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ORIGINAL CONTRIBUTIONS

Solid Versus Liquid—Satiety Study in Well-Adjusted Lap-Band Patients

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Abstract
Background Patients following laparoscopic adjustable gastric banding (LAGB) are generally advised to avoid liquid calories, opt for solids and refrain from drinking with meals as this is believed to prolong satiety. The role of food consistency and satiety following LAGB is largely uninvestigated. The purpose of the study was to: (1) determine if food consistency impacts on post meal satiety in participants with well-adjusted LAGB and (2) compare the level of satiety achieved after consuming a solid versus a liquid meal between groups.
Methods Twenty intervention (well-adjusted LAGB) and 20 control participants were recruited. All participants consumed three iso-caloric breakfasts that were randomised for nine mornings. Participants were asked to rate their satiety on visual analogue scales (VAS) at set times after the test meal. Areas under the curve (AUC) VAS scores were compared within and between groups.
Results Solids (bars) with or without water provided greater satiety than the liquids (shakes) for both groups. Drinking water with the bar did influence satiety in the intervention group. For the intervention group (LAGB), AUC VAS values for the bar with water were 77.4±11.2* and 72.4±16.7* for the controls.
Conclusion Solid meals are more satisfying in both LAGB and non-LAGB individuals. However, a solid meal with accompanying water did not alter meal satiety.

Keywords Obesity · Laparoscopic adjustable banding · Food consistency · Satiety

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Introduction

The prevalence of obesity (BMI ≥30 kg/m^2), especially severe obesity (BMI ≥40 kg/m^2), has dramatically increased over the past few decades [1, 2]. The causes of obesity are complex, and prevention and successful management are proving difficult [3]. Alarmingly, with the increase of the percentage of the population with a BMI of above 30 kg/m^2, there has been an associated increase in obesity-related co-morbidity including: diabetes, lipid disorders, hypertension, cancer and heart disease. The World Health Organisation (WHO) recognises obesity as a societal and environmental issue, associated with changes in behaviour that have occurred as a result of modern economic development [4]. Genes and the gene–environment interaction are also critical in pre-disposing individuals to severe obesity in the current obesenogenic environment that is observed globally [5].

To date, bariatric surgery, including laparoscopic adjustable gastric banding (LAGB), has been the only reliable method in providing substantial and sustained weight loss in chronic and severe obesity [6–10]. A recent randomised controlled trial showed that LAGB produced more sustainable

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weight loss results than very-low-calorie diets, lifestyle and medical therapy [10]. Associated with the weight loss are improvements in health, quality of life, emotional well-being and reduced mortality and morbidity [11]. LAGB has become established as a safe and effective surgical option generating long-term and sustainable weight loss that is greater than current non-surgical options [12].

Despite the common use of LAGB, the mechanism that generates early satiation, prolonged satiety and sustained weight loss is poorly understood, but insight is emerging. It has been demonstrated that the passage of food through the banded area and gastric emptying is not substantially delayed and cannot account for the prolonged satiety [13, 14]. Hypotheses propose the mechanism is mediated by pressure-activating gastric mechanoreceptors that act centrally via vagal afferents to increase satiation and prolong satiety without physically restricting the meal size [13, 15–17]. The former belief that the band acts by restriction, that meal cessation is effectively driven by pouch distension with food, which is then slowly released into the stomach, has generated some recommendations about food consumption with a band that should be challenged. One common recommendation focuses on the consistency of food, suggesting that energy intake should be strictly limited to solids [18] and that drinking with meals should be avoided [19].

Satiety is a complex process which is influenced by a number of factors including the nutritional and textural properties of food, and it has recently been speculated that satiety can be influenced by age, sex and gender [20]. For example, differing appetite responses have been noted previously for protein, carbohydrates and fats, with protein being reported to be the most satisfying [21, 22]. Based on current literature in healthy individuals, it seems that liquids fail to trigger the physiological satiety mechanisms as strongly as solids, and this has been shown to lead to increased total caloric intake, as the human body's appetite mechanisms respond in compensation for the seemingly fewer calories ingested [23, 24]. However, one study reported no differences in subjective satiety after liquid and solid meals [25], indicating that the effect of food consistency on satiety is not entirely clear. Ingestion of fluid calories has been suggested to lead to an increased risk of becoming overweight.

