ($p>0.05$). Both CLA and MCT increased satiety and reduced energy intake, indicating a potential role in aiding the maintenance of energy balance.

Keywords: Medium chain triglycerides; conjugated linoleic acid; satiety; food intake

1. Introduction

According to the World Health Organisation [1], obesity has nearly doubled worldwide since 1980 and obesity rates in both men and women have increased by over 10% in the UK alone since 1993 [2]. Obesity can develop into a major health problem increasing the risk of developing numerous diseases, including type II diabetes, cardiovascular disease and premature death [3]. The leading causes of obesity are lack of physical activity and overconsumption of high energy food [4]. With individuals and governments searching for different solutions to weight loss and fat reduction, the use of dietary supplements has increased significantly in recent years [5] [6]. It is possible that satiety may play a key role in the development of obesity [7].

Benelam [8] defines satiety as "the feeling of fullness that persists after eating, potentially suppressing further energy intake until hunger returns". It is possible that increasing satiety, and thus, delaying the onset of food intake can lead to less food intake at the next meal and throughout the rest of the day. If food intake is lowered then the risk of obesity will potentially reduce. It is possible that certain foods can play a role in increasing satiety, and thus, reduce overall food intake. At the very least they may encourage individuals to be less distracted by cues to consume, and enable them to maintain regular eating habits [9].

Conjugated linoleic acid (CLA) refers to a class of positional and geometric conjugated dienoic isomers of linoleic acid that is naturally present in the meat of ruminants. Cis-9, trans-11 CLA and trans-10, cis-12 make up the main isomers of CLA [10]. CLA is believed to have a positive effect on human health, particularly on body weight and body fat [11]. It is thought that the isomer trans-10, cis-12 is responsible for positive changes in body

composition [10]. Some studies have shown that daily intake of CLA can reduce both body weight and body fat [12-14] though the clinical relevance of these changes is still open to debate [15]. There has been little research conducted on the effects of CLA on satiety. Several studies have assessed the effect of CLA on appetite [16-18]. However this research has primarily focused on subjective ratings of appetite or following a CLA intervention. To the authors knowledge no data has examined the effect on actual food intake during a one day trial. In rats however, some studies found decreased energy intakes following CLA consumption [19-21] whereas other studies observed no effect on food intake [22-24]. It is known that intake of CLA decreases the uptake of fatty acids into adipocytes and increases β-oxidation in muscle cells. A potential theory is that this may result in a shift towards fat oxidation that could result in glycogen being spared. This may in turn serve as a satiety signal, as has been proposed by several researchers [25, 26]. However this mechanism has not been proved in other research [27, 28] so speculation as to how CLA can increase satiety remains open to debate. Studies on medium-chain triglycerides have been much more frequent.

Medium-chain triglycerides (MCTs) are triglycerides with a fatty acid chain length varying between 6 and 10 carbon atoms. MCTs are soluble in water, rapidly absorbed and preferentially oxidised compared to long-chain triglycerides (LCTs). The most common sources of MCTs are coconut oil, palm oil and dairy fat; however it is most commonly used as a weight loss aid in the form of synthetic oil [29] where over 16 weeks it has been shown to result in greater weight losses than olive oil (-1.67 +/- 0.67 kg) [30]. MCT has demonstrated it's ability to increase satiety by delaying meal requests and reducing food intake by up to 698kJ compared to a saturated lipid [31]. MCTs ability to increase satiety is believed to be due to its increased oxidative capacity; however the exact mechanisms are

unknown. MCTs undergo nearly complete hydrolysis to free fatty acids (FFA) after ingestion, and are then absorbed directly into the portal vein. Then they are transported rapidly to the liver for β-oxidation. LCTs, differ however, as they are absorbed via the intestinal lymphatic ducts at a much slower rate and transported by chylomicrons into the systemic circulation prior to oxidation or storage. MCTs are faster oxidised than LCTs [32]. Therefore they are a much more readily available energy source. Several studies have been unable to detect differences in satiety following MCT [33, 34] , however other studies have shown MCT's can be beneficial to increasing satiety and reducing energy intake, and thus, causing weight loss [35]. However, how different lipids compare in terms of their ability to increase satiety is less well known.

The objectives of this study were twofold. Firstly, to examine the effect of CLA on satiety and food intake. To the author's knowledge this has not previously been completed in a single day trial assessing food intake and subjective satiety. The second objective of this study was to compare the effect of CLA to MCT in terms of satiety and food intake. The authors hypothesize that MCT will increase satiety more than CLA or a control lipid. The methods used to measure satiety in this study included a self-requested *ad libitum* buffet lunch and visual analogue scales.

