Lead Article

Effects of meal frequency on weight loss and body composition: a meta-analysis

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It has been hypothesized that eating small, frequent meals enhances fat loss and helps to achieve better weight maintenance. Several observational studies lend support to this hypothesis, with an inverse relationship noted between the frequency of eating and adiposity. The purpose of this narrative review is to present and discuss a meta-analysis with regression that evaluated experimental research on meal frequency with respect to changes in fat mass and lean mass. A total of 15 studies were identified that investigated meal frequency in accordance with the criteria outlined. Feeding frequency was positively associated with reductions in fat mass and body fat percentage as well as an increase in fat-free mass. However, sensitivity analysis of the data showed that the positive findings were the product of a single study, casting doubt as to whether more frequent meals confer beneficial effects on body composition. In conclusion, although the initial results of this meta-analysis suggest a potential benefit of increased feeding frequencies for enhancing body composition, these findings need to be interpreted with circumspection.

INTRODUCTION

The prevailing body of research indicates that weight management is predicated on energy balance.[1] Specifically, when caloric intake exceeds caloric expenditure, excess energy is stored, primarily as triglycerides in adipose tissue in the absence of regimented resistance exercise. Conversely, a shift in energy balance favoring expenditure over intake results in a loss of body mass. The energy balance equation is consistent with the first law of thermodynamics, which essentially states that energy is neither created nor destroyed but rather changed from one form to another.

Because the human body is considered an open system, various nutritional factors can impact the storage or expenditure of energy within the context of the first law of thermodynamics.[2] One such mitigating factor often cited by researchers and practitioners is meal frequency. Specifically, it has been hypothesized that eating small, frequent meals enhances fat loss and helps to achieve better weight maintenance.[3] A number of observational studies lend support to this hypothesis, with an inverse relationship noted between the frequency of eating and adiposity.[4–7] Proposed mechanisms that explain the phenomenon include better appetite control,[8–10] improved glucose homeostasis,[11–13] and an increase in the thermic effect of food.[14,15]

There also is evidence that frequent macronutrient intake may be beneficial to anabolism. Several studies show that protein synthesis and accretion are heightened when protein-containing meals are consumed frequently throughout the day. Moore et al.[16] found that ingestion of protein every 3 h optimized increases in net protein balance following a bout of lower body resistive exercise. In relative agreement with these findings, Areta et al.[17] demonstrated that post-exercise

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protein synthesis was maximal with a protein intake spaced out over regimented 3-h intervals. Beneficial effects of smaller, more frequent feedings on lean mass have been attributed to an irreversible oxidation of amino acids from larger protein boluses.[17] In addition to having important implications for functional capacity, an increase in lean mass would conceivably aid in weight management due to enhancements in resting metabolic rate.[18]

Despite an apparent theoretical basis, results from randomized controlled trials have been disparate regarding an advantageous effect of frequent meals on measures of body composition; while some studies have reported benefits, others have not. Small sample sizes and a consequent lack of statistical power may be responsible for contradictory findings. By pooling results from the body of literature and controlling for confounding variables, a meta-analysis may help to provide clarity on the topic. The purpose of this article, therefore, was to carry out a meta-analysis with regression and to present an associated narrative review that evaluates experimental research on meal frequency with respect to changes in fat mass and lean mass.

METHODOLOGY

Inclusion criteria

Studies were deemed eligible for inclusion if they met the following criteria: 1) randomized controlled trial published in an English-language refereed journal; 2) compared unequal feeding frequencies of $\leq$ 3 meals a day with $\geq$ 3 meals a day; 3) had a study duration of at least 2 weeks; 4) reported a pre- and post-intervention measure of body composition (body mass, body fat, lean mass); and 5) was carried out in human participants >18 years of age. Studies investigating participants who had undergone bariatric surgery were excluded from analysis.

Search strategy

To carry out this meta-analysis and narrative review, English-language literature searches of the PubMed and Cochrane Library databases were conducted for all time periods up to November 2013. Combinations of the following key words were used as search terms: meal frequency, feeding frequency, eating frequency, meal pattern, feeding pattern, eating pattern, body composition, weight loss, fat loss, lean mass, and fat mass. Per the methods outlined by Greenhalgh and Peacock,[19] the reference lists of articles retrieved in the search were then screened for any additional articles that had relevance to the topic. Abstracts from conferences, reviews, and unpublished dissertations/theses were excluded from analysis.

A total of 327 studies were evaluated based on the search criteria. To reduce the potential for selection bias, each study was independently evaluated by 2 of the investigators (B.J.S. and A.A.A.), and a mutual decision was made as to whether or not it met the basic inclusion criteria. Any interreviewer disagreements were settled by consensus and/or consultation with the third investigator (J.W.K.). A total of 15 studies were identified that investigated meal frequency in accordance with the criteria outlined and provided adequate data for analysis (Figure 1). Table 1 summarizes the studies included for analysis.

Coding of studies

Studies were read and individually coded by 2 of the investigators (B.J.S. and A.A.A.) for the following variables: descriptive information of participants by group, including gender, body mass, body mass index, age, and stratified participant age (classified as either young [18–49 years] or elderly [50 + years]); whether or not total energy intake was equated between groups; whether the study was a parallel-group or crossover design; the number of participants in each group; duration of the study; whether exercise was included in the study and, if so, if it was endurance, resistance, or both; whether participants were in an energy deficit, energy balance, or energy surplus; and type of body composition measurement (scale weight, bioelectrical impedance analysis (BIA), dual x-ray absorptiometry (DXA), etc.). Coding was cross-checked between coders, and any discrepancies were resolved by mutual consensus. To assess potential coder drift, 4 studies were randomly selected for recoding as described by Cooper et al.[35] Per-case agreement was determined by dividing the number of variables coded the same by the total number of variables. Acceptance required a mean agreement of 0.90.

Statistical analyses

The variance within each intervention group was calculated as the squared standard error of the mean (SEM) of the difference between pre- and post-diet outcomes. Where the SEM of the difference was not reported, it was calculated using the P value or confidence interval (CI) where available. Otherwise, an upper bound on the SEM was calculated using the following formula in which s_1 and s_2 represent the standard deviation for the pre- and post-test means, respectively.[36]

$$\mathrm{SEM} = \sqrt{\left(\left(s_1{}^2/n\right) + \left(s_2{}^2/n\right)\right)}$$

If this calculation could not be made due to missing standard deviation data, then missing within-group

