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Review

Potential role of meal frequency as a strategy for weight loss and health in overweight or obese adults

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ABSTRACT

Improved dietary strategies for weight loss are necessary to decrease metabolic disease risk in overweight or obese adults. Varying meal frequency (MF; i.e., increasing or decreasing eating occasions beyond the traditional pattern of three meals daily) has been thought to have an influence on body weight regulation, hunger control, and blood markers of health. It is common practice for weight management clinicians to recommend increasing MF as a strategy for weight management and to improve metabolic parameters. However, limited research exists investigating the effect of MF during controlled hypocaloric dietary interventions. Furthermore, MF literature often speculates with regard to efficacy of MF treatments based on research using normal weight, overweight/obese, or some combination, where much diversity exists within these various populations. In this review, we suggest that normal-weight and overweight/obese populations, as well as free-living versus investigator-controlled research trials, should be studied independently. Therefore, the objective of the present review is to survey the literature to assess whether the alteration of MF influences body weight regulation, hunger control, and/or blood markers of health in overweight/obese participants undergoing a controlled hypocaloric diet to induce weight loss. Findings of this review indicate that there is uncertainty in the literature when interpreting the optimal MF for obesity treatment, where reduced MF may even show more favorable lipid profiles in obese individuals compared with increased MF. Furthermore, the simple relationship of comparing MF with body fatness or body mass index should also consider whether eating frequency is associated with other healthy factors (e.g., increased physical activity).

Introduction

According to a recent release of Healthy People 2020, one primary public health concern in the United States is the prevalence of overweight and obese Americans [1]. Currently, more than one-third of U.S. adults are obese, with no indication that the prevalence is decreasing [2]. It has been estimated that more than 300 000 U.S. adults die each year due to obesity-related comorbidities (15.2% of all deaths) [3].

Presently, numerous dietary strategies are believed to play a role in combating overeating and obesity (defined as body mass index [BMI] $\geq$ 30 kg/m^2) [4–6]. Due to the need for clinical clarification, evidence-based weight loss interventions are considered crucial for decreasing the prevalence of overweight and obese Americans.

Since the early 1960s, the idea of implementing increased dietary structure in regard to meal frequency (MF) has been debated. Currently, weight management professionals recommend dietary weight loss plans that substitute the classical eating pattern (i.e., three large meals daily) with eating smaller meals more frequently throughout the day in order to spread out daily caloric intake [7,8]. Increased MF for weight management, body weight regulation, hunger control, and metabolic disease management is supported anecdotally, but this strategy lacks evidence in the associated scientific literature. Due to the potential effect of MF to manage hunger, satiety, regulation of

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appetite hormones, and lipemia, increasing MF has been hypothesized to effect energy intake and the favorable regulation of body weight [7,9]. Furthermore, it has been shown that those who maintain weight loss tend to eat more frequently throughout the day (three meals and two snacks) than those who tend to regain weight lost, although the research is inconclusive during active weight loss [10]. The purpose of this review is to investigate the role of MF as a dietary strategy for individuals undergoing active weight loss during controlled hypocaloric dietary interventions.

Observational research has demonstrated mixed results in free-living adults versus controlled research trials when investigating the relationship between MF and body weight. Some researchers contend that higher MF is related to a healthy weight [8,11,12]. More specifically, those consuming a greater frequency of small meals throughout the day are more likely to have a normal BMI, healthy levels of certain risk markers for disease (e.g., triglycerides [TGs], cholesterol, and glucose metabolism), and consequently, a reduced risk for developing or having a diagnosis of coronary heart disease (CHD) and/or other metabolic diseases such as obesity and type 2 diabetes [8,11,12]. Conversely, others have reported that higher frequency of ad libitum eating may lead to increased weight gain and obesity because it presents increased opportunities to eat and overeat throughout the day [13–16].

Furthermore, research investigating the role of MF in disease regulation has shown variable results when investigating glucose and insulin levels and postprandial lipid profiles. Frequent meals have been proposed to reduce the occurrence of excess caloric consumption and provide better glucose control and reduced insulin secretion [17]. Benefits of increasing MF on glucose control have been shown in overweight/obese individuals [18] and in those who have impaired glucose tolerance [19,20]; however, research with normal-weight or normoglycemic individuals are mixed.

