Eating versus skipping breakfast has no discernible effect on obesity-related anthropometric outcomes: a systematic review and meta-analysis [version 3; peer review: 1 approved, 1 approved with reservations]

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Abstract

Background: Eating or skipping breakfast for weight interests scientific and lay communities. Our objective was to systematically review and meta-analyze causal effects of eating versus skipping breakfast on obesity-related anthropometric outcomes in humans.

Methods: Six databases were searched for obesity- and breakfast-related terms (final search: 02 JAN 2020). Studies needed to isolate eating versus skipping breakfast in randomized controlled trials. Mean differences were synthesized using inverse variance random effects meta-analysis for each outcome. Positive estimates indicate higher outcomes in breakfast conditions (e.g., weight gain). Leave-one-out sensitivity analysis, secondary baseline habit-by-breakfast assignment analysis, and study duration cumulative analysis were performed. Risk of bias was assessed using Cochrane risk of bias tool.

Results: Ten articles (12 comparisons; 6d-12wk) were included. Conditions included recommendations to eat versus skip breakfast, or provision of some or all meals. 95% confidence intervals of all main analyses included the null value of no difference for each outcome: body weight (0.17 kg [-0.40,0.73], k=12, n=487, I²=74.5), BMI (0.07 kg/m² [-0.10,0.23, k=8, n=396, I²=54.1]), body fat percentage (-0.27% [-1.01,0.47], k=6, n=179, I²=52.4), fat mass (0.24 kg [-0.21,0.69], k=6, n=205, I²=0.0), lean mass (0.18 kg [-0.08,0.44], k=6, n=205, I²=6.7), waist circumference (0.18 cm [-1.77,2.13], k=4, n=102, I²=78.7), waist:hip ratio (0.00 [-0.01,0.01], k=4, n=102, I²=8.0), sagittal...
abdominal diameter (0.19 cm [-2.35, 2.73], k=2, n=56, I²=0.0), and fat mass index (0.00 kg/m² [-0.22, 0.23], k=2, n=56, I²=0.0). Subgroup analysis showed only one statistically significant result. The interaction effect for BMI (-0.36 [-0.65, -0.07]) indicates assignment to conditions consistent with baseline habits had lower BMI. Leave-one-out analysis did not indicate substantial influence of any one study.

Conclusions: There was no discernible effect of eating or skipping breakfast on obesity-related anthropometric measures when pooling studies with substantial design heterogeneity and sometimes statistical heterogeneity.

Registration: PROSPERO CRD42016033290.

Keywords
Breakfast, skipping, obesity, weight, meta-analysis, systematic review, randomized controlled trials
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Introduction

Whether one should eat or skip breakfast for weight control or loss is a topic of continued interest in both the scientific and lay communities. In 2013\(^1\), we documented how breakfast eating versus breakfast skipping served as an example of how beliefs about diet can go beyond the evidence within and beyond the scientific community. The evidence at the time was dominated by over 90 observational studies – most cross-sectional – leading us to conclude that eating versus skipping breakfast as a strategy for weight was a presumption: a belief “held to be true for which convincing evidence does not yet confirm or disprove their truth”\(^2,3\). The limited scientific evidence on the topic has been translated directly to the public. For instance, we noted in our prior paper that the website of the Dr. Oz Show included an article stating, “The fact is, when you’re trying to lose body fat, you can’t skip breakfast”\(^4\). More recently, Dr. Oz himself stated, “I think for 2020, the first thing I’m going to do is ban breakfast”\(^5\), and using the social media hashtag of #TeamNoBreakfast. Meanwhile, continued scientific interest in the topic is evidenced by many more cross-sectional observational and other studies having been published; more recent narrative review articles summarizing existing literature on the topic\(^6\); a meta-analysis evaluating breakfast eating versus skipping on weight\(^7\) that confirmed our prior registered preliminary analyses\(^8,9\); and another group registering an analysis similar to ours after our registration (PROSPERO CRD42018110858; subsequently published\(^1\).

With mixed messaging over time about the importance of eating or skipping breakfast for the ongoing obesity epidemic, and with continued interest in the topic both scientifically and generally, it is important to synthesize the causal evidence on the effect of breakfast eating versus skipping on obesity and related outcomes, rather than relying on weaker study designs or popular opinion.

Since our earlier summaries, additional RCTs have been conducted and published (as reviewed herein). Herein, we extend our prior work to synthesize causal evidence from RCTs on eating versus skipping breakfast in humans on all reported obesity-related anthropometric outcomes we were able to extract from relevant literature.

Methods
Registration

Our study was registered with the PROSPERO international prospective register of systematic reviews (CRD42016033290) on 21 JAN 2016. The initial registration limited papers up to the registration date; however, because of the time between initial registration and this manuscript, the search was updated to 02 JAN 2020 (see Search and review strategy, below). Earlier versions of this work were published as abstracts for the American Society for Nutrition’s Annual Meeting and Scientific Sessions\(^6,10\).

Inclusion and exclusion criteria

Inclusion criteria were:

- the study had at least one breakfast skipping condition and one breakfast eating condition regardless of modality (e.g., whether recommended or provisioned);
- the study was a randomized, controlled trial (RCT);
- study length (i.e., time on intervention) was greater than 72 hr;
- participants were normal weight or greater, as defined by original study authors, who did not have diseases that influence weight; and
- the study reported weight or other anthropometric outcomes.

Studies were excluded if:

- participants had diseases or conditions that affected weight except for obesity, diabetes, and CVD;
- breakfast eating versus breakfast skipping were confounded with other intervention components (e.g., study designs that altered intake to ensure individual weight maintenance; multicomponent behavioral interventions including breakfast without matching those components in the skipping group; or enforcing time restricted feeding apart from breakfast skipping).

Search and review strategy

Our first search was completed on 20 JAN 2016, the search refreshed on 26 JAN 2017, and the search finalized on 02 JAN 2020, with results from prior searches being deduplicated from subsequent searches.

In all search phases, searches were executed by using the application programming interfaces (APIs) of AllHealthWatch, CINAHL, Proquest Theses and Dissertations Global, PsycInfo, and Scopus using R (version 3.5.2). The following was used to search Scopus, with analogous search strategies adapted for the other databases:

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TITLE-ABS-KEY((Obesity OR obese OR adipose OR adiposity OR overweight* OR "over weight"* OR "weight gain"* OR "weight reduce"* OR "weight loss"* OR "weight maint"* OR "weight decreas"* OR "weight control"* OR "weight restrict"* OR "BMI" OR "FMI" OR "BMlz" OR "zBMI" OR "weight percentile" OR "gestational weight" OR "weight for height" OR "waist circumference" OR "skinfold thickness" OR "body composition" OR "body size" OR "fat mass" OR "body fat" OR "body mass" OR "body weight" OR "bodyweight" OR "waist hip ratio") AND (breakfast OR "break
Search results across databases were compared for duplication, including by title, abstract, and PubMed ID. Studies with titles and abstracts addressing animals that did not also include words related to human subjects were excluded programatically. Titles and abstracts were then coded independently by at least two authors for inclusion/exclusion criteria. If both authors excluded a study for violation of any inclusion or exclusion criterion, it was excluded; if at least one did not exclude it, the paper was passed on for full text review.

**Meta-analysis**

All data and code used to estimate effect sizes and meta-analyses are provided as Extended data at https://doi.org/10.5281/zenodo.4970781. Additional details are included as comments within the code, including exact approaches to estimating each effect size within a study.

Effect sizes comparing breakfast eating versus skipping on each outcome were calculated for each study. Each effect size was calculated as a difference-in-difference in the native units of the outcome (e.g., kg for weight). Only outcomes for which there was more than one effect size were meta-analyzed: body weight, BMI, body fat percentage, fat mass, lean mass, fat free mass, adipose tissue mass, waist circumference, waist:hip ratio, fat mass index, sagittal abdominal diameter, and lean tissue mass. Lean mass, fat-free mass, and lean tissue mass were meta-analyzed together as ‘lean mass’; fat mass and adipose tissue mass were meta-analyzed together as ‘fat mass’. Total body water percentage and muscle mass are both reported in Ogata et al.; although muscle mass as an outcome was excluded, Ogata et al. also reported lean mass, which is captured in the pooled lean mass analysis.

Farshchi et al. reported pre and post means and standard deviations separately for each treatment period in a two-arm cross-over design. Although the unbiased estimate of the difference-in-difference was calculable from the pre and post means in each condition, the lack of information on the correlation of change within or between conditions precluded us from directly calculating the variance of the effect. We requested summaries from the authors, but the authors informed us they no longer had the raw data given that the paper was published in 2005. Thus, within-condition and between-condition correlations had to be estimated. Sievert et al. used a correlation coefficient of 0.3 for post-only values. We chose to estimate within-period change scores based on the within-condition correlation coefficients we estimated from Geliebter et al. because Geliebter et al. had all values needed to estimate within-condition, pre-post correlation coefficients. All correlation coefficients from Geliebter et al. were greater than 0.99. Effect sizes were estimated for each outcome. Because Farshchi et al. reported no statistically significant results for any outcome, any statistically significant estimates were recalculated using the largest within-condition correlation that resulted in non-significant effect sizes. This approach may underestimate the variance, which would provide the study more weight in the meta-analysis; however, the leave-one-out analysis described below gives Farshchi the lowest weight possible.

