Are large dinners associated with excess weight, and does eating a smaller dinner achieve greater weight loss? A systematic review and meta-analysis

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Abstract

There are suggestions that large evening meals are associated with greater BMI. This study reviewed systematically the association between evening energy intake and weight in adults and aimed to determine whether reducing evening intake achieves weight loss. Databases searched were MEDLINE, PubMed, Cinahl, Web of Science, Cochrane Library of Clinical Trials, EMBASE and SCOPUS. Eligible observational studies investigated the relationship between BMI and evening energy intake. Eligible intervention trials compared weight change between groups where the proportion of evening intake was manipulated. Evening intake was defined as energy consumed during a certain time – for example 18.00–21.00 hours – or self-defined meal slots – that is 'dinner'. The search yielded 121 full texts that were reviewed for eligibility by two independent reviewers. In all, ten observational studies and eight clinical trials were included in the systematic review with four and five included in the meta-analyses, respectively. Four observational studies showed a positive association between large evening intake and BMI, five showed no association and one showed an inverse relationship. The meta-analysis of observational studies showed a non-significant trend between BMI and evening intake ($P = 0.06$). The meta-analysis of intervention trials showed no difference in weight change between small and large dinner groups (-0.89 kg; 95 % CI -2.52, 0.75, $P = 0.29$). This analysis was limited by significant heterogeneity, and many trials had an unknown or high risk of bias. Recommendations to reduce evening intake for weight loss cannot be substantiated by clinical evidence, and more well-controlled intervention trials are needed.

Key words: Obesity: Meal timings: Meal patterns: Circadian rhythms: Energy intakes: Weight loss

Standard weight loss interventions focus on creating an energy deficit by energy intake restriction and increasing physical activity. Although body weight is ultimately determined by total energy intake and total energy expenditure, recent hypotheses suggest that not only what and how much one eats but *when* one eats plays a role in weight regulation[1–3]. As such, the circadian system has emerged as a growing area of interest in obesity research.

Circadian rhythms are centrally regulated by the 'master' oscillator, located within the suprachiasmatic nuclei (SCN) of the anterior hypothalamus[4], and coordinate processes including sleep/wake rhythms, core body temperature and melatonin secretion[5]. The SCN also synchronises downstream, 'peripheral' clocks distributed throughout the body's various tissues[6,7], which regulate the circadian expression and activity of enzymes and hormones involved in nutritional physiology and metabolism[7,8].

Although evidence suggests that nocturnal eating can result in metabolic disruption[9–11], so far there is no recommendation for the optimal distribution of daily energy intake. Over time, there has been a reduction in daytime energy intake with

a commensurate increase in mid-afternoon and evening intakes[12]. As foods and beverages consumed in the evening tend to be more energy dense[13], dinner is typically the most energy-dense meal of the day[14]. Large evening intake may be driven by several factors. First, time constraints imposed by regularised work hours during the day means that there is more time for meal preparation and eating in the evening. Second, during work hours, individuals may find that they can attenuate or ignore their hunger sensations as their attention is held by other activities – that is work tasks[15]. Heightened evening subjective hunger may also drive larger evening intake, with one study observing a peak in the evening (around 20.00 hours) and trough in the morning (around 08.00 hours) among non-obese adults[16]. However, there is little complementary literature to support this observation[17]. It is possible that habitual intake may entrain hunger such that anticipation of food at certain times of day elicits an appetitive response[18]. Consuming large evening meals habitually may entrain increased evening hunger. Further, after a large evening meal, the individual may not be in a totally post-absorptive state the following morning, resulting in reduced breakfast intake and

further perpetuation of the eating pattern. Last, the notion that dinner ought to be the most substantial meal of the day is a sociocultural norm that persists in 'Anglo' culture.

Research also suggests that energy metabolism is less efficient during the evening. It has been observed that morning-diet-induced thermogenesis (DIT) is significantly higher than afternoon[19] and night DIT[20], which may be due to reduced nocturnal insulin sensitivity[21]. Moreover, fat oxidation is lower in the evening compared with that in the morning[22,23]. These physiological mechanisms coupled with factors that drive greater evening consumption may play a role in obesity aetiology.

Previous studies[24,25] have found that individuals with obesity consume a greater proportion of daily energy intake in the evening. A recent publication[26] reviewed observational studies examining global trends in time-of-day energy intake and its association with obesity. The ten full-text articles included reported on studies in adults (n 5), children (n 4) or both (n 1) and the association between time-of-day energy intake and obesity. They concluded that there is limited evidence of this association. Despite this, the idea of eating 'breakfast like a king' and 'dinner like a pauper' remains a commonly held belief.

The current review will build on the previous review by also including and examining clinical trials. Its aims were (1) to review the association between large evening energy intake and weight/BMI in adults and (2) to determine the effectiveness of reducing the evening energy intake for weight loss.

Methods

Inclusion and exclusion criteria for observational studies

Observational study designs included in this review were cohort studies, cross-sectional studies and case–control studies. Only original research studies were included; review articles, case studies, surveys, abstracts and conference papers were excluded but the references of review articles were searched for further studies. In the instance in which cross-sectional data from a cohort study were reviewed, data from the most recent time point were used.

To be included in the review, publications must have studied adults (≥18 years of age). Children (<18 years of age) were excluded as their dietary patterns are heavily influenced by parental eating behaviours. The variable of interest was the proportion of daily energy consumed in the 'evening'. Included studies needed to quantify the proportion of daily energy intake consumed in the evening period – for example quantiles, proportion of total daily energy intake (TDEI) or the published data allowed for its calculation. Outcome measures of interest were weight, BMI or a measure of association between end-of-day energy intake and weight – that is OR, correlation coefficient.

As there is no standard definition of 'evening' intake, a range of definitions deemed appropriate by the reviewers were used and these are presented in Table 1. There was no limit placed on the year of publication. Studies were excluded if participants did shift work. Participants with night eating syndrome (NES) were also excluded as dietary behaviours of NES patients were

considered beyond the scope of 'normal' eating. The criteria for NES according to the Diagnostic and Statistical Manual of Mental Disorders 5 (DSM-5) is defined as '…eating after awakening from sleep or by excessive food consumption after the evening meal…The night eating causes significant distress and/or impairment in functioning. The disordered pattern of eating is not better explained by binge-eating disorder or another mental disorder, including substance use, and is not attributable to another medical disorder or to an effect of medication'. Exclusion of NES participants was intended to enhance the generalisability of results. Studies investigating Ramadan fasting (nil by mouth from dawn to sunset) were also excluded.

Inclusion and exclusion criteria for meta-analysis of observational studies

In addition to the above criteria, observational studies included in the meta-analysis needed to report BMI and standard deviations of groups with high and low evening energy intake.