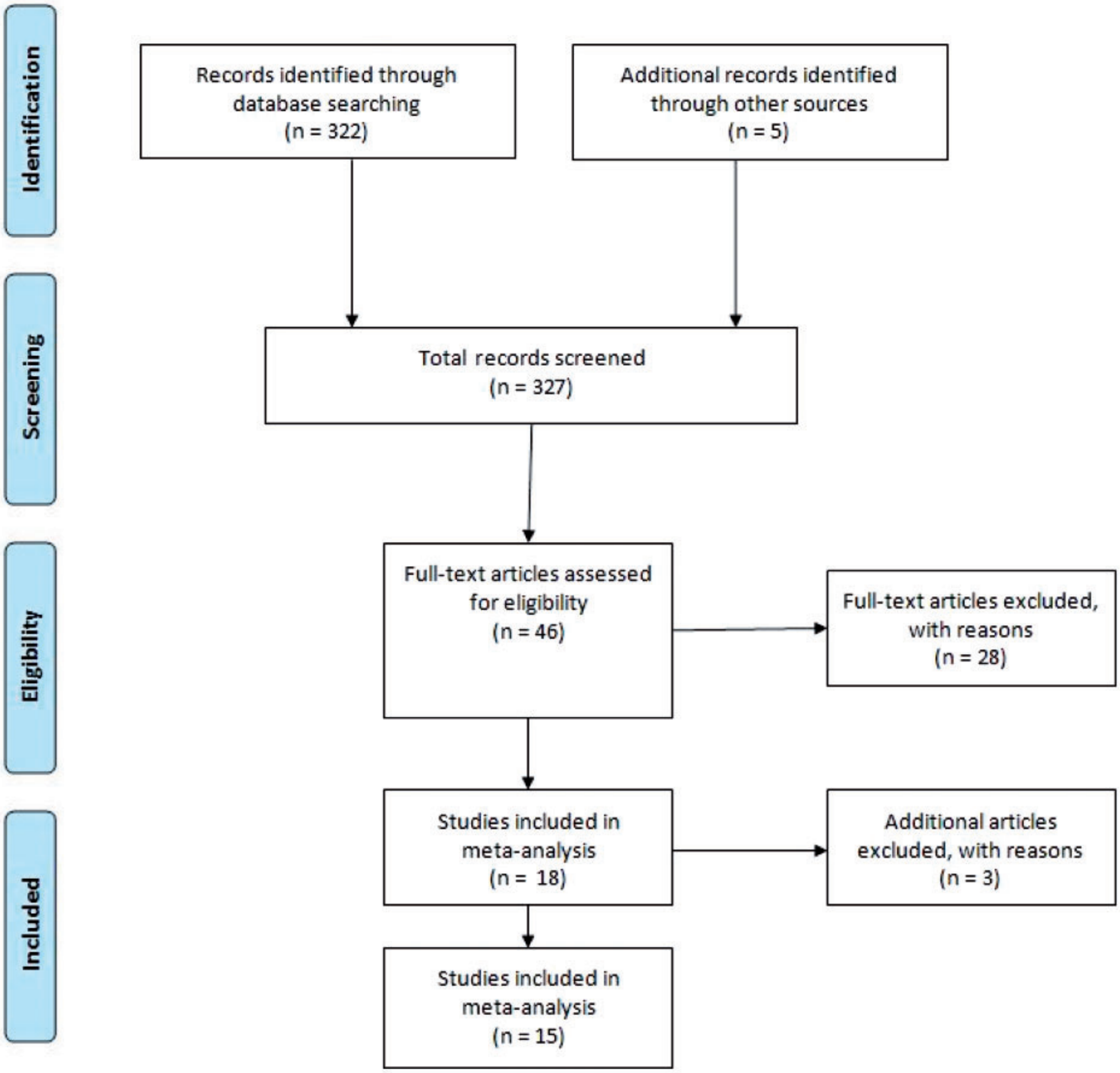

Figure 1 **Flow diagram of literature search**

variance data were imputed using multiple imputation.[37] Fifty imputed data sets were created and analyzed for each outcome, and the results were combined for statistical inferences.

Meta-analyses were performed using hierarchical linear mixed models, modeling the variation between studies as a random effect, the variation between treatment groups as a random effect nested within studies, and group-level predictors as fixed effects.[38] The within-group variances were assumed known. Observations were weighted by the inverse of the within-group variances. Model parameters were estimated by the method of restricted maximum likelihood[39]; an exception was made during the model reduction process, in which parameters were estimated by the method of maximum likelihood, as likelihood ratio tests (LRTs) cannot be used to compare nested models with restricted maximum likelihood estimates. Denominator degrees of freedom for statistical tests and CIs were calculated according to Berkey et al.[40] For each outcome, an intercept-only model was created. Models were constructed for the change in body mass, fat-free mass (FFM), percent body fat (% BF), and fat mass. For each outcome, a simple model was created with only number of meals as a continuous predictor. Full models were then created with the following predictors: initial body mass (kilograms), weeks, calorie intake, and number of meals. Models were reduced by removing predictors one at a time, starting with the most insignificant predictor.[41] The final model represented the reduced model with the lowest Bayesian information criterion,[42] which was not significantly

Table 1 **Summary of studies evaluated**

Reference	Age[a]	Study length	Body mass category	Exercise	No. of meals	Design	Findings
Arciero et al. (2013)[20]	Young	4 weeks	Overweight	No	3 vs. 6	Parallel	6 meals per day in a high-protein condition (35% of total energy) was superior to 3 meals per day with a high-protein or traditional protein intake (15%) for decreasing abdominal fat and preserving fat-free mass
Antoine et al. (1984)[21]	Mixed	2 weeks	Obese	No	3 vs. 6	Crossover	Slightly greater weight loss and less loss of nitrogen with 6 meals per day compared with 3 meals per day
Bachman and Raynor (2012)[22]	Old	26 weeks	Obese	Yes	3 vs. grazing	Parallel	No between-group differences in body mass index reduction or energy intake reduction
Berteus-Forslund et al.(2008) [23]	Young	52 weeks	Obese	No	3 vs. 6	Parallel	No between-group difference in weight loss; high-density lipoprotein increased in the 3 meals group but not the 3 meals + 3 snacks group
Bortz et al. (1966)[24]	Mixed	18 days	Obese	No	1 vs. 9	Crossover	No between-group differences in weight loss, nitrogen balance, serum lipids, or respiratory quotient (RQ) across conditions
Cameron et al. (2010)[25]	Young	8 weeks	Obese	No	3 vs. 6	Parallel	No between-group differences in reductions of weight, fat, and lean mass
Chapelot et al. (2006)[26]	Young	4 weeks	Lean	No	3 vs. 4	Parallel	Increased fat mass resulted from reducing meal frequency from 4 meals per day to 3 meals per day, but no change in fat mass occurred from an increase of 3 meals per day to 4 meals per day
Finkelstein and Fryer (1971)[27]	Young	9 weeks	Obese	No	3 vs. 6	Parallel	No between-group differences in weight loss, nitrogen balance, or serum lipids
Iwao et al. (1996)[28]	Young	2 weeks	Lean	Yes	2 vs. 6	Parallel	No between-group differences in weight loss, but those who consumed 2 meals per day lost more lean mass and showed more muscle protein breakdown (via 3-methylhistidine) than those who consumed 6 meals per day
Poston et al. (2005)[29]	Young	24 weeks	Obese	No	2 vs. 5	Parallel	No between-group differences in weight loss
Schlundt et al. (1992)[30]	Mixed	12 weeks	Obese	No	2 vs. 3	Parallel	Habitual breakfast eaters lost more weight in the no-breakfast treatment, habitual breakfast skippers lost more weight in the breakfast treatment; those who made the most substantial changes in eating habits had better results
Stote et al. (2007)[31]	Young	8 weeks	Lean	No	1 vs. 3	Crossover	Total body weight and fat mass decreased with 1 meal per day but not with 3 meals per day; no between-group differences in fat-free mass
Vander Wal et al. (2006)[32]	Young	4 weeks	Obese	No	4 vs. 5	Parallel	A post-dinner snack in conjunction with a meal replacement product did not further enhance weight loss or impart benefits in chronic disease risk
Verboeket-van de Venne and Westerterp (1993)[33]	Young	4 weeks	Obese	No	2 vs. 4	Parallel	No between-group differences in weight loss, body composition change, or 24-h energy expenditure (EE)
Young et al. (1971)[34]	Young	5 weeks	Obese	No	1 vs. 3 vs. 6	Crossover	No between-group differences in weight loss, body composition change, or nitrogen balance