Geliebter et al. reported three conditions: skipping, corn flakes, and oat porridge. We used the recommended method of the Cochrane Handbook, which is to “combine multiple groups that are eligible as the experimental or comparator intervention to create a single pair-wise comparison”. Because we were interested in breakfast eating versus breakfast skipping, the two breakfast conditions were pooled together.

Leidy et al. also reported three conditions: skipping, a normal protein breakfast, and a high protein breakfast. We requested summaries from Leidy et al., who graciously provided us with separate group means and standard deviations for the changes. We used the recommended method of the Cochrane Handbook to combine breakfast conditions as described above.

Neumann et al. reported three conditions: skipping, high carbohydrate breakfast, and high protein breakfast. Again, we used the method recommended by the Cochrane Handbook to combine breakfast conditions. Neumann et al. reported individual-level data in their supplementary table. While reviewing the values in their supplement, we found some results to be implausible. We reached out to the authors, who clarified several subjects’ data. For our analysis, we used the updated values, and include the final updated dataset in our supplement.

Schlundt et al. reported follow-up data at 6 months, but the methods descriptions were unclear as to whether the interventions to eat or skip breakfast were continued past the 12-week intervention. Authors were contacted about this detail and for additional outcomes data at 12 weeks that were either not directly reported or reported as no significant strata (i.e., habitual breakfast eaters or skippers) or treatment effects; the authors informed us they no longer had the raw data given the study was published in 1992. We therefore chose to only use the change in body weight data from 12-weeks. Independent effect sizes were estimated for habitual breakfast eaters and habitual breakfast skippers.

Dhurandhar et al. reported body weight for the completers-only analysis in their paper. Because they registered their study as also measuring BMI, and because of the mention of an intention to treat analysis, we contacted the authors (one of whom, DBA, is a coauthor on the present meta-analysis), who provided us with summary data. Note that they also had a third group, in which participants received no specific breakfast eating or breakfast skipping recommendations; we limited our analysis to the intention to treat analyses of the breakfast eating and breakfast skipping groups. Independent effect sizes were estimated for habitual breakfast eaters and habitual breakfast skippers.

LeCheinnant et al. were contacted for estimates of change over time for data in their Table 3. The authors graciously provided estimates of change within each group for each
outcome. The data used herein, as shared by the authors, differs slightly from their publication because of increased precision and because of a reporting error in which percent body fat did, in fact, have a small but non-significant increase in the no breakfast group. This error does not change the results of their study, but the corrected values are used herein.

Ogata et al., Betts et al., and Chowdhury et al. effect sizes were calculated with routine equations.

Meta-analyses were calculated using the metafor package (version 2.1-0) in R. Each of 12 independent effects sizes (10 papers; 2 stratified by baseline habit) were included in each analysis as possible, depending on which outcomes were reported in which studies. Random effects analyses were calculated; no fixed effects analyses were calculated because design heterogeneity made the assumption of effect sizes being part of a homogenous distribution tenuous. The adjustment by Knapp and Hartung was used given the relatively small number of effect sizes. Two effect sizes were derived from separate papers of the Bath Breakfast Project (BBP; Betts et al. and Chowdhury et al.). Because these were independent samples (normal or with obesity) we treated them as independent even though they came from the same overarching study. Similarly, although there is plausibly some correlation amongst effect sizes calculated within the habit strata in Dhurandhar et al. and Schlundt et al. by nature of being part of the same overarching study, we treated the effect sizes as independent.

Leave-one-out analysis was used as a sensitivity analysis to investigate the influence of any single study for each outcome, in which each study was omitted from the dataset at a time, and then the meta-analysis was recalculated.

Effect estimates are displayed as mean differences with 95% confidence intervals in the native units of the outcome. F (%) and p-values for tests of heterogeneity are also reported. No multiple-comparison corrections are applied within or among outcomes. There are few effect sizes (k=12), there is substantial design heterogeneity (e.g., study length, types of breakfast, different populations), and there is statistical heterogeneity in several outcomes; therefore, funnel plot asymmetry is not presented because visual estimation of asymmetry is unreliable for small k, the test is underpowered for small k, and any association between effect size and variance may plausibly be explained by study design or other factors rather than just publication bias.

We also calculated secondary analyses. First, we compared habitual breakfast eaters versus habitual breakfast skippers, as defined by the authors of the published papers. This subgroup analysis completed the preliminary analyses we initially published as abstracts. If baseline habits were not reported, or if authors reported that the baseline habits of the participants were mixed, the study arms were excluded. Second, we conducted a cumulative meta-analysis, sequentially adding studies from the longest (16 weeks) to the shortest (6 days) to address concerns that breakfast effects may differ based on study duration. The secondary analyses were based on the same effect size estimates generated for the primary analysis. The same functions were used in R, except for modeling the outcome variable as a function of both assigned condition and baseline breakfast habits, or sequentially adding effect sizes, respectively. Additional methods can be found in the subgroup analysis document and code located in https://doi.org/10.5281/zenodo.4970781.

Risk of bias

Risk of bias was assessed independently by two investigators (MMBB/JEM for all but Ogata 2019 and MMBB/AWB for Ogata 2019) using Cochrane’s Risk of Bias Tool. Given that the interventions are obvious to participants (eating versus skipping breakfast), we only coded blinding of personnel, and readers should be aware of the risk of non-blinded interventions. We do not use the approach of assigning a binary risk of bias to an entire study (e.g., if one criterion is high risk in a study, the entire study is considered high risk); however, we provide the individual ratings for each article and readers can apply such an approach if they wish.

Results

PRISMA diagram

The search results are shown in the PRISMA diagram in Figure 1. The results of each of the three phases of the search are shown.

Inclusion table

Ten papers were included with 12 effect sizes (see Table 1 for descriptions). Briefly, of the 10 studies included: six were conducted in the United States, three in the United Kingdom, and one in Japan; two were cross-over RCTs and eight were parallel arm RCTs; length ranged from 6 days to 16 weeks; five provisioned some or all foods and five were recommendations for dietary consumption; two stratified on baseline eating or skipping habits, two included only habitual breakfast eaters, three included only habitual breakfast skippers, two reported mixed baseline habits, and one did not specify baseline habits; four reported race/ethnicity of participants; four included females only, one included males only, and five included both females and males. For breakfast definitions, dietary compositions, and timing, see Table 1 and Figure 2. Breakfast definitions and timing of consumption varied amongst the studies included and ranged from highly controlled and prescribed to broad recommendations (Figure 2).

Meta-analyses of anthropometric outcomes

Figure 3 shows a composite forest plot that includes all meta-analyzable, obesity-related, anthropometric outcomes. In all cases, the 95% confidence intervals included the null of no differences between skipping and eating breakfast (frequently interpreted as “not statistically significant”). Table 2 shows the numerical estimates of the values displayed in the forest plots. Therefore, no discernible effects of breakfast eating or breakfast skipping on body weight (kg), BMI (kg/m²), body fat percentage (%), fat mass (kg), lean mass (kg), waist (cm), waist:hip ratio, sagittal abdominal diameter (cm) and fat mass index (kg/m²) were found in these primary analyses.
In the secondary analysis comparing habitual breakfast eaters versus habitual breakfast skippers (as defined by the authors of the published papers), forest plots and a summary table can be found in the subgroup between group forest plots document and subgroup between group summary table located in https://doi.org/10.5281/zenodo.4970781. Briefly, there was no discernible effect of stratification of baseline habits on four of the outcomes: body weight (4 effect sizes for habitual breakfast eaters; 4 effect sizes for habitual breakfast skippers), body fat percentage (2 and 2 effect sizes, respectively), fat mass (1 and 2 effect sizes, respectively), or lean mass (1 and 2 effect sizes, respectively). Insufficient study arms existed to test differences for waist circumference, waist:hip ratio, sagittal abdominal diameter, and fat mass index. Only BMI was statistically significant (2 and 4 effect sizes, respectively). The negative estimate of −0.36 [−0.65, −0.07] BMI units indicates that individuals assigned to conditions consistent with their baseline habits had lower values than those assigned opposite of their habits. That is, habitual breakfast skippers had lower BMI when skipping breakfast and habitual breakfast eaters had lower BMI when eating breakfast, compared to skippers eating and eaters skipping.