The WHO has documented and recognised the link between increased consumption of calorie-containing beverages and the alarmingly escalating obesity rates [4]. Currently, there are limited long-term data on the effect of food consistency, satiety and long-term weight in healthy individuals; however, one short-term randomised controlled trial has indicated that avoidance of carbohydrates in liquid forms, especially in the form of glucose-sweetened beverages, is beneficial for weight management [26].

Lower ghrelin and insulin responses have been reported after a solid meal replacement when compared to a nutritionally equivalent liquid meal replacement [27], providing biochemical evidence to suggest that hunger is reduced to a greater extent after a solid meal. Reducing calorie-containing drinks has been a standard recommendation for the prevention and management of obesity and is noted in LAGB patient reference guides [18].

Health practitioners globally advise LAGB patients to consume calories in the form of solids rather than liquids and to avoid soft foods and consuming liquids during and 30 min following a meal [28–30]. This advice assumed a restrictive mechanism of band action, with the implication that these practices would be critical to successful sustained weight loss. Evidence for these stricter recommendations for LAGB patients is lacking, however, with one study finding that the number of meals consumed in a day and the consistency of the food, solid, soft or liquid, did not influence weight loss at 12 months after surgery [31].

In a clinical setting, many patients who have undergone LAGB surgery report struggling with the concept of consuming a meal without an accompanying drink, such as water. However, the relevance of avoiding fluids with meals has not been adequately explored. To date, no studies could be found that adequately explored satiety and the relevance of solids versus liquids, and consuming liquids with a meal, in LAGB participants. Therefore, it is important to critically evaluate the dietary advice given to LAGB patients by health professionals.

The aim of this study was to determine whether consistency of food or drinking water with a solid meal impacts on the level of satiety achieved in patients with a LAGB and to compare the level of satiety achieved after consuming a solid meal and a liquid meal, and drinking water with a solid meal in LAGB participants and non-LAGB participants.

It was hypothesised that participants with a LAGB would not experience greater difference in satiety, when compared to matched control subjects without a band (LAGB), following three conditions—consumption of (1) iso-caloric macronutrient-balanced solid bar (B), (2) liquid shake (S) and (3) solid bar (B) with accompanying liquid meals.

Method and Materials

Study Design

This was a case–control study with two convenience groups; the intervention group (participants who had LAGB) were recruited by the health professionals at LapSurgery Australia (Victoria, Australia). The control group (participants without any form of bariatric surgery) were recruited using the snowball method by advertisement to family, friends and employees of the practice [32]. The research team

endeavoured to achieve a sample of controls that reflected the gender ratio of 80 % females/20 % males across the population of patients who have undergone LAGB.

Inclusion Criteria for Each Group

Inclusion for both groups were the following: aged between 30 and 60 years, weight stable and have a BMI within the range of 20–40 kg/m^2 and not using any appetite-suppressant medications. The intervention (LAGB) group were patients who had successful LAGB for more than 2 years and who were in the 'green zone', that is, where the LAGB is providing adequate hunger suppression and portion control to allow for the maintenance of a >40 % excess weight loss.

Exclusion Criteria

Exclusion for both groups were the following: shift workers; pregnant women; taking medication known to influence appetite such as duramine, sibutramine, corticosteroids and psychotropic medication associated with weight gain; unable to consume a full meal replacement within 15–20 min; unable to speak and/or understand English to a level of providing written informed consent and understanding study requirements.

Materials

The meal replacements used in this study were provided free of charge by Nestlé Australia from the Optifast© VLCD range. Nutritionally equivalent liquid and solid meal replacements were selected and used as the test meals, specifically the strawberry shake and berry crunch bar [33]. These two meal replacements were the most closely matched in macro- and micronutrients, and neither contain caffeine which has been suggested to have a possible influence on appetite [34] and appears to have an influence on insulin and blood glucose levels in individuals with diabetes [35]. In order to ensure consistency of the energy content and macronutrient composition between the shakes and the bars, participants were instructed to supplement the shakes with 3.65 g (1 teaspoon) of Benecalorie©. This increased the kilojoule content by 122 kJ, making the liquid meal replacement consistent with the energy content of the solid meal replacement. This product was also provided by Nestle Australia for this study at no charge.