[a]For age, young is defined as 18–49 years and old is $\geq$50 years.

different ($P > 0.05$) from the full model when compared using a likelihood ratio test. Number of meals was not removed during the model reduction process. After the model reduction process, identical reduced models were created with number of meals as either a categorical (1–2 meals, 3–4 meals, and 5 + meals) or binary (lower and higher, equivalent to the lower or higher frequency within each study) predictor. Adjustments for post hoc multiple comparisons among meal categories were made using a Hochberg correction.[43] Because meta-regression can result in inflated false-positive rates when heterogeneity is present and/or when there are few studies,[44] a permutation test described by Higgins and Thompson[44] was used to verify the significance of the predictors in the final reduced models; 1,000 permutations were generated.

In order to identify the presence of highly influential studies that might bias the analysis, a sensitivity analysis was carried out for each model by removing 1 study at a time and then examining the meal frequency predictor. Studies were identified as influential if removal resulted in a change of the meal frequency predictor going from significant or a trend ($P \leq 0.10$) to nonsignificant ($P > 0.10$), or vice versa.

All analyses were performed using S-Plus 8.2 (Tibco Spotfire, Boston, MA, USA). Effects were considered significant at $P \leq 0.05$, and trends were declared at $0.05 < P \leq 0.10$. Data are reported as $\bar{x} \pm$ SEM and 95% CIs.

RESULTS

Body mass change

The analysis of changes in participants' body mass comprised 30 treatment groups from 15 studies. The change in body mass among these studies was -4.41 ± 0.76 kg (95% CI: -5.96 to -2.86).

In the simple model with number of meals as a continuous predictor, meal frequency was not significantly associated with change in body mass (change in body mass with each unit increase in number of meals: -0.03 ± 0.06 kg; 95% CI: -0.15 to 0.09; $P = 0.65$). This was also true in the full model and reduced models (-0.03 ± 0.06 kg; 95% CI: -0.15 to 0.10; $P = 0.64$) (Table 2). In the reduced model with meal frequency as a categorical predictor, there were no significant differences in body mass change among the 1–2 meals, 3–4 meals, and 5+ meals groups (Figure 2). In the reduced model with meal frequency as a binary predictor, there was no significant difference between lower and higher frequencies for body mass change (difference = 0.20 ± 0.21; 95% CI: -0.23 to 0.63; $P = 0.35$) (Figure 3).

Fat mass change

The analysis of changes in participants' fat mass comprised 18 treatment groups from 10 studies. The change in fat mass among these studies was -3.55 ± 1.12 kg (95% CI: -5.90 to -1.19).

In the simple model with number of meals as a continuous predictor, meal frequency was significantly associated with change in fat mass (change in fat mass with each unit increase in number of meals: -0.25 ± 0.11 kg; 95% CI: -0.49 to -0.01; $P = 0.04$). This was also true in the full model and reduced models (-0.27 ± 0.11 kg; 95% CI: -0.52 to -0.03; $P = 0.03$) (Table 3). However, permutation test results failed to support the significance of the meal frequency predictor ($P = 0.41$). In the reduced model with meal frequency as a categorical predictor, there was a trend for 5 + meals to result in greater fat loss than 1–2 meals (difference = 1.24 ± 0.49 kg; 95% CI: -0.11 to 2.59; $P = 0.07$), with no other differences among categories (Figure 4). In the reduced model with meal frequency as a binary predictor, higher meal frequencies were associated with greater fat loss compared with lower frequencies (difference = 0.89 ± 0.39; 95% CI: 0.06 to 1.71; $P = 0.04$) (Figure 5).

Sensitivity analyses revealed that the significant impact of meal frequency on fat loss was highly affected by the study performed by Iwao et al.[28] When this study was removed from the analysis, the impact of meal frequency on change in fat mass was no longer significant (change in fat mass with each unit increase in number of meals: -0.16 ± 0.19 kg; 95% CI: -0.61 to 0.30; $P = 0.44$) (Figure 5).

Fat-free mass change

The analysis of changes in participants' FFM included 17 treatment groups from 9 studies. The change in FFM

Table 2 **Reduced model for change in body mass**

Effect	Coefficient[a]	95% Confidence interval	P value
Intercept	-8.24 ± 1.29	-10.86 to -5.61	<0.0001
Weeks	-0.10 ± 0.05	-0.21 to 0.01	0.07
Energy intake (kcal)	0.0032 ± 0.0006	0.002 to 0.004	<0.0001
Number of meals	-0.03 ± 0.06	-0.15 to 0.09	0.60

[a]Negative values of coefficients indicate larger decreases in body mass for each unit increase in the covariate. Positive values indicate smaller decreases in body mass for each unit increase in the covariate.

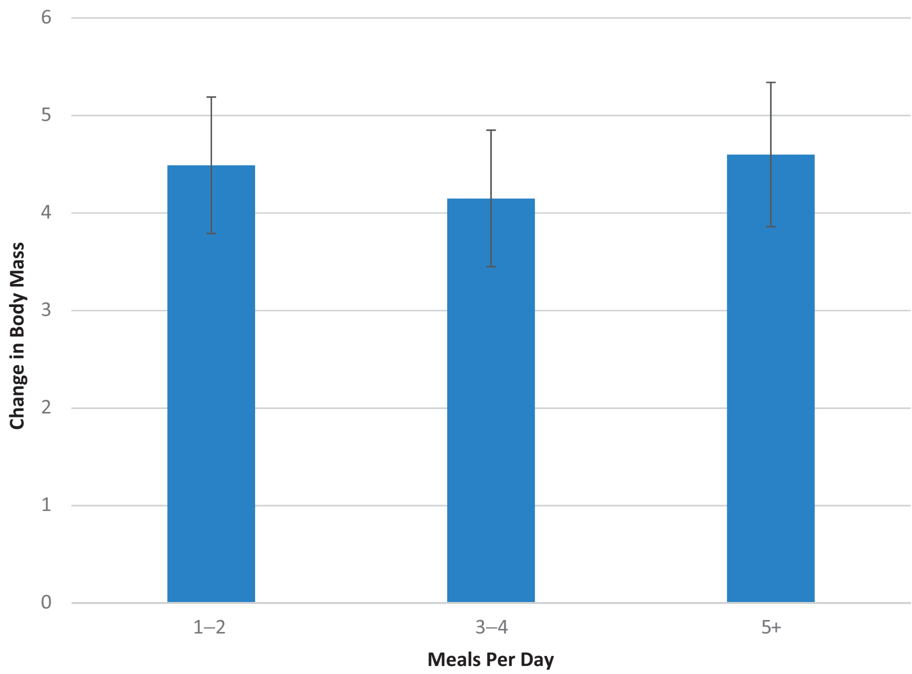

Figure 2 **Reduced model for differences in change in body mass with meal frequency. Values in kilograms**