Inclusion and exclusion criteria for clinical trials

Only original research studies were included; review articles, abstracts and conference papers were excluded but the references of review articles were searched for further studies. To be included in the review, trials must have met the following criteria:

(1) the trial should have studied adults (≥18 years of age);
(2) it should be a randomised or a non-randomised clinical trial;
(3) it should have compared at least two treatment arms whereby the distribution of circadian energy intake was the manipulated variable;
(4) it should have daily energy prescriptions that were isoenergetic between treatment arms or standardised on the basis of participants' estimated energy requirements;
(5) it should have weight change as an outcome measure; and
(6) it did not include participants who were shift workers, those with NES or used a forced desynchrony protocol.

Inclusion and exclusion criteria for meta-analysis of clinical trials

In addition to the above criteria, trials included in the meta-analysis had to use an intervention of a hypoenergetic diet for at least 4 weeks, as this was considered sufficient time to observe weight loss. The participants, intervention, comparator and outcomes for trials included in the meta-analysis are given in Table 2.

Search strategy

Databases included in this search were MEDLINE, PubMed, Cinahl, Web of Science, Cochrane Library of Clinical Trials, EMBASE and SCOPUS from their inception to May 2016. Both MeSH and free text search terms were used. All languages were included and papers in languages other than English were translated. Limits were set so that only studies involving humans

Table 1. Characteristics of observational studies*
(Mean values and standard deviations; mean values with their standard errors; odds ratios and 95 % confidence intervals)

First author, year	Sample size (n) and participant characteristics	Study design	Definition of 'evening' intake	Dietary assessment method	Self-reported energy intake validation	Exposed group	Comparator group	Outcome measure	Outcome assessment method	Results
Aljuraiban et al., 2015[44]	n 2385 48 % female; mean age = 48·9 (SD 5·4) years; mean BMI = 28·3 (SD 4·9) kg/m² Participants were excluded if they potentially under-reported energy intake and did not attend all four visits	Cross-sectional	Morning intake: energy intake from 06.00 to 11.55 hours; evening intake: energy intake from 18.00 to 23.55 hours	Four standardised 24-h recalls by trained dietary interviewers. 2 recalls on consecutive days, and then again 3 weeks later. The average of the 4 d was calculated	The ratio of estimated energy intake: predicted BMR based on the Schofield equation was calculated. Identification of under-reporters was based on a ratio of energy intake to estimated energy expenditure	Evening:morning intake ratio ≥2·0 (fourth quartile) (n 595)	Evening morning intake ratio <1·0 (first quartile) (n 594)	BMI (kg/m²)	Measured height and weight. BMI calculated using average of two sets of height and weight measurements	Exposed: 28·7 (SD 11·2) Comparator: 27·5 (SD 10·0) Significance: P = 0·08
Almoosawi et al., 2013[45]	n 1253; 51 % female; mean age = 43 years; mean BMI not specified	Cohort (data analysed are cross-sectional)	Participants allocated all foods and beverages to predefined meal slots while completing food diary. Evening intake encompassed 'dinner' and 'late evening' time slots	5-d estimated diet diary using household measures and photographs to estimate portion sizes	Not validated	Fifth quintile for % TDEI consumed at dinner and late evening (n 250)	First quintile for % TDEI consumed at dinner and late evening (n 250)	BMI (kg/m²)	Measured height and weight	Dinner – exposed: 24·4 (SD 3·6); comparator: 24·5 (SD 3·6; significance: P = 0·112 Late evening: exposed: 23·7 (SD 3·6); comparator: 23·5 (SD 3·6); significance: P = 0·241
Baron et al.[52]	n 52; 48 % female; mean age = 31 (SD 12) years; mean BMI = 24·7 (SD 4·9) kg/m²	Cross-sectional	Energy intake after 20.00 hours	7-d estimated food diary	Not validated	Energy intake after 20.00 hours	Energy intake after 20.00 hours	Correlation with BMI (kg/m²)	Self-reported height and weight	Correlation: 0·37 Significance: P < 0·01
Bo et al., 2014[50]	n 1245; sex not specified, age range = 45–64 years; mean BMI = 24·8 (SD 2·8) kg/m²	Cohort (data analysed are cross-sectional)	Dinner: energy intake from 19.00 to 22 00 hours	3-d estimated diet diary using photos and measuring guides to assist portion size estimation	The ratio of estimated energy intake: predicted BMR based on the Schofield equation was calculated. Subjects with a ratio of <0·88 were classified as under-reporters	Third tertile of dinner intake (≥48 % TDEI) (n 404)	First tertile of dinner intake (<33 % TDEI) (n 423)	BMI (kg/m²) at 6 year follow-up	Measured height and weight	Exposed: 25·5 (SD 3·2) Comparator: 24·8 (SD 3·1) Significance: P < 0·01
Kant et al., 1995[51]	n 1802; women only: mean age = 35 (SD 0·3) years; mean BMI = 24·4 (SD 0·4) kg/m²	Cross-sectional	Energy intake from 17.00 hours to the last reported time	24-h food recall	Not validated	Third tertile of evening intake (n 601)	First tertile of evening intake (n 600)	BMI (kg/m²)	Self-reported height and weight	Exposed: 24·6 (SD 12·7) Comparator: 24·4 (SD 8·5) Significance: P > 0·05
Kant et al., 2006[13]	n 39 094; 5·14 % female; age range = 25–74 years; mean BMI not specified	Repeated cross-sectional	Energy intake from 17.00 hours to the last reported eating episode	24-h food recall	Not validated	% TDEI from evening intake (n not specified)	NA	Correlation coefficient (β)	Measured height and weight	− 0·0005 (SE 0·001) Significance: P = 0·6