2. Methods and materials

2.1.Participants

Participants were recruited through the use of posters, social networking and word of mouth. Prior to participation all participants were tested for suitability through both a pre-test

151 questionnaire and a dietary restraint questionnaire [36]. Twenty-six participants were
152 recruited in total. Eating behaviour was determined using the Dutch eating behaviour
153 questionnaire [37]. Only those who did not consciously restrain their food intake due to
154 psychological reasons, weight concerns and external stimuli were included in the study.
155 Those who fulfilled all the acceptable criteria (age 18-60 years; body mass index <30 kg/m^2;
156 blood pressure 110-120/75-85 mmHg; non-smoking; not highly physically active or involved
157 in sports at the endurance and competitive levels (>10 hours a week vigorous exercise); not
158 suffering from any eating disorders; not allergic/intolerant to any of the foods presented in the
159 study; habitually consuming breakfast and lunch; not on prescription medication; no genetic
160 or metabolic diseases) were included in the study. On the day before each test, participants
161 were asked to restrict their intake of alcohol and caffeine containing drinks and to refrain
162 from strenuous physical activity.

163 All participants were given an information sheet explaining the study and the possible risks to
164 taking part prior to giving informed consent. Ethical approval was granted by the Research
165 Ethics officer at Oxford Brookes University in line with the Declaration of Helsinki.
166 Participants were asked to fast for 12 hours prior to testing and to not do any strenuous
167 exercise the morning of the test. 19 participants (12f; 31.4 ± 18.0 yr; 169 ± 11 cm; 68.6 ±
168 11.7 kg) completed the study (figure 1).
169
170 *2.2. Experimental design*
171
172 Participants took part in a randomised, single blind study. Participants were required to attend
173 the laboratory from 9am to 2pm on three separate non-consecutive days. Participants
174 consumed a test breakfast containing CLA, MCT or a control oil (vegetable oil), following
175 which their appetite and satiety were monitored. Prior to the first test participants recorded

176 the previous day's food intake using a weighed food diary and repeated this food intake on
177 the day prior to the subsequent tests.
178
179 *2.3. Breakfast*
180
181 The test breakfast consisted of 250ml of Tesco red berries smoothie - 123 kcal (515 kJ), 0.8 g
182 protein, 29.8 g carbohydrate, 27.0 g sugar and 0 g fat. Added to it was 193 kcal (808kJ) of
183 lipids, consisting of either 5 g CLA (Trec Nutrition, London, UK) and 16g vegetable oil, 25 g
184 MCT (Trec Nutrition, London, UK) or 22 g vegetable oil as a control (Tesco, Cheshunt, UK).
185 All lipids were added in these doses so that smoothies had the same energy and fat content.
186 The total energy content of each smoothie was 316 kcal (1323kJ). Doses used for each lipid
187 was based on previous studies, considered safe and sufficient enough to see a possible effect
188 [14, 38]. Pretesting was undertaken to ensure that the three drinks tasted similar and palatable.
189
190 *2.4.Subjective satiety*
191
192 Satiety was measured using visual analogue scales (VAS). Participants were asked to fill out
193 a 100mm VAS before and after the test breakfast. The VAS were anchored at the left and
194 right ends with opposing statements for feelings of hunger, fullness, desire to eat and
195 prospective food consumption. The specific questions asked were, 'How hungry do you
196 feel?', 'How full do you feel?', 'How strong is your desire to eat?' and 'How much food do
197 you think you can eat?'. The VAS contained numbers ranging from 1-10, with 1 being low
198 and 10 being high. The VAS were completed by participants every half hour after the
199 breakfast up until the participant felt hungry enough to request lunch. The time taken between
200 breakfast and the request for lunch was measured for each participant as previously

undertaken by Van Wymelbeke et al [31]. Because the participants requested their lunches and dinners at different times, the scores given in the VAS were analysed up to 60 minutes as this was the time at which the first person requested their lunch. This was the method previously used by Van Wylebeke et al [31]. Participants were allowed 500ml of water during the time between breakfast and lunch on the first test. This was measured and repeated in subsequent tests.