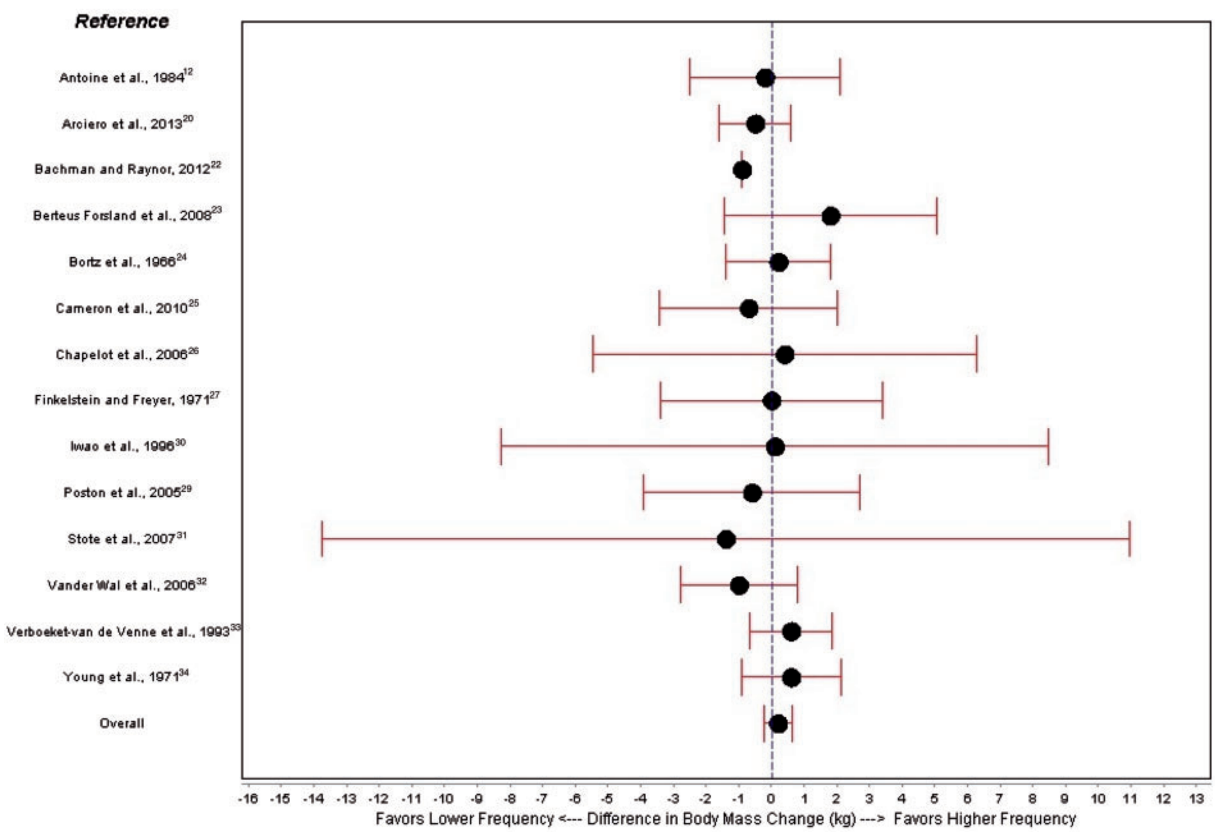

Figure 3 **Forest plot of meal frequency on body mass**

Table 3 **Reduced model for change in fat mass**

Effect	Coefficient[a]	95% Confidence interval	*P* value
Intercept	3.19 ± 3.06	−3.36 to 9.73	0.31
Initial body mass (kg)	−0.08 ± 0.03	−0.15 to −0.01	0.03
Weeks	−0.33 ± 0.13	−0.60 to −0.06	0.02
Energy intake (kcal)	0.0017 ± 0.0009	−0.0002 to 0.0036	0.08
Number of meals	−0.27 ± 0.11	−0.52 to −0.03	0.03 [b]

[a]Negative values of coefficients indicate larger decreases in fat mass for each unit increase in the covariate. Positive values indicate smaller decreases in fat mass for each unit increase in the covariate.
[b]This covariate was not significant using a permutation test ($P = 0.41$). Also, sensitivity analyses revealed that the significance of this covariate was highly influenced by the study by Iwao et al.[28] When this study was removed from the analysis, the impact of meal frequency on change in fat mass was no longer significant (change in fat mass with each unit increase in number of meals: −0.16 ± 0.19 kg; 95% confidence interval: −0.61 to 0.30; $P = 0.44$).

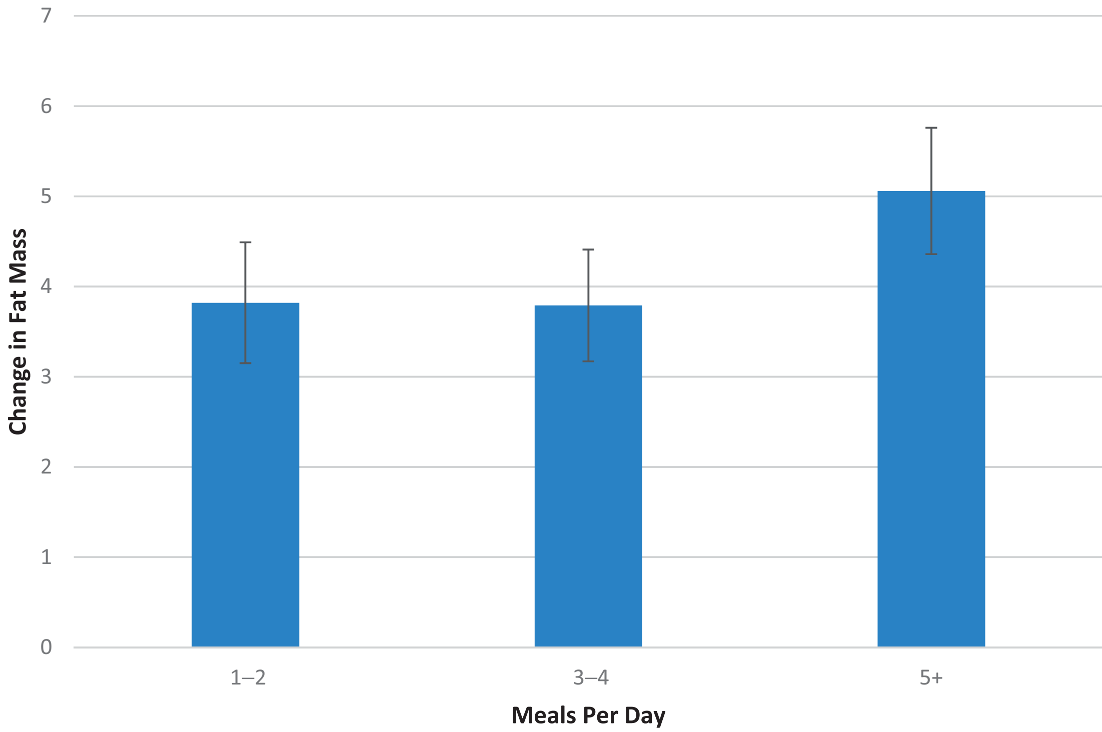

Figure 4 **Reduced model for differences in change in fat mass with meal frequency. Values in kilograms**

among these studies was −1.88 ± 0.54 kg (95% CI: −3.03 to −0.74).