Table 1. *Continued*

First author, year	Sample size (n) and participant characteristics	Study design	Definition of 'evening' intake	Dietary assessment method	Self-reported energy intake validation	Exposed group	Comparator group	Outcome measure	Outcome assessment method	Results
Morse *et al.*, 2006[46]	n 714; 56 % female; mean age unable to be determined; 32·1 % participants obese (BMI > 30 kg/m²) and with type 1 or type 2 diabetes mellitus	Cross-sectional	Energy intake after 'suppertime'	Single question used to determine the amount of daily food intake that participants consumed after 'suppertime'	Not validated	> 25 % TDEI after 'suppertime' (n 68)	≤ 25 % TDEI after 'suppertime' (n 645)	OR of obesity	Self-reported BMI	Exposed: 2·6; 95 % CI 1·5–4·5 Comparator: 1·0
Striegel-Moore *et al.*, 2006[47]	n 29 148; 52 % female; mean age unable to be determined; mean BMI not specified	Cross-sectional	Energy intake between 19.00 and 04.59 hours the following morning	NHANES data set: 24-h food recall CSFII data set: two 24-h food recalls three to 10 d apart, but only the 1st day was used for analysis	Not validated	≥ 25 % TDEI during the evening (n not specified)	<25 % TDEI during the evening (n not specified)	Difference in BMI between exposed and comparator groups	NHANES data set: measured height and weight; CFSII data set: self-reported height and weight	Exposed: BMI of exposed group = − 0·44 kg/m² less than BMI of comparator group (for NHANES III data only) significance: not specified
Summerbell *et al.*, 1996[49]	n 187; mean age unable to be determined; mean BMI for working age = 22·3 (SD 1·6) kg/m²; middle-aged = 25·2 (SD 4·5) kg/m²; elderly = 23·7 (SD 5·8) kg/m²	Cross-sectional	Energy intake during the 'evening meal' and 'evening snacks' as determined by the investigator who coded the 7-d food diaries	7-d weighed food diary	Validated by calculating the mean physical activity level (PAL) and BMR from the Schofield equation. PAL values below 1·10 were defined as invalid and those above 1·09 were defined as valid	Third tertile of evening energy intake (n approximately 20 for working age, n approximately 13 for middle-aged, n approximately 30 for elderly)	First tertile of evening energy intake (n approximately 20 for working age, n approximately 13 for middle-aged, n approximately 30 for elderly)	BMI (kg/m²)	Unsure as publication only states that BMI was 'assessed'	All participants: working age = 22·3 *v.* 22·3, middle-aged = 24·1 *v.* 26·5, elderly = 23·4 *v.* 23·6; significance: not significant (*P* > 0·05) Valid diaries only: working age = 22·2 *v.* 22·4, middle-aged = 22·7 *v.* 25·8, elderly = 22·8 *v.* 23·7; significance: Not significant (*P* > 0·05)
Wang *et al.*, 2014[48]	n 326; 65 % female; mean age unable to be determined; mean BMI unable to be determined	Cross-sectional	Energy intake from 17.00 to 00.00 hours	Eight web-based 24-h food recalls. Mean energy intakes calculated from three 24-h food recalls completed within 2 week administration of doubly labelled water (Day 3, Day 5 and Day 13)	Total energy expenditure (TEE) measured using doubly labelled water. True reporters were those whose self-reported energy intake was ± total energy expenditure	≥ 33 % EI during the evening (n 72)	<33 % EI during the evening (n 176)	OR of being overweight or obese (BMI ≥ 25 kg/m²)	Measured height and weight. BMI calculated using average of two sets of height and weight measurements	Exposed (total sample): 2·00; 95 % CI 1·03, 3·89 Comparator: 1·0 Exposed (true reporters): 2·10; 95 % CI 0·60, 7·29 Comparator: 1·0

TDEI, total daily energy intake; NHANES, National Health and Nutrition Examination Survey; CFSII, Continuing Survey of Food Intakes by Individuals; EI, energy intake.
* Time is 24 h (00.00 hours).

Table 2. PICO clinical question for clinical trials to be included in the meta-analysis

P – participants	Adults (≥18 years old)
I – intervention	Hypoenergetic (weight loss) diet where a smaller proportion of TDEI is consumed in the evening for ≥4 weeks
C – comparator group	Hypoenergetic (weight loss) diet where a greater proportion of TDEI is consumed in the evening for ≥4 weeks or hypoenergetic (weight loss) diet where TDEI is consumed as multiple meals throughout the day
O – outcome	Weight change from baseline to end of intervention

TDEI, total daily energy intake.

and adults were included. Reference lists of all relevant articles, as well as review articles, were searched to ensure that all relevant studies were found. The following example shows the specific key words (or MeSH terms) used for the search of MEDLINE: anag* or balanc* or reduc* or chang*)).tw. OR obesity/ OR body weight/ Or body mass index/ OR weight gain/ OR weight reduction/ OR weight loss.tw OR energy metabolism/ OR overweight/ Or body composition/ OR fat free adj2 free.tw OR adiposity/ OR waist circumference/ OR weight reduction programs/.

The example search strategy for MEDLINE (above) was adapted to suit each database. The full search strategy used for MEDLINE is available in the online Supplementary Material.

Data extraction and analysis

Two authors (M. F. and C. D. M.) screened the titles and abstracts of the studies identified in the above search independently. The full texts of potentially relevant studies were retrieved and were screened by the same authors independently (M. F. and C. D. M.) according to the inclusion and exclusion criteria. Additional articles from other sources known to authors were also included in this review if appropriate – that is from conference attendance and if full texts were available. Authors were contacted if further information was required.

M. F. (author) extracted the following data from each observational study, as summarised in Table 1: author, year, sample size, participant characteristics (sex, age, BMI), exposure, comparison and outcome. The same author extracted the following data from each clinical trial: author, year, sample size, participant characteristics, description of intervention and weight change (Table 3). All data extraction was checked by an additional author (C. D. M.).

For consistency, energy expressed as kcal was converted to kJ (1 kcal = 4·18 kJ) and time is expressed in a 24-h format (00.00 hours). Articles published in languages other than English were translated by native, foreign-language speakers if speakers were accessible. Articles that were unable to be translated were considered ineligible for inclusion[35–39]. These articles were published in Norwegian[35], Czech[36], Japanese[37,38] and Greek[39].

Where standard deviation was not provided, it was calculated from standard errors. When trials did not report weight change, this was calculated from baseline and end of trial weight using a standard formula, which imputes a correlation for the baseline

and follow-up weights. This method has been used in two previously published trials[40,41].

Risk of bias

Risk of bias was assessed by two review authors (M. F. and C. D. M.) independently by the use of Cochrane methodology[42]. The risk of selection bias, detection bias, attrition bias and reporting bias in each study was classified as low, high or unclear. The risk of performance bias was not assessed as blinding of participants and study personnel to the treatment allocation was not feasible because of the nature of the intervention. Assessment of bias is detailed in Table 4.

Analysis strategy

As outcomes varied widely between observational studies and clinical trials, these two categories of studies were analysed separately. Meta-analyses were conducted for eligible clinical trials using Review Manager 5.3 statistical analysis package[43]. Random effects models were used as the diversity of intervention components, and control conditions meant that treatment effects were expected to differ. A pooled mean difference was calculated for the weight change at the end of intervention and I^2 was reported to quantify heterogeneity. If standard deviation was not provided by the authors, it was calculated using raw data or converted from standard errors.

Results

Search results

From the seven databases searched, a total of 18 096 search results were retrieved, which reduced to 11 014 publications once duplicates were removed. Following screening of titles and abstracts, 121 full texts were assessed for inclusion in the review, including one publication sourced from a reference list. A total of 102 texts did not meet the review eligibility criteria. A total of twenty texts including one previously known to authors were included in this systematic review. A flow diagram of the publication selection process is detailed in Fig. 1.

Study characteristics of observational studies

Ten observational trials[13,44–52] were included in the review and comprised nine cross-sectional studies[13,44–49,51,52] and one cohort study[50]. All study characteristics of observational studies are given in Table 1.

The sample size ranged from 52 to 39 094 participants (median = 980), and one study[51] examined women only. All other studies included males and females, with the percentage of female participants ranging from 48 to 68 %. Age and BMI of participants were expressed in a variety of ways, making it difficult to synthesise results. Studies included both healthy-weight participants and those with obesity.