For the cumulative meta-analysis, in which studies were sequentially added from longest to shortest, a forest plot for body weight and BMI are included in the supplementary material at https://doi.org/10.5281/zenodo.4970781. Only when studies were 4 weeks and longer were results statistically significant in favor of skipping breakfast (0.57 [0.08, 1.07] kg and 0.16 [0.03, 0.30] kg/m², respectively). Results were not statistically significant when including only studies longer than 4 weeks or adding studies shorter than 4 weeks, with point estimates spanning both sides of the null.

**Risk of bias**

Risk of bias varied by study (Figure 4). Two studies had low risk of bias across all categories: Dhurandhar 2014 and Ogata 2019. Two studies, Betts 2014 and Chowdhury 2016, were coded as high risk of bias for the criterion of blinding participants and personnel because the authors clearly indicated that personnel were not blinded. Given that the interventions are obvious to participants (eating versus skipping breakfast), we only focus on blinding of personnel, and readers should be aware of the risk of non-blinded interventions. On the other hand, many of the categories in the risk of bias in each study were unclear, and it is therefore uncertain whether the risk was high or low.

**Sensitivity analysis: Leave-one-out analysis**

The leave-one-out analysis is shown in Figure 5. Little difference is noted among the analyses, with substantial overlap of confidence intervals in all cases. When considering statistical significance (i.e., confidence intervals that do not include 0), leaving Farshchi et al. out of the analysis results in significantly greater BMI in the breakfast conditions than the skipping conditions. When Leidy et al. is excluded, fat mass is greater in the breakfast than the skipping conditions. Waist:hip ratio is centered on zero with no estimable confidence interval when Chowdhury et al. is left out because the other three estimates are all 0.00. We reiterate that none of these summaries took multiple comparisons into account.
<table>
<thead>
<tr>
<th>Study</th>
<th>Location</th>
<th>Population</th>
<th>Baseline BMI ± SD (*SEM)</th>
<th>Weight-related inclusion criteria and context</th>
<th>Age (Mean ± SD)</th>
<th>Race/Ethnicity</th>
<th>Intervention</th>
<th>Provision of Food</th>
<th>Baseline Breakfast Habits (Eaters vs Skippers)</th>
<th>Breakfast Eating and Breakfast Skipping Definitions</th>
<th>Dietary Composition</th>
<th>Weight-related anthropometric measures preregistered as primary or secondary outcome</th>
<th>Weight-related anthropometric measures reported</th>
</tr>
</thead>
<tbody>
<tr>
<td>Betts 2014</td>
<td>UK</td>
<td>Adults: n=33 64% Female 21 – 60 y</td>
<td>All: 22.4 ± 2.2 BF: 22.0 ± 2.2 Skip: 22.8 ± 2.3</td>
<td>Weight stable (1 kg past 6 mo) DXA fat mass index ≤11 kg/m² women; ≤7.5 kg/m² men</td>
<td>All: 36 ± 11 y BF: 36 ± 11 y Skip: 36 ± 11 y</td>
<td>Not reported</td>
<td>6 wk parallel arm RCT Recommendation to eat or skip breakfast</td>
<td>No</td>
<td>Mixed</td>
<td>Breakfast group: consume energy intake of ≥700 kcal before 1100 h daily, with at least half consumed within 2 h of waking Fasting group (skip): Extend overnight fast by abstaining from ingestion of energy-providing nutrients (plain water only) until 1200 h each day.</td>
<td>No recommendation for the diet was given.</td>
<td>Yes</td>
<td>ISRCTN31521726</td>
</tr>
<tr>
<td>Chowdhury 2016</td>
<td>UK</td>
<td>Adults: n=23 69% Female 21 – 60 y</td>
<td>All: 33.7 ± 4.9 BF: 35.4 ± 6.1 Skip: 31.9 ± 2.3</td>
<td>Weight stable (2% past 6 mo) DXA fat mass index ≥13 kg/m² women; ≥9 kg/m² men</td>
<td>All: 44 ± 10 y BF: 44 ± 10 y Skip: 44 ± 10 y</td>
<td>Not reported</td>
<td>6 wk parallel arm RCT Recommendation to eat or skip breakfast</td>
<td>No</td>
<td>Mixed</td>
<td>Breakfast group: consume energy intake of ≥700 kcal before 1100 h daily, with at least half consumed within 2 h of waking Fasting group (skip): Extend overnight fast by abstaining from ingestion of energy-providing nutrients (plain water only) until 1200 h each day.</td>
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<td>Provision of Food</td>
<td>Baseline Breakfast Habits (Eaters vs Skippers)</td>
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<td>Dietary Composition</td>
<td>Weight-related anthropometric measures preregistered as primary or secondary outcome</td>
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<tr>
<td>Dhurandhar 2014</td>
<td>USA</td>
<td>Adults: n=185 76% Female 20 – 65 y</td>
<td>Not reported</td>
<td>• Interested in weight loss; no weight reduction program past 3 mo; no weight loss/gain &gt;= 5% past 6 mo; BMI &gt; 25 but &lt; 45</td>
<td>BF: 40.6 ± 12.0 y Skip: 42.0 ± 12.4 y</td>
<td>Total: WHN: 93, BH8: 17, BH12: 0.12 Breakfast: WHN: 45, BH8: 40, WH5: 0.6 Skip: WHN: 48, BNH: 34, WH12: 0.6</td>
<td>16 wk parallel arm RCT Recommendation to eat breakfast, skip breakfast, or neither (control group); all three treatment groups were given a USDA pamphlet with a handout instructing participants to consume breakfast before 1000 h every day. The breakfast group received the USDA pamphlet with a handout instructing participants to consume breakfast before 1000 h every day. The breakfast handout also provided suggestions of food items that might constitute a healthy breakfast; however, no specific restrictions were given on types of foods that could be consumed for the breakfast meal. The skipping group received the USDA pamphlet with a handout instructing participants not to consume any calories before 1000 h every day, and only water or zero-calorie beverages could be consumed from the time of waking until 1100 h. No specific composition was recommended.</td>
<td>No</td>
<td>Stratified</td>
<td>Breakfast Eating: meal before 1000 h. Skipping: no eating or caloric consumption prior to 1100 h.</td>
<td>Yes: NCT01781780</td>
<td>BW, BMI</td>
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</table>
| Study          | Location | Population | Baseline BMI ± SD (*SEM) | Weight-related inclusion criteria and context | Age (Mean ± SD)