In the simple model with number of meals as a continuous predictor, there was a trend for more meals to be associated with better FFM retention (change in FFM with each unit increase in number of meals: 0.22 ± 0.11 kg; 95% CI: −0.02 to 0.46; $P = 0.07$). In the full and reduced models, the trend became significant (0.25 ± 0.10 kg; 95% CI: 0.03 to 0.47; $P = 0.03$) (Table 4). However, permutation test results failed to support the significance of the meal frequency predictor ($P = 0.25$). In the reduced model with meal frequency as a categorical predictor, there was a trend for 5+ meals to result in greater FFM retention compared with 1–2 meals (difference = 1.09 ± 0.41 kg; 95% CI: −0.07 to 2.24; $P = 0.06$), with no other differences between categories (Figure 6). In the reduced model with meal frequency as a binary predictor, there was no impact of meal frequency on FFM retention (difference = 0.62 ± 0.52; 95% CI: −0.49 to 1.74; $P = 0.25$) (Figure 7).

Sensitivity analyses revealed that the significant impact of meal frequency on FFM retention was highly affected by the study performed by Iwao et al.[28] When this study was removed from the analysis, the impact of meal frequency on FFM was no longer significant (change in FFM with each unit increase in number of meals: −0.02 ± 0.30 kg; 95% CI: −0.68 to 0.65; $P = 0.96$).

Percent body fat change

The analysis of changes in participants' % BF included 17 treatment groups from 9 studies. The change in % BF among these studies was −1.81 ± 0.63% (95% CI: −3.15 to −0.48).

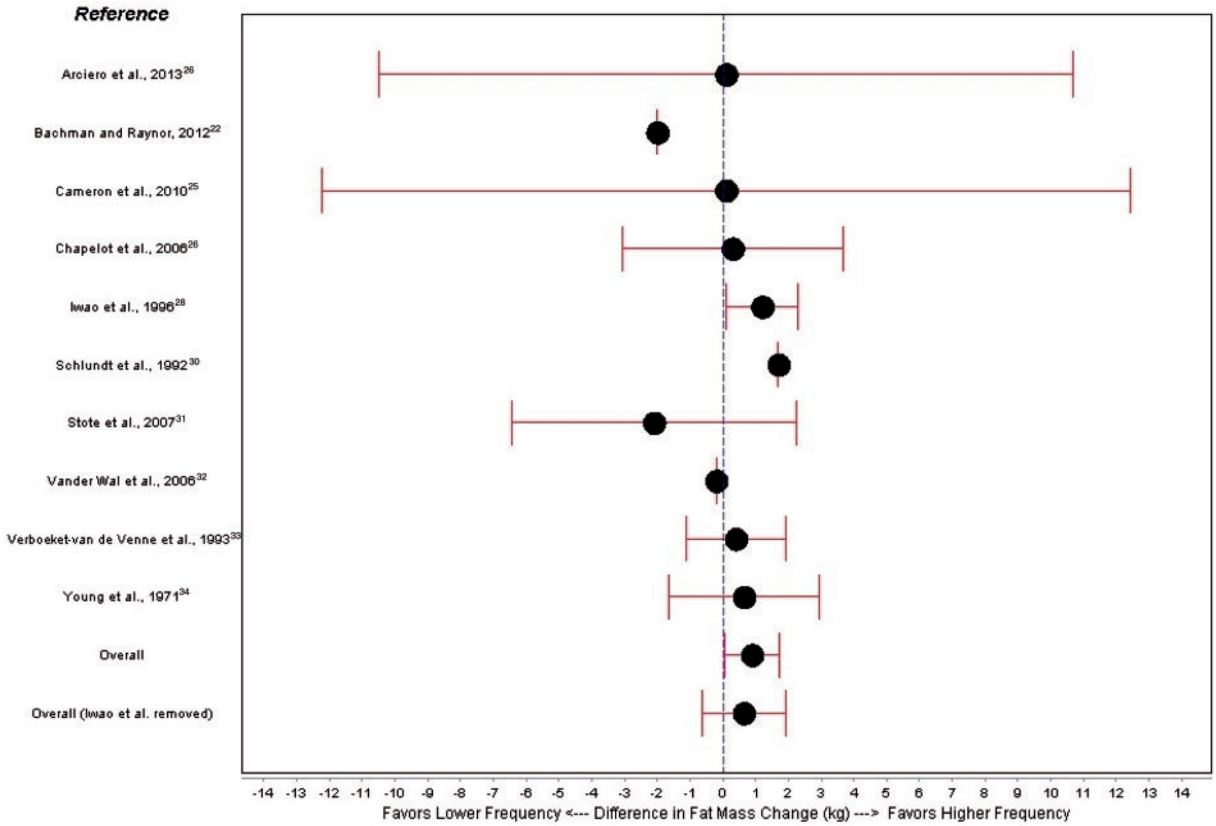

Figure 5 **Forest plot of meal frequency on fat mass**

Table 4 **Reduced model for change in fat-free mass**

Effect	Coefficient[a]	95% Confidence interval	*P* value
Intercept	−7.35 ± 1.81	−11.31 to −3.40	0.002
Initial body mass (kg)	0.06 ± 0.02	0.01 to 0.11	0.03
Number of meals	0.25 ± 0.10	0.03 to 0.47	0.03 [b]

[a]Negative values of coefficients indicate larger decreases in fat-free mass for each unit increase in the covariate. Positive values indicate smaller decreases in fat-free mass for each unit increase in the covariate.
[b]This covariate was not significant using a permutation test ($P = 0.25$). Also, sensitivity analyses revealed that the significance of this covariate was highly influenced by the study by Iwao et al. When this study was removed from the analysis, the impact of meal frequency on fat-free mass was no longer significant (change in fat-free mass with each unit increase in number of meals: −0.02 ± 0.30 kg; 95% CI: −0.68 to 0.65; $P = 0.96$).

In the simple model with number of meals as a continuous predictor, a higher number of meals was associated with a greater decrease in % BF (change in % BF with each unit increase in number of meals: −0.23 ± 0.09%; 95% CI: −0.43 to −0.03; $P = 0.03$). However, permutation tests failed to support the significance of the meal frequency predictor ($P = 0.13$). Also, the significant effect disappeared upon control for other covariates in the full and reduced models (−0.09 ± 0.16%; 95% CI: −0.43 to 0.25; $P = 0.58$) (Table 5). In the reduced model with meal frequency as a categorical predictor, there were no significant differences in % BF between 1–2 meals, 3–4 meals, and 5+ meals (Figure 8). In the reduced model with meal frequency as a binary predictor, there was no impact of meal frequency on % BF change (difference = 0.08 ± 0.40; 95% CI: −0.78 to 0.94; $P = 0.85$) (Figure 9).

Sensitivity analyses revealed that the significant impact of meal frequency in the simple model was highly affected by the study by Arciero et al.[20] When this study was removed from the analysis, the impact of meal frequency on % BF was no longer significant (change in % BF with each unit increase in number of meals: −0.005 ± 0.27 kg; 95% CI: −0.60 to 0.59; $P = 0.99$).

