

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

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1 **Medium chain triglycerides and conjugated linoleic acids in beverage form increase**
2 **satiety and reduce food intake in humans.**

3

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26 **List of abbreviations**

27

28 CLA - conjugated linoleic acid

29 MCT - medium chain triglycerides

30 VAS - visual analogue scales

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51 **Abstract**

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

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

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76 1. Introduction

77

78 According to the World Health Organisation [1], obesity has nearly doubled worldwide since
79 1980 and obesity rates in both men and women have increased by over 10% in the UK alone
80 since 1993 [2]. Obesity can develop into a major health problem increasing the risk of
81 developing numerous diseases, including type II diabetes, cardiovascular disease and
82 premature death [3]. The leading causes of obesity are lack of physical activity and
83 overconsumption of high energy food [4]. With individuals and governments searching for
84 different solutions to weight loss and fat reduction, the use of dietary supplements has
85 increased significantly in recent years [5] [6]. It is possible that satiety may play a key role in
86 the development of obesity [7].

87

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

95

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

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

116

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

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

136

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

144

145 **2. Methods and materials**

146

147 *2.1. Participants*

148

149 Participants were recruited through the use of posters, social networking and word of mouth.

150 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 $<30 \text{ kg/m}^2$;
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; $68.6 \pm$
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

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

207

208 2.5. Food intake

209

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

224

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

229

230 *2.6. Statistical analyses*

231

232 Statistical analyses was performed using Statistical Package for the Social Sciences (version
233 20.0; SPSS, Chicago, IL, USA) and data and figures were processed using Microsoft Excel
234 (2006, Reading, UK). A power calculation was conducted for the primary outcome measure
235 of energy intake. A sample size of 19 was required to detect a 300 kJ difference in energy
236 intake with a standard deviation of 250kJ and α set at 0.05 and a power of 90% [31].

237

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

243

244 **3. Results**

245

246 *3.1. Ad libitum lunch*

247

248 For the *ad libitum* lunch (Table 2) there were no significant differences in intake between the
249 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.

275

276 *3.4. Time until meal request*

277

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

282

283 *3.5. Visual analogue scale*

284

285 There were no significant differences between any of the three tests on any of the four
286 questions hunger, fullness, desire to eat or prospective consumption ($p>0.05$; Figure 2).

287 Perceived satiety increased immediately following the breakfast and then decreased again at
288 30 and 60 minute.

289

290 **4. Discussion**

291

292 As far as the authors of this study are aware, this is the first study that has compared the
293 effect of both CLA and MCTs on food intake and satiety within the same study. The results
294 from this study show that both CLA and MCTs reduce and delay food intake over a day when
295 compared to a control. The results showed that there were significant differences in time to
296 lunch request, energy and macronutrient intakes for the rest of the day (after test breakfast
297 and *ad libitum* lunch) and over the entire day between the three meals. These differences
298 were seen between the CLA and MCT compared to the control. There were no significant
299 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

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

342

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

349

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

366

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

373

374

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377 from Trec Nutrition.

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402 **References**

403

404 [1] World Health Organisation. Obesity and Overweight. 2014 [cited 2015 13th January];

405 Available from: <http://www.who.int/mediacentre/factsheets/fs311/en/>

406 [2] Lifestyles statistics team HaSCIC (2014) *Statistics on Obesity, Physical Activity and Diet -*
407 *England*

408 [3] Wellman NS, Friedberg B. Causes and consequences of adult obesity: health, social and
409 economic impacts in the United States. *Asia Pac J Clin Nutr* 2002;11 Suppl 8:S705-9.

410 [4] National Institutes of Health. Causes Overweight and Obesity. 2012 [cited 2014 13th

411 January]; Available from: <http://www.nhlbi.nih.gov/health/health->

412 [topics/topics/obe/causes.html](http://www.nhlbi.nih.gov/health/health-topics/topics/obe/causes.html)

413 [5] Johansson K, Neovius M, Hemmingsson E. Effects of anti-obesity drugs, diet, and exercise on
414 weight-loss maintenance after a very-low-calorie diet or low-calorie diet: a systematic
415 review and meta-analysis of randomized controlled trials. *Am J Clin Nutr* 2014;99(1):14-23.