<table>
<thead>
<tr>
<th>Race/Ethnicity¹</th>
<th>Intervention</th>
<th>Provision of Food</th>
<th>Baseline Breakfast Habits (Eaters vs Skippers)</th>
<th>Breakfast and one snack</th>
<th>Dietary Composition¹</th>
<th>Weight-related anthropometric measures reported¹</th>
</tr>
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<tbody>
<tr>
<td>Forsch 2005</td>
<td>UK</td>
<td>Adults: n=10100% Female 19 – 38 y</td>
<td>All: 23.2 ± 1.6</td>
<td>• Not dieting (score &gt;30 on The Eating Inventory) • “Lean”</td>
<td>Total 25.5 ± 5.7 y</td>
<td>Not reported</td>
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<tr>
<td>Study</td>
<td>Location</td>
<td>Population</td>
<td>Baseline BMI ± SD (*SEM)</td>
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<tr>
<td>Geliebter 2014</td>
<td>USA</td>
<td>Adults: n=36 50% Female 8 – 65 y</td>
<td>All: 32.9 ± 4.7</td>
<td>• Weight stable (&lt;5% in 3 mo) not currently or intending weight-loss diet or exercise program BMI &gt; 25</td>
<td>Total sample: 33.9 ± 7.5 y M:35.6 ± 6.1 y F:32.3 ± 8.6 y</td>
<td>Total: W:16, B:10, H:6, A:3, O:3 Skip: W:4, B:3, H:3, A:1, O:1 C: W:6, Breakfast:3, H:2, A:2, O:1 P: W:6, B:4, H:1, A:0, O:1</td>
</tr>
<tr>
<td>LeCheminant 2017</td>
<td>USA</td>
<td>Adults: n=49 100% Female 18 – 55 y</td>
<td>BF: 22.6 ± 3.9 7.5 y 21.5 ± 3.9 Skip: 21.5 ± 3.9</td>
<td>• Weight stable (3 mo); not dieting or excessive activity • “Apparently healthy as indicated by a health history questionnaire”</td>
<td>BF: 23.7 ± 7.5 y Skip: 23.6 ± 5.0 y</td>
<td>Not reported</td>
</tr>
<tr>
<td>Study</td>
<td>Location</td>
<td>Population</td>
<td>Baseline BMI ± SD (*SEM)</td>
<td>Weight-related inclusion criteria and context</td>
<td>Age (Mean ± SD)¹</td>
<td>Race/Ethnicity¹</td>
</tr>
<tr>
<td>--------</td>
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</tr>
<tr>
<td>Leidy 2015 USA</td>
<td>Adolescent n=54 57% Female 19 y (mean)</td>
<td>Skip: 29.1 ± 6.3 Normal Protein: 29.3 ± 4.8 High Protein: 30.3 ± 3.7</td>
<td>• Not currently/ previously on a weight loss diet  • BMI 25-39.9</td>
<td>Skip:19 ± 1 y Normal Protein BF: 18 ± 1 y High Protein BF: 19 ± 1 y</td>
<td>Total: W:33, B:19, O:2 Skip: W:6, B:3, O:0 Normal Protein: W:16, B:5, O:1 High Protein: W:11, B:11, O:2</td>
<td>12 wk parallel arm RCT Recommendation to skip breakfast compared to the provision of normal protein and high protein breakfasts in habitual skippers</td>
</tr>
<tr>
<td>Study</td>
<td>Location</td>
<td>Population</td>
<td>Baseline BMI ± SD (*SEM)</td>
<td>Weight-related inclusion criteria and context</td>
<td>Age (Mean ± SD)¹</td>
<td>Race/Ethnicity²</td>
</tr>
<tr>
<td>-----------</td>
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</tr>
<tr>
<td>Neumann 2016</td>
<td>USA</td>
<td>Adults: n = 24 100% Female 11 – 36 y</td>
<td>Skip: 27.8 ± 2.2* Carbohydrate: 26.0 ± 1.9* Protein: 26.6 ± 2.1*</td>
<td>• Not trying to lose weight/ restricting eating, not lost weight in 6 mo • Not reported</td>
<td>Skip: 27.1 ± 1.8 y Carbohydrate: 21.9 ± 0.9 y Protein: 23.3 ± 1.3 y</td>
<td>Skip: C5, H1, B1, A0, I1 Carbohydrate: C3, H1, B1, A2, I1 Protein: C6, H1, B1, A0, I0</td>
</tr>
<tr>
<td>Study</td>
<td>Location</td>
<td>Population</td>
<td>Baseline BMI ± SD (SEM)</td>
<td>Weight-related inclusion criteria and context</td>
<td>Age (Mean ± SD)</td>
<td>Race/Ethnicity^1</td>
</tr>
<tr>
<td>------------</td>
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</tbody>
</table>
| Ogata 2019 | Japan    | Adult: n=10 0% Female 20 – 30 y | BF to Skip: 23.1 ± 3.7  
Skip to BF: 23.8 ± 1.5 | • Not reported  
• “Healthy males” | BF to Skip: 24.8 ± 2.9 y  
Skip to BF: 25.6 ± 3.0 y | Japanese: 10 | 6 d per condition, cross-over RCT  
Intervention to eat or skip breakfast | All food | Habitual eaters | Breakfast eating group consumed breakfast at 0700 h, breakfast skipping group nothing prior to lunch at 1230 h. | Breakfast eating group had 33.3% of daily energy intake for each of the three meals of breakfast (0700 h), lunch (1230 h), and dinner (1800 h). The breakfast skipping group had 0% for breakfast, 50% of daily energy intake each for lunch (1230 h) and dinner (1800 h). The 24-h energy intake was equal for both dietary conditions. The meals provided were individually adjusted (3042 ± 598 kcal/d, 14% protein, 25% fat, and 61% carbohydrates). | Yes | UMIN000032346 | BW, BMI, FM, FFM, TBWP |
<table>
<thead>
<tr>
<th>Study</th>
<th>Location</th>
<th>Population</th>
<th>Baseline BMI ± SD (*SEM)</th>
<th>Weight-related inclusion criteria and context</th>
<th>Age (Mean ± SD)</th>
<th>Race/Ethnicity</th>
<th>Intervention</th>
<th>Provision of Food</th>
<th>Baseline Breakfast Habits (Eaters vs Skippers)</th>
<th>Breakfast Eating and Breakfast Skipping Definitions</th>
<th>Dietary Composition</th>
<th>Weight-related anthropometric measures preregistered as primary or secondary outcome</th>
<th>Weight-related anthropometric measures reported</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schlundt 1992</td>
<td>United States</td>
<td>Adults: n= 45 100% Female 18 – 55 y</td>
<td>All: 30.6 ± 0.5</td>
<td>• Interested in weight-loss research; no weight loss of &gt; 4.5 kg past 1 mo or &gt; 9 kg past 6 mo • 30-60% above ideal body weight from Metropolitan Life Tables</td>
<td>Only range stated</td>
<td>Not reported</td>
<td>12 wk parallel arm RCT</td>
<td>Baseline breakfast eaters and skippers were assigned to either eat or skip breakfast with total diet composition and caloric content same between groups</td>
<td>No</td>
<td>Stratified</td>
<td>Menus and instructions for 3 meals (breakfast, lunch and dinner) or 2 meals (lunch and dinner), timing not specified in the paper.</td>
<td>Total dietary composition: 50-55% of energy from carbohydrates, 15-20% from protein, and 25-30% from fats. No breakfast diet consisted of two meals, lunch (1672 kJ) and supper (3344 kJ). Breakfast diet consisted of three meals, breakfast (1672 kJ), lunch (1254 kJ), and supper (2090 kJ).</td>
<td>Not registered</td>
</tr>
</tbody>
</table>

1BF: Breakfast.

1A, Asian; B, Black; BH, Black Hispanic; BHN, Black Non-Hispanic; C: Caucasian; H, Hispanic; I, Indian; O, Other; W, White; WH, White Hispanic; WHN, White Non-Hispanic.

1Definitions paraphrased from each study paper.

1ATM, adipose tissue mass; BF%, body fat percentage; BW, body weight; FFM, fat-free mass; FM, fat mass; FM index, lean mass; LTM, lean tissue mass; MM, muscle mass; SAD, sagittal abdominal diameters; TBWP, total body water percentage; WC, waist circumference; WHR, waist:hip ratio. Some additional outcomes might have been mentioned in the paper, but quantitative results may not have been reported after the intervention.
Figure 2. Schematic of breakfast versus skipping timing and patterns. The top section outlines the patterns for the included studies; the middle section shows a few examples of studies we did not classify as eating versus skipping breakfast that are explained further in the 'Notable Exclusions' section and in Table 3; and the bottom is a legend for the figure. 'Inferred eating window' represents the times we inferred that participants were permitted or recommended to consume food as reported in the papers; 'specified eating window', 'breakfast eating window', and 'assigned eating times' were reported by the authors in either absolute or relative times (e.g., number of hours since waking). For more details for the included studies, see Table 1.
Figure 3. Composite forest plot of seven meta-analyzable anthropometric outcomes. Sagittal abdominal diameter and fat mass index were only included in the two papers from the Bath Breakfast Project (Betts et al. and Chowdhury et al.), and are not plotted here; outcomes of muscle mass and total body water percent were only included in Ogata et al., and so no meta-analyzable estimate was possible. See Table 2 for the numerical values of these seven analyses, plus the sagittal abdominal diameter and fat mass index. Studies without point estimates and confidence intervals within an outcome indicates that the study did not report that outcome. 95% confidence intervals for individual studies and for the width of the diamond representing the summary estimate are presented. Horizontal dotted lines for the summary of the meta-analyses represents the 95% prediction interval. For the column ‘Habit’: e, habitual eaters; s, habitual skippers; u, unspecified or mixed. Values to the left of 0 indicate that the breakfast condition had a greater decrease in the outcome relative to the skipping condition. For all outcomes except lean mass, values to the left would therefore traditionally be considered ‘favoring’ the breakfast condition (e.g., lower body weight).

Notable exclusions
Notable exclusions are located in Table 3. Broad areas to note are the lack of a skipping group for comparison to breakfast groups, intervention periods that were less than 72 hr in duration, studies that had the comparison of interest but did not measure body weight, and studies whose primary purpose did not isolate breakfast eating versus breakfast skipping, such as time restricted feeding and shift in consumption periods. Two examples of the latter include Wehrens et al., who shifted all meals by 5 hours (as well as not being in a randomized order), to extreme time restriction of Halberg et al. who assigned only breakfast or dinner (Figure 2).

In this meta-analysis, our included studies were all conducted in adults/adolescents, but, as noted in Table 3, there have been several related studies conducted in children; however, none of the studies in children had a true skipping group. For instance, Rosado et al. had a control group with no intervention, which is not equivalent to assigning children to skip breakfast. Similarly, Powell et al. did have a group that was assigned to consume a slice of orange as an attention placebo control, but again the children were not assigned to otherwise skip breakfast.

Discussion
Summary
The causal effect of eating versus skipping breakfast on obesity-related anthropometric outcomes was non-significantly different from zero across body weight, BMI, body fat percentage, fat mass, lean mass, waist circumference, waist: hip ratio, sagittal abdominal diameter, and fat mass index. Our results largely match our prior analyses, as well as the analysis of body weight conducted by Sievert et al.

