A systematic review and meta-analysis of medium-chain triglycerides effects on acute satiety and food intake

Article

Supplemental Material

Tables and figures

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Table 1. Keywords included in database search strategy.

Medium Chain Triglycerides	Satiety		Human
MCT	Appetite	Diar*	*In vivo*
Medium chain fatty	Hunger	*Ad lib**	Man
MCFA	Satiety	Calori* intake	Woman
Caproic	Fullness	Energy density	Men
C6:0	Desire to eat	Hormon*	Women
Hexanoic	Prospective food consumption	Peptide*	Volunteer*
Caprylic	Nausea	Gut	Participant
C8:0	Time to meal request	Peptide YY	Lean
C10:0	TTMR	Tyrosine	Healthy
Lauric	Motivation to eat	PYY	Overweight
C12:0	Palatability	Ghrelin	Obese
Dodecanoic	Food reward	Acylated	
Coconut*	Hedonic	GLP*	
Palm kernel oil	Liking	Glucagon-like peptide*	
	Wanting	Pancreatic polypeptide	
	Food intake	Oxyntomodulin	
	Food consumption	OXM	
	Energy intake	Cholescystokinin	
	Compensation	CKK	
	Protein intake	Leptin	
	Fat intake	Ketone*	
	Carbohydrate intake	Beta-hydroxybutyrate	
	Macronutrient*	Butyrate	
	Diet	BHB	
	Diary	Satiety hormone*	

Table 2. Analysis of bias using the Cochrane Collboration's Tool for assessing risk of bias.

Study	Random sequence generation	Allocation concealment	Blinding of participants	Blinding of personnel	Blinding of outcome assessment	Incomplete outcome data	Selective reporting	Other sources of bias
Barbera *et al*. (2000)	Unclear	High	Low	Unclear	High	High	High	Unclear
Clegg, Golsorkhi and Henry(2013)	Unclear	High	Unclear	Unclear	High	High	High	Unclear
Clegg *et al*. (2012)	Unclear	High	Low	High	High	High	High	Unclear
Coleman, Quinn and Clegg (2016)	Unclear	High	Low	High	High	High	High	Unclear
Feltrin *et al.* (2008)	Unclear	Low	Low	Low	Low	High	High	Unclear
Feltrin *et al.* (2004)	Unclear	Low	Low	Low	Low	High	High	Unclear
Kinsella, Maher and Clegg (2017)	Unclear	High	Low	High	High	High	High	Unclear
Krotkiewski (2001)	High	High	Low	Low	Low	High	High	Unclear
Poppit et al. (2010)	Unclear	High	Low	High	High	High	Unclear	Low
Rizzo *et al.* (2016)	Unclear	High	Low	High	High	High	High	Unclear
Rolls *et al.* (1988)	Low	High	Low	Low	Low	High	High	Unclear
St-Onge *et al.* (2014)	Low	High	Low	High	High	Low	Low	Unclear
Stubbs and Harbron (1996)	Unclear	High	Unclear	Unclear	Unclear	Unclear	High	Unclear
Valente *et al.* (2017)	Low	High	Low	High	High	Low	Low	Unclear

Van Wymelbeke *et al.* (1998)	Low	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear
Van Wymelbeke *et al.* (2001)	Low	High	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear

Table 3. Characteristics and main outcomes of studies comparing LCT to MCT included in systematic review.