Increasing MF in overweight or obese individuals has shown reduced glycemic load [19], improved glucose and insulin metabolism [18,19,21], and improved hunger control [9,18]. However, in healthy normal weight individuals and/or persons without impaired glucose metabolism, no significant differences were found in postprandial glucose regulation [22], in reducing the concentrations of lipids and/or hormones [23], or in feelings of hunger [24].

Current meal patterns and body weight

One of the most notable limitations in the literature examining eating patterns associated with MF is the predominance of observational, cross-sectional studies. In this regard, some studies have reported an inverse relationship between eating frequency and percentage of body fat or BMI in both normal weight and obese adults [25,26]. According to a study investigating eating patterns and prevalence of obesity in free-living U.S. adults, eating four or more times per day was associated with a lower risk for obesity compared with eating three or less times per day [26]. However, those who habitually skipped breakfast were 1.35 times more likely to be obese than those who always had breakfast [26]. Research analyzing eating patterns of U.S. adults showed that obese individuals eating ad libitum are more likely to skip breakfast, "gorge" during mid-morning or lunch, and then "gorge" again for dinner, with no snacks or meals in between [26]. Observational studies investigating eating patterns of weight-stable and weight-gaining individuals showed that weight-gaining individuals eat an average of 1645 kJ/d more than weight-stable individuals; this difference is attributed to increased carbohydrate and fat consumption through larger portion sizes [27]. These studies provide evidence of the need for more controlled feeding studies. Findings from a 2002 study suggest that without holding total caloric intake constant, the usefulness of MF and meal-timing data can be limited [27].

Current limitations in the literature

Several limitations exist within the MF research to date, including a lack of standardized terminology and use of multiple terms when describing eating occasions, such as meal frequency, eating frequency, and feeding frequency. Furthermore, definitions of caloric requirements for a meal or snack differ [11,22,28]. Additionally, due to the differences in responses of healthy normal weight versus overweight/obese adults, comparisons should be made between similar populations rather than grouping them together. Grouping different populations may produce differing responses to MF, lipid and glucose metabolism, hormonal appetite regulation, or sensations of hunger/satiety [21,23,27,29]. Differences also occur, in part, due to varied research methodologies; limited research exists using strict dietary and/or controlled methods. Although it is important to understand the behaviors of free-living adults, controlled trials should not be compared with free-living observational studies to investigate plausible strategies to be used by clinical professionals for weight management. Moreover, due to the common error seen with individuals underreporting caloric intake, other potential differences can occur when drawing conclusions about optimal MF when using self-reported dietary intake versus portion-controlled products [30].

Therefore, the goal of this review is to clarify the effect of different MF on body composition and weight management, lipid and glucose metabolism, hunger and satiety, and hormonal appetite regulation in overweight/obese adults based on scientific evidence from randomized controlled, hypocaloric diet trials. Previous review papers investigating the effect of varied MF on these parameters have not studied the impact of MF with only overweight/obese adults undergoing a hypocaloric dietary intervention to induce weight loss [14,31–33]. Because outcome measures can vary between normal weight and overweight/obese individuals, the results of interventions with overweight/obese individuals during a hypocaloric dietary trial will be discussed in order to discern possible treatment mechanisms for obesity management. This review will investigate randomized controlled research trials using reduced-calorie controlled dietary interventions that include altering MF. We also will assess whether there is evidence to suggest that increasing MF during a reduced-calorie diet may be a treatment strategy for reducing obesity. Additionally, we will highlight areas in need of further research.

Literature search criteria

The scientific literature was reviewed and studies were incorporated in this review if they included healthy overweight or obese (BMI $\geq$ 25 kg/m^2) adults (males and/or females, ages 18–66 y), who were consuming a hypocaloric diet during a controlled feeding study. Keywords included in the search were a combination of *obese, hypocaloric, reduced calorie, meal, eating, frequency, occasion*, and *timing*. The following sources were used: MedLine, PubMed, Proquest, Cochrane Database, and Google Scholar. Studies published between 1970 and 2012 were included if they were written in the English language and incorporated a randomized study design with a hypocaloric dietary intervention in an overweight or obese population and investigated one or more of the following outcome measures: changes in body weight or composition; blood markers of health, including glucose, insulin, or lipid concentrations; hunger or satiety responses via appetite hormone measurements; or estimates of hunger sensation or satiety following a test meal. A summary of studies yielded by the search criteria and distribution of terms provided is presented in Table 1.