The choices of inclusion/exclusion criteria, adjustments, and assumptions to use when meta-analyzing data can influence the interpretation of results, so we highlight some of our choices here. Our choice of including studies greater than 72 hours in duration (with the shortest actually included being 6 days) should avoid including experiments measuring only transient differences from hydration, glycogen, or other very acute physiological responses. Furthermore, this approach allowed us to collate all relevant experiments and enables readers to reanalyze our results with their preferred study duration cutoff should the reader so choose.

We chose to define breakfast eating versus breakfast skipping according to the intentions of the original study authors where possible. This was primarily done because a common recommendation is to eat breakfast to lose weight without any other qualifications. Similarly, skipping breakfast is sometimes suggested to be an antecedent to weight gain, and thus regular consumption of breakfast has been recommended in lay discussions as a form of primary prevention of obesity. We therefore included studies that 1) may or may not have had a focus on weight loss or active prevention of weight gain, 2) included a range of baseline participant weight characteristics, and
**Table 2. Effect sizes for each study and meta-analyzable anthropometric outcome shown in Figure 3.** Data are presented as mean [95% CI] for each study and the summary estimate, expressed as mean difference. Positive values are higher during breakfast conditions. n represents the total number of individuals within a study; k is the number of effect sizes in a meta-analytic estimate; MD is mean difference; $I^2$ represents heterogeneity, with the associated p-value representing the statistical test for significant heterogeneity. Outcomes of muscle mass and total body water percent were only included in Ogata et al., and so no meta-analyzable estimate was possible.

<table>
<thead>
<tr>
<th>Study</th>
<th>n</th>
<th>Body weight (kg)</th>
<th>BMI</th>
<th>Body fat (%)</th>
<th>Fat mass (kg)</th>
<th>Lean mass (kg)</th>
<th>Waist circumference (cm)</th>
<th>Waist:hip ratio</th>
<th>Sagittal abdominal diameter (cm)</th>
<th>Fat mass index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Betts 2014</td>
<td>33</td>
<td>0.20 [-0.46,0.86]</td>
<td>0.11 [-0.12,0.34]</td>
<td>-0.20 [-1.36,0.96]</td>
<td>0.00 [-0.85,0.85]</td>
<td>0.00 [-0.82,0.82]</td>
<td>-0.30 [-1.58,0.98]</td>
<td>0.00 [-0.02,0.02]</td>
<td>0.00 [-0.64,0.64]</td>
<td>0.01 [-0.28,0.30]</td>
</tr>
<tr>
<td>Chowdhury 2016</td>
<td>23</td>
<td>0.80 [-0.19,1.79]</td>
<td>0.26 [-0.08,0.60]</td>
<td>-0.24 [-2.21,1.73]</td>
<td>-0.10 [-2.12,1.92]</td>
<td>0.40 [-1.63,2.43]</td>
<td>2.20 [-0.56,4.96]</td>
<td>0.02 [-0.00,0.04]</td>
<td>0.40 [-0.28,1.08]</td>
<td>-0.04 [-0.76,0.68]</td>
</tr>
<tr>
<td>Dhurandhar 2014e</td>
<td>109</td>
<td>0.06 [-1.68,1.80]</td>
<td>0.03 [-0.59,0.65]</td>
<td>0.06 [-1.68,1.80]</td>
<td>0.06 [-1.68,1.80]</td>
<td>0.06 [-1.68,1.80]</td>
<td>0.06 [-1.68,1.80]</td>
<td>0.06 [-1.68,1.80]</td>
<td>0.06 [-1.68,1.80]</td>
<td>0.06 [-1.68,1.80]</td>
</tr>
<tr>
<td>Dhurandhar 2014s</td>
<td>95</td>
<td>-0.31 [-2.09,1.46]</td>
<td>-0.09 [-0.72,0.54]</td>
<td>-0.31 [-2.09,1.46]</td>
<td>-0.31 [-2.09,1.46]</td>
<td>-0.31 [-2.09,1.46]</td>
<td>-0.31 [-2.09,1.46]</td>
<td>-0.31 [-2.09,1.46]</td>
<td>-0.31 [-2.09,1.46]</td>
<td>-0.31 [-2.09,1.46]</td>
</tr>
<tr>
<td>Farshchi 2005</td>
<td>10</td>
<td>-0.50 [-1.07,0.07]</td>
<td>-0.20 [-0.40,0.00]</td>
<td>-0.60 [-1.45,0.25]</td>
<td>-0.60 [-1.45,0.25]</td>
<td>-0.60 [-1.45,0.25]</td>
<td>-0.60 [-1.45,0.25]</td>
<td>-0.60 [-1.45,0.25]</td>
<td>-0.60 [-1.45,0.25]</td>
<td>-0.60 [-1.45,0.25]</td>
</tr>
<tr>
<td>Gelleberter 2014</td>
<td>36</td>
<td>1.30 [0.46,2.14]</td>
<td>0.24 [0.03,0.44]</td>
<td>0.29 [-0.17,0.75]</td>
<td>0.41 [-0.03,0.85]</td>
<td>0.06 [-0.21,0.33]</td>
<td>0.85 [0.27,1.43]</td>
<td>0.00 [-0.01,0.01]</td>
<td>0.00 [-0.02,0.02]</td>
<td>0.00 [-0.02,0.02]</td>
</tr>
<tr>
<td>LeCheminant 2017</td>
<td>49</td>
<td>0.64 [0.09,1.19]</td>
<td>0.24 [0.03,0.44]</td>
<td>0.29 [-0.17,0.75]</td>
<td>0.41 [-0.03,0.85]</td>
<td>0.06 [-0.21,0.33]</td>
<td>0.85 [0.27,1.43]</td>
<td>0.00 [-0.01,0.01]</td>
<td>0.00 [-0.02,0.02]</td>
<td>0.00 [-0.02,0.02]</td>
</tr>
<tr>
<td>Leidy 2015</td>
<td>54</td>
<td>-1.20 [-3.90,1.50]</td>
<td>-0.39 [-1.30,0.52]</td>
<td>-1.91 [-3.41,-0.42]</td>
<td>-1.77 [-3.62,0.08]</td>
<td>0.55 [-0.74,1.85]</td>
<td>0.00 [-0.01,0.01]</td>
<td>0.00 [-0.02,0.02]</td>
<td>0.00 [-0.02,0.02]</td>
<td>0.00 [-0.02,0.02]</td>
</tr>
<tr>
<td>Neumann 2016</td>
<td>23</td>
<td>0.37 [-0.41,1.16]</td>
<td>0.17 [-0.16,0.49]</td>
<td>0.37 [-0.41,1.16]</td>
<td>0.37 [-0.41,1.16]</td>
<td>0.37 [-0.41,1.16]</td>
<td>0.37 [-0.41,1.16]</td>
<td>0.37 [-0.41,1.16]</td>
<td>0.37 [-0.41,1.16]</td>
<td>0.37 [-0.41,1.16]</td>
</tr>
<tr>
<td>Ogata 2019</td>
<td>10</td>
<td>-0.93 [-1.37,0.49]</td>
<td>0.12 [-0.93,1.17]</td>
<td>0.31 [-0.43,1.05]</td>
<td>0.54 [-0.18,1.26]</td>
<td>0.00 [-0.01,0.01]</td>
<td>0.00 [-0.01,0.01]</td>
<td>0.00 [-0.01,0.01]</td>
<td>0.00 [-0.01,0.01]</td>
<td>0.00 [-0.01,0.01]</td>
</tr>
<tr>
<td>Schlundt 1992e</td>
<td>29</td>
<td>2.70 [-0.19,5.59]</td>
<td>0.70 [-1.00,2.33]</td>
<td>0.07 [-1.00,2.33]</td>
<td>-0.27 [-1.01,0.47]</td>
<td>0.24 [-0.21,0.69]</td>
<td>0.18 [-0.08,0.44]</td>
<td>0.18 [-1.77,2.13]</td>
<td>0.00 [-0.01,0.01]</td>
<td>0.19 [-2.35,2.73]</td>
</tr>
<tr>
<td>Schlundt 1992s</td>
<td>16</td>
<td>-1.70 [-5.55,2.15]</td>
<td>-0.40 [0.03,0.07]</td>
<td>0.07 [-1.00,2.33]</td>
<td>-0.27 [-1.01,0.47]</td>
<td>0.24 [-0.21,0.69]</td>
<td>0.18 [-0.08,0.44]</td>
<td>0.18 [-1.77,2.13]</td>
<td>0.00 [-0.01,0.01]</td>
<td>0.19 [-2.35,2.73]</td>
</tr>
<tr>
<td>MD [CI]</td>
<td></td>
<td>0.17 [-0.40,0.73]</td>
<td>0.07 [-0.10,0.23]</td>
<td>-0.27 [-1.01,0.47]</td>
<td>0.24 [-0.21,0.69]</td>
<td>0.18 [-0.08,0.44]</td>
<td>0.18 [-1.77,2.13]</td>
<td>0.00 [-0.01,0.01]</td>
<td>0.19 [-2.35,2.73]</td>
<td>0.00 [-0.22,0.23]</td>
</tr>
<tr>
<td>k (n)</td>
<td></td>
<td>12 (487)</td>
<td>8 (396)</td>
<td>6 (179)</td>
<td>6 (205)</td>
<td>6 (205)</td>
<td>4 (102)</td>
<td>4 (102)</td>
<td>2 (56)</td>
<td>2 (56)</td>
</tr>
<tr>
<td>$I^2$ (p for $I^2$)</td>
<td></td>
<td>74.5 (&lt;0.001)</td>
<td>54.1 (0.036)</td>
<td>52.4 (0.055)</td>
<td>0.0 (0.311)</td>
<td>6.7 (0.682)</td>
<td>78.7 (0.002)</td>
<td>8.0 (0.413)</td>
<td>0.0 (0.376)</td>
<td>0.0 (0.895)</td>
</tr>
</tbody>
</table>
Figure 4. Risk of bias assessment. Each included paper was assessed for risk of bias using the Cochrane Risk of Bias tool. Given that the interventions are obvious to participants (eating versus skipping breakfast), we only coded blinding of personnel, and readers should be aware of the risk of non-blinded interventions.