Reference	n	Gender (M/F)	Characteristics	Study design	Lipids used	Test meal	Time between test meal and *ad libitum* meal	Energy Intake	Postprandial Appetite Method – analysis Parameters	Hormone Measures
Barbera *et al.* (2000)	9	6/3	Age: 20-56 y	Randomised crossover duodenal infusion study	0.9% Saline *then* 20% LCT emulsion 20% MCT emulsion	Infusions Total energy: 250.6 kJ	NA	NA	VAS – mm Duration: immediately after infusions Satiation* ↑ in LCT Fullness Abdominal Bloating Nausea* ↑ in LCT Pain	Somatostatin PP* ↑ in LCT CCK* ↑ in LCT GIP* ↑ in LCT Neurotensin* ↑ in LCT
Clegg, Golsorkhi and Henry (2013)	7	1/6	Age: 26 ± 4 y W: 62.5 ± 7.5 kg H: 1.69 ± 0.09 m	Randomised acute crossover postprandial feeding study	Sunflower oil (18.40 g) MCT oil (20.00 g	Fried breakfast containing: Pepper and sunflower oil Pepper and MCT oil Chilli and sunflower oil Chilli and MCT oil Total energy: 449 kJ	NA	NA	Duration: 240 min Hunger Fullness Desire to Eat Prospective Food Consumption *Gastrointestinal comfort* Nausea Belching Bloatedness Headache Cramping	NA
Clegg *et al.* (2012)	10	2/8	Age: 26 ± 4 y W: 61.8 ± 9.6 kg H: 1.70 ± 0.09 m	Randomised acute crossover postprandial feeding study	Sunflower oil (24.40 g) Olive Oil (24.40 g) Butter (26.90 g) MCT oil (24.30 g) Control (no oil added)	Pancakes Total energy: 2523 kJ	NA	NA	Duration: 240 min Hunger Fullness Desire to Eat Prospective Food* ↑ in butter compared to LCT Consumption *No other differences between MCT and any LCT condition*	NA
Coleman, Quinn and Clegg (2016)	19	7/12	Age: 31 ± 18 y W: 68.6 ± 11.7 kg H: 1.69 ± 0.11 m	Randomised acute crossover postprandial feeding study	Vegetable oil (22.00 g) CLA and vegetable oil (5.00 g CLA, 16.00 g vegetable oil) MCT (25.00 g)	Mango and passionfruit smoothie Total energy: 1323 kJ	300 min	*Ad libitum* lunch CON: 3343 ± 870 kJ CLA: 3051 ± 789 kJ MCT: 3051 ± 766 kJ Diet diary CON: 4905 ± 1919 kJ* CLA: 2931 ± 1346 kJ* MCT: 2708 ± 1314 kJ Total days intake CON: 8248 ± 2790 kJ CLA: 5891 ± 2135 kJ* MCT: 5759 ± 2080 kJ*	Duration: 60 min Hunger Fullness Desire to Eat Prospective Food Consumption	NA