416 [6] Jeukendrup AE, Randell R. Fat burners: nutrition supplements that increase fat metabolism.
417 *Obesity Reviews* 2011;12(10):841-851.

418 [7] Halford JC, Harrold JA. Satiety-enhancing products for appetite control: science and
419 regulation of functional foods for weight management. *Proc Nutr Soc* 2012;71(2):350-62.

420 [8] Benelam B. Satiating, satiety and their effects on eating behaviour. *Nutrition Bulletin*
421 2009;34(2):126–173.

422 [9] Hetherington MM, Cunningham K, Dye L, Gibson EL, Gregersen NT, Halford JC et al. Potential
423 benefits of satiety to the consumer: scientific considerations. *Nutr Res Rev* 2012;26(1):22-38.

424 [10] Dilzer A, Park Y. Implication of conjugated linoleic acid (CLA) in human health. *Crit Rev Food*
425 *Sci Nutr* 2012;52(6):488-513.

426 [11] Rainer L, Heiss CJ. Conjugated linoleic acid: health implications and effects on body
427 composition. *J Am Diet Assoc* 2004;104(6):963-8, quiz 1032.

- 428 [12] Gaullier JM, Halse J, Høye K, Kristiansen K, Fagertun H, Vik H et al. Supplementation with
429 conjugated linoleic acid for 24 months is well tolerated by and reduces body fat mass in
430 healthy, overweight humans. *J Nutr* 2005;135(4):778-84.
- 431 [13] Chen SC, Lin YH, Huang HP, Hsu WL, Hwang JY, and Huang CK. Effect of conjugated linoleic
432 acid supplementation on weight loss and body fat composition in a Chinese population.
433 *Nutrition* 2012;28(5):559-65.
- 434 [14] Blankson H, Stakkestad JA, Fagertun H, Thom E, Wadstein J, and Gudmundsen O. Conjugated
435 linoleic acid reduces body fat mass in overweight and obese humans. *J Nutr*
436 2000;130(12):2943-8.
- 437 [15] Onakpoya IJ, Posadzki PP, Watson LK, Davies LA, Ernst E. The efficacy of long-term
438 conjugated linoleic acid (CLA) supplementation on body composition in overweight and
439 obese individuals: a systematic review and meta-analysis of randomized clinical trials. *Eur J*
440 *Nutr* 2012;51(2):127-34.
- 441 [16] Medina EA, Horn WF, Keim NL, Havel PJ, Benito P, Kelley DS et al. Conjugated linoleic acid
442 supplementation in humans: effects on circulating leptin concentrations and appetite. *Lipids*
443 2000;35(7):783-8.
- 444 [17] Lambert EV, Goedecke JH, Bluett K, Heggie K, Claassen A, Rae DE et al. Conjugated linoleic
445 acid versus high-oleic acid sunflower oil: effects on energy metabolism, glucose tolerance,
446 blood lipids, appetite and body composition in regularly exercising individuals. *Br J Nutr*
447 2007;97(5):1001-11.
- 448 [18] Kamphuis MM, Lejeune MP, Saris WH, Westerterp-Plantenga MS. Effect of conjugated
449 linoleic acid supplementation after weight loss on appetite and food intake in overweight
450 subjects. *Eur J Clin Nutr* 2003;57(10):1268-74.
- 451 [19] Miner JL, Cederberg CA, Nielsen MK, Chen X, Baile CA. Conjugated linoleic acid (CLA), body
452 fat, and apoptosis. *Obes Res* 2001;9(2):129-34.