Most studies reported on the proportion of TDEI eaten in the evening defined as quantiles[45,49–51] or percentage TDEI[13,46,47]. One study reported on the ratio between morning and evening energy intake[44] and another[52] defined evening
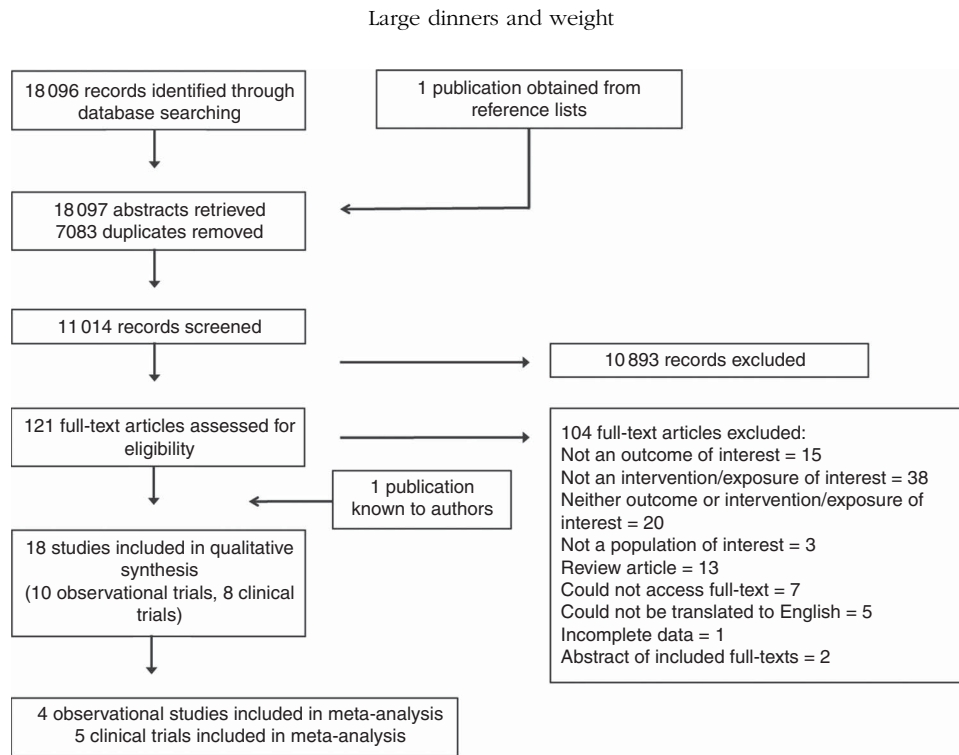
Fig. 1. Flow diagram for the process of publication selection, inclusion and exclusion from this systematic review and meta-analysis.

energy intake as 'energy content after 18.00 hours' although numerical data were not provided. Five studies[44,45,49–51] reported BMI, one study[47] reported on difference in BMI between groups, two studies[46,48] reported on the odds of being overweight (BMI ≥ 25 kg/m²) or obese (BMI ≥ 30 kg/m²) and two studies[13,52] reported on the correlation with obesity (BMI > 30 kg/m²).

Two publications that claimed to investigate NES patients were included, as these participants did not meet the DSM-5 criteria. Diagnosis in these studies was only based on the proportion of TDEI consumed after suppertime[46] and from 19.00 to 04.59 hours the following morning[47].

Study characteristics of clinical trials

Eight clinical trials[27–34] with sample size ranging from 10 193 participants (mean = 62) were included in the review. Four trials[30–33] included women only and one trial[34] did not specify the sex of participants. All other studies included both males and females, with the percentage of female participants ranging from 60 to 90 %. Mean baseline BMI ranged from 28·0 to 35·8 kg/m². One trial[27] reported baseline weight as percentage relative body weight (%RBW), with mean baseline weight being 159 (sd 9) % RBW. All clinical trial characteristics are shown in Table 3.

Intervention characteristics of clinical trials

The duration of interventions ranged from 18 d to 16 weeks. Only one study[29] had a follow-up period, and participants were followed up 16 weeks post intervention. All interventions prescribed a hypoenergetic diet to promote weight loss. Dietary prescriptions varied, with two trials standardising

recommended energy intake based on predictive equations (Harris–Benedict)[31] or actigraphy[32]. All other interventions[27–30,34,53] prescribed daily energy targets ranging from 2508 to 6688 kJ/d (600–1600 kcal/d). Energy prescriptions for these trials were isoenergetic between treatment arms.

The majority of interventions manipulated the distribution of TDEI so that a greater proportion was either consumed at the breakfast or dinner meal[29–33]. Two trials compared single meals consumed during the day or in the evening[28,34], and another trial[27] included a third group who consumed daily energy intake at three meals throughout the day.

Dietary compliance was assessed through self-reported written food records verified by a dietitian[30], a feedback form[33] or a food checklist[29]. One study assessed dietary reporting accuracy by comparing self-reported intake with estimations of BMR[32]. In a number of studies[27,28,31,34], participants were housed in a metabolic suite for the duration of the trial and were provided all foods and beverages by study personnel. Self-reported dietary compliance was not assessed for these trials.

Synthesis of results for observational studies

Four[46,48,50,52] of the ten studies showed an association between a large evening intake and greater weight, BMI or odds of being overweight and/or obese. However, a few caveats were noted. Wang et al.[48] observed that 'larger' evening intake defined as ≥33 % of total energy intake was associated with increased odds of being overweight or obese (OR 2·00; 95 % CI 1·03, 3·89) among the whole sample population after adjusting for age, sex, race, education, TDEI and physical activity level. However, this association was not significant when analysis was restricted to 'true reporters' only – that is those participants

Table 3. Characteristics of clinical trials*
(Mean values and standard deviations; mean values with their standard errors)