Reference	Participants			Study information					Outcomes		
	n	Gender (M/F)	Characteristics	Study design	Lipids used	Test meal	Time between test meal and *ad libitum* meal	Energy Intake	Method – analysis Parameters		Hormone Measures
Feltrin *et al.* (2008)	13	13/0	Age: 26 ± 2 y BMI: 22.9 ± 0.6 kg/m²	Randomised double-blind crossover duodenal infusion study	0.9% saline (control) Oleic acid (C18, 4.88 g) Lauric acid (C12, 4.52 g)	Infusions at a rate of 1.569 kJ min⁻¹ Total energy: 100 kJ	60 min	*Ad libitum* brunch CON: 5293 ± 385 kJ C18: 4745 ± 335 kJ C12: 5226 ± 301 kJ†	VAS – mm Duration: 60 min Hunger Fullness Nausea Bloating		CCK*† ↑ in both C18 and C12 compared to control ↑ in C18 compared to C12 PYY*† ↑ in both C18 and C12 compared to Con. ↑ in C18 compared to C12
Feltrin *et al.* (2004)	8	8/0	Age: 24 ± 4 y BMI: 22.0 ± 1.6 kg/m²	Randomised double-blind crossover duodenal infusion study	CON (distilled water) Decanoic acid (C10) Lauric acid (C12)	Infusions at a rate of 1.569 kJ min⁻¹ Total energy: 141 kJ	90 min	*Ad libitum* brunch Control: 4604 ± 464 kJ C10: 4109 ± 589 kJ C12: 1747 ± 633 kJ†	VAS – mm Duration: 90 min Hunger† ↓ in Lauric acid Fullness Desire to eat† ↓ in Lauric acid Prospective Food Consumption Nausea Bloating		CCK*† ↑ in both C10 and C12 compared to control ↑ in C12 compared to C10 GIP* ↑ in C12 compared to both C10 and control.
Kinsella, Maher and Clegg (2017)	24	6/18	Age: 28 ± 6 y W: 64.5 ± 8.5 kg H: 1.68 ± 0.07 m BMI: 22.9 ± 2.4 kg/m²	Randomised acute crossover postprandial feeding study	CON: Vegetable oil (23.00 g) CO (26.00 g) MCT oil (25.00 g)	*Mango and passionfruit smoothie* Total energy: 1456 kJ	180 min	*Ad libitum* lunch CON: 7023 ± 2084 kJ CO: 6738 ± 2099 kJ* MCT: 6011 ± 2397 kJ† Total days intake CON: 12518 ± 2995 kJ CO: 11338 ± 2284 kJ* MCT: 10722 ± 3841 kJ*	VAS - AUC Duration: 180 min Hunger Fullness† ↑ in MCT Desire to Eat Prospective Food Consumption		NA
Krotkiewski (2001)	66	0/66	*Low-fat group* Age: 45 ± 3 y W: 94.6 ± 2.8 kg H: 1.69 ± 0.04 m BMI: 33.1 ± 0.6 kg/m² *LCT group* Age: 43 ± 4 y W: 95.6 ± 2.4 kg H: 1.68 ± 0.04 m BMI: 34.1 ± 0.5 kg/m² *MCT group* Age: 43 ± 4 y W: 95.5 ± 2.6 kg H: 1.69 ± 0.04 m BMI: 34.1 ± 0.3 kg/m²	Group matched 4-week dietary intervention	*Very low-calorie diet (2420.9 kJ/d) with either* Low fat (control) (2.70 g) LCT (7.92 g) MCT (8.91 g)	NA	NA	NA	Duration: 120 min Hunger* ↓ in MCT Fullness* ↑ in MCT Appetite* ↓ in MCT Prospective Food Consumption		NA