DISCUSSION

This is the first meta-analysis to evaluate the effects of differing meal frequencies on body composition. The primary novel and important findings of the analysis are that increased feeding frequency appeared to be

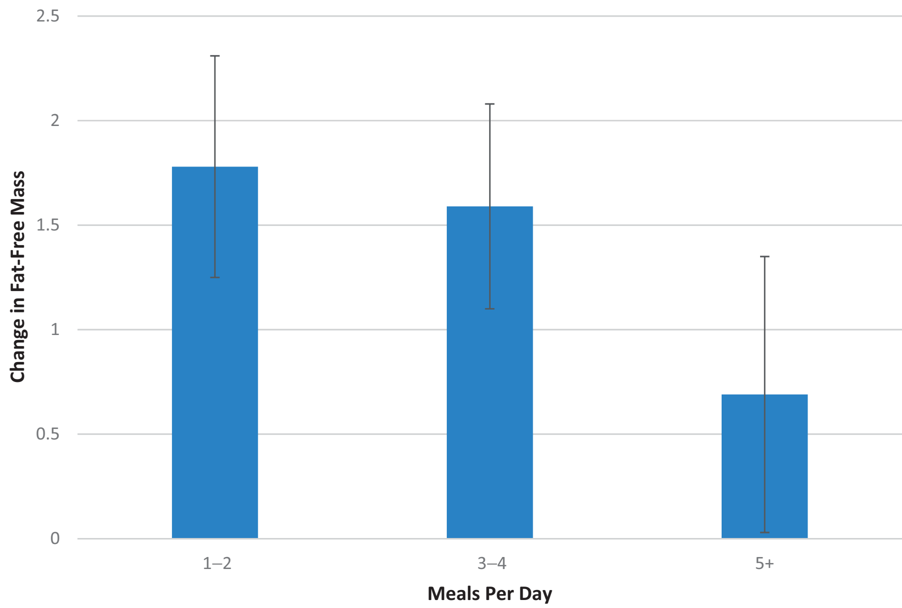

Figure 6 **Reduced model for differences in change in fat-free mass with meal frequency. Values in kilograms**

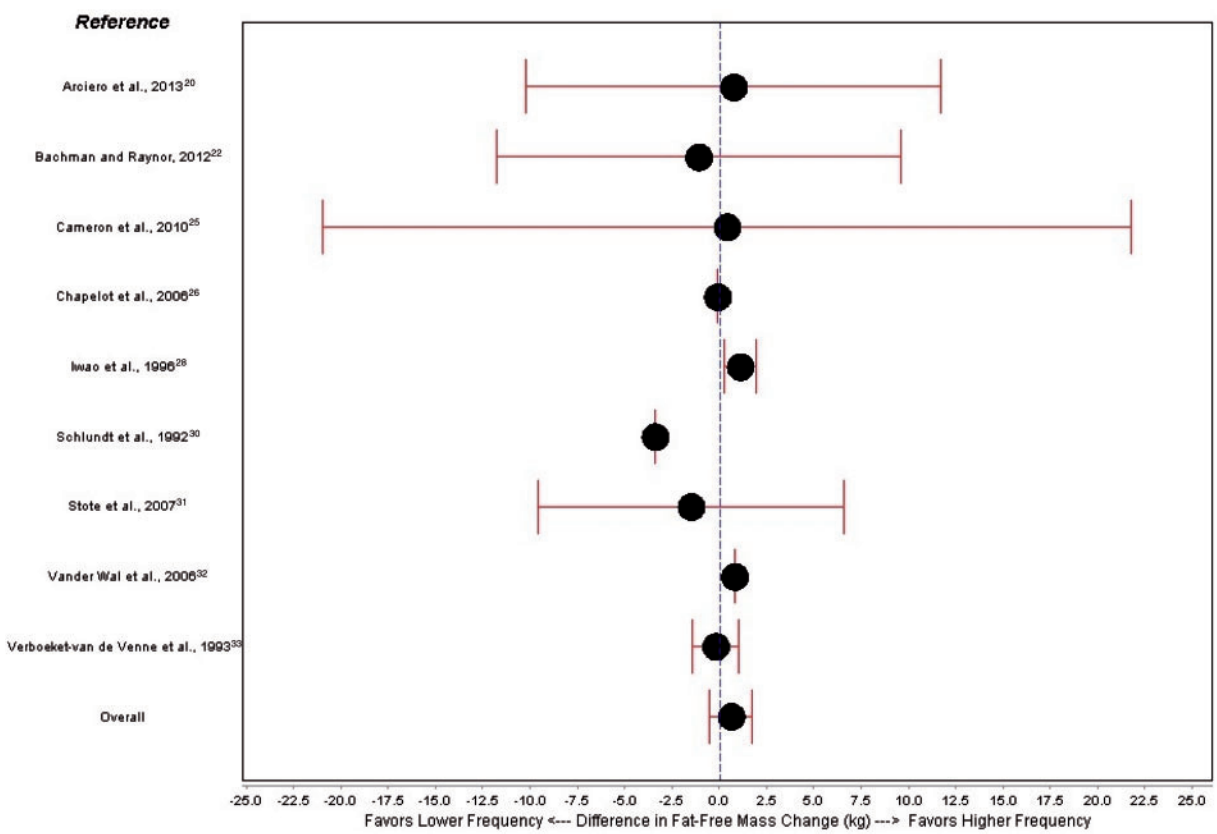

Figure 7 **Forest plot of meal frequency on fat-free mass**

positively associated with reductions in fat mass and body fat percentage as well as an increase in FFM. However, sensitivity analysis of the data showed that the positive findings were largely the product of a single study, casting doubt as to whether more frequent meals confer beneficial effects on body composition. These results have important implications with respect to the popular suggestion that eating small, frequent meals is a

Table 5 **Reduced model for change in percent body fat**

Effect	Coefficient[a]	95% Confidence interval	*P* value
Intercept	5.45 ± 1.68	1.81 to 9.08	0.007
Weeks	−0.36 ± 0.13	−0.65 to −0.07	0.02
Energy intake (kcal)	−0.002 ± 0.0005	−0.003 to −0.001	0.0003
Number of meals	−0.09 ± 0.16	−0.43 to 0.25	0.58

[a]Negative values of coefficients indicate larger decreases in percent body fat for each unit increase in the covariate. Positive values indicate smaller decreases in percent body fat for each unit increase in the covariate.