- 453 [20] Park Y, Albright KJ, Storkson JM, Liu W, Cook ME, and Pariza MW. Changes in body
454 composition in mice during feeding and withdrawal of conjugated linoleic acid. *Lipids*
455 1999;34(3):243-8.
- 456 [21] West DB, Delany JP, Camet PM, Blohm F, Truett AA, and Scimeca J. Effects of conjugated
457 linoleic acid on body fat and energy metabolism in the mouse. *Am J Physiol* 1998;275(3 Pt
458 2):R667-72.
- 459 [22] Azain MJ, Hausman DB, Sisk MB, Flatt WP, Jewell DE. Dietary conjugated linoleic acid
460 reduces rat adipose tissue cell size rather than cell number. *J Nutr* 2000;130(6):1548-54.
- 461 [23] DeLany JP, Blohm F, Truett AA, Scimeca JA, West DB. Conjugated linoleic acid rapidly reduces
462 body fat content in mice without affecting energy intake. *Am J Physiol* 1999;276(4 Pt
463 2):R1172-9.
- 464 [24] Sisk MB, Hausman DB, Martin RJ, Azain MJ. Dietary conjugated linoleic acid reduces
465 adiposity in lean but not obese Zucker rats. *J Nutr* 2001;131(6):1668-74.
- 466 [25] Flatt JP. Glycogen levels and obesity. *Int J Obes Relat Metab Disord* 1996;20 Suppl 2:S11-11.
- 467 [26] Melanson KJ, Westerterp-Plantenga MS, Campfield LA, Saris WH. Appetite and blood glucose
468 profiles in humans after glycogen-depleting exercise. *J Appl Physiol (1985)* 1999;87(3):947-
469 54.
- 470 [27] Shetty PS, Prentice AM, Goldberg GR, Murgatroyd PR, McKenna AP, Stubbs RJ et al.
471 Alterations in fuel selection and voluntary food intake in response to isoenergetic
472 manipulation of glycogen stores in humans. *Am J Clin Nutr* 1994;60(4):534-43.
- 473 [28] Stubbs RJ, Murgatroyd PR, Goldberg GR, Prentice AM. Carbohydrate balance and the
474 regulation of day-to-day food intake in humans. *Am J Clin Nutr* 1993;57(6):897-903.
- 475 [29] Marten B, Pfeuffer M, Schrezenmeir J. Medium-chain triglycerides. *International Dairy*
476 *Journal* 2006;16(11):1374–1382.

- 477 [30] St-Onge MP, Bosarge A. Weight-loss diet that includes consumption of medium-chain
478 triacylglycerol oil leads to a greater rate of weight and fat mass loss than does olive oil. *Am J*
479 *Clin Nutr* 2008;87(3):621-6.
- 480 [31] Van Wymelbeke V, Himaya A, Louis-Sylvestre J, Fantino M. Influence of medium-chain and
481 long-chain triacylglycerols on the control of food intake in men. *Am J Clin Nutr*
482 1998;68(2):226-34.
- 483 [32] Dulloo AG, Fathi M, Mensi N, Girardier L. Twenty-four-hour energy expenditure and urinary
484 catecholamines of humans consuming low-to-moderate amounts of medium-chain
485 triglycerides: a dose-response study in a human respiratory chamber. *Eur J Clin Nutr*
486 1996;50(3):152-8.
- 487 [33] Bendixen H, Flint A, Raben A, Hoy CE, Mu H, Xu X et al. Effect of 3 modified fats and a
488 conventional fat on appetite, energy intake, energy expenditure, and substrate oxidation in
489 healthy men. *Am J Clin Nutr* 2002;75(1):47-56.
- 490 [34] Poppitt SD, Strik CM, MacGibbon AK, McArdle BH, Budgett SC, and McGill AT. Fatty acid
491 chain length, postprandial satiety and food intake in lean men. *Physiol Behav*
492 2010;101(1):161-7.
- 493 [35] Clegg ME. Medium-chain triglycerides are advantageous in promoting weight loss although
494 not beneficial to exercise performance. *Int J Food Sci Nutr* 2010.
- 495 [36] Urbszat D, Herman CP, Polivy J. Eat, drink, and be merry, for tomorrow we diet: effects of
496 anticipated deprivation on food intake in restrained and unrestrained eaters. *J Abnorm*
497 *Psychol* 2002;111(2):396-401.
- 498 [37] van Strien T, Frijter JER, Bergers GPA, Defares PB. The Dutch Eating Behaviour Questionnaire
499 (DEBQ) assessment of restrained, emotional, and external eating behavior. *Int J Eat Disord*
500 1986;5(2):295-315.

501 [38] Clegg ME, Golsorkhi M, Henry CJ. Combined medium-chain triglyceride and chilli feeding
502 increases diet-induced thermogenesis in normal-weight humans. *Eur J Nutr*
503 2013;52(6):1579-85.

504 [39] Ranawana V, Muller A, Henry CJ. Polydextrose: its impact on short-term food intake and
505 subjective feelings of satiety in males-a randomized controlled cross-over study. *Eur J*
506 *Nutr*;52(3):885-93.