Body composition

A number of studies using both animal and human subjects have reported that MF can affect body weight and composition [25,26,28,34]. One of the studies discovered an inverse relationship associated with observed habitual MF and body weight in normal weight humans [25]. This research is thought to be largely responsible for the idea that meal timing may play a role in appetite regulation and body composition. Since that time, there has been much debate in the literature regarding the role of MF for the treatment of obesity as it relates to body weight and/or composition. For example, some recent cross-sectional studies have reported no relationship between MF and BMI or body fatness [9,35,36], whereas a 2007 study reported opposing results indicating a positive relationship between MF and obesity [28].

Eight experimental studies investigating overweight/obese individuals during a hypocaloric weight loss intervention designed to induce body weight or composition changes met the search criteria. Limited evidence exists demonstrating a relationship between weight loss in the overweight/obese population and MF. Of these studies, the most recent was conducted in 2012 [9]. This controlled trial randomized participants (age, 51 $\pm$ 9.9 y; BMI, 35.5 $\pm$ 4.8 kg/m^2, 57.8% women) into either a “gorging” three meals/d eating approach (n = 25) or a “grazing” approach, where the participants were instructed to eat at least 100 kcal every 2 to 3 h and to distribute calories as they wished (n = 26) [9]. Assessments for weight loss and average hunger ratings were done at 0, 3, and 6 mo. No significant differences were found in energy intake or BMI between groups at any time point [9]. It is important to note that participants were told to maintain a non-individualized diet of either 1 200 kcal/d (body weight $\leq$ 90.71 kg) or 1 500 kcal/d (body weight $>$ 90.71 kg) for the 6-mo study duration. Adherence was based on self-reported 3-day food records [9].

Another study using a controlled experimental design [36] examined 16 obese (BMI 37.1 $\pm$ 4.5 kg/m^2) individuals during an 8-week equi-energetic hypocaloric diet. These individuals consumed either three meals plus three snacks per day or three meals per day with no snacks. Losses of body weight, fat mass, and lean mass were similar between groups [36]. Cameron and colleagues [36] did prescribe an individualized hypocaloric diet where a 700 kcal/d deficit was individualized to study participants.

These findings are similar to a number of previously published studies [37–42], in which no significant differences were reported in body weight changes in overweight/obese individuals using three versus six eating occasions [37,41,42], four versus five eating occasions [38], or two versus three or five eating occasions [40]. Only two of these studies used partial meal replacements and/or portioned products to alleviate some measurement error [38,39]. Other studies provided meal plans and relied on self-reported intake for adherence. In this respect, Vander Wal and colleagues [38] used Kashi products for breakfast, mid-morning snack, and lunch, with a balanced meal for dinner, whereas Poston et al. [39] provided Slimfast products to be eaten a minimum of twice per day. Although both used some portion-controlled products, no significant differences were found in the amount of weight lost after 8 [38] or 24 wk [39].

Many MF patterns have been tested with respect to the number of meals/snacks administered as well as the duration of intervention. However, the research shows no significant findings for changes in body composition with varied MF. At this time, it appears MF does not have a significant role in body composition changes or weight reduction during controlled feeding trials with overweight/obese adults. The lack of significant differences in weight loss or changes in body fat with varied MF may suggest that the differing patterns of MF and methods of measurement may or may not play a role in the results. Furthermore, confounding factors also have influenced this relationship between eating frequency and body weight. This may indicate that those who tend to eat more frequently may be more inclined to act on other health-promoting actions, such as increased physical activity or choosing to consume healthier food options [34]. Additionally, the variable methodologies used in these studies make it difficult to reach a conclusion with respect to the relationship between MF and body composition changes. Furthermore, based on the knowledge that under-reporting of calories consumed is common in both obese and non-obese individuals, findings from studies using self-reported dietary intake must be interpreted with [30].