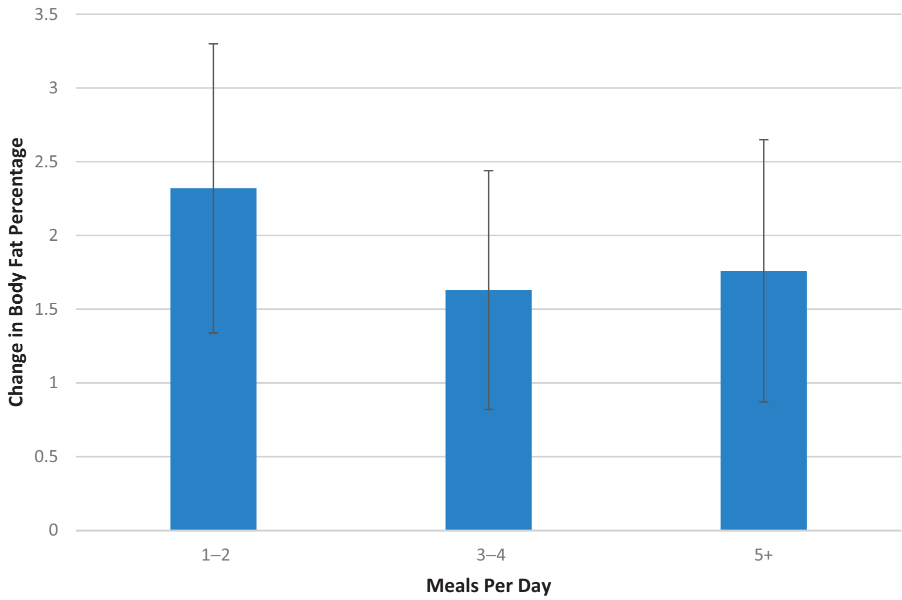

Figure 8 **Reduced model for differences in change in percent body fat with meal frequency. Values in percentages**

preferred method for optimizing weight management in the general population.[3]

Increasing meal frequency is often promoted as a beneficial strategy for reducing fat mass.[3] Justification for this claim generally revolves around the belief that frequent feedings enhance postprandial thermogenesis, defined as the increase in heat production that occurs for up to 8 h after consumption of a meal.[45] LeBlanc et al.[15] demonstrated that feeding dogs 4 small meals doubled the thermogenic response compared with eating the same number of total calories as a large, single meal. In a follow-up study, the same group of researchers found similar results in humans, which the authors attributed to repeated stimulation of the sympathetic nervous system.[14] However, the majority of studies on the topic have failed to show a positive relationship between meal frequency and energy expenditure,[46–50] and 1 trial with adult women actually found a greater thermic effect from consuming a single food bolus as compared with 6 small calorie-equated meals.[45] Interestingly, Smeets et al.[10] found no differences in diet-induced thermogenesis or energy expenditure in the consumption of 2 versus 3 calorie-equated meals a day but did note that 24-h fat oxidation was greater in the 3-meal condition.

On the surface, the results of the present analysis seem to provide support for the contention that eating more frequently results in greater body fat losses. A significant positive effect was found between frequency of feeding and reductions in fat mass, with an additional 0.27 kg loss of fat noted for each additional meal. These results held true even after controlling for total energy intake. In multiple comparisons, there was a trend for a superiority of 5+ meals compared with 1–2 meals (a difference of 1.24 kg and an adjusted *P* value of 0.07); no other differences in fat loss were detected between categories. The binary higher frequency variable also showed significance, with the higher frequency in each study associated with a 0.9-kg greater reduction in fat mass. To determine if a particular study heavily influenced outcomes, a sensitivity analysis was performed whereby 1 study was removed at a time in order to examine the effect of meal frequency on fat mass. This analysis showed that removal of the study by Iwao et al.[28] completely eliminated the significant impact of meal frequency, with the *P* value changing from 0.04 to 0.44. The standard error in this study was much smaller than that of the other studies, thereby giving it a disproportionate weighting in the analysis. Similarly, although the basic model for the present analysis displayed a

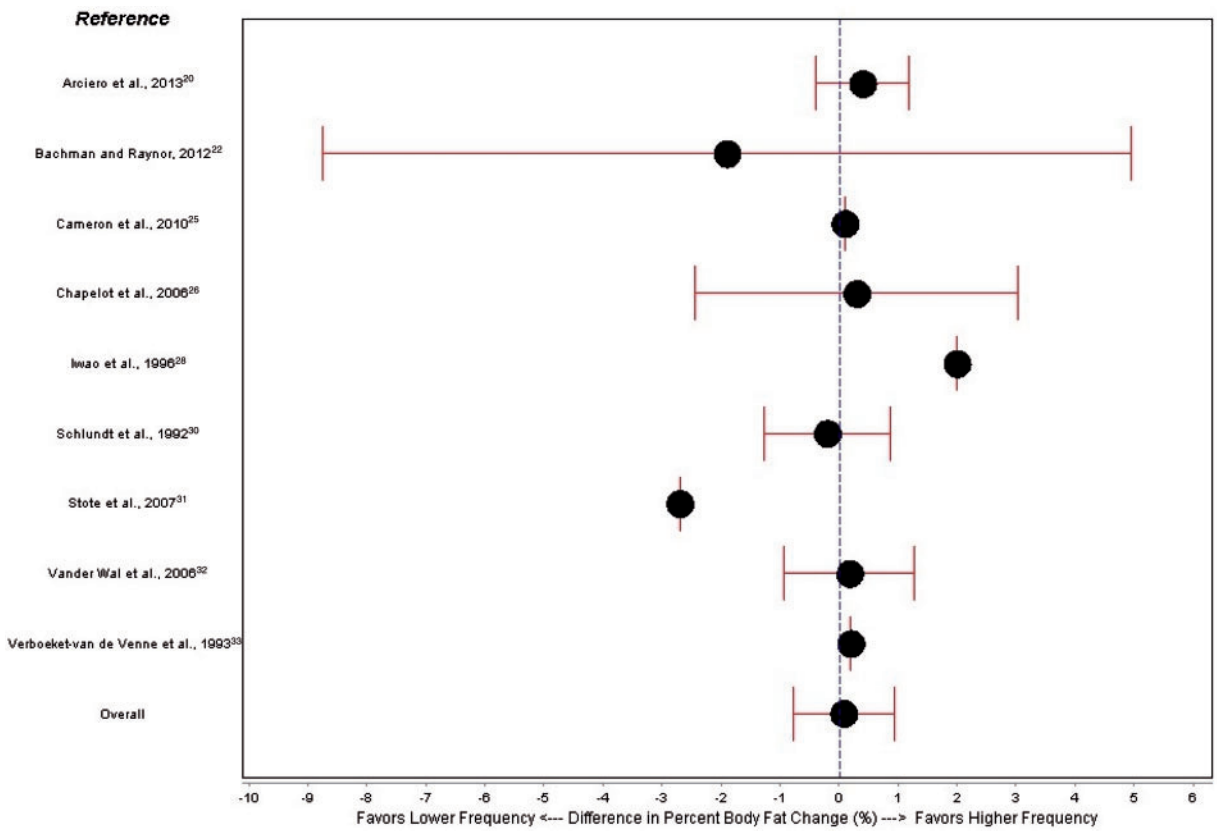

Figure 9 **Forest plot of meal frequency on percent body fat**

significant positive effect for greater meal frequencies on body fat percentage when covariates were not controlled, subanalysis showed that this effect was fully explained by variances in total daily energy intake; after accounting for this variable, no differences were seen in body fat percentages regardless of the number of meals consumed. In combination, the totality of findings indicate that the significant impact of meal frequency on measures of fat loss is a false positive rather than a true effect and can be attributed to undue weighting of a single study (i.e., Iwao et al.[28]).

A potential confounding issue with the present analysis was an inability to assess the size and composition of each eating episode. These variables could potentially account for differences in postprandial food intake and could, thus, mediate a change in body mass over time. To account for any such discrepancies, a subanalysis was run whereby the studies that did not control for caloric intake were separated from those that were energy equated. All but 2 of the studies meeting the inclusion criteria did, in fact, equate calories consumed.[26,32] Removal of these studies via regression analysis had no impact on any of the outcomes, indicating that under calorie-controlled conditions, meal frequency does not alter measures of body composition.