Reference	Participants			Study information				Outcomes		
	n	Gender (M/F)	Characteristics	Study design	Lipids used	Test meal	Time between test meal and *ad libitum* meal	Energy Intake	<mark>Postprandial Appetite</mark> Method – analysis Parameters	Hormone Measures
Poppit et al. (2010)	18	18/0	Age: 27 ± 9 y W: 73.4 ± 10.0 kg BMI: 22.8 ± 1.8 kg/m²	Randomised acute crossover postprandial feeding study	High-LCT: Beef tallow (52 g) High-MCT: Coconut oil (10 g coconut oil, 42 g LCT) High-SCT: Soft fraction milk fat (3 g SCT, 7 g MCT, 42 g LCT)	Savoury breakfast muffins Total energy: 3315 kJ	210 min	*Ad libitum* lunch High-LCT: 4490 ± 324 kJ High-MCT: 4422 ± 306 kJ High-SCT: 4406 ± 366 kJ	VAS – mm <mark>Duration: 390 min</mark> Hunger Fullness Prospective Food Consumption, Nausea	NA
Rizzo *et al.* (2016)	36	0/36	Age: 29.7 ± 4 y W: 66.4 ± 4.9 kg H: 1.50 ± 0.06 m BMI: 21.7 ± 0.1 kg/m²	Randomised acute crossover postprandial feeding study	High CO: 75%CO:25%SO Equal: 50:50 High SO: 75%SO:25%CO	*Ice cream containing different ratios of CO and SO* Total energy: 1130 kJ	45 min	*Ad libitum* dinner High-CO: 7881 ± 504 kJ Equal: 8190 ± 503 kJ High-SO: 8287 ± 518 kJ *Ad libitum* snacks High-CO: 2069 ± 276 kJ * Equal: 1548 ± 180 kJ High-SO: 1573 ± 201 kJ	VAS - AUC <mark>Duration: 480 min</mark> Hunger Fullness Desire to Eat Prospective Food Consumption Satisfaction	NA
Rolls *et al.* (1988)	24	0/24	*Dieters* Age: 27 ± 2 y W: 68.9 ± 4.5 kg H: 1.69 ± 0.02 m *Non-dieters* Age: 28 ± 2 y W: 55.3 ± 1.7 kg H: 1.67 ± 0.01 m	Randomised acute crossover postprandial feeding study	418.4 kJ (11.11 g LCT, 12.04 g MCT) 836.8 kJ (22.22 g LCT, 24.09 g MCT) 1255.2 kJ (33.33 g LCT, 31.14 g MCT)	*30% fat liquid preload. Three doses of each* Energy density of the drinks: 3.47 kJ/100 mL	30 min	*Ad libitum* lunch (non-dieters) LCT: 418.4 kJ: 563.2 ± 54.6 g 836.8 kJ: 495.6 ± 64.4 g 1255.2 kJ: 510.3 ± 71.5 g MCT: 418.4 kJ: 535.3 ± 71.2 g* 836.8 kJ: 455.7 ± 56.4 g* 1255.2 kJ: 413.5 ± 52.1 g* *Ad libitum* lunch (dieters) 418.4 kJ: 590.5 ± 38.1 g 836.8 kJ: 466.8 ± 73.8 g 1255.2 kJ: 483.3 ± 65.3 g MCT: 418.4 kJ: 539.6 ± 66.0 g 836.8 kJ: 446.8 ± 47.2 g 1255.2 kJ: 432.8 ± 42.1 g	VAS – mm <mark>Duration: 30 min</mark> Hunger Desire to Eat Stomach Fullness Gastric aching* ↑ in MCT	NA
St-Onge *et al.* (2014)	17	*Study 1* 10/0 *Study 2* 7/0	*Study 1* Age: 29.7 ± 4 y W: 87.1 ± 1.7 kg H: 1.76 ± 0.01 m BMI: 28.2 ± 0.01 kg/m² *Study 2* Age: 39.6 ± 2.1 y W: 91.9 ± 5.1 kg H: 1.79 ± 0.04 m BMI: 28.4 ± 0.5 kg/m²	Two randomised, acute crossover postprandial feeding studies	*Study 1:* LCT: 20.0 g MCT: 20.0 g *Study 2:* 3h after breakfast LCT: 10.0 g MCT: 10.0 g	*Study 1* Muffin and orange juice Total energy: 2671 kJ *Study 2* Liquid meal replacement, and a yoghurt preload Total energy: 2510 kJ (breakfast) 728 kJ (preload)	*Study 1* 180 min *Study 2* 60 min	*Ad libitum* lunch Study 1 LCT: 2773 ± 532 kJ MCT: 2548 ± 457 kJ Study 2 LCT: 3369 ± 769 kJ MCT: 2227 ± 616 kJ*	NA	*Study 1* No significant differences *Study 2* Active ghrelin* ↑ in MCT Leptin* ↑ in MCT *Combined analysis* Leptin* ↑ in MCT PYY* ↑ in MCT