Markers of health

According to the Centers for Disease Control and Prevention *Summary of Health Statistics*, 2010, 34% of Americans 18 y and older are overweight and 28% are obese, whereas $>$ 25% have been diagnosed with CHD. Type 2 diabetes (T2DM), dyslipidemia, hypertension, and physical inactivity are some of the leading risk factors for developing CHD in the United States [43]. There is a paucity of research on the effect of MF on metabolic markers of health, including glucose and insulin metabolism as well as blood lipid concentrations during a hypocaloric diet for overweight/obese individuals. Several studies investigated changes in postprandial insulin and glucose concentrations in normal weight [17,22,44,45] and/or non-hypocaloric dietary interventions [24,45]. Our review of studies found only seven that met our criteria and investigated one or more of the following: glucose concentrations, insulin responses, and/or blood lipid changes in overweight or obese populations.

Insulin and glucose metabolism

Mechanisms for improved glucose regulation in overweight/obese individuals or those with impaired glucose tolerance indicate that increased MF can decrease the postprandial surge of glucose and thus decrease the amount of insulin released in response [39]. Furthermore, small sporadic meals are also thought to aid in the management of T2DM. They are thought to provide more stable blood sugar levels by increasing glucose uptake and disposal by the muscles as fuel, as well as providing a possible suppression of free fatty acid (FFA) release from the adipose tissue [14,29]. Although there is very limited research on glucose and insulin responses and MF in overweight/obese individuals, a controlled study was previously conducted [19]. T2DM patients (BMI 32.2 $\pm$ 1.3 kg/m^2) were studied to investigate postprandial glucose and insulin responses. Researchers

Table 1
Summary of weight loss studies meeting search criteria

Study (y)	Population	Methodology	Measurements	Significant findings
Bachman and Raynor (2012)[7]	51 ± 9.9 y 35.5 ± 1.3 kg/m^2 57.8% women	6-mo RCT of 120–1500 kcal/d). Randomized to either the three-meal group (3 meals/d) (n = 25) or the grazing group (at least 100 kcal every 2–3 h) (n = 26)	3-d diet records, VAS, physical activity questionnaire, and body composition (BIA) at 0, 3, & 6 mo.	Grazing reported significant reductions in VAS hunger from 0 to 6 mo.
Heden et al. (2012)[16]	39 ± 3 y BMI 34.5 ± 4.8 kg/m^2 8 women	RCT 2 d; one 3-meal, the other 6-meal feedings MR (1500 kcal/d). Participants monitored for 12 h.	Body composition (BodPod), waist and hip circumferences, fasting blood glucose and cholesterol, LDL, HDL, LDL, TGs at 0 and every 30 min for 12 h.	Insulin Area-under-the curve (iAUC) significantly higher during the 3-meal condition. iAUC for TGs significantly lower for 3-meal condition.
Cameron et al. (2010)[23]	18–55 y, 37.1 ± 4.5 kg/m^2 8 women, 8 men	8-wk RCT (of –2931 kJ or −700 kcal/d) randomized to either the high MF (3 meals + 3 snacks/d) or low-MF (3 meals/d)	RMR, body composition (DEXA), VAS, total ghrelin, Peptide YY, at 0 & 8 wk	No significant findings
Berteus Forslund et al. (2008)[34]	18–60 y 38.3 ± 5.3 kg/m^2 104 women, 36 men	52-wk RCT (individualized caloric restriction) randomized to either the 3 meals + 3 snacks/d group or the 3 meals/d group	Dietary compliance monitored by phone interviews. Body weight, waist and hip circumferences, blood pressure, fasting glucose, insulin, cholesterol, LDL, HDL, and TGs at 0 & 52 wk.	HDL had inverse relationship to the number of snacks eaten per day.
Vander Wal et al. (2006)[35]	18–65 y Mean BMI 38 kg/m^2 61 women, 19 men	8-wk RCT partial MR program (Kashi ®) n = 29 to “post-dinner snack” (3 meals + 1 snack) and n = 32 to “no snack” (3 meals/d) group	Dietary compliance via questionnaire and empty packages. Body composition (BodPod), waist circumference, TGs, cholesterol, HDL, LDL, at 0 & 8 wk	No significant findings
Poston et al. (2005)[36]	35–55 y BMI 25–30 kg/m^2 84–96% women	24-wk RCT partial MR program (SlimFast ®) (1200 kcal women, 1500 kcal men). Snackers vs non-snackers randomized to 3 MR only or 3 MR + 3 snacks	Dietary compliance via self-reported intake. Body weight, blood pressure, fasting glucose, insulin, cholesterol, HDL, LDL, VLDL at 0, 12, & 24 wk	No significant findings
Bertelsen et al. (1993)[17]	64 ± 2 y 32.2 ± 1.3 kg/m^2 NIDDM patients 4 women, 8 men	2 d, 1 of 2 meals, another 6 meal feedings (811 kcal/d). Participants monitored for 8 h, blood drawn every 30 min	Glucose, insulin, & FFA at 0 & every 30 min for 8 h	2 meals produced an 84% greater max amplitude in glucose concentrations and increased FFA
Antonie et al. (1984)[39]	16–59 y BMI 31.8 kg/m^2 10 women	14-d crossover (1200 kcal/d) randomized to 3 or 6 meals/d	All food except fruits/veggies provided to subjects. Nitrogen balance, fasting cholesterol, and TGs at 0 and 14 d.	Nitrogen losses lower with higher MF
Finkelstein and Fryer (1971)[38]	20–22 y BMI 27–33 8 women	60-d RCT (1700 kcal or 1400 kcal/d) n = 4 randomized to 6 meals/d, n = 4 randomized to 3 meals/d	Meals served in metabolic suite for adherence. Body weight, 6-d nitrogen balance, fasting glucose, total serum lipids, and cholesterol at 0 and 60 d	No significant findings