Study Schedule

Participants were asked to consume nine meal replacements over a 2-week period, in a randomised manner, at the breakfast meal only (fasting). The replacement meals comprised three solid bars (B), three liquid shakes (S) and three solid bars consumed with a 250-ml glass of water (BW). The type of meal replacement for a particular breakfast was randomised and unknown to participants; instructions were provided in nine sealed envelopes. Participants were instructed to open one envelope each morning during the intervention period. The envelope contained one of three instructions for each of the three conditions:

1. Consume a bar for breakfast (B)
2. Consume a shake for breakfast (S) or
3. Consume a bar and a glass of water (BW)

A box containing nine replacement meals and envelopes was given to each participant, along with detailed instructions for liquid shake preparation. Participants were shown how to complete the satiety score visual analogue scale (VAS) (Fig. 1) [36] and asked to record their satiety on five occasions each day: 30 min prior to consuming the meal replacement, then 30, 60, 120 and 180 min post consumption. Participants were required to fast and not consume zero-calorie liquids prior to breakfast and avoid zero-calorie liquids for an hour after breakfast.

Statistical Analysis

Demographic data were calculated by mean ± SD. The trapezoid rule was used to obtain area under the curve (AUC) levels for satiety scores at fasting, 30, 60,120 and 180 min per condition type. Differences between the satiety ratings for the three different conditions were compared within groups using paired two-tailed Student's t tests. Differences between the intervention and control groups' satiety ratings were also compared using an unpaired two-tailed Student's t test. $p \leq 0.05$ was considered statistically significant, and all analyses were performed using SPSS for Windows version 20. This study was approved by the Monash University Ethics committee.

Results

Forty-four participants were recruited to the study; 22 in the intervention group (LAGB) and 22 in the control group completed the study. Of those, two withdrew from the intervention group, and one withdrew from the control group. Reasons for withdrawing included family reasons, intolerance of the test meal products and lost to follow-up. The characteristics of study participants are shown in Table 1.

Satiating Effect of Solid Versus Liquid and Drinking with a Meal

In both groups, VAS scale satiety ratings increased significantly within the first 30 min for all three conditions (B, S, BW) and then began to steadily decline over the intervention period (Fig. 2a and b). In the initial stages of

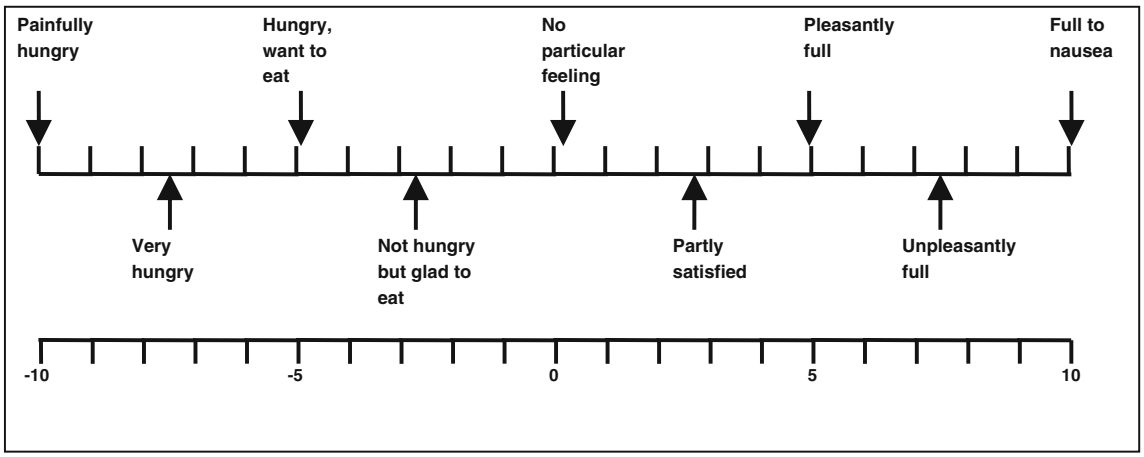

Fig. 1 Visual analogue scale [36]

meal consumption (conditions Band S), differences recorded by the solid bar (B) and liquid shake (S) meal consistencies were obvious, with the liquid shake (S) being significantly less satisfying for both groups (Table 2, Fig. 2a and b).