3) included a variety of breakfast compositions, timings, and definitions. Indeed, as one reviewer noted, “Many of the studies included in this and other SR [systematic reviews] are small, and are often conducted in participants with a mixed usual breakfast habit who are not overweight or attempting to limit their energy intake or reduce their body weight.” We therefore cannot rule out the possibility that breakfast eating versus skipping may result in different effects in a weight-gain-prevention versus weight-loss context, or for people in different weight classes. The data from included studies is insufficient for us to test these additional hypotheses.

Furthermore, we cannot rule out that there may be some statistically significant combination of studies, subgroups, splitting-versus-pooling of different breakfasts, or different imputation strategies. However, we note that the results are fairly consistently centered near zero. We also note that Sievert et al. and Bonnet et al. both concluded small but statistically significant differences in favor of breakfast skipping. Each review included a different subset of studies, predominantly driven by duration of studies included. For one specific point of comparison, Sievert et al. used a different imputation strategy than we did for Farshchi et al. We estimated the correlations based on the estimates from Geliebter et al., while constraining the interval to the statistically non-significant results. Bonnet et al. did not include Farshchi et al. because it was too short (2 weeks) for their cutoff of 4 weeks. Our cumulative analysis similarly concluded a statistically significant difference.
Figure 5. Leave-one-out analysis. Within each column, the diamond represents the meta-analytic summary estimate when leaving out the study in a particular row. Row and column combinations without diamonds represent outcomes that are not reported for that particular study. *The waist:hip ratio had no estimable confidence interval because the three remaining estimates were all 0.00. Sagittal abdominal diameter and fat mass index were only included in the two papers from the Bath Breakfast Project (Betts et al. and Chowdhury et al.), and therefore a leave-one-out analysis would include only a single study; outcomes of muscle mass and total body water percent were only included in Ogata et al., and so a leave-one-out analysis is not possible.

Table 3. Notable studies that were excluded with reasons.

<table>
<thead>
<tr>
<th>Study</th>
<th>Reason for exclusion*</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alwatter 2015</td>
<td>No weight or anthropometry</td>
<td>Adolescent girls</td>
</tr>
<tr>
<td>Frape 1997</td>
<td>No weight or anthropometry</td>
<td>Adults</td>
</tr>
<tr>
<td>Gwin 2013</td>
<td>No weight or anthropometry</td>
<td>Adults</td>
</tr>
<tr>
<td>Halsey 2012</td>
<td>No weight or anthropometry</td>
<td>Adults</td>
</tr>
<tr>
<td>Hoertel 2014</td>
<td>No weight or anthropometry</td>
<td>Adolescent girls</td>
</tr>
<tr>
<td>Leidy 2013</td>
<td>No weight or anthropometry</td>
<td>Adolescent girls</td>
</tr>
<tr>
<td>Reeves 2014</td>
<td>No weight or anthropometry</td>
<td>Adults</td>
</tr>
<tr>
<td>Reeves 2015</td>
<td>No weight or anthropometry</td>
<td>Adults</td>
</tr>
<tr>
<td>Rosi 2018</td>
<td>Less than 72 hr</td>
<td>Adult men; no weight</td>
</tr>
<tr>
<td>Yoshimura 2017</td>
<td>Less than 72 hr</td>
<td>Adult women; one-day study</td>
</tr>
<tr>
<td>Zakrewski-Frue 2017</td>
<td>Less than 72 hr</td>
<td>Adolescent girls; only baseline weight</td>
</tr>
<tr>
<td>Carlson 2007</td>
<td>Not about breakfast</td>
<td>Adults; did not include weight outcomes; compared 1 vs 3 meals per day with weight being deliberately maintained (see Figure 2)</td>
</tr>
<tr>
<td>Hirsch 1975</td>
<td>Not about breakfast</td>
<td>Adults; dinner only versus breakfast only (see Figure 2)</td>
</tr>
<tr>
<td>Keim 1997</td>
<td>Not about breakfast</td>
<td>Adult Women; distribution of calories as 70% morning versus 70% evening</td>
</tr>
<tr>
<td>Tinsley 2019</td>
<td>Not about breakfast</td>
<td>Adult women; time-restricted feeding versus not (see Figure 2)</td>
</tr>
<tr>
<td>Wehrens 2017</td>
<td>Not about breakfast</td>
<td>Adult men; non-randomized order; all meals (not just breakfast) shifted 5 hours (see Figure 2)</td>
</tr>
</tbody>
</table>
only when studies of 4 weeks and longer were included for body weight and BMI (but not when shorter studies were included, or only studies longer than 4 weeks were included).

Our leave-one-out analyses, produced only two values that became statistically significantly different in favor of skipping breakfast: BMI when Farshchi et al. was excluded, and fat mass when Leidy et al. was excluded.

The subgroup analysis of baseline breakfast habits included few effect sizes to estimate interaction effects between baseline breakfast habits and breakfast assignment. We could test for differences in 5 of the outcomes. Of these, BMI showed a significant interaction between baseline habits and assigned condition. The statistical significance of these secondary estimates should be considered within the following contexts. In the leave-one-out analyses, the 95% confidence intervals did not differ substantially from other leave-one-out analyses.

In the subgroup analyses, few effect sizes were available for comparison. There were 4 treatment effect estimates each for habitual breakfast eaters and habitual breakfast skippers for body weight, while there were only 2 and 4, respectively, for BMI. Some outcomes had only 1 and 2 effect estimates for eaters and skippers, respectively. In all cases, we did not adjust for multiple comparisons because of their exploratory nature. Given the small departure of the confidence intervals from 0, it is likely these would no longer be statistically significant if multiple comparisons were considered. Even if effects turned out to be non-zero, the 95% confidence and prediction intervals of the outcomes include effect sizes of low clinical significance, and thus further work would be needed to determine if non-zero effects are actually clinically meaningful.

Despite this relative consistency in summary effect sizes, we note that there was substantial design heterogeneity. The length of studies, for instance, varied substantially. To be confident in effects of obesity-related interventions, longer term studies are desired. However, the need for longer-term studies is often to guard against concluding that early effects (weeks to months) will result in sustained weight loss over months to years. Given the overall null findings herein, suggesting a need for longer studies would serve to test whether these relatively acute null findings reflect long-term adaptations to establishing breakfast habits. In addition, some have argued that it is not merely eating versus skipping breakfast that is important, but rather that the *type* of breakfast matters (c.f., Leidy et al. 2016). Such an argument does not invalidate the question asked or the findings of this meta-analysis, however. If, for instance, a breakfast of a particular characteristic is what influences weight – be it fiber content, protein, energetic load, timing from waking, or others – then the question would not be whether eating versus skipping breakfast matters; rather, research would need to test the effects of that particular breakfast versus comparator groups, whether those comparator groups be different breakfasts or no breakfast at all. Similarly, whether effects exist that depend on baseline anthropometry, or in different contexts (e.g., weight loss versus prevention of weight gain), also may warrant further study.