BIA, bioelectrical impendence; BodPod, air displacement plethysmography; DEXA, dual-energy-X-ray absorptiometry; FFA, Free-fatty acids; HDL, high-density lipoprotein; LDL, low-density lipoprotein; MF, meal frequency; MR, meal replacement; NIDDM, non-insulin dependent diabetes mellitus; RCT, randomized controlled trial; TG, triglyceride; VAS, visual analog scale; VLDL, very low-density lipoprotein investigated the differences between two isocaloric conditions in which two bolus feedings and six intermittent feedings were analyzed on separate occasions for differences in glucose and insulin responses [19]. They found that the two-meal approach induced an 84% greater maximum amplitude in glucose concentrations and increased circulating FFA when compared with the six-meal approach [19]. Preliminary findings were indicative of poor metabolic control that can be ameliorated with higher MF in this population.

However, research results investigating the changes in insulin and/or glucose responses to differing MF in healthy overweight/obese individuals are mixed; some studies found no significant differences [37,39,41], whereas others found significant differences between feeding patterns [18]. One study [39] investigated whether meal replacements with snacks would have an effect on blood glucose and insulin responses in obese men and women who were already "snackers" versus "non-snackers." The researchers found no significant differences between those consuming three larger meals consisting of meal replacements and no snacks compared with those consuming meal replacements plus snacks three times per day [39]. The caloric prescription for this study required participants to maintain a daily diet of 1200 kcal for women and 1500 kcal for men. It is important to note that the researchers relied on self-reported dietary intake by study participants, a condition in which underreporting of energy intake is known to occur [30]. Similar findings were shown in a trial [37] that studied 140 obese adults eating on three versus six occasions per day during a 1-y intervention. Individualized baseline caloric intake was assessed to adjust diets so that intake was reduced by approximately 30% to induce weight loss. Fasting glucose and insulin concentrations were assessed at baseline and 1 y later, with no significant differences being found between MF groups [37]. Potential shortcomings of this study relate to the lack of postprandial glucose or insulin responses, as well as the use of self-reported food records and telephone interviews to determine compliance with caloric intake and allocated MF. Only fasting levels of glucose and insulin at baseline and following the 1-y intervention were used for assessment. Using similar methods and a 60-d intervention, Finkelstein and Fryer [41] also reported no significant changes in fasting glucose concentrations from baseline to the follow-up in healthy young obese women.

Eight healthy obese women (BMI 34.5 $\pm$ 1.3 kg/m^2) were recruited for assignment into one of two isocaloric 12-h treatment conditions of three and six eating occasions [18]. The changes in postprandial insulin concentrations were studied following both interventions. The insulin incremental area under the curve (AUC) was significantly higher during the three-meal condition when compared with the six-meal condition when individuals were followed for 12 h. Insulin is indirectly related to the formation of fatty acids. Because insulin secretion upregulates enzymes known to be involved in cholesterol synthesis and enhanced lipogenesis, increased insulin levels may promote the progression of cardiovascular disease [11,22].