Reference	Participants			Study information					Outcomes		
	n	Gender (M/F)	Characteristics	Study design	Lipids used	Test meal	Time between test meal and *ad libitum* meal	Energy Intake	**Postprandial Appetite** Method – analysis Parameters		Hormone Measures
Stubbs and Harbon (1996)	6	6/0	Age: 27 ± 4 y W: 63.3 ± 7.3 kg H: 1.72 ± 0.05 m	Randomised crossover study, each arm consisting of a 14-day dietary manipulation	High energy (639 kJ/100 g) diets containing 62:28:10 percentage fat, carbohydrate and fat. Ratios of MCT:LCT were: Low MCT: 1:2 (35.8 g/1000g of food) Medium MCT: 1:1 (55.5 g MCT per 1000g of food) High MCT: 2:1 (73.2 g MCT per 1000g of food)	NA	NA	*Daily habitual energy intake* Low MCT: 13.5 ± 1.8 MJ Medium MCT: 13.7 ± 1.6 MJ High MCT: 12.4 ± 1.5 MJ†	VAS – mm Duration: 15 min after each meal Pleasantness of food Satisfaction* ↑ In High MCT		NA
Valente *et al.* (2017)	15	0/15	Age: 27 ± 1 y BMI: 27.7 ± 0.4 kg/m^2	Randomised acute crossover postprandial feeding study	25.00 mL EVOO 25.00 mL VCO	White bread and a strawberry milkshake Total energy: 2067 kJ	NA	NA	VAS - iAUC Duration: 240 min Hunger* ↑ in VCO Fullness* ↓ in VCO Satisfaction* ↓ in VCO Desire to eat something sweet Desire to eat something salty Desire to eat something savoury Desire to eat something fatty		NA
Van Wymelbeke *et al.* (1998)	12	12/0	Age: 21 ± 2 y BMI: 21.7 ± 1.6 kg/m^2	Randomised acute crossover postprandial feeding study	70 kJ fat substitute *or* 1460 kJ from different fats: Saturated LCT (from 42 g lard) Monounsaturated LCT (from 40 g olive oil) MCT (from 43 g of Ceres MCT oil)	Pasta and tomato sauce Total energy: 3130 kJ (LCT-S, LCT-U, MCT) 1740 kJ (Sub)	*Time to meal request* *Breakfast to lunch* Sub: 252.0 ± 10.0 mins LCT-S: 285.0 ± 14.3 mins LCT-U: 273.0 ± 9.8 mins MCT: 286.0 ± 16.6 mins *Lunch to dinner* Sub: 350.0 ± 11.9 mins LCT-S: 334 ± 15.5 mins LCT-U: 331.0 ± 16.8 mins MCT: 320 ± 8.0 mins	*Ad libitum* lunch Sub: 3715 ± 246 kJ LCT-S: 3798 ± 207 kJ LCT-U: 3278 ± 328 kJ MCT: 3100 ± 277 kJ Diet diary Sub: 8028 ± 558 kJ LCT-S: 8522 ± 466 kJ LCT-U: 8787 ± 500 kJ MCT: 8414 ± 466 kJ	VAS - mm Duration: 150 min (breakfast to lunch) Duration: 240 min (lunch to dinner) Hunger		NA

Reference	Participants			Study information					Outcomes		
	n	Gender (M/F)	Characteristics	Study design	Lipids used	Test meal	Time between test meal and *ad libitum* meal	Energy Intake	Postprandial Appetite Method – analysis Parameters		Hormone Measures
Van Wymelbeke *et al.* (2001)	10	10/0	Age: 22 ± 0.6 y BMI: 21.9 ± 1.7 kg/m²	Randomised acute crossover postprandial feeding study	40 kJ fat substitute (Sub) 32 g LCT 35 g MCT 53 g CHO and 8 g LCT (CHO)	Potato flakes, mashed carrots, apple sauce Total energy: 3510 kJ (LCT, MCT, CHO) 2380 kJ (Sub)	*Time to meal request* Sub: 362.6 ± 18.0 mins LCT: 364.3 ± 11.0 mins MCT: 372.4 ± 13.0 mins CHO: 413 ± 22 mins	*Ad libitum* dinner Sub: 4375 ± 262 kJ LCT: 4143 ± 390 kJ* MCT: 3602 ± 258 kJ* CHO: 4351 ± 373 kJ	VAS - iAUC Duration: 300 min Hunger		NA

LCT: long-chain triglycerides; MCT: medium-chain triglycerides; PP: pancreatic polypeptide; CCK: cholecystokinin; GIP: gastric-inhibitory peptide; CON: control, CLA: conjugated linoleic acid; PYY: peptide YY; CO: coconut oil; SCT: short-chain triglycerides; SO: sunflower oil; EVOO: extra virgin olive oil; VCO: virgin coconut oil; CHO: carbohydrate; AUC: area under the curve; iAUC: incremental area under the curve; VAS: visual analogue scale; mm: millimetre; NA: Not assessed.