2.5. Food intake

Participants were asked to let the researchers know when they felt hungry enough to eat lunch following the test breakfast. Participant had to stay in the laboratory until 2pm regardless of how soon they requested their *ad libitum* lunch. All time cues were removed from the participants view – clocks on laptops were covered with paper and tape and phones and watches were removed. Once lunch was requested, sandwiches were given *ad-libitum* to measure food intake similar to that used by Ranawana et al [39] and Clegg and Thondre [40]. Prior to testing participants were given a choice of sandwiches from a list prior to testing and asked to choose which ones they liked. All the sandwich recipes were formulated to contain the same energy content per portion (Table 1). The lunch consisted of three weighed plates each containing two sandwiches cut into quarters. Participants were given all the sandwiches at once so that it was in excess and asked to eat until they felt comfortably full. Participants were given the same sandwiches for each test. The subjects were presented with the meal under identical conditions on each test day. They ate in the same laboratory on their own with no distractions and were given 30 minutes in which to eat their ad libitum meal.

When participants finished eating and the remaining food leftover was weighed to measure food intake. A food diary was used to measure food intake for the rest of the day. Food diaries were analysed using the software package Nutritics Professional (Est. 2011, Dublin, Ireland).

2.6. Statistical analyses

Statistical analyses was performed using Statistical Package for the Social Sciences (version 20.0; SPSS, Chicago, IL, USA) and data and figures were processed using Microsoft Excel (2006, Reading, UK). A power calculation was conducted for the primary outcome measure of energy intake. A sample size of 19 was required to detect a 300 kJ difference in energy intake with a standard deviation of 250kJ and α set at 0.05 and a power of 90% [31].

A repeated measures ANOVA with Bonferroni correction was performed on the food intake and time-to-meal-request data to gage if there were any significant differences in satiety levels between lipids. A repeated measures ANCOVA was used for analysis of the VAS data up to and including the 60 minute data. The baseline was used as a covariate in the analysis. The significance value was set at $p<0.05$.

3. Results

3.1.Ad libitum lunch

For the *ad libitum* lunch (Table 2) there were no significant differences in intake between the control, CLA or MCT tests on energy or any macronutrients ($p>0.05$). Energy and

250 macronutrient intake was highest amongst the control group, an average of 70 kcal (293kJ)
251 more than CLA and MCT. Macronutrient intake was similar after consumption of both CLA
252 and MCT at lunch.
253
254 *3.2.Rest of day intake*
255
256 There were significant differences in food intake from the rest of the day (Table 2) following
257 the *ad libitum* lunch between the three meals ($p<0.001$). These differences were found
258 between the MCT meal and the control, and between the CLA meal and the control. The
259 MCT breakfast resulted in the least amount of energy consumed after lunch and the control
260 had the highest intake, with an average of 471 kcal (1972 kJ) more consumed following the
261 control compared to CLA and 525 kcal (2198 kJ) more compared to MCT. There were also
262 significant differences in intake of all macronutrients following the three breakfasts (protein
263 $p=0.003$, fat $p<0.001$; carbohydrate $p<0.001$). These differences were found between the two
264 test lipids and the control for all three macronutrients with the exception of protein, in which
265 the CLA was not significantly different to the control.
266
267 *3.3.Total days intake*
268
269 The results showed that having the control breakfast resulted in the greatest energy intake, an
270 average of 541 kcal (2265 kJ) more compared to CLA and 594 kcal (2487 kJ) more than
271 MCT ($p<0.001$). There were significant differences following the control compared to CLA
272 and MCT for total energy intake and on all macronutrient intakes with the exception of
273 protein between the control and the CLA breakfast. The MCT showed the greatest satiating
274 effect.

3.4.Time until meal request

The time until a meal request (Table 3) showed that there was a significant difference in the time until lunch was requested between the three meals ($p=0.016$). These differences existed between the control breakfast and the CLA breakfast ($p=0.049$). The control delayed the meal request the least, followed by the MCT with the CLA delaying the time until lunch the most.

3.5.Visual analogue scale

There were no significant differences between any of the three tests on any of the four questions hunger, fullness, desire to eat or prospective consumption ($p>0.05$; Figure 2). Perceived satiety increased immediately following the breakfast and then decreased again at 30 and 60 minute.