Blood lipids

Lipid profile markers associated with increased risk for coronary artery disease include elevated levels of plasma TGs, low-density lipoprotein cholesterol (LDL-C), and total cholesterol (TC), combined with decreased concentrations of plasma high-density lipoprotein (HDL) cholesterol [46]. Cross-sectional evaluations with the general population have found that both TC and LDL-C are decreased with habitual increases in MF [47,48]. As with other areas, more research is needed to fully elucidate any relationship between MF and lipid profile changes, particularly in specialized populations, such as overweight/obese adults undergoing a reduced-calorie diet [11].

Significant associations investigating MF and blood lipid concentrations were found in two studies meeting our search criteria. In a randomized controlled trial (RCT) on MF [37], researchers found no significant differences between conditions for fasting levels of TC, LDL-C, and TGs; the exception was HDL-C. Using self-reported intake, those consuming three meals daily for 1 y were found to have significantly higher HDL-C values than did those consuming three meals plus three snacks each day [37]. Additionally, it was previously found that a significantly lower AUC value for TGs during the three daily eating occasions compared with the six daily eating occasions in obese individuals [18]. Researchers argue that one potential mechanism for these findings could be the greater postprandial insulin concentrations during the three-meal condition (see the section on Postprandial lipemia) [18].

Additionally, four other studies also reported no significant differences in blood lipids due to varied MF in overweight or obese adults during a reduced-calorie diet. One study [38] reported that an 8-wk meal replacement program plus one late-night snack did not significantly improve TC, LDL-C, TGs, or HDL-C values in obese adults. It appears that the intervention may not have been robust enough to see improvements in these parameters because only one extra eating occasion was added to the individual's typical regimen. However, three other studies [39,41,42] reported similar findings. Collectively, no significant differences were identified relative to TC, LDL-C, TGs, or HDL-C following a 60-d RCT with eight obese females, a 2-wk RCT with 10 obese females, or a 24-wk RCT with 100 obese adults, respectively.

Postprandial lipemia

Research using obese individuals following a hypocaloric intervention [18] and interventions designed to promote weight maintenance [22] have shown significant increases in postprandial insulin concentrations during a three-meal condition versus either 6 or 17 meals, respectively. One study [18] speculated that a possible mechanism for significantly lower TG AUC for the three-meal condition is mediated by postprandial insulin responses. The increased insulin response is thought to lead to a decreased surge in TGs. Insulin stimulates adipose tissue lipoprotein lipase activity, thus this will function to hydrolyze TGs to non-esterified fatty acids and glycerol [18,49]. The non-esterified fatty acids are taken up by adipocytes and are then reesterified into a TG droplet to be stored [49]. This lower TG AUC is said to occur approximately 1 h after the fall of the FFAs [49]. Consequently, the increased insulin concentrations that occur because of an increased postprandial glucose surge during lower MF may be increasing postprandial TG clearance and its storage following meals [18].

Overall, evidence showing changes in glucose, insulin responses, and blood lipids in overweight/obese adults during a reduced-calorie diet is limited. Some of the differences in study findings are thought to be because of differing MF, sample sizes, and/or study conditions [18]. More controlled research designed to increase adherence and compliance to dietary interventions is needed. Currently, there is not enough evidence in the literature to support or refute the effect of MF during a hypocaloric diet as beneficial for glucose and/or insulin control or blood lipid changes during a weight loss program.

Appetite

Hypocaloric diets often leave individuals feeling hungry. This increases their risk for relapse and decreases compliance [39]. However, a recent study has investigated an approach to reduce feelings of hunger by increasing MF and spreading out daily caloric intake [7]. The effect of MF on hunger and satiety during a hypocaloric diet in overweight/obese individuals is less understood than with normal-weight individuals.

Hunger and satiety ratings

There are papers that discuss MF and its effects on gastric sensations of “emptiness” or “fullness” before or after a meal [50], although only two studies were found using a controlled reduced-calorie diet of altered MF in overweight or obese individuals [9,36]. Eating more frequently has been thought to reduce hunger, leading to a reduced overall energy intake [7,9]. One study [9] showed that participants in the “grazing” MF condition had a significant reduction in hunger ratings, whereas those “gorging” had no significant changes in hunger throughout the duration of their study [9]. These authors further suggest that obese patients better tolerate a reduced-calorie diet to induce weight loss when MF is increased [9]. Conversely, no significant differences were shown in a study [36] for the desire to eat, hunger, fullness, or prospective food consumption.