For the intervention group (LAGB), there was a significant difference between both solid (B) and the liquid meals (S). In contrast to the control group, there was a significant increase in satiety rating over the course of the test period with the bar consumed with 250 ml of water (BW) when compared with the bar alone (B). In the same test, when compared to the control group, the intervention group reported that the bar with water (BW) was more satisfying.

For the control group, there was a significant difference between satiety responses reported from the solid bar (B) and the liquid meal shake (S); however, there was no significant difference in appetite response between the bar alone and consuming 250 ml of fluid with the bar (BW) (Fig. 2a and b).

Comparison of Three Conditions Between the Intervention (LAGB) and the Control Group

Observably, the intervention group had similar satiety ratings at each time point as the control group (Fig. 2a and b).

Table 1 Demographic characteristic of the two groups

	LAGB (n=20)	Control (n=21)
Sex (male/female)	3:17	4:17
Age (years)	47±5.5*	43±8.0*
BMI (kg/m^2)	33.9±5.2*	30.1±6.5*
Time with band (months)	Median 27 (IQR, 24–45; range, 22–96)	NA
Weight lost % (post-LAGB)	23.0±9.0 %	NA

*$p \leq 0.05$, indicating a between-group difference

When comparing the AUC levels between groups, there was no significant difference in satiety between the solid (B) on its own (p=0.38) or the shake (p=0.939), indicating that meal consistency does not alter the solid versus liquid

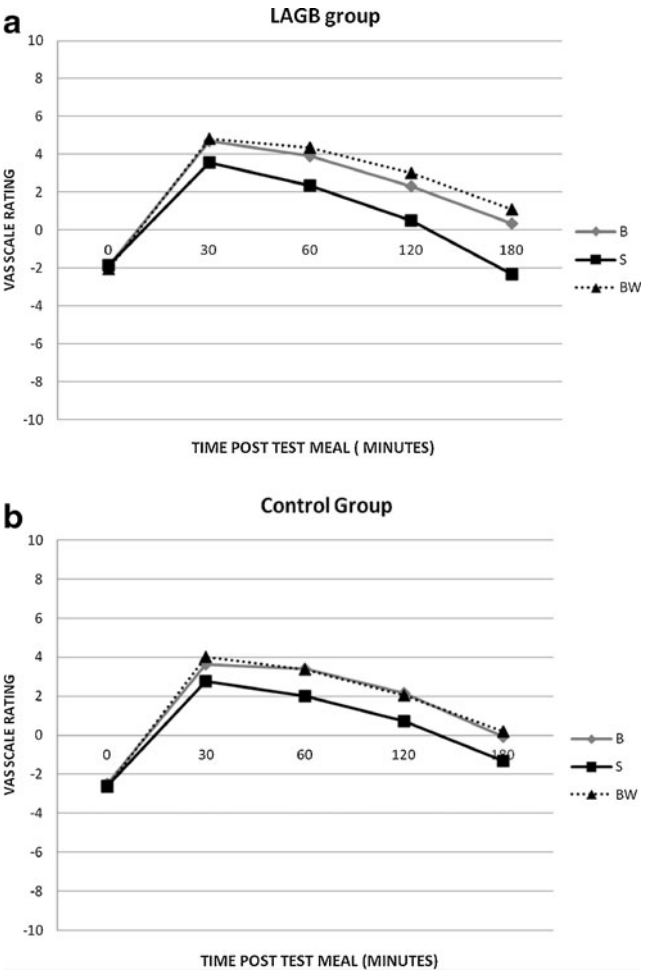

Fig. 2 **a** and **b**. Mean hunger-satiety scores at each time point, per condition type. *B* bar, *S* shake, *BW* bar consumed with water