We clarify that our results are limited to obesity-related anthropometric outcomes. As stated previously, “Just because breakfast

<table>
<thead>
<tr>
<th>Study</th>
<th>Reason for exclusion*</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ask 2006</td>
<td>No skipping condition</td>
<td>Children; quasi-experiment</td>
</tr>
<tr>
<td>Crepinsek 2006</td>
<td>No skipping condition</td>
<td>Children</td>
</tr>
<tr>
<td>Douglas 2019</td>
<td>No skipping condition</td>
<td>Adults</td>
</tr>
<tr>
<td>Jakubowicz 2012</td>
<td>No skipping condition</td>
<td>Adolescent girls</td>
</tr>
<tr>
<td>Powell 1998</td>
<td>No skipping condition</td>
<td>Children</td>
</tr>
<tr>
<td>Rosado 2008</td>
<td>No skipping condition</td>
<td>Children</td>
</tr>
<tr>
<td>St Onge 2015</td>
<td>No skipping condition</td>
<td>Children</td>
</tr>
<tr>
<td>Versteeg 2017</td>
<td>No skipping condition</td>
<td>Adult men</td>
</tr>
<tr>
<td>Zakrewski-Frue 2018</td>
<td>No skipping condition</td>
<td>Adolescent girls; breakfast skipping was alternate day skipping; no weight beyond baseline</td>
</tr>
<tr>
<td>Chowdhury 2019</td>
<td>Data published elsewhere</td>
<td>BBP: weight data in Chowdhury 2016</td>
</tr>
<tr>
<td>Tuttle 1954</td>
<td>Confounded design</td>
<td>Boys, men, and women; non-counterbalanced crossover; some participants were assigned to gain or lose weight</td>
</tr>
</tbody>
</table>

* Studies were excluded for at least one reason; the reasons given in this column may not be the only reason for exclusion.
consumption may not have a statistically significant effect on weight does not make breakfast a bad recommendation"\textsuperscript{10}, nor does it necessarily make it a good recommendation. Our results do not inform whether eating versus skipping breakfast is of value for blood glucose control (c.f.,\textsuperscript{7}), cardiometabolic risk factors (c.f.,\textsuperscript{11,12}), school performance (c.f.,\textsuperscript{58}), or other outcomes; nor do our results inform the effects of eating versus skipping breakfast as part of a multicomponent behavioral/intensive lifestyle intervention or time restriction paradigm (e.g., early vs late time-restricted feeding). The inference of the results of this study are limited to the broad and simplistic recommendation to eat or skip breakfast to affect anthropometric outcomes.

Conclusion
There was no discernible effect of eating or skipping breakfast on obesity-related anthropometric measures when pooling studies with substantial design heterogeneity and sometimes statistical heterogeneity in our primary analyses.

Data availability
Underlying data
All data underlying the results are available as part of the article and no additional source data are required.

Extended data
Zenodo: Supplemental files for “Eating versus skipping breakfast has no discernible effect on obesity-related anthropometric outcomes: a systematic review and meta-analysis.” https://doi.org/10.5281/zenodo.4970781\textsuperscript{12}.

This project contains the following extended data:
• calculations.R (calculates individual effect sizes for each study)
• metaanalysis with subgroup.R (reproduces the composite forest plot, leave-one-out plot, the summary table, and the subgroup analyses)
• neumann2016.csv (contains the raw data from Neumann 2016 with authors’ corrections)
• rho estimates for farshchi.R (uses data from Geliebter et al. to estimate within-condition pre-post correlations)
• Subgroup analysis - methods and results.pdf (provides the methods, results, summary table, and forest plots for the subgroup interaction estimates between baseline habits and assigned breakfast conditions)

Reporting guidelines
Zenodo: PRISMA checklist for “Eating versus skipping breakfast has no discernible effect on obesity-related anthropometric outcomes: a systematic review and meta-analysis”. https://doi.org/10.5281/zenodo.4970781\textsuperscript{12}.

Data are available under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).

Acknowledgments
The authors would like to thank Xiwei Chen, MS, with the Indiana University School of Public Health-Bloomington Biostatistics Consulting Center for confirming the statistical approach used for the meta-analyses. We also thank the authors of the original studies who provided us with and permitted us to use additional data or information, as described in the methods.

References

14. Farshchi HR, Taylor MA, Macdonald IA: Deleterious effects of omitting breakfast on insulin sensitivity and fasting lipid profiles in healthy lean


44. Keim NL, Van Loan MD, Horn WF, et al.: Weight loss is greater with consumption of large morning meals and fat-free mass is preserved with large evening meals in women on a controlled weight reduction regimen. J Nutr. 1997; 127(1): 75-82. PubMed Abstract | Publisher Full Text


52. Chowdhry EA, Richardson JD, Gonzales JT, et al.: Six Weeks of Morning Fasting Causes Little Adaptation of Metabolic or Appetite Responses to
PubMed Abstract | Publisher Full Text | Free Full Text

Publisher Full Text

PubMed Abstract | Publisher Full Text

PubMed Abstract | Publisher Full Text

PubMed Abstract | Publisher Full Text | Free Full Text
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Nerys Astbury
Nuffield Department of Primary Care Health Sciences, NIHR Oxford Biomedical Research Centre, University of Oxford, Oxford, UK

Although some changes have been made to this manuscript, I do not believe that some of the authors arguments are valid.

If the purpose of the review was to review the literature to determine whether breakfast has an effect on obesity related anthropometric measures - studies of 72 hours are not useful as they argue. If this were true, weight loss diets would be in this time range - whereas it is generally accepted that in order to see any clinically meaningful weight loss 12+ of changes in behaviour is required, although I do admit changes may be apparent before this.

The other point that the authors have not adequately addressed is related to the differentiation between studies that simply recruit (usually normal weight) individuals who are not trying to lose weight or are not advised an energy restricted diet and studies nested within an active weight loss attempt.

This is so important because eating/skipping breakfast may not have any impact in those who are not trying to restrict energy. However, in those who are trying to actively lose weight eating/skipping breakfast may have effects on appetite and regulation of energy intake may influence adherence to such strategies, thus having impact on weight change and anthropometric measures. This should be carefully discussed because many of the RCT of breakfast are the former (weight stable, healthy weight individuals), and looking at an effect of bw and body fatness in this population is to me like exploring the effect of a drug treatment for a disease in healthy (non-diseased individuals).

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Weight loss, Obesity, Appetite regulation, body composition
I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Michelle M Brown, Indiana University School of Public Health - Bloomington, Bloomington, USA

We appreciate Dr. Astbury’s thoughtful comments. The comments reinforce that there are many details about recommendations to eat or skip breakfast that need to be considered beyond simplistic advice, including duration of intervention and to whom the advice is being supplied. Our prior revision addressed one such concern: whether eating versus skipping differs depending on baseline habits. Here, we supply an additional analysis accounting for duration of intervention and include more details about the participants in the original studies.

Study (and, by extension, intervention) duration is important for the chronic management and prevention of obesity. Yet, all study duration thresholds for original studies and for meta-analysis inclusion are arbitrary. Our choice of 72 hours is arbitrarily short, but extends beyond just differences in eating (e.g., differences in weight from the actual digestive contents of eating versus skipping). Another meta-analysis arbitrarily chose 4 weeks as the cutoff, and we interpret Dr. Astbury’s remarks as suggesting 12+ weeks would be more reasonable. To address differences in study duration threshold for study inclusion, we now present a cumulative meta-analysis. This cumulative meta-analysis adds studies from the longest to the shortest duration. Studies (and strata within studies) are added by duration. Within a study duration (that is, if more than one study is of the same duration), studies and strata are added in an arbitrary order as organized in the data set. The cumulative meta-analysis including all studies of a particular duration or longer are represented by the last addition from top to bottom in the supplementary cumulative meta-analysis figure. Body weight and BMI had enough effect sizes to meaningfully synthesize results cumulatively across study durations. Using Dr. Astbury’s reasonable suggestion of 12 weeks, there is no significant differences between skipping and eating breakfast on body weight and BMI, as shown in the supplementary cumulative meta-analysis figure (see results in the row for Schlundt 1992s for body weight and Leidy 2015 for BMI). Using the 4 week cutoff used in another review, there is a significant estimate in favor of skipping, as shown in the supplementary cumulative meta-analysis figure (see the row for LeCheminant 2017). We emphasize that because this cumulative meta-analysis results in multiple testing, interpretation of any statistically significant results should be made with caution.

Regarding the baseline obesity status, weight stability, and context of studies, we now include two new columns in Table 1. One column presents the baseline participant BMIs, and the other column presents information about weight stability, weight-related inclusion criteria, and context of the study. We discuss the importance of these considerations in the discussion section. Unfortunately, stratification by these factors is in some cases not easy to classify for a subgroup meta-analysis (e.g., baseline BMI categories are not harmonized across studies). Even in cases where classification seems possible, there are too few effect...
sizes to meaningfully synthesize.

Given that our original analyses (including leave one out analyses), the stratified analyses by baseline breakfast habit submitted on the previous revision, and the cumulative analysis we submit with this revision were all generally robust to analytical decisions, we do not (and in many cases cannot) present additional quantitative syntheses on these important factors.

