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Daily ingestion of alginate reduces energy intake in free-living subjects.

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Abstract

Sodium alginate is a seaweed-derived fibre that has previously been shown to moderate appetite in models of acute feeding. The mechanisms underlying this effect may include slowed gastric clearance and attenuated uptake from the small intestine. In order to assess whether alginate could be effective as a means of appetite control in free-living adults, sixty-eight males and females (BMI range: 18.50-32.81kg/m²) completed this randomised, controlled two-way crossover intervention to compare the effects of 7 day daily ingestion of a strong-gelling sodium alginate formulation against a control. A sodium alginate with a high guluronate content was chosen because, upon ingestion, it forms a strong gel in the presence of calcium ions. Daily preprandial ingestion of the sodium alginate formulation produced a significant 134.8 kcal (7%) reduction in mean daily energy intake. This reduced energy intake was underwritten by significant reductions in mean daily carbohydrate, sugar, fat, saturated fat and protein intakes. The absence of any significant interaction effects between the main effect of preload type and those of gender, BMI classification and/or timing of preload delivery indicates the efficacy of this treatment for individuals in different settings. These findings suggest a possible role for a strong-gelling sodium alginate formulation in the future management of overweight and obesity.

Keywords: Alginate; Appetite; Energy intake; Soluble fibre; Preload; Free-living

Introduction

Obesity greatly increases the risk of developing diseases such as type 2 diabetes, hypertension and dyslipidaemia, as well as moderately increasing the risk of coronary heart disease and osteoarthritis (Haslam et al., 2006). Routine positive energy balance, leading to the accumulation of body fat, can result from either or both increased energy intake and reduced energy expenditure. Independent of dietary energy density, habitual overconsumption of both fat and carbohydrate have been epidemiologically shown to be strong predictors of elevated BMI with potential to lead to obesity.

In contrast, fibre-rich diets are widely acknowledged to be associated with a lower prevalence of obesity, and are therefore of interest to those concerned with its treatment and prevention (Howarth et al., 2001, He et al., 2004). Although the mechanisms through which fibre-rich diets modulate food intake have not been fully described, their low energy density, hypolipidaemic properties, ability to effectively maintain relative glycaemic homeostasis, capacity to delay nutrient absorption and potential to cause gastric distension and improved satiety may be important (Anderson et al., 1999, Smith and Holm, 1982, Lavin and Read, 1995 & Marciani et al., 2001).

Several studies have used fibre interventions to assess the potential application of fibre to modify feeding behaviour. Rigaud et al. (1998) showed a significant difference in energy intake after a preload with psyllium compared to a control in their small-scale, acute trial. Contrastingly, a study conducted on normal-weight female volunteers showed that following a preload of locust bean gum there was no difference in energy intake for the remainder of the day or the next day after a test-meal when compared to a control (Weststrate, 1993). Similarly, van de Ven et al. (1994) found no difference in 24 hour energy intake following a test-meal after a soluble guar gum preload compared to a control in healthy, weight-concerned female volunteers. Pasman et al. (1997) supported this finding and demonstrated that suppressed energy intake could be maintained over time following twice daily ingestion of guar gum. Similarly, Cani et al. (2006) demonstrated that twice daily ingestion of 8g oligofructose significantly reduced energy intake at breakfast and lunch compared to a placebo over two weeks in a small-scale, crossover trial ($n = 10$). Reasons why such dissonant outcomes are found is not clear, but may stem from

different study designs, sample populations and in particular the differing choice and source of fibres used in these studies.