First author, year	Sample size (n) and participant characteristics	Duration and design of intervention(s)	Description of intervention	Living condition of participants	Dietary assessment, compliance and validation	Weight change (kg)
Caviezel et al., 1984[27]	n 52; 70 % female; age range = 19–56 years; mean weight = 159 (SD 64·9) %IBW	30-d weight-loss intervention	Breakfast group: single 2472 kJ meal consumed at 09.00 hours each day. Dinner group: single 2472 kJ meal consumed at 18.00 hours each day. Three low-energy meals: 2472 kJ/d with 16 % at 08.00 hours, 42 % at 12.00 hours and 42 % at 18.00 hours (groups had identical macronutrient ratios)	Laboratory	NA	Moderately obese (<170 % RBW): breakfast group: −7·9 kg; dinner group: −8·1 kg; three low-energy meals: −5·5 kg; significance: P < 0·05 for dinner group v. three low energy meals. Severely obese (>170 % RBW): three low-energy meals: −7·9 kg; breakfast group: −7·0 kg; dinner group: −10·0 kg; significance: P < 0·01 for dinner group v. three low-energy meals and breakfast group. All weights are estimates based on bar graphs. Actual figures not provided
Del Ponte et al., 1984[28]	n 10; 90 % female; mean age 46 (SD 18·4) years; mean weight = 110.18 (SD 15·2) kg	18-d weight-loss intervention	Breakfast group: single 2860 kJ meal consumed at 10.00 hours each day. Dinner group: single 2860 kJ meal consumed at 18.00 hours each day (groups had identical macronutrient ratios)	Laboratory	NA	Breakfast group: −6·86 (SD 3·1) kg. Dinner group: −6·57 (SD 3·1) kg. Significance: 'It is not statistically significant'. No P value provided
Jakubowicz et al., 2012[29]	n 193; 60 % female; mean age = 47 (SD 7 years); mean BMI = 32·3 (SD 1·8) kg/m²	32 weeks total (16-week intervention and 16-week follow-up)	Breakfast group (women): 5768 kJ/d with 43 % BF, 36 % L and 21 % D; Follow-up: weight maintenance. Breakfast group (men): 6592 kJ/d with 38 % BF, 38 % L and 24 % D, follow-up: weight maintenance. Dinner group (women): 5768 kJ with 21 % BF, 36 % L and 43 % D, follow-up: weight maintenance. Breakfast group (men): 6592 kJ with 19 % BF, 38 % L and 43 % D, follow-up: weight maintenance (groups had different macronutrient ratios)	Free-living	Intake was monitored every 4 weeks by a dietitian who reviewed the participants' daily diet intake checklists. Assessment of compliance and validation not reported	Breakfast group (Week 16): −13·6 (SD 2·3) kg (completers), −1·4 (SD 1·6) kg (withdrawals). Dinner group (Week 16): −15·3 (SD 1·9) kg (completers), −2·1 (SD 2·6) kg (withdrawals). Significance (Week 16): P = 0·11 (completers only). Breakfast group (Week 32): −20·6 (SD 2·8) kg. Dinner group (Week 32): −3·5 (SD 2·7) kg. Significance (Week 32): P < 0·001 (completers only)
Jakubowicz et al., 2013[30]	n 93; women only; mean age = 29·4 (SD 5·4) years; mean BMI = 32·3 (SD 0·2); the metabolic syndrome present	12-week weight-loss intervention	Breakfast group: 5852 kJ/d with 50 % at 06.00–09.00 hours, 36 % at 12.00–15.00 hours and 14 % at 18.00–21.00 hours. Dinner group: 5852 kJ/d with 14 % at 06.00–09.00 hours, 36 % at 12.00–15.00 hours and 50 % at 18.00–21.00 hours (groups had identical macronutrient ratios)	Free-living	Participants completed a 3-d estimated food diary. Non-compliance events defined as a deviation of ±10 % from the recommended energy intake were recorded by the dietitian. The number of non-compliant days were divided by seven to calculate weekly non-compliance. Those with weekly non-compliance of 42·9 % (>3 d/week) were withdrawn from the study. Assessment of validation not reported	Breakfast group: −8·7 (SD 8·6) kg (completers only). Dinner group: −3·6 (SD 9·0) kg (completers only). Significance: P < 0·0001 (completers only)
Keim et al., 1996[31]	n 12; women only; mean age = 29·4 (SD 5·4) years; mean BMI = 28·0 (SD 4·2)	15 weeks (3-week stabilisation followed by two different 6-week weight-loss interventions)	Breakfast first phase: 3-week weight stability followed by 6-week 'Breakfast First' phase (35 % BF, 35 % L, 15 % D, 15 % after D) then cross over to 'Dinner' phase (15 % BF, 15 % L, 35 % D, 35 % after D). Dinner first phase: 3-week weight stability followed by 6-week 'Dinner first' phase (15 % BF, 15 % L, 35 % D, 35 % after D) then cross over to 'Breakfast' phase (35 % BF, 35 % L, 15 % D, 15 % after D) (groups had identical macronutrient ratios)	Laboratory	NA	Breakfast first phase: −3·90 (SD 0·6) kg/6 week. Dinner first phase: −3·27 (SD 0·8) kg /6 week. Significance: P < 0·01
Lombardo et al., 2014[32]	n 42; women only; mean age = 46·3 (SD 2·3) years; mean BMI = 35·8 (SD 5·2) kg/m²	3-month weight-loss intervention	Breakfast group: 2508 kJ/d less than total energy expenditure (determined by multisensory armband worn for 36 h) with 70 % across BF, morning snack and L, and 30 % across afternoon snack and D. Dinner group: 2508 kJ/d less than total energy expenditure (determined by multisensory armband worn for 36 h) with 55 % energy across BF, morning snack and L, and 45 % across afternoon snack and D	Free-living	Participants completed a 3-d food diary at the beginning of the study and then weekly throughout follow-up. Participants whose self-reported energy intake was <110 % of their estimated BMR were excluded	Breakfast group: −8·2 (SD 3·0) kg. Dinner group: −6·5 (SD 3·4) kg. Significance: P = 0·028
Madjd et al., 2016[33]	n 80; women only; mean age = 33·6 (SD 7·0) years; mean BMI = 32·2 (SD 2·3) kg/m²	12 weeks weight loss intervention	Breakfast group: hypoenergetic diet with 15 % BF, 15 % snacks, 50 % lunch and 20 % D. Dinner group: hypoenergetic diet with 15 % BF, 15 % snacks, 20 % L and 50 % D	Free-living	Participants completed a feedback form reporting on their dietary compliance during the intervention. A dietitian phoned participants weekly to monitor adherence to meal pattern. Assessment of compliance not report. Assessment of validation not reported	Breakfast group: −5·73 (SD 1·9) kg. Dinner group: −4·3 (SD 1·9) kg. Significance: P = 0·002
Sensi et al., 1987[34]	n 25; sex not specified; mean age = 46 (SD 5·8) years; mean weight = 204 (SD 8·8) %IBW	18 d weight loss intervention	Breakfast group: single 2859 kJ meal consumed at 10.00 hours each day. Dinner group: single 2859 kJ meal consumed at 18.00 hours each day	Laboratory	NA	Breakfast group: −348 (SEM 55) g/d. Dinner group: −359 (SEM 55) g/d. Significance: not specified

IBW, ideal body weight; BF, breakfast; L, lunch; D, dinner; RBW, relative body weight.
* If mean age and mean BMI were not provided in the article, it was manually calculated by the first author (M. F.). Time is 24 h (00.00 hours).

whose self-reported energy intake was within ±25 % of total energy expenditure as assessed by the doubly labelled water method (OR 2·10; 95 % CI 0·60, 7·29).

Morse et al.[46] found that >25 % TDEI consumed after 'suppertime' was associated with increased odds (OR 2·6; 95 % CI 1·5, 4·5) of being obese (BMI > 30 kg/m^2) after controlling for age, sex, race and major depression status. Similarly, a study by Bo et al.[50] found that individuals ranked in the highest tertile of evening energy intake (≥48 % TDEI) had a higher mean BMI than those in the lowest tertile (<33 % TDEI) ($P < 0.01$). These results did not significantly change after excluding under-reporters (those with a ratio of <0·88 of estimated energy intake:predicted BMR based on the Schofield equation). Baron et al.[52] investigated the correlation between sleep timing and energy intake and BMI. They found that energy intake after 20·00 hours were correlated with BMI (0·37, $P < 0.01$) after adjusting for sleep timing.