4. Discussion

As far as the authors of this study are aware, this is the first study that has compared the effect of both CLA and MCTs on food intake and satiety within the same study. The results from this study show that both CLA and MCTs reduce and delay food intake over a day when compared to a control. The results showed that there were significant differences in time to lunch request, energy and macronutrient intakes for the rest of the day (after test breakfast and *ad libitum* lunch) and over the entire day between the three meals. These differences were seen between the CLA and MCT compared to the control. There were no significant differences between CLA and MCT intakes at any stage or for any parameter. These results

300 show that both test lipids increased satiety and thus reduced energy intake hence rejecting the
301 original hypothesis that only MCT would increase satiety above the control.
302
303 Data on CLA and satiety is limited. One previous study [18] found that CLA did not reduce
304 *ad libitum* energy intake during breakfast after consuming a dose of either 1.8g or 3.6g per
305 day and after an overnight fast, though feelings of fullness and satiety were increased and
306 feelings of hunger were decreased compared to placebo. However, this study was looking at
307 the effect of a 13 week CLA intervention and CLA had not been consumed since the day
308 before. This may indicate that the results are due to long term dietary changes rather than the
309 effect of a single dose of CLA. A similar study conducted by Lambert *et al*. [17] found no
310 significant reduction in subjective satiety ratings after a standardised breakfast following
311 CLA supplementation for 12 weeks. The current study was able to demonstrate the effect of a
312 single dose of CLA on meal request and food intake.
313
314 In contrast to CLA the short term effects of MCTs are well documented, showing a decreased
315 intake at lunch following an MCT rich breakfast [31, 41]. However the current study did not
316 find a difference in food intake at lunch or a significant delay in the meal request, though this
317 did approach significance. It is possible taking a dose of at least 25g of MCTs in the morning
318 can reduce energy intake later in the day i.e. after lunch. This result is similar to that in other
319 studies where intake of MCT reduced energy intake later in the day [42] , and research that
320 showed that food intake at dinner was reduced following an MCT lunch but similar to the
321 current study the meal request was not delayed [43]. Interestingly the current study was not
322 able to detect any difference in satiety between the two test lipids indicating that they both
323 were equally as satiating as the other.
324

For the *ad libitum* lunch, there were no significant differences in intakes between CLA, MCT or the control. However this may be due to the meal request being earlier following the CLA and MCT and may indicate that the participants were truly able to detect their level of hunger and accurately compensate for this. The methods used were chosen to test the possibility that the test lipids allow a longer time period between breakfast and lunch. Had participants been given lunch at a set time, it would not have allowed the possibility to test the duration of satiety. It was decided that participants would be taken into the laboratory in the morning, given the test breakfast, and sent back out to a waiting area. There was no set time for lunch and participants were told to tell the researchers when they felt hungry enough to eat lunch, which worked efficiently in a previous study [31]. Participants were told they were to be in the laboratory from 9 a.m. to 2 p.m. This eliminated the temptation to request lunch in order to be able to leave the laboratory prior to feeling genuine hunger. If participants finished lunch prior to 2 p.m. they were asked to wait in the laboratory until then. Participants were asked to fill out food diaries for the rest of the day after the *ad libitum* lunch. Although this was aimed to replicate a free -living element to the study it is known that people often underestimate their food intake when filling out food diaries or don't eat as they normally would as they know they are recording it [44] which could impact on the results.

Nausea, stomach cramping and other gastrointestinal problems are a known side effect of MCTs [35]. Five participants in the present study reported suffering side effects of this nature after ingesting the MCT breakfast. This shows that even a dose as small as 25g of MCTs can have side effects which may have impacted in their food intake. One participant suffered gastrointestinal discomfort from ingesting the CLA. There were no side effects from ingesting the control.

There were several limitations to this study. The use of food diaries as highlighted previously does not control the environment in which the participant is tested, however they do have their merits including high external validity and applicability to real life situations [45]. The two test lipids were not matched in terms of energy content due to a compromise between seeing positive results and not having adverse effects on the participants. Instead doses were chosen based on previous literature. Although pretesting was completed in a different population, no direct measures of palatability were completed in the current volunteers so they would not be concerned about differences between the beverages. However there is a chance that the current cohort of volunteers was able to detect differences that might have influenced their palatability and intake. GI disturbances were not recorded during the study but the participant was asked about these after each day so as not to influence their thoughts on this issue. Finally each individual had the same sandwiches for all three of their ad libitum meals which may have become monotonous and caused sensory specific satiety however the volunteers were given sandwiches to suit their preferences. Johnson and Vickers[46] have previously outlined that there is a trend for less-liked test meals to drop more in liking than the well-liked test meals following repeated exposure.

The present study reveals that both CLA and MCT can increase satiety and decrease food intake over a period of a day. Given the side effects seen following MCT consumption and that CLA consumption resulted in had similar satiating effects, CLA may be proposed as an alternative food ingredient to increase satiety. This may be beneficial to future prevention and/or treatment of obesity; however more research is needed including longer duration laboratory trials particularly on CLA and its effect on satiety and food intake.