507 [40] Clegg ME, Thondre PS. Molecular weight of barley beta-glucan does not influence satiety or
508 energy intake in healthy male subjects. *Appetite* 2014;83:167-72.

509 [41] Rolls BJ, Gnizak N, Summerfelt A, Laster LJ. Food intake in dieters and nondieters after a
510 liquid meal containing medium-chain triglycerides. *Am J Clin Nutr* 1988;48(1):66-71.

511 [42] Stubbs RJ, Harbron CG. Covert manipulation of the ratio of medium- to long-chain
512 triglycerides in isoenergetically dense diets: effect on food intake in ad libitum feeding men.
513 *Int J Obes Relat Metab Disord* 1996;20(5):435-44.

514 [43] Van Wymelbeke V, Louis-Sylvestre J, Fantino M. Substrate oxidation and control of food
515 intake in men after a fat-substitute meal compared with meals supplemented with an
516 isoenergetic load of carbohydrate, long-chain triacylglycerols, or medium-chain
517 triacylglycerols. *Am J Clin Nutr* 2001;74(5):620-30.

518 [44] Black AE, Prentice AM, Goldberg GR, Jebb SA, Bingham SA, Livingstone MB et al.
519 Measurements of total energy expenditure provide insights into the validity of dietary
520 measurements of energy intake. *J Am Diet Assoc* 1993;93(5):572-9.

521 [45] Blundell J, de Graaf C, Hulshof T, Jebb S, Livingstone B, Lluch A et al. Appetite control:
522 methodological aspects of the evaluation of foods. *Obes Rev* 2010;11(3):251-70.

523 [46] Johnson J, Vickers Z. Effects of flavor and macronutrient composition of food servings on
524 liking, hunger and subsequent intake. *Appetite* 1993;21(1):25-39.

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528 *Figure 1: Flow chart showing participant recruitment*

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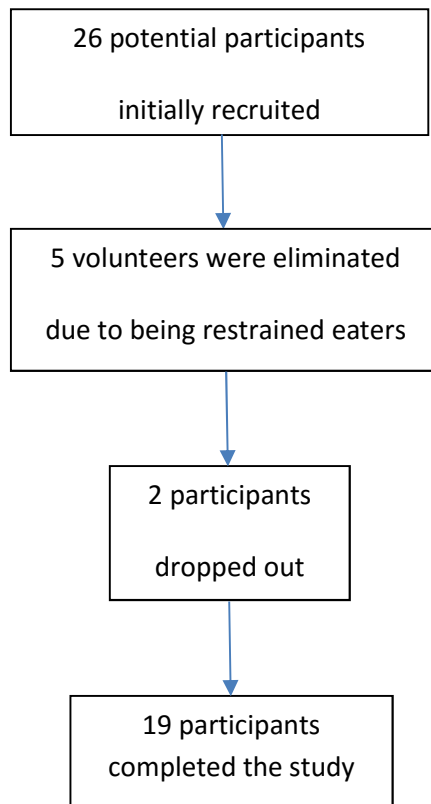
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553 *Figure 2: Visual analogue scale data for hunger, fullness, desire to eat and prospective*
554 *consumption at baseline (0 min), after breakfast (post break), and 30 and 60 min after*
555 *breakfast* ^a.

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557 ^a Values are means \pm SD

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578 *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

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580 ^a Three plates of sandwiches were served at each *ad libitum* lunch

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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
<i>Ad Libitum Lunch</i>			
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
<i>Rest of day intake</i>			
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*
<i>Total days intake</i>			
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*

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594 * p<0.05 compared to control

595 ^a Values are means ± SD

596 ^b n=19

597 ^c Data analysed using RM-ANOVA

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621 *Table 3: Time until meal request* ^{a, b, c, d}.

	<i>Control</i>	<i>CLA</i>	<i>MCT</i>
<i>Time (minutes)</i>	142.11 ± 42.25	181.58 ± 61.15*	167.37 ± 40.50

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623 * p<0.05 compared to control

624 ^a Data is given in minutes for all tests for total time between the test breakfast and when

625 participants asked for lunch

626 ^b Values are means ±SD

627 ^c n=19

628 ^d Data analysed using RM-ANOVA

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