Five studies[13,44,45,49,51] showed no association between large evening intake and weight/BMI. Interestingly, one study[47] found BMI to be weakly, inversely associated with end-of-day energy intake. The BMI of participants who consumed ≥25 % of TDEI between 19·00 and 04·59 hours the following morning was 0·44 kg/m^2 less than those who consumed <25 % TDEI during this time after controlling for age group, racial/ethnic group, sex and TDEI. However, this association was only observed for the National Health and Nutrition Examination Survey III (NHANES III) data set.

Meta-analysis of observational studies

Four independent studies[44,45,50,51] were included in the analysis. Of the eight studies excluded from the analysis, seven did not report BMI as an outcome[13,46–48,52,54,55] and one study[49] that reported BMI did not provide standard deviations. Almoosawi et al.[45] reported results for 'dinner' and 'late evening' intakes and both of these results were included in the meta-analysis.

The analysis showed that the BMI of those with low evening energy intake was on average 0·39 kg/m^2 less than those with high evening energy intake (95 % CI −0·80, 0·01, $P = 0.06$). The I^2 was 38 %, indicating low heterogeneity among studies. Fig. 2 details the results of the meta-analysis as a forest plot.

Synthesis of results for clinical trials

Six trials[27,29–33] out of eight trials showed that reducing evening intake produced greater weight loss than reducing breakfast intake or eating three meals throughout the day. In one

study[27], this was only true for severely obese participants (>170 % RBW) and there was no difference in treatment arms for moderately obese participants (<170 % RBW). It is worth noting that weight change was only represented graphically in this publication. The authors were unable to be contacted for raw data, and therefore numerical results were estimated by reviewers.

Jakubowicz et al.[30] showed that weight loss at 12 weeks for the breakfast group (50 % TDEI at breakfast and 14 % TDEI at dinner) and dinner group (14 % TDEI at breakfast and 50 % TDEI at dinner) was −8·7 (SD 8·6) and −3·6 (SD 9·0) kg, respectively ($P < 0.0001$). In their similar follow-up trial[29], it was found that there was no difference in weight change between treatment groups from baseline to end of intervention (Week 16) ($P = 0.11$). However, weight change from baseline to end of follow-up (Week 32) was significantly higher in the breakfast group (38 % TDEI at breakfast and 25 % TDEI at dinner for men and 43 % TDEI at breakfast and 21 % TDEI at dinner for women) compared with the dinner group (19 % TDEI at breakfast and 44 % TDEI at dinner for men and 21 % TDEI at breakfast and 43 % TDEI at dinner for women) (−20·6 (SD 2·8) v. 3·5 (SD 2·7) kg, $P < 0.001$).

Keim et al.[31] observed similar results whereby participants in the 'breakfast group' (35 % TDEI at breakfast and 30 % TDEI at and after dinner) lost significantly more weight than those in the 'dinner group' (30 % TDEI at breakfast and 70 % TDEI at and after dinner) ($P < 0.01$) after 6 weeks. Lombardo et al.[32] and Madjd et al.[33] observed that participants in the 'breakfast group' lost significantly more weight than those in the 'dinner group' over approximately 3 months (−8·2 (SD 3·0) v. − 6·5 (SD 3·4) kg and −5·73 (SD 1·9) v. −4·61 (SD 1·9) kg, respectively).

Conversely, Sensi et al.[34] and Del Ponte et al.[28] found that a single meal of 2860 kJ produced greater weight loss when consumed for 18 d at 18·00 hours compared with 10·00 hours. However, no statistical test of significance was performed in either trial, making it difficult to assess the significance of the results.

Meta-analysis of clinical trials

A summary of the characteristics of clinical trials is presented in Table 3, and Fig. 3 details the results of the meta-analysis as a forest plot. One trial[27] was excluded as weight change, and standard error means were only reported graphically. The intervention length of two trials was too short to include[28,34]. As only one study[29] had a follow-up period, only results from
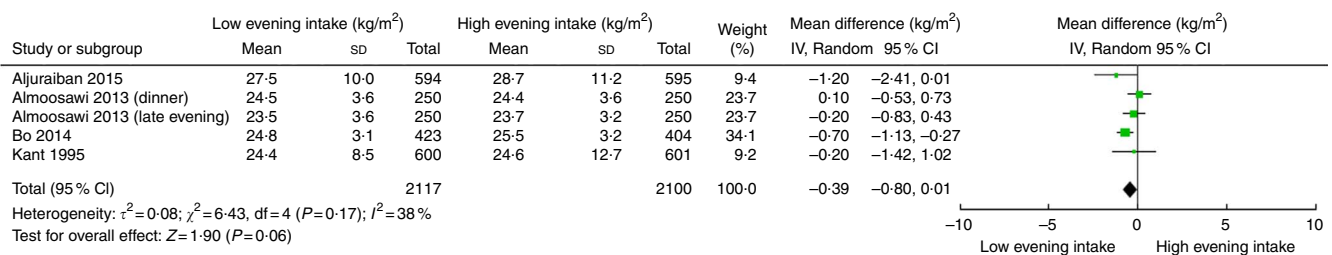
Study or subgroup	Low evening intake (kg/m^2)			High evening intake (kg/m^2)			Weight (%)	Mean difference (kg/m^2) IV, Random 95 % CI	Mean difference (kg/m^2) IV, Random 95 % CI
	Mean	SD	Total	Mean	SD	Total			
Aljuraiban 2015	27·5	10·0	594	28·7	11·2	595	9·4	−1·20 −2·41, 0·01	
Almoosawi 2013 (dinner)	24·5	3·6	250	24·4	3·6	250	23·7	0·10 −0·53, 0·73	
Almoosawi 2013 (late evening)	23·5	3·6	250	23·7	3·2	250	23·7	−0·20 −0·83, 0·43	
Bo 2014	24·8	3·1	423	25·5	3·2	404	34·1	−0·70 −1·13, −0·27	
Kant 1995	24·4	8·5	600	24·6	12·7	601	9·2	−0·20 −1·42, 1·02	
Total (95 % CI)			2117			2100	100·0	−0·39 −0·80, 0·01	

Heterogeneity: $\tau^2 = 0.08$; $\chi^2 = 6.43$, df = 4 ($P = 0.17$); $I^2 = 38$ %
Test for overall effect: $Z = 1.90$ ($P = 0.06$)

−10 −5 0 5 10
Low evening intake High evening intake

Fig. 2. Forest plot for meta-analysis of observational studies.