Our work is particularly focussed on understanding the potential role that sodium alginate, a soluble fibre isolated from the cell walls of brown algae, has in modifying feeding behaviour. Sodium alginate is utilised widely as a gelling and viscosity-increasing additive in pharmaceutical and food applications. It has been extensively characterised biochemically and the relationship between its chemical structure and physicochemical properties is well understood (Haug et al., 1967 & Draget et al., 1994). A property of alginate that may be important when considering its potential to modify feeding behaviour is its ability to gel upon contact with multivalent cations (Ohta et al. 1997). The gelling properties of sodium alginate are an important point of differentiation when compared to other fibres such as guar gum and psyllium. Sodium alginate can gel and form a stabilised three-dimensional network when sufficient cross-links develop between its polymer chains. Sodium alginate can be cross-linked in the presence of either multivalent cations (ionic gelation) or through the formation of intra-molecular hydrogen bonds when the pH is lowered below 3.5 (acid gelation). Ionic gelation has been exploited to formulate alginate-based products that specifically gel in the stomach. Intra-gastric gelation of sodium alginate is readily achieved by mixing alginate with an acid soluble calcium salt. Following ingestion, solubilisation of the calcium salt in acidic gastric fluid liberates free calcium ions which are then available to cross-link the sodium alginate. Forming gels via ionic gelation, as opposed to relying solely on acid gelation, is favoured because it yields stronger gels. The strength of the gel formed after ionic gelation is dependent on the structure of the alginate. Alginate is composed of two uronic acids, α -L-guluronic acid and β -D-mannuronic acid grouped into homopolymeric segments of guluronic (G blocks) and mannuronic acid (M blocks) respectively and a block of alternating residues (MG blocks). In the presence of multivalent cations, alginates which are rich in G blocks form the strongest gels. This is because G blocks adopt a spatial conformation that favours ionic cross-linking (Draget et al., 1994 & Smidsrod and Draget, 1996).

A number of studies have shown that compositions based on alginate and an acid-soluble calcium salt can moderate various markers of appetite. Hoad et al. (2004) measured the postprandial perception of hunger and fullness following ingestion of a 1% w/v sodium alginate based milk beverage. They tested alginates

with a high and low guluronate content and showed that the stronger gelling (guluronate rich alginate) beverage was associated with a greater perception of postprandial fullness. Using MRI imaging, they then demonstrated that their alginate formulation produced an increased volume of gelled lumps in the gastric antrum. They proposed that the gel increased the perception of fullness due to antral distension resulting from delayed gastric emptying and intragastric gelation and altered nutrient absorption via nutrient entrapment in the gel matrix. Wolf et al. (2002) measured the postprandial glycaemic response following ingestion of a glucose based beverage containing either sodium alginate and tricalcium phosphate or a control beverage containing gum arabic and guar gum. It was found that the postprandial glycaemic response was attenuated following consumption of the alginate based glucose beverage. Williams et al. (2004) incorporated sodium alginate and dicalcium phosphate into a nutritional crispy bar and again found that following consumption of the alginate bar the postprandial glycaemic response was attenuated. Both Wolf et al. (2002) and Williams et al. (2004) suggest that the effect of alginate on glucose absorption may be a consequence of reduced gastric emptying and nutrient absorption due to viscosification of gastric contents.

To date, only a limited number of studies have been published investigating the effect of an alginate-based dietary intervention on food intake. Mattes (2007) conducted a double-blind, randomized, cross-over study to determine the effect of a dual fibre (alginate:guar gum) based breakfast bar on energy and macronutrient intake. The breakfast bar was consumed daily for 5 days and food intake recorded on 3 randomly selected days. It was found that compared to a non-fibre containing control breakfast bar the addition of alginate and guar gum to a solid matrix did not statistically significantly influence either energy or macronutrient intake or satiety. Mattes suggested that poor gelation of the alginate in the stomach may provide an explanation for the lack of treatment effects. Similar findings were demonstrated in an earlier study by Appleton et al. (2004) in which *ad libitum* food intake was unaltered following a meal replacer with added alginate (at 0.4% and 0.8%) compared to a meal replacer alone. In this study the meal replacer plus 0.8% alginate did, however significantly attenuate subsequent measures of hunger for several hours. Satiety was also improved in a study by Peters et al. (2006) in which both weak- and strong-gelling alginate ingestion was compared to low- and high-viscosity guar gum and a control; however, food intake was not measured. Contrary to the food intake findings presented above,

Pelkman et al. (2007) found that a calcium gelled alginate-pectin beverage (of differing strengths) ingested twice daily significantly reduced energy intake in overweight and obese women with low rigid restraint scores.