↑ denotes increased or greater; ↓ denotes decreased or lesser.

* - Different from Control/LCT or lowest dose/concentration ($p < 0.05$).

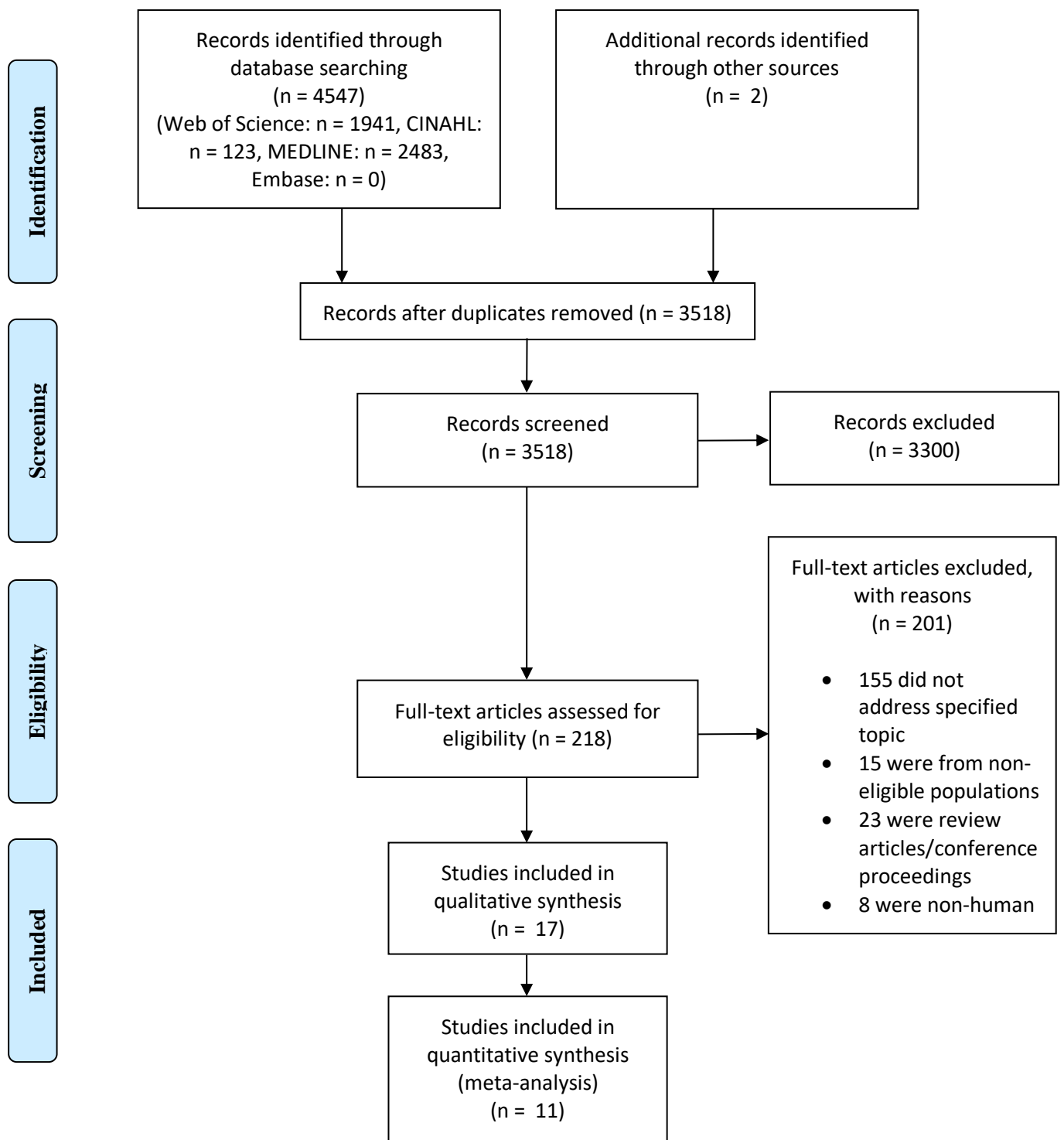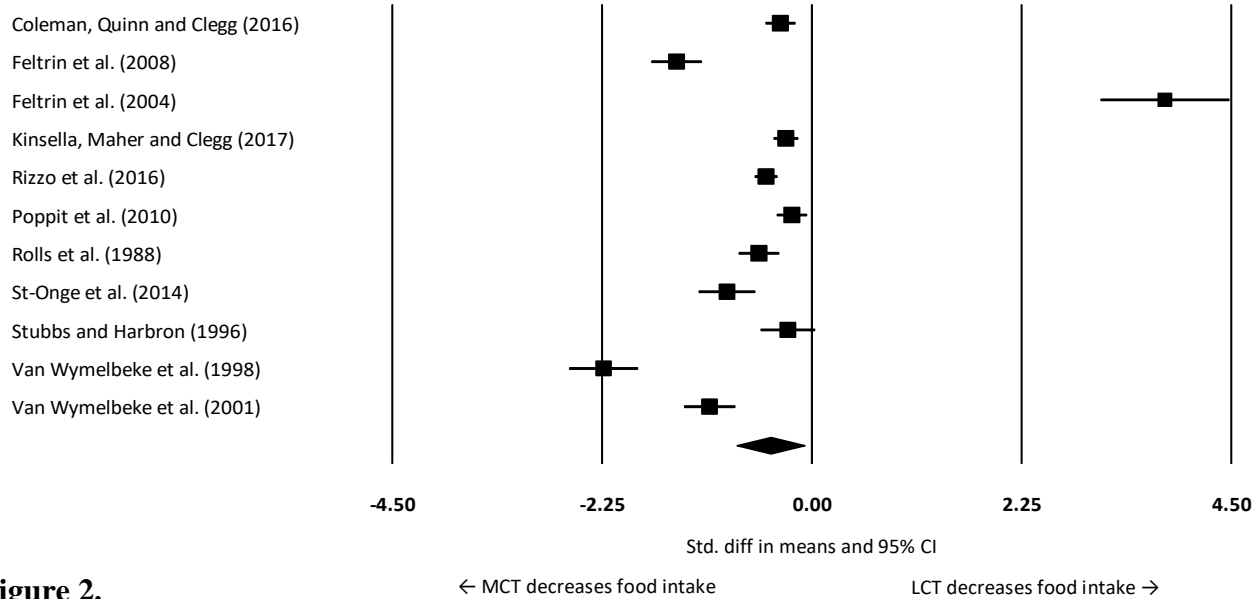† - Different from all other trials ($p < 0.05$).