Study or subgroup	Smaller dinner (kg) Mean	SD	Total	Larger dinner (kg) Mean	SD	Total	Weight (%)	Mean difference (kg) IV, Random	95 % CI
Jakubowicz 2012	−13·6	2·3	96	−15·3	1·9	97	24·3	1·70	1·10, 2·30
Jakubowicz 2013	−8·7	8·6	38	−3·6	9·0	36	10·0	−5·10	−9·11, −1·09
Keim 1997	−3·9	0·6	10	−3·27	0·8	10	24·3	−0·63	−1·25, −0·01
Lombardo 2014	−8·2	3·0	18	−6·5	3·4	18	17·8	−1·70	−3·79, 0·39
Madjd 2016	−5·73	1·91	40	−4·31	1·93	40	23·6	−1·42	−2·26, −0·58
Total (95 % CI)			202			201	100·0	−0·89	−2·52, 0·75

Heterogeneity: $\tau^2 = 2\cdot77$; $\chi^2 = 54\cdot83$, df = 4 ($P < 0\cdot00001$); $I^2 = 93\%$
Test for overall effect: $Z = 1\cdot06$ ($P = 0\cdot29$)

Fig. 3. Forest plot for meta-analysis of clinical trials.

baseline to end of intervention were included. Five independent clinical trials[29–33] were included in the meta-analysis.

The analysis showed that weight loss between treatment groups was not significantly different and the overall mean difference was −0·89 kg (95 % CI −2·52, 0·75, $P = 0\cdot29$) favouring the small dinner intervention. The I^2 was 93 %, indicating very high heterogeneity among studies.

Risk of bias

The assessment of bias in intervention trials is summarised in Table 4. Generally, many studies did not provide sufficient information to judge bias in detail. Only one trial[33] had a low risk of selection bias and reported the process used for random sequence generation and allocation concealment. The risk of selection bias was unclear in all other studies[27–32,34] as neither of these processes was reported. No trials reported blinding of outcome assessment and therefore had an unclear risk of detection bias. However, it is unlikely that the collection of anthropometric data would be affected by bias in this instance.

Seven trials[27–32,34] had a high risk of attrition bias with three[27,28,34] not disclosing the number of completers. Risk of attrition bias was low in one study[33] where attrition rates between treatment groups were similar and imputation methods were used to account for missing data. As study protocols were not accessible, it was difficult to assess selective outcome reporting. Therefore, most studies[28,29,32,33] had an unclear risk of reporting bias. However, four studies had a high risk of bias as they did not report important information such as baseline weight[27,31,34], the outcome used for the power calculation[30], sex of participants[34] and the mean weight change for all treatment arms[34].

The risk of bias was also assessed in the observational trials. Three studies[13,44,45] were at a low risk of selection bias as the sample population was representative of the general population. In all other studies[46–52], sample populations were restricted to a particular sex, disease states, BMI categories, narrow age ranges and races/ethnicities, and therefore the risk of selection bias was high.

Data collection methods varied in their reliability and validity. Three[46,51,52] studies used self-reported height and weight, whereas five[13,44,45,48,50] measured height and weight. Information on anthropometric data collection was unable to be sourced for one study[49]. Striegel-Moore *et al.*[47] used a combination of measured and self-reported anthropometric data

from the NHANES III and Continuing Survey of Food Intakes by Individuals (CSFII) data sets, respectively.

Three studies[13,46,47] used poor methods of dietary assessment such as single 24-h recalls, unvalidated questionnaires and single questions. Seven[44,45,48–52] studies used dietary assessment methods with greater validity such as multiple, non-consecutive 24-h recalls, multiday, estimated food records and multiday, weighed food records. It should be noted that although Wang *et al.*[48] used multiple web-based 24-h recalls timing of beverage consumption was not recorded and the associated energy contribution was distributed evenly throughout the day for analytical purposes. Four studies validated participants' self-report dietary/energy intake through the use of either doubly labelled water[48] or estimated energy expenditure based on the Schofield equation[44,49,50]. Only one study[50] mentioned blinding of outcome assessment. Although it was poorly documented, it is unlikely that being unblinded to anthropometric measures would contribute to the risk of bias.

Discussion

The trials reviewed here show conflicting evidence regarding the distribution of energy intake and its relation to BMI and intentional weight loss. Four of the observational studies showed a positive association with BMI, whereas five showed no association and one indicated a weak, inverse relationship. There was considerable inconsistency in the definitions of meal timing, the quantification of energy intake, dietary assessment methods and outcome measures. The meta-analysis of observational studies showed only a slight trend between greater BMI and greater evening energy intake ($P = 0\cdot06$). The majority of clinical trials reported that a smaller evening meal produced greater weight loss; however, the meta-analysis showed no significant difference between groups ($P = 0\cdot29$). The dietary protocols, living conditions of participants, dietary assessment methods and validation varied greatly and many studies had an unknown or high risk of bias (Table 4). This was reflected by the high heterogeneity ($I^2 = 93\%$) among the considerably small sample (n 5) of intervention trials that were included in the meta-analysis. Given these results, we are not to make sound conclusions about the relationship between the evening meal and its effect on intentional weight loss. Our findings challenge the popular belief that eating a smaller dinner is beneficial for weight management, and would make a valuable addition to

Table 4. Assessment of the risk of bias using Cochrane methodology

Studies	Selection bias		Detection bias	Attrition bias	Reporting bias	Other sources of bias
	Random sequence generation	Allocation concealment	Blinding of outcome assessment	Incomplete outcome data	Selective outcome reporting	
Caviezel et al., 1984[27]	Unclear risk of bias: randomisation process not specified	Unclear risk of bias: allocation concealment process not reported	Unclear risk of bias: assessment process not specified	High risk of bias: number of completers not specified	High risk of bias: unspecified baseline weight and end of intervention weight	
Del Ponte et al., 1984[28]	Unclear risk of bias: randomisation process not specified	Unclear risk of bias: allocation concealment process not reported	Unclear risk of bias: assessment process not specified	High risk of bias: number of completers not specified	Unclear risk of bias: protocol not available	
Jakubowicz et al., 2012[29]	Unclear risk of bias: randomisation process not specified; women only	Unclear risk of bias: allocation concealment process not reported	Unclear risk of bias: assessment process not specified	High risk of bias: subjects who withdrew were younger and had higher craving scores and dropout rate was 25 %	Unclear risk of bias: protocol not available	
Jakubowicz et al., 2013[30]	Unclear risk of bias: randomisation process not specified	Unclear risk of bias: allocation concealment process not reported	Unclear risk of bias: assessment process not specified	High risk of bias: dropout rates similar in both group but no method of imputation of missing data	High risk of bias: powered for weight but reported percentage weight change	
Keim et al., 1997[31]	Unclear risk of bias: randomisation process not specified; women only 80 % Caucasian	Unclear risk of bias: allocation concealment process not reported	Unclear: nurses measured weight but they were not blinded to outcome	High risk of bias: originally 12 participants enrolled but no reason provided for dropout. Analysis includes completers only	High risk of bias: baseline weight of participants not reported	Small sample size (n 10)
Sensi et al., 1987[34]	Unclear risk of bias: randomisation process not specified	Unclear risk of bias: allocation concealment process not reported	Unclear risk of bias: assessment process not specified	High risk of bias: number of completers not specified	High risk of bias: sex, baseline and end of intervention weight not specified. Weight loss of group 2 and 3 not specified	
Lombardo et al., 2014[32]	High: randomisation process not specified. All subjects were white, female, European homemakers who attended the outpatient service at the Obesity Centre	Unclear risk of bias: allocation concealment process not reported	Unclear risk of bias: assessment process not specified	High risk of bias: similar attrition rates between groups but analysis for completers only	Unclear risk of bias: protocol not available	
Madjd et al., 2016[33]	Low risk of bias: computer-generated random numbers method by project coordinator; women only	Low risk of bias: allocation concealed from subjects and dietitians until first intervention appointment	Low risk of bias: allocation concealed from subjects and dietitians until first intervention appointment	Low risk of bias: similar attrition rates between groups (15 and 13 %) and multiple imputations used to impute missing values	Unclear risk of bias: protocol not available	Did not disclose how participants were told to adhere to energy distribution