The conclusions drawn from the literature suggest a possible role for alginate-based products in the modulation of human appetite; however the requirement for the product to undergo intragastric gelation appears critical. The purpose of the work reported in this study was to assess the affect of a novel alginate beverage, specifically designed to undergo enhanced intragastric gelation, on mean daily intake of energy and macronutrients. The beverage differs from other alginate products in that it does not rely on gastric acid secretion to 'trigger' gelation. Ionic gelation of sodium alginate occurs independently of endogenous acid secretion which should ensure a substantial, robust gelled matrix forms within the stomach upon ingestion.

Methods

Subjects

Sixty nine adults (over 18 years), with body mass indexes $\geq 18.5\text{kg/m}^2$ (range: 18.50-32.81 kg/m^2) were recruited to take part in this study. Subjects with irritable bowel syndrome, inflammatory bowel disease, Cushing's syndrome, Dumping syndrome, severe constipation, severe diarrhoea or Coeliac disease, type 1 or type 2 diabetes, food allergies or any serious medical condition, as well as females who were either pregnant or breastfeeding, were excluded from taking part. Anyone who had recently suffered with food poisoning was also excluded. Subjects reported themselves as 'healthy'.

Potential subjects were recruited via the University email and electronic blackboard systems and via posters placed around the University campus and in local gyms. Respondents were fully briefed before signing consent forms and having their height and weight measured. Subjects were not screened for restrained eating behaviour.

All aspects of the study were approved by the Faculty of Organisation and Management Research Ethics Committee of Sheffield Hallam University (Reference Number: OMREC/FIRC/2005/01).

Design

The study was conducted as a randomised, controlled, single-blinded, two-way crossover intervention. The two arms to the study were (i) a 'treatment' arm where subjects ingested a single dose of the alginate preload before food each day for seven days and (ii) a control arm where the alginate preload was replaced with a Slim.Fast preload. Each seven-day (7 d) arm of the trial was conducted at least two weeks apart. The order of presentation of the preloads was randomised across subjects. Subjects were asked to maintain their habitual lifestyles outside of the daily ingestion of a preload as described below.

Preloads

The composition of the alginate preload was based on those described in Patent Number WO2007039294 and contained 1.5g sodium alginate (Protanal, 65-75% guluronate content, FMC BioPolymer), 0.7g calcium carbonate, 2.8g glucono-delta-lactone, 0.5g sodium bicarbonate, 0.05g malic acid, 0.24g vanilla flavour and 7g fructose. It is a dry powder (12.79g in total weight) which is reconstituted to 100 ml with tap water to form a vanilla-flavoured, viscous beverage. The energy content of each 100 ml dose was calculated to contribute no more than 27 kcal to daily energy intake (7g fructose at 3.75kcal/g (Sigman-Grant & Morita, 2003) and negligible energy from other ingredients) and the dietary fibre content, allowing for 10% w/w moisture content, calculated to be 1.35g. The beverage differs from other alginate products in that following ingestion it does not rely on gastric acid secretion to 'trigger' its gelation. It will therefore gel independently of endogenous acid secretion and concentration. This was achieved by adding glucono-delta-lactone, an acidulant, to the beverage. When the beverage is reconstituted in water the glucono-delta-lactone hydrolyses to gluconic acid and a controlled reduction in beverage pH results. Controlling the acidification of the beverage in this manner allows the solubilisation of calcium carbonate to be controlled and in turn the rate of alginate gelation. Through judicious choice of the sodium alginate, buffering system and calcium carbonate the reconstituted beverage was found to be initially a pourable, drinkable liquid that when added to weak acid gastric fluid formed a robust gel. Upon initial reconstitution the viscosity of the alginate beverage, measured using a Brookfield Viscometer (Brookfield Engineering, MA, USA), was 0.32 Pa-S. Following gelation the gel was capable of supporting its own weight under gravity and could not be measured using standard rheological methods. Gel strength was

therefore determined using the texture analysis method described by Richardson et al. (2007). The alginate beverage preload had a gel strength of less than 0.05 N immediately after reconstitution. When added to 50 mL of weak acid gastric fluid (modified USP simulated gastric fluid (pH 5.5, 37°C)) the gel strength increased to $30 \text{ N} \pm 1.5$ (Mean $n = 5 \pm \text{SD}$) after 30 minutes.