Table 2 Area under the curve (mean ± SD) for subjective hunger/satiety scores, as measured using the visual analogue scale, for the three types of meal

Condition	LAGB (n=20)	Control (n=21)
Bar VAS (AUC)	74.6±14.5 a c	71.8±16.6 a
Shake VAS (AUC)	64.5±15.1 b	64.5±15.0 b
Bar and water VAS (AUC)	77.4±11.2* a d	72.4±16.7* a

Within columns, 'a' and 'b' were statistically different, $p \leq 0.001$, and 'c' and 'd' were different, $p \leq 0.05$

*$p \leq 0.05$, indicating a between-group difference

satiety pattern in patients following LAGB surgery (Fig. 3). There was, however, significant difference in satiety levels between groups for the bar with water (p=0.03), with the intervention group (LAGB) showing a higher satiety level than the control group (Fig. 3).

Qualitative Comments

After completing the test meal schedule, some participants provided written comments, and others provided verbal comments on their experiences. Nineteen participants provided comments, nine from the intervention group and ten from the control group. Eleven (nine from the intervention group) of the 19 reporting participants reported finding the VAS scale useful as it was easy to use and made them aware of their intake:

> 'The VAS made me stop and think about my hunger rather than mindlessly going on to my next intake of food, water, coffee etc.' (Participant 1004, control group).

This was not the case for all participants, as one reported finding rating hunger as

> 'Too much pressure' and another did not find it useful as they 'nearly always feel hungry'. (Participant 1003, control group).

Four participants (two from each group) commented that it was difficult to consume the bar without water (B):

> 'Bar on its own was harder to take than having the bar with water'. (Participant, intervention group)

> 'The bars though, I liked, but were a bit dry and hard to finish without the water'. (Participant 1024, control group)

Discussion

This study demonstrated that nutritionally equal, solid meals are more satisfying than liquid forms, regardless of whether participants had undergone LAGB or not; no significant difference in the satiety level was found between groups. These results are consistent with the findings of several studies that involved healthy, non-LAGB subjects [24, 27], but one study found no difference [25]. With emerging understanding that the mechanism of LAGB is not restrictive but is more likely to influence central hunger and satiety [14, 15, 33], and with no statistically significant differences between satiety from liquids and solids between groups, it is reasonable to suggest that meal consistency alone does not appear to be a selective determinant of the prolonged satiety seen in LAGB patients, and reducing liquid calories may enhance both surgical and non-surgical weight loss programmes.

As meal replacements, very-low-energy and ketogenic diets gain popularity as form of weight loss, it is important to consider differences in satiety between liquid and solid forms. From the results of this study and others [24, 26, 27] on the human body's seemingly stronger recognition for solids, it would be reasonable to suggest that health professionals recommend the use of solid meal replacements for weight loss interventions. This may be particularly important with very-low-calorie and ketogenic diets during the first days before ketosis suppresses appetite. This may

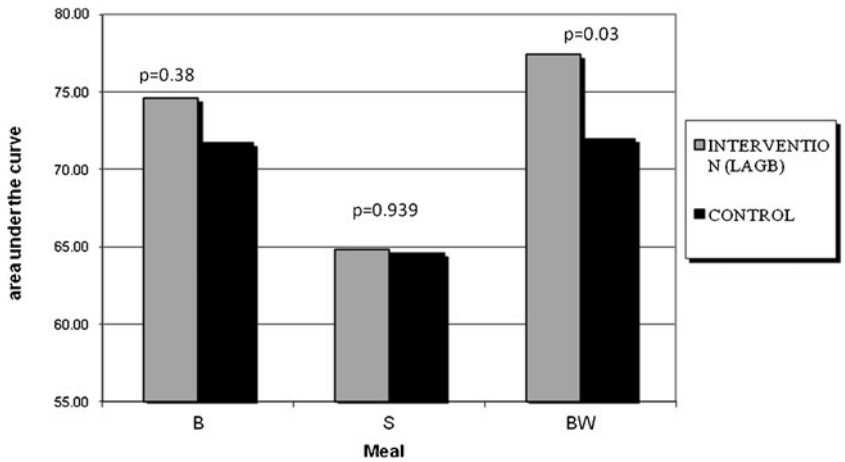

Fig. 3 AUC hunger-satiety level comparison between both groups, per condition. *B* bar, *S* shake, *BW* bar consumed with water

indeed promote better weight loss results; however, this requires further investigation.