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Figure 1: Flow chart showing participant recruitment

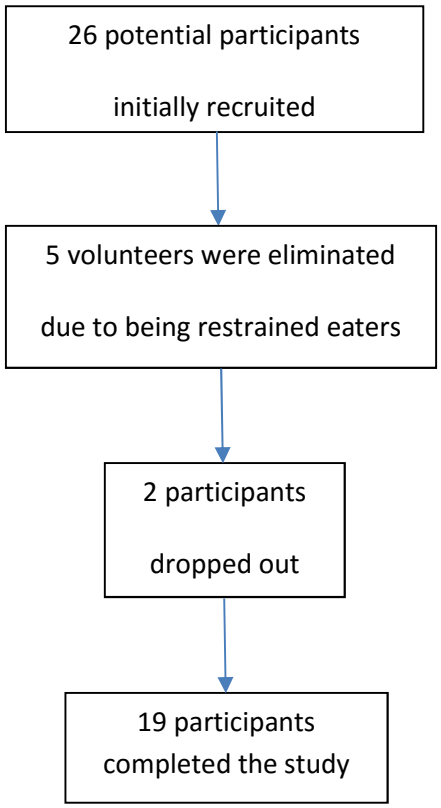

Figure 2: Visual analogue scale data for hunger, fullness, desire to eat and prospective consumption at baseline (0 min), after breakfast (post break), and 30 and 60 min after breakfast [a].

[a] Values are means ± SD

Table 1: Nutritional content of sandwiches (*ad libitum* lunch)[a].

Sandwich:	Weight (g)	Energy (kcal (kJ))	Carbohydrate (g)	Protein (g)	Fat (g)
Egg mayo	223	408.20 (1709)	36.68	17.46	19.81
Cheese and tomato	185	406.06 (1700)	36.62	19.73	18.51
Tuna mayo	146	402.79 (1686)	35.30	18.37	19.56
Chicken salad	221	406.48 (1701)	37.51	18.61	18.66
Cheese and pickle	148	404.75 (1695)	38.98	19.03	17.75
Ham and cheese	153	405.43 (1698)	35.62	21.49	18.21
Roast beef and tomato	181	404.30 (1693)	36.55	20.02	18.11

[a] Three plates of sandwiches were served at each *ad libitum* lunch

591 *Table 2:* Energy and macronutrient intake at the *ad libitum* lunch, for the rest of the day

592 following the lunch and the day's total intake [a, b, c]

	Control	CLA	MCT
	Ad Libitum Lunch		
Energy (kcal)	798.45 ± 207.91	728.61 ± 188.38	728.73 ± 182.91
kJ	3343 ± 870	3051 ± 789	3051 ± 766
Carbohydrate (g)	71.87 ± 19.27	65.38 ± 16.51	65.40 ± 16.12
Protein (g)	37.90 ± 10.24	34.43 ± 8.53	34.48 ± 8.51
Fat (g)	36.73 ± 9.36	33.73 ± 9.45	33.72 ± 9.06
	Rest of day intake		
Energy (kcal)	1171.63 ± 458.36	699.95 ± 321.49*	646.74 ± 313.75*
kJ	4905 ± 1919	2931 ± 1346	2708 ± 1314
Carbohydrate (g)	124.32 ± 60.48	69.74 ± 42.60*	64.08 ± 41.56*
Protein (g)	65.05 ± 30.41	47.79 ± 23.01	44.49 ± 20.55*
Fat (g)	39.85 ± 16.82	23.63 ± 13.76*	21.68 ± 13.04*
	Total days intake		
Energy (kcal)	1970.08 ± 666.27	1428.56 ± 509.87*	1375.46 ± 496.67*
kJ	8248 ± 2790	5891 ± 2135	5759 ± 2080
Carbohydrate (g)	196.18 ± 79.75	135.12 ± 59.12*	129.49 ± 57.67*
Protein (g)	102.96 ± 40.66	82.22 ± 31.54	78.97 ± 29.05*
Fat (g)	76.58 ± 26.18	57.36 ± 23.21*	55.40 ± 22.10*

593

594 * $p<0.05$ compared to control

595 [a] Values are means ± SD

[b] n=19

[c] Data analysed using RM-ANOVA

Table 3: Time until meal request [a, b, c, d].

	Control	*CLA*	*MCT*
Time (minutes)	142.11 ± 42.25	181.58 ± 61.15*	167.37 ± 40.50

* $p<0.05$ compared to control

[a] Data is given in minutes for all tests for total time between the test breakfast and when participants asked for lunch

[b] Values are means ±SD

[c] n=19

[d] Data analysed using RM-ANOVA