The control used in the study was an 18.2 g dose of Slim.Fast Simply Vanilla Milk Shake Powder (Unilever, UK) reconstituted to 100 ml in tap water. Like the alginate preload, it is a fibre-based vanilla beverage. Slim.Fast Simply Vanilla Milk Shake Powder contains inulin, gum arabic, xanthan gum, guar gum, cellulose and sodium carboxymethylcellulose. According to the manufacturer's nutritional information, the dietary fibre and energy content of the dose used were 2 g and 66 kcal respectively. Upon initial reconstitution the viscosity of the Slim.Fast beverage, measured using a Brookfield Viscometer (Brookfield Engineering, MA, USA), was 0.14 Pa-S and the gel strength less than 0.05 N. When added to 50 mL of weak acid gastric fluid (modified USP simulated gastric fluid (pH 5.5, 37°C)) the gel strength was also less than 0.05 N after 30 minutes. Harden and Paxman (unpublished data) used the alginate and Slim.Fast preloads described here in an acute study examining the effect of the preloads on response to a subsequent test meal in healthy and overweight males ($n = 34$). In this study, whilst there was a significant difference in the perceived pleasantness of the two preparations ($p < .0005$) there was no significant difference in the perceived pleasantness of the subsequent test meal consumed 30 minutes later ($p = .352$). From this it can be assumed that any discernable changes in dietary intake between treatments in the current study will not be directly attributable to differences in the palatability of the preloads.

Subjects were instructed to ingest the preload thirty minutes before either breakfast or evening meal and to maintain this behaviour throughout the whole of the trial. A preprandial ingestion time of 30 minutes was chosen on the basis of previous studies (Lavin and Read, 1995 & Paxman, 2007).

In both the alginate and the control conditions subjects were supplied with seven coded plastic bottles with tamper evident caps each containing one dose of dry-mix preload. Bottles were marked with a 100 ml level line. Subjects were instructed to break the seal at the point of ingestion before adding cold water

up to the line, returning the cap to the bottle, shaking vigorously for twenty seconds then drinking the beverage in full.

Dietary assessment

Subjects maintained 7 day estimated measures food diaries throughout each arm of the trial. Subjects were instructed to record all items of food or drink consumed both at home and outside of the home. Portion sizes were estimated using standard household measures. Food diaries were analysed using NetWISP dietary analysis software (Version 3.0 for Windows, Tinuviel Software, Warrington, UK.). Subjects were given the opportunity to report any side-effects in their food diaries. Harden and Paxman (unpublished data) conducted an acute study ($n = 34$) in which subjects consumed the two preloads described here and reported how 'uncomfortable' they felt at 10 time points from baseline (pre-ingestion) to 330 mins (270 mins after a test-lunch). There was no significant difference in AUC discomfort (with subtraction of the basal values) between the two groups ($p = .540$).

Statistical analysis

Mean daily intakes of energy and macronutrients were calculated from the 7 day diaries. These data are presented as mean \pm SD. Mean daily intake was calculated in order to help eliminate bias induced by daily fluctuations in energy intake, especially at times of usual overconsumption (e.g. weekends). A mixed linear model with repeated measures was used to analyse the main outcomes of mean daily energy, carbohydrate, sugar, fat, saturated fat and protein intake. Fixed factor effects were subject gender, subject BMI classification ($<25 \text{ kg/m}^2$ or $\geq 25 \text{ kg/m}^2$) and timing of preload administration (pre-breakfast or pre-evening meal). Subject characteristics for men versus women, those of BMI $<25 \text{ kg/m}^2$ versus those of BMI $\geq 25 \text{ kg/m}^2$, and those who ingested the preload pre-breakfast versus those who ingested it pre-evening meal were compared using independent 't' tests. Differences in means were considered significant at $p < 0.05$. Data were analysed using SPSS (version 13.0 for Windows, SPSS Inc., Chicago, IL, USA).