Notably, the intervention group in this study had similar satiety ratings at all time points (including fasting) when compared to the control group, further supporting previous research which reported that LAGB counters the major appetite stimulatory effect of significant weight loss despite orexigenic hormone profile generated with weight loss [33, 37, 38]. Therefore, the weight loss participants would be expected to be less satisfied by a small meal and perhaps have a higher appetite after weight loss.

These results are also consistent with research involving appetite changes in individuals with LAGB who had optimal and reduced restriction [33]. That study showed that well-adjusted LAGB participants had higher VAS satiety scores both at pre- and postprandial, and when compared to LAGB participants with reduced restriction [33].

Most participants in this study reported they found rating their appetite using a VAS scale as useful, as it helped them to be more aware of hunger signals and habitual behaviours. For example, one participant from the control group reported that rating her satiety in the morning brought her attention to her dependency of coffee in the mornings; others reported becoming more aware of their appetite. Perhaps the VAS scale may be a useful tool for health professionals working with obesity, as it may assist in increasing individuals' awareness of their appetite patterns and habitual behaviours and aid in the development of strategies that target behavioural change.

Meal consistency and LAGB has often been questioned [17], leading to the idea that health professionals should be strict in advising that patients do not drink with their meals, as this is expected to increase the fluid-like nature of the total meal and reduce satiety [19]. The effect of consuming a glass of fluid with a solid meal on satiety has been poorly studied, with only few studies having been undertaken with healthy subjects and none, to our knowledge, in LAGB patients. One study found that participants indicated a higher satiety rating at the time of the solid meal if they consumed fluids with it; however, this satiety was not significantly prolonged beyond the time of meal consumption [39]. Another found that consuming a beverage with a meal did not affect satiety; however, consuming a meal portion with increased water content (and subsequently lower energy) led to increased fullness [40]. Anecdotally, in a clinical setting, LAGB patients tend to struggle with the notion of not being able to drink with their meals.

This study found that drinking 250 ml of calorie-free fluid with a solid meal replacement did not influence satiety. Within the intervention group (LAGB), the bar with fluid (BW) appeared to be more satisfying, and this was a statistically significant difference to the control participants. This study does not support the notion of strictly recommending that patients refrain from consuming a glass of fluid with their meal if they are comfortable doing so. This aspect of the results supports the theory that the effect of LAGB is due to central and peripheral mechanisms, and perhaps, the additional pressure from combined fluid and solid meal is the reason for increased perceived satiety in the LAGB group. Four participants also reported that they preferred consuming the bar with water as it made it easier to consume. It would be logical to suggest that health professionals could recommend that patients opt for having calorie-free fluids with their meal, particularly at breakfast.

Care must be taken to ensure that patients understand that a drink with their meal is not going to reduce their satiety; however, the difference between this and maladaptive eating behaviours such as drinking large volumes of fluid in order to 'flush' moist foods through the band must be emphasized. This study used a solid and dense meal replacement with 250 ml of water only. This could be applied to a solid breakfast meal and a cup of black tea for example.

One limitation of this study is the small sample size; however, given the current lack of research on food consistency and LAGB, it is reasonable to suggest that health professionals are correct in recommending against fluid calories and need to re-consider recommendations in regard to LAGB patients and drinking with a solid meal. Another limitation is that this study used meal replacements only at breakfast and not typical everyday food and meal combinations. Further research is required on standard meals at differing meal times (for example, lunch or dinner) in order to increase evidence behind current recommendations.

Conclusions

This study found that solids were more satisfying than liquids, and there was little difference in satiety between LAGB and non-LAGB individuals, except when a solid meal is consumed with some fluid, which created greater satiety for the LAGB participants.

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