Large dinners and weight

'Myths, Presumptions and Facts about Obesity' in which Casazza et al.[56] list common myths relating to obesity.

The review by Almoosawi et al.[26] also observed varied results among observational studies. Although most showed an association between time-of-day energy intake and weight/ BMI, large heterogeneity made it difficult to draw a definitive conclusion. Almoosawi et al. noted that a greater BMI may be correlated with greater TDEI rather than its circadian distribution. However, of the five studies included in the current review that did adjust for TDEI[13,45,47,49,51], only one[47] showed a weak effect but no measure of significance was provided. Therefore, it is not likely that omitting adjustment for TDEI affected the results. Importantly, research has shown that evening energy intake predicts TDEI[52,57]. Therefore, it is possible that those who consume a high proportion of TDEI in the evening consume a greater TDEI overall, which will increase the risk of obesity.

Compared with the review by Almoosawi et al., our review included a more open search strategy (including clinical trials) and therefore allowed us to identify more evidence and summarise observational and randomised controlled trials. The previous review excluded studies that only assessed energy intake at specific eating occasions (i.e. breakfast) without reporting energy intake at other eating occasions. Our current review did not apply these restrictions, and articles were included provided that the proportion of TDEI contributed by the morning and evening meal could be calculated. As such, we included five more observational studies on adults and were able to conduct a meta-analysis. The inclusion of these additional articles and clinical trials facilitated a more comprehensive investigation of the research question.

The meta-analysis of clinical trials showed that in the short term (approximately 1–3 months), manipulating the circadian distribution of TDEI so that evening intake is smaller does not result in greater weight loss. However, heterogeneity among the clinical trials was very high ($I^2 = 93$ %), and although there is no real consensus on how to interpret heterogeneity measures in meta-analysis 93 % may be considered too large to make a meaningful interpretation. Heterogeneity may be due to differences in intervention duration, dietary protocol and the living condition of participants (laboratory v. free living), which has implications for dietary adherence. However, when the only laboratory trial[31] was removed from the meta-analysis, the mean difference increased to 0·46 kg but was not significant (95 % CI −0·01, 0·93).

The null effect of the intervention observed in some trials may be attributable to a few factors. In studies that used a very low-energy diet[27,28,34], severe energy restriction may have masked the effect of meal timing, potentially confounding the results. In addition, there is a small amount of emerging evidence that has examined chronotypes (one's 'morningness' and 'eveningness') and weight loss. An evening chronotype has been associated with obesity and less weight loss after bariatric surgery[58]. Therefore, we can postulate that there may be an interaction between one's chronotype, circadian energy distribution and weight regulation. Second, weight loss may not have been observed because modest, albeit statistically significant, differences in circadian energy metabolism are simply

not large enough to affect weight in the short term. Bo et al.[20] showed that DIT was 8017 kJ (95 % CI 7498, 8540) v. 7347 kJ (95 % CI 6895, 7795) (1916 kcal (95 % CI 1792, 2041) v. 1756 kcal (95 % CI 1648, 1863)) ($P < 0·001$) after the morning and evening meal, respectively. A difference of 669 kJ/d (160 kcal/d) may not be large enough to affect weight in the short term. There was also large inter-individual variability in morning DIT, which may also account for the null effect observed in some trials. It is possible that benefits may be observed in the long term if dietary shifts were adopted over a greater period of time as seen in the trial by Jakubowicz et al.[29].

Strengths and limitations

The main strength of the current review is the inclusion of meta-analyses of observational studies and clinical trials. To our knowledge, our study is the first to conduct meta-analyses in this field. Other strengths include the comprehensive search strategy used, the use of two independent review authors throughout the review and the use of Cochrane methodology to appraise the risk of bias.

There were a number of limitations of the current study, the most significant being the high level of heterogeneity in the studies included. A number of potential sources of bias may have affected reliability of study results. Interestingly, the study by Madjd et al.[33] appears to represent the trial with the lower risk of bias and showed that reducing evening intake can increase weight loss.

Observational studies assessing dietary intake through single 24-h dietary recalls, unvalidated questionnaires or single questions are more likely to produce unreliable results compared with those using multiple recalls or multiday food diaries. Studies that validated dietary intake provided even greater reliability; however, these were few. Similarly, studies that used self-reported height and weight data may obscure the reliability of results. Although there were no restrictions placed on language of publication, a number of studies published in languages other than English were excluded as they were unable to be translated by native speakers. This may have potentially led to the exclusion of otherwise valuable data. Inconsistency in the definitions of meal timing is an inherent issue in this field of research and highlights the need to reach consensus on definitions of meal timing to reduce ambiguity in future research.

Future research

More well-controlled, intervention studies with a low risk of bias similar to that of Madjd et al.[33] would provide more definitive information on the effect of a smaller dinner on weight. Dietary compliance is of particular importance and can be tightly controlled in a laboratory setting. To increase dietary compliance in free-living participants, future studies could provide participants with menus that prescribe a certain proportion of daily energy during specific time frames. Research should also assess individuals' acceptability of a smaller evening meal, as this meal pattern may not be congruous with modern social and cultural norms. Measuring diurnal subjective appetite would also provide information about the sustainability of this

eating pattern and whether appetite entrainment occurs. Studies investigating the effect of a small evening meal in participants on an isoenergetic diet would provide insight into the relationship between circadian energy distribution and weight gain prevention.

Conclusion

Overall, because of high heterogeneity and a high or unknown risk of bias among observational and intervention trials, it is difficult to draw conclusions about the effect of large evening energy intake on weight control and intentional weight loss. Therefore, recommendations to reduce the evening meal for weight loss cannot be substantiated by clinical evidence.

Supplementary material

For supplementary material/s referred to in this article, please visit https://doi.org/10.1017/S0007114517002550

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