Results

Subject characteristics

Sixty nine subjects were enrolled in the study. No side-effects were reported at any time during the trial. One subject was excluded from the analysis due to an incomplete dataset. The final sample consisted of sixty eight subjects; their characteristics are shown in Table 1.

Energy and macronutrient intake

The effect of preload on mean daily energy intake is shown in Figure 1. The data indicate that during the alginate arm of the trial, subjects consumed significantly fewer daily calories; $1830.1 \text{ kcal} \pm 472.2$ compared to $1964.9 \text{ kcal} \pm 474.6$ in the control arm. The 134.8 kcal reduction in mean daily energy intake was statistically significant ($p = 0.019$) and represented a 7% reduction. Mean daily intake of each macronutrient was also significantly reduced (Figure 2).

Males and females responded similarly to preload type (no significant interaction effect) for mean daily energy and macronutrient intake (Table 2). Both BMI groups ($<25\text{kg/m}^2$ and $\geq 25\text{kg/m}^2$) responded similarly to preload type (no significant interaction effect) for mean daily energy and macronutrient intake (Table 2). For the duration of intervention arm, subjects were allowed to choose whether to consume the preload before breakfast or before evening meal, but were asked to adhere to this regime throughout the course of both arms of the study. Subjects who chose to ingest the preload before breakfast and those who chose to consume it before their evening meal responded similarly to preload type (no significant interaction effect) for mean daily energy and macronutrient intake (Table 2).

Discussion

The results from this study demonstrate for the first time that an alginate based dietary intervention can reduce energy intake in free-living healthy male and female adults. Subjects reduced their mean daily energy intake by 135 kcal when ingesting alginate daily compared to the control. Following the alginate preload mean intakes of carbohydrate and protein significantly decreased. Importantly, similar findings were evident for the potentially obesogenic nutrients, sugar, fat and saturated fat. One of the most striking findings of the current study was that the reduction in intake could be achieved using a single daily dose of 1.5g sodium alginate. Although other fibre-based interventions have been shown to reduce

food intake in both acute and chronic settings, high doses of fibre have been used; for example, 7.4g psyllium (Rigaud et al., 1998), 40g guar gum (Pasman et al., 1997) or 20g psyllium:wheat bran mix (Delargy et al., 1995).

The reported reduction in energy intake is an underestimate of the actual effect of the preload as the energy content of the preload itself was necessarily excluded from the nutritional analysis. The control preload contributed 66 kcal to total daily energy intake compared to no more than 27 kcal for the alginate preload indicating that the actual reduction in energy intake during the alginate arm of the trial relative to the control arm was 174 kcal rather than 135 kcal. It is not clear from the present study whether this reduction was a result of altered intake at the subsequent meal or across the entire day. Future work should attempt to establish this.

A mean daily reduction in energy intake of more than 170 kcal per day is meaningful in terms of weight management: Hill et al. (2003) estimate that affecting the energy balance by 100 kcal per day could prevent weight gain in 90% of the American population. They suggest that small behavioural changes that encourage both increased energy expenditure and reduced energy intake would be sufficient to eliminate most of the weight gain seen in the population. Lean et al. (2006) purport that a “small changes” strategy, in which energy intake is decreased and energy expenditure is increased each by 100 kcal is also realistic for targeting the current UK obesity epidemic. They comment that some individuals who become obese consume 100 kcal a day more than they expend, leading to a weight gain of 5 kg per annum. They conclude that any intervention that reduces positive energy balance will prevent the accumulation of body fat. The findings from the current study suggest that medium- to long-term use of a daily strong-gelling sodium alginate formulation, alongside suitable healthy lifestyle changes, may help individuals to achieve this target reduction in energy intake.