The consumption of frequent meals also has been postulated to enhance the retention of FFM and possibly even increase muscle protein accretion. The anabolic impact of feeding has been estimated to last approximately 5–6 h based on the postprandial rate of amino acid metabolism.[51] Some studies in rodents[52,53] and in humans[54,55] suggest that the rise in muscle protein synthesis (MPS) following consumption of amino acids or a protein-rich meal is more transient, with levels returning to baseline after approximately 3 h. This phenomenon is thought to occur despite sustained elevations in amino acid availability, leading to the "muscle-full hypothesis" whereby MPS becomes refractory and circulating amino acids are oxidized rather than used for tissue-building purposes when a bolus of more than approximately 20 g of amino acids is consumed by young individuals. Anabolic sensitivity is diminished with age so that the saturable limit in the elderly rises to approximately 40 g per serving. The muscle-full hypothesis, therefore, suggests that multiple daily feedings of 20–40 g, depending on age, are needed to maximize anabolism. The findings from nitrogen-balance studies have been inconsistent on the topic, with some showing a positive correlation between meal frequency and nitrogen retention[56] and others showing no such relationship.[27] It should be noted that the nitrogen-balance technique measures whole-body protein flux and, thus, does not necessarily reflect skeletal muscle protein metabolism.[57] With respect to direct effects on skeletal muscle, Areta et al.[17] found that 4 doses of 20 g whey protein consumed every 3 h produced superior acute increases in MPS compared with a bolus provision (2 doses of 40 g every 6 h) or a pulse feeding (8 doses of 10 g every 1.5 h), which is consistent with the muscle-full hypothesis.[58] The initial analysis performed for this review, with number of meals as a continuous predictor, did, in fact, show a trend for positive effects of increased feeding frequencies on FFM, and this became significant in the full and reduced models. However, as with the effects on fat mass, sensitivity analysis revealed that the results were unduly influenced by the results of Iwao et al.[28] and removal of this study negated any benefit related to the number of meals consumed per day, with a change in P value from 0.03 to 0.96. This suggests that findings can be attributed to a false positive and that varying the frequency of feeding does not lead to a greater accumulation of FFM. The reasons for these divergent findings remain elusive. However, it should be noted that acute measures of MPS do not necessarily correlate with long-term increases in muscle hypertrophy.[59]

It is tempting to assume that a within-day distribution of dietary protein that is even has more favorable effects on body composition than a distribution that is skewed. However, this area of study is largely unresolved as findings are conflicting. Mamerow et al.[60] recently found that consuming 3 mixed meals with approximately 30 g protein each stimulated approximately 25% more 24-h MPS than skewing the protein toward the evening meal (approximately 10, 15, and 65 g at breakfast, lunch, and dinner, respectively). However, this acute finding is challenged by longitudinal research that measured effects on body composition. A 14-day trial by Arnal et al.[61] found no difference in FFM or nitrogen retention between young women who consumed a "pulse-feeding" pattern with 79% of the day's protein needs (approximately 54 g) in 1 meal versus protein spread evenly across 4 meals.

Interestingly, a previous study by Arnal et al.[62] in elderly participants found that protein pulse-feeding resulted in more positive nitrogen balance compared with an evenly spread feeding pattern. The discrepant responses between the young and elderly participants could potentially be due to age-associated anabolic resistance, where elicitation of robust MPS levels requires a larger protein dose per meal in older participants.[63] It is possible that the pulse-feeding condition provided a protein dose containing sufficient essential amino acids (leucine, in particular) to maximize the anabolic response to one of the meals. In contrast, it is possible that none of the meals in the spread condition reached the leucine threshold necessary for triggering MPS.

Recent work by Adechian et al.[64] further challenges the presumed benefits of evenly distributing protein intake throughout the day. No significant between-group differences in body composition change were seen in a 6-week comparison of whey versus casein consumed in a "pulse" meal pattern (8/80/4/8%) versus a "spread" pattern (25/25/25/25%). Collectively, these findings strengthen the hypothesis that the within-day meal frequency and distribution pattern should be determined by individual preference. Further research is necessary to elucidate discrepancies between acute and longitudinal studies and determine if certain feeding strategies are, in fact, better than others with respect to muscle anabolism.

This meta-analysis had several limitations. First, the vast majority of studies analyzed were conducted in a sedentary population, so the findings may not apply to athletes or those involved in structured physical activity programs. Indeed, the one RCT that investigated the effects of meal frequency in an athletic population showed a favorable effect on body composition from more frequent feedings.[28] Moreover, a published abstract by Benardot et al.[65] showed a significant increase in FFM and a decrease in fat mass following provision of a 250-calorie snack versus placebo over a 2-week period in college athletes. This has led to speculation that increased meal frequency may be beneficial for enhancing body composition in those who participate in vigorous physical exercise.[57] Unfortunately, the paucity of research on the topic precludes the formation of evidence-based conclusions. Further investigation is needed to better determine whether altering meal frequency has a positive effect on body composition in well-trained individuals.

Second, it is not clear if the results of this analysis apply to diets that include higher daily protein intakes. Virtually all of the studies on this topic to date used low to moderate amounts of protein. The one exception, a study by Arciero et al.[20] did show significant improvements in body composition when an energy-equated high-protein diet (approximately 34% of total calories) was consumed in 6 versus 3 daily meals. The researchers speculated that these results were related to an enhanced thermogenic response with the greater meal frequency. Future research should seek to determine whether spreading out feedings over the course of a day confers beneficial effects in those consuming high-protein diets.

Third, the present findings are specific to changes in body composition. Although improvements in body composition are often related to better health-related outcomes, this analysis did not directly investigate the influence of meal frequency on factors related to cardiometabolic risk. There is some evidence that increasing the frequency of feeding can have positive effects on glucose homeostasis, insulin sensitivity, and lipid levels,[12,13,66,67] although not all studies support this hypothesis.[67,68] The scope and generalizability of these effects cannot be determined from the present analysis and, thus, warrant further investigation.

Finally, the present study did not determine whether meal frequency might play a role in suppressing appetite. Acute studies on the topic have been conflicting. While several trials reported that appetite was reduced when meals were spaced out over the course of a day,[8–10,31] others failed to detect such differences regardless of feeding frequency.[25,69] Moreover, some studies found that eating 3 as opposed to 6 daily meals actually promotes greater feelings of satiety.[49,70] Pooled analysis of the data did show a positive effect of meal frequency on body fat that was negated after accounting for energy intake, which suggests that more frequent feedings may have contributed to better appetite control. These findings require further study in controlled ad libitum trials.

CONCLUSION

Although the initial results of the present meta-analysis suggest a potential benefit of increased feeding frequencies for enhancing body composition, these findings need to be interpreted with circumspection. The positive relationship between the number of meals consumed and improvements in body composition were largely attributed to the results of a single study, calling into question the veracity of results. Moreover, the small difference in magnitude of effect between frequencies suggests that any potential benefits, if they exist at all, have limited practical significance. Given that adherence is of primary concern with respect to nutritional prescription, the number of daily meals consumed should come down to personal choice if one's goal is to improve body composition.

There is emerging evidence that an irregular eating pattern can have negative metabolic effects, at least in the absence of formal exercise.[71,72] This gives credence to the hypothesis that it may be beneficial to stay consistent with a given meal frequency throughout the week.

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