**Competing Interests:** No competing interests were disclosed.

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**Version 1**

**Reviewer Report 29 May 2020**

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**Enhad A. Chowdhury**

Department for Health, University of Bath, Bath, UK

**Overview**

The work of Bohan Brown *et al* examines the impact of breakfast skipping versus consumption on obesity related anthropometric measures using meta-analytical methods. The authors have selected a focused question and I found the description of the methods and decisions behind inclusion/exclusion of papers to be thorough. As a non-statistician, I do not feel best placed to provide a critique of the statistical approach, but at face value do not see anything unusual. Generally, the data presentation was clear, and the interpretation of the results was appropriate to the scope of the work. I have outlined some specific comments for the authors consideration below, relating to small clarifications and the inclusion of a very recently published piece of work as point of context.

**Introduction**

I found the introduction appropriate to set the context for the work.

As an area of nutrition that has been historically dominated by cross-sectional studies, it is of clear interest to examine the causal data relating to breakfast and body composition.

I am not completely clear on the timings of the relative publications, but at time of review, the work by Bonnet referenced in the Prospero registration has now been published in Obesity. [https://onlinelibrary.wiley.com/doi/abs/10.1002/oby.22791](https://onlinelibrary.wiley.com/doi/abs/10.1002/oby.22791) If possible, I would suggest this
Methods

I generally found the description of the methods to be thorough and clear.

“One breakfast skipping condition” and one “breakfast eating” condition. While the authors state regardless of modality – can I clarify whether this is based upon the original authors original definitions of these conditions (I assume this to be the case – but think it is useful to state here if so, in the same way that you have below in this section for weight status)?

I found the description of included and excluded studies to be very thorough.

As a non-statistician I do not consider myself well placed to examine the meta-analytical methods used thoroughly, this would be more appropriate for a statistician to evaluate. At face value, there does not seem to be anything particularly unusual about the approach employed.

Results

I found the description of the results to be clear and thorough and the figures to be generally clear.

Figure 2 – I think it is helpful to have a visual representation of the different implementations of the interventions. However, is it possible to make this figure colour and make the different elements more distinct? With these very similar grey shades and fill patterns this figure is a little difficult to interpret.

Figure 3 – I think it would be helpful to write in simple terms what each side of the 0 line represents on this figure within the figure legend, as you do for the description of Table 2. I also appreciate this may be for practical reasons, but the figures with only one missing value on the axis look a little strange – I presume this might be because the labels do not fit, but if easily adjustable I would suggest it might be beneficial to add this single missing label.

Discussion

I generally found the discussion clear and highlighted appropriately the limitations based on the scope of the work.

As outlined for the introduction – the work of Bonnet is now published, and is potentially of interest, as they suggest based on their analysis a small but significantly reduced body weight (-0.54kg (CI: -1.05 to -0.03), which is also broadly in line with Sievert, suggesting a very small reduction in body mass with breakfast skipping. If possible, I would suggest this study is cited.

I understand that clearly any effects in favour of breakfast skipping for body mass are small, but I think as the two other meta-analyses conducted conclude this, this is worth incorporating into your second paragraph about the potential for non-zero effects as a point of context. I don't think this impacts upon your general point that any potential for effects are likely of low clinical significance.
I think that with such a small set of studies with a very large variation between them, narrative reviews can often be valuable in this context for examining and considering the nuance of the results from different designs. I think it is good that you have clearly highlighted the limits of the meta-analytical approach used.

I appreciate your point that longer term studies are often to determine the longer-term trajectory of interventions that may show short term impacts on body composition. Given that two other meta-analyses conclude that there may be a significant reduction overall (albeit small) with breakfast skipping is there also added value in determining if breakfast skipping over long durations causes more substantial weight loss?

I am unclear as to the relevance of the “[j]ust because”? If this is a typo – it should be amended.

While I think it is helpful that you have outlined the limitations of your analysis for informing the overall benefit of breakfast, I have two suggestions:

- I think it is relevant to acknowledge that breakfast consumption/omission has previously been shown to impact upon specific components of energy balance that may have independent effects upon health.

- I would suggest providing some references for studies/reviews examining the different factors that you highlight as not being examined in the present work (i.e. blood glucose control, cardiometabolic risk etc), should the reader be interested in those aspects.

References

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
I cannot comment. A qualified statistician is required.

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes
**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Energy balance, breakfast consumption, appetite regulation

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

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**Author Response 28 Sep 2020**

Michelle M Brown, Indiana University School of Public Health - Bloomington, Bloomington, USA

*We thank Dr. Chowdhury for the feedback. We address the critiques below:*

*Regarding Bonnet et al, we have now added the reference. It was published between our first submission and our response to reviewers.*

*Regarding ‘one breakfast skipping condition’, we depend on the original authors’ definition where possible. We have expanded our exclusion criteria to give examples of situations where we would have excluded a breakfast/skipping group.*

*We have updated Figure 2. We prefer to avoid color to make figures color-blind friendly, and amenable to gray scale printing. We therefore have increased the contrast among three of the bars (light gray, dark gray, black), and increased the contrast and pattern of the one that previously had a dotted fill pattern. We hope this makes the figure more distinct.*

*We have updated the legend to Figure 3 to describe what left and right of zero means. We reprogrammed the code to generate the figures to make the tick marks consistent, rather than depending on the software defaults.*

*We now discuss Bonnet and Sievert’s meta-analyses in our discussion. It would seem that the instability of findings, including across meta-analyses that included only studies of longer duration, may warrant longer studies to confirm the effects of eating versus skipping on weight.*

*We changed the “[j]ust”, which was a stylistic artifact that was no longer needed.*

*We now cite papers that talk about outcomes beyond obesity, and we try to better emphasize that our analysis is limited to the binary eat versus skip breakfast on anthropometric measurements.*

**Competing Interests:** No competing interests were disclosed.
This is a systematic review of randomised controlled trials comparing the consumption of breakfast with skipping breakfast and follows other similar SR on breakfast eating/skipping.

There has been a long held debate regarding the potential effect of breakfast on energy intake, body weight and anthropometric measures, as the authors note this was driven by observational studies, but in recent years more RCT have emerged investigating effects.

The methods are meretriciously reported and follow standard or gold standard procedures. Justification for some inclusion criteria should be included - to allow the reader to make a judgement whether the methods of this paper match its intended objectives. Since outcome is bodyweight/composition what is the purpose of including studies of 72hrs duration where likelihood of effect is minimal?

I feel that the discussion is weak and could be strengthened considerably. Limitations of this manuscript are not limited to the statistical methods and assumptions for dealing with missing data. Limitations of the current review should be discussed and critically analysed. Many of the studies included in this and other SR are small, and are often conducted in participants with a mixed usual breakfast habit who are not overweight or attempting to limit their energy intake or reduce their body weight. Further discussion on the clinical/research implications of this SR (and similar ones recently published) is warranted.

The absence of is a substantial clinical trial of breakfast eating/skipping within the context of weight loss attempt is notable, could this be related to issues surrounding potential conflicts of interest and industry involvement, -would be worth discussion. Some mention of contextual setting is important- it would be difficult to determine if eating/skipping breakfast aids/impairs weight loss if the participants in are not attempting to limit daily energy intake or weight loss. However breakfast may affect appetite regulation, thus aiding/impairing adherence to energy restricted diets (or it may not)? Could usual skippers made to eat have different response than usual consumers made to skip? Could sub-group differences be affecting ability to detect effects of breakfast on body weight and composition?

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Partly

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Weight loss, Obesity, Appetite regulation, body composition

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

---

Author Response 28 Sep 2020

**Michelle M Brown**, Indiana University School of Public Health - Bloomington, Bloomington, USA

We thank Dr. Astbury for the feedback. We address the critiques below:

We have added to our discussion to outline more completely some of the limitations and choices we have made. We specifically address our choice of 72 hours, choices for defining breakfast and skipping, the fact that these effect estimates are pooled across weight loss backgrounds, weight categories, and breakfast compositions/timings. We have gone further to finish the subgroup analysis stratified by baseline breakfast habit. We initially presented a draft of the stratified analysis in our meeting abstracts. Completing it here addresses some of the reviewer's concerns and allows us to uphold transparency by completely reporting analyses we have tried. This includes 5 new interaction-effect forest plots, a summary table, supplemental methods and results, and updated code.

We now discuss Bonnet and Sievert's meta-analyses in our discussion, and briefly discuss some methodological and analytical differences that may explain differences in conclusions. We also highlight that these minor differences in analyses result in qualitatively different conclusions (i.e., differences in statistical significance), which reinforces the overall uncertainty in conclusions that can be drawn from this body of evidence.

We hope that these additions and clarifications, in addition to the limitations we initially discussed about length of studies, baseline breakfast habits, types of breakfast, and other considerations, more fully orient the reader to the limitations both of our analysis and the evidence base for these questions.
Competing Interests: No competing interests were disclosed.

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