Few studies have demonstrated that fibre interventions reduce energy/macronutrient intake outside the acute setting. Cani et al. (2006) performed a placebo-controlled short-term pilot study determining the influence of twice daily ingestion of 8g oligofructose on energy intake. Free-living subjects ingested the fibre supplement or a placebo for two weeks and recorded their food consumption daily. Mean daily

energy intake was reduced by 120 kcal (concomitant with enhanced satiety and reduced hunger) during the fibre supplementation phase; an energy intake reduction comparable to the alginate beverage used in this study. Pasman et al. (1997) have also reported that a guar gum based beverage could reduce mean daily energy intake. Post-obese women ($n = 17$) supplemented their habitual diet for seven days with a twice daily dose of 20g guar gum in a non-blinded, controlled, cross-over study. A reduction in mean daily energy intake of 310 kcal was recorded and although apparently superior to the alginate preload used in the present study a number of factors may explain this difference: the mean daily energy intake was based on data recorded over the last three days of each 7 day intervention period and the dose (20g, twice daily) of guar gum was significantly in excess of that used in the present study.

The findings from the present study also showed that the efficacy of the alginate preload was unaffected by subject characteristics. The magnitude of the reduction in intake was not influenced by gender or body mass index and was statistically significant compared to the control. Mean body mass index in the $\geq 25\text{kg/m}^2$ group was expectedly relatively low ($27.2 \pm 1.9 \text{ kg/m}^2$) as subjects were required to be otherwise healthy. Further investigation with obese or morbidly obese subjects may provide interesting evidence as to how the alginate preload performs in mild to moderate insulin resistance that tends to accompany accumulation of adipose tissue. Additionally, the timing of preload ingestion was found not to influence efficacy. It should be noted that the group who ingested the preload pre-evening meal had a significantly elevated BMI compared to the group who ingested the preload before breakfast, however given that BMI status did not influence the efficacy of the treatment, this unlikely to have any bearing on this finding. The robustness of the intervention indicated by the independence over gender, BMI and timing highlights the versatility of the alginate preload design.

Hill & Davies (2001) have reviewed the validity of self-reported energy intake against doubly labelled water. They found that in most settings, studies report a trend towards under-reporting of energy intake using most dietary assessment tools, including 7 d estimated measures diaries. However, it has been shown that 7 d estimated measures diaries are more reliable than some other forms of dietary assessment such as food frequency questionnaires (McKeown et al., 2001) and that findings from such diaries correlate quite well with biomarkers of nutrient intake such as urinary nitrogen (McKeown et al., 2001).

Nevertheless, findings such as those from the current study should be interpreted with caution as all forms of dietary assessment are inherently confounded by multiple factors and future work may use biomarkers to verify findings. Future studies should also aim to establish whether the findings reported from the week long intervention in the present study are reproducible over longer intervention periods.

Reduction in energy intake following consumption of an alginate preload can be achieved in one of two non-mutually exclusive ways. Acute intake can be modulated through earlier satiation, thus bringing feeding to a close sooner and limiting energy consumed at that meal. Alternatively, energy intake can be attenuated through the prolongation or enhancement of satiety, by increasing the intermeal interval, i.e. staying fuller for longer, or by reducing the number or size of eating episodes following ingestion (Mattes et al., 2005). It should be noted that there were differences in the initial viscosity of the alginate beverage (0.32 Pa-S) compared to the Slim.Fast beverage (0.14 Pa-S). Differences in viscosity have been shown to affect feelings of fullness (Marciani et al., 2001); however, the difference between the initial viscosities of the two preloads is of a magnitude unlikely to fully explain the effects observed. It is more likely that the modulation in food intake is derived from the differences between the gelling characteristics of the two preloads. The gelling alginate preload may influence food intake via an affect on gastric distension and nutrient absorption; dependent on gastric emptying, nutrient entrapment and size of the resultant gel 'lump' (Hoad et al., 2004). Marciani et al. (2001) have shown that adding a viscous polysaccharide to a test meal increased the perception of fullness and this correlated with the gastric volume occupied by the test meal. The authors attribute the relationship between fullness and volume to the activation of mechanoreceptors in the gastric body and fundus during distension (Marciani et al., 2001). The 100 ml alginate preload used here may reduce food intake through a similar mechanism. Previous work has suggested volumes over and above 400 ml may be required to elicit reduced hunger or increased fullness, with little attenuative effect on feeding behaviour (Oesch et al., 2006); however, it is established that where bulk is accompanied by nutrients, the volume required to restrict feeding behaviour may be lower (Strubbe, 1994). Alginate may also influence food intake by altering nutrient absorption with consequent alterations in gut-brain signalling. Torsdottir et al. (1991) have shown that adding sodium alginate to a test meal diminished the postprandial rise in blood glucose. It was suggested that increasing the viscosity of gastric contents reduced gastric emptying and slowed intestinal absorption. Alginate has also been

shown to increase the excretion of fatty acids. Sandberg et al. (1994) studied the metabolic effects of alginate ingestion in subjects with ileostomies and found that the addition of alginate to a test meal increased the ileal output of fatty acids. This was attributed to fatty acids becoming bound or trapped within the alginate gel matrix. Additionally, sodium alginate has been shown to reduce the intestinal absorption of cholesterol and glucose in various animal models (Kimura et al., 1996, Vaugelade et al., 2000 & Jimenez-Escrig and Sanchez-Muniz, 2000). It is apparent that sodium alginate can moderate a number of physiological processes controlling food intake; an effect related to its ability to viscosify and gel within the gastrointestinal tract. The efficacy and potency of the alginate preload used at relatively low doses in the current study might be attributed to its enhanced ability to undergo intragastric gelation; future studies will address this hypothesis directly.

In conclusion, pre-prandial daily ingestion of 1.5g sodium alginate formulated in a novel beverage capable of enhanced intragastric gelation has been shown to significantly reduce mean daily energy, carbohydrate, sugar, fat, saturated fat and protein intake over 7 days in free-living adult subjects. The efficacy was unaffected by gender, BMI and timing of dosing and reduction in energy intake was in-line with that proposed for weight management. These findings suggest a possible future role for a strong-gelling alginate formulation in the management of the growing problem of overweight and obesity.

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Figure Legends

Fig. 1. Mean Daily Intake. Mean daily energy intake was significantly greater in the control condition than in the alginate intervention ($p = 0.019$). Since there were no interactions with gender, BMI classification or timing of preload ingestion, overall mean intake (\pm SD) for each arm of the trial is shown.

Fig. 2. Mean Daily Macronutrient Intake. Mean daily intake of carbohydrate, sugar, fat, saturated fat, and protein was significantly greater in the control condition than in the alginate intervention ($p = 0.007$, $p = 0.004$, $p = 0.004$, $p = 0.004$ and $p = 0.003$, respectively). Since there were no interactions with gender, BMI classification or timing of preload ingestion, overall mean intakes (\pm SD) for each arm of the trial are shown.

Table 1
Subject characteristics (mean \pm SD)

Parameter	All subjects (n = 68)	Gender ^a		BMI classification ^b		Timing of preload ingestion ^c	
		Female (n = 38)	Male (n = 30)	<25kg/m ² (n = 44)	\geq 25kg/m ² (n = 24)	Pre-breakfast (n = 41)	Pre-evening meal (n = 27)
Age (years)	24.6 \pm 9.3	25.0 \pm 9.7	24.1 \pm 9.0	24.7 \pm 10.0	24.5 \pm 8.1	24.3 \pm 9.8	25.1 \pm 8.7
Body mass index (kg/m ²)	23.5 \pm 3.3	23.6 \pm 3.6	23.3 \pm 2.9	21.5 \pm 1.7	27.2 \pm 1.9	22.0 \pm 2.6	25.8 \pm 2.9

^a No significant differences in age or body mass index were observed between females and males (independent 't' test).

^b No significant difference in age was observed between those of BMI classification <25kg/m² and those of BMI classification \geq 25kg/m². Naturally, those of BMI <25kg/m² had a significantly reduced BMI compared to and those of BMI classification \geq 25kg/m² ($p = 0.000$; both independent 't' tests).

^c No significant difference in age was observed between those who ingested the preload pre-breakfast and those who ingested the preload pre-evening meal. However, those who consumed the preload pre-breakfast has a significantly reduced BMI compared to and those who consumed the preload pre-evening meal ($p = 0.000$; both independent 't' tests).

Table 2

Mean daily energy and macronutrient intake by preload type, gender, body mass index (BMI) classification and timing of preload ingestion (mean \pm