It has been suggested that the use of increased MF as a dietary strategy in free-living adults is related to the amount of food consumed at subsequent meals. Using a small ($n = 7$) sample size of obese men, one study [51] investigated the effects of eating one-third their daily energy needs ($\sim$ 1000 kcal) as either a single meal or as five equal portions on subsequent ad libitum food intake. Although there were no significant differences between hunger ratings, those consuming the single preload ate 27% more (or $\sim$ 358 kcal) during the ad libitum meal than those consuming the same meal in five portions [51]. This study suggests that the increased MF can be a successful dietary strategy for reducing total daily caloric intake with some dietary portion and control over meal timing. Future research merits investigation of this approach during a reduced calorie intervention for weight loss. It is unknown whether these same results can be a benefit when increasing MF in order to keep the amount of calories consumed less than those expended.

Appetite-stimulating hormones and hypothalamic control

The majority of the research investigating the hormonal responses of weight management and weight reduction interventions has studied two main hormones known to stimulate appetite: ghrelin and peptide YY (PYY) [8,50]. Ghrelin is a hormone produced primarily in the gastrointestinal tract, where the majority of the hormone is secreted from the stomach to trigger the hypothalamus to sense feelings of hunger [50]. PYY is a gut hormone that belongs to the pancreatic polypeptide family. It is released in response to meals, and its reduction stimulates hunger cascades [52]. Some researchers suggest that increasing MF may have a direct effect on gastric stretch, hormones, and emptying, which contribute to hunger and satiety during weight loss [51]. Solomon and colleagues [53], suggest that a larger preprandial surge in ghrelin occurs with larger less-frequent meals, which is influenced by the increased gastric stretch at meal times. This could cause hormonal influences that increase initiation of meals that can lead to more between-meal snacking behavior and a higher daily caloric intake [53,54]. Additionally, the postprandial release of ghrelin is somewhat mediated by the release of insulin; ghrelin and insulin have an inverse relationship in healthy normal-weight adults [53,55].

Only one study [36] investigated ghrelin and PYY in obese (BMI 37.1 ± 4.5 kg/m^2) individuals undergoing a controlled hypocaloric feeding study for 8 wk. The study reported no significant differences in feelings of hunger, fullness, or ghrelin and PYY between groups consuming an equi-hypocaloric diet in either three or six meals per day [36].

Although there is no unanimous agreement in the literature, it does appear that eating more frequently during a hypocaloric dietary intervention can reduce hunger and increase satiety ratings compared with eating less frequently; however, the research using controlled feeding studies in overweight/obese adults is limited. Increased MF may lead to reduced consumption at subsequent meals and/or overall daily caloric intake [53]. In conjunction with a hypocaloric diet plan, the effect of increasing MF and its ability to reduce hunger-stimulating hormones and feelings of hunger offers an interesting preliminary mechanistic basis to warrant further implementation into practice. Regardless, more research is needed before we have the evidence to put this into practice.

Conclusion

Although there is widespread anecdotal evidence, the amount of controlled research that has examined the impact of differing MF strategies is limited. Although more studies have been published recently, the availability of research in more specific populations of interest, such as the overweight and obese, is still lacking. Currently, the literature lacks consistency in terms of the number of meals/snacks administered, as well as the duration of interventions. Additional research is still needed to more fully understand the effects of MF on body weight and composition, markers of health, hunger and satiety ratings, and hormonal changes, particularly in obese samples. Finally, most of the literature reviewed uses self-reported dietary intake for adherence to prescribed MF or caloric intake.

Future direction

Interesting areas of exploration yet to be studied are changes in body composition, glucose, insulin, lipemia, and appetite measures in obese individuals using prepackaged portion-controlled meal replacements for all food products consumed. This approach could be advantageous in order to minimize the underreporting error (a nearly ubiquitous problem with dietary-interventions research), while also minimizing the logistical burden of eating more often. Although more evidence is becoming available, the literature surrounding the effect of meal frequency is still sparse. This area of research needs to be explored because of the associated findings that can be applied to clinical situations, as well as the common desire to lose or better manage weight. From a macro perspective, this may be a small step toward attaining the Healthy People 2020 goals of decreasing the current prevalence of obesity and decreasing obesity-related comorbidities in the United States and across the globe.

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