Identification

Records identified through database searching
(n = 4547)
(Web of Science: n = 1941, CINAHL: n = 123, MEDLINE: n = 2483, Embase: n = 0)

Additional records identified through other sources
(n = 2)

Screening

Records after duplicates removed (n = 3518)

Records screened
(n = 3518)

Records excluded
(n = 3300)

Eligibility

Full-text articles assessed for eligibility (n = 218)

Full-text articles excluded, with reasons
(n = 201)

- 155 did not address specified topic
- 15 were from non-eligible populations
- 23 were review articles/conference proceedings
- 8 were non-human

Included

Studies included in qualitative synthesis
(n = 17)

Studies included in quantitative synthesis (meta-analysis)
(n = 11)

Figure 1.

Figure 2.

Std. diff in means and 95% CI

← MCT decreases food intake   LCT decreases food intake →
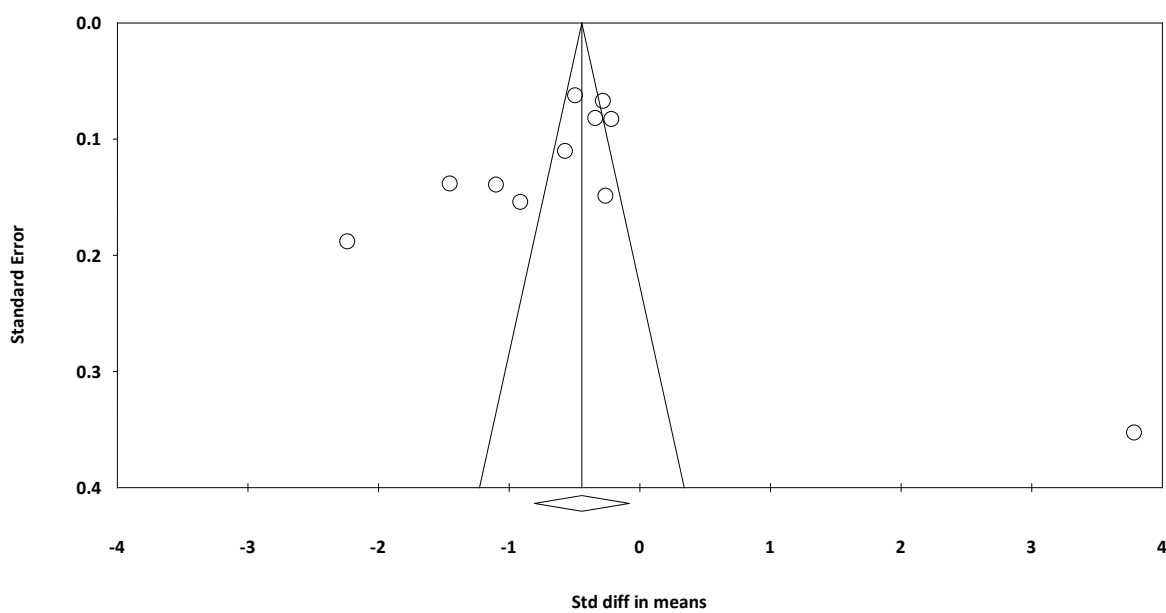

Figure 3.

Figure captions

Figure 1. Flowchart of methodology used for identifying studies included in the systematic review.

Figure 2. Forrest plot of effects sizes (means ± 95% confidence intervals) for studies examining the effect of MCT compared with LCT on energy intake using a random effects model.

Figure 3. Funnel plot of standard error by standard difference in means for studies evaluating the influence of MCT on energy intake (acute *ad libitum* intake: $n = 10$; habitual daily intake: $n = 1$).

Supplementary table 1. Individual study statistics for studies examining energy intake

Study	Standard difference in means	Standard error	Variance	Lower 95% confidence interval	Upper 95% confidence interval	Z-value	p-value	Weight (%)
Coleman, Quinn and Clegg (2016)	-0.336	0.082	0.007	-0.497	-0.175	-4.080	<0.0001	9.50
Feltrin *et al.* (2008)	-1.451	0.139	0.019	-1.723	-1.179	-10.454	<0.0001	9.18
Feltrin *et al.* (2004)	3.789	0.353	0.125	3.096	4.481	10.729	<0.0001	7.17
Kinsella, Maher and Clegg (2017)	-0.278	0.068	0.005	-0.411	-0.146	-4.116	<0.0001	9.56
Rizzo *et al.* (2016)	-0.491	0.063	0.004	-0.614	-0.367	-7.806	<0.0001	9.58
Poppit *et al.* (2010)	-0.213	0.083	0.007	-0.376	-0.050	-2.560	0.010	9.50
Rolls *et al.* (1988)	-0.568	0.111	0.012	-0.785	-0.351	-5.127	0.001	9.36
St-Onge *et al.* (2014)	-0.911	0.155	0.024	-1.214	-0.608	-5.890	<0.0001	9.07
Stubbs and Harbron (1996)	-0.258	0.149	0.022	-0.511	-0.035	-1.728	0.015	9.11
Van Wymelbeke *et al.* (1998)	-2.235	0.189	0.036	-2.605	-1.865	-11.852	<0.0001	8.80
Van Wymelbeke *et al.* (2001)	-1.096	0.140	0.020	-1.370	-0.822	-7.844	<0.0001	9.18
Mean	-.444	0.185	0.034	-0.808	-0.080	-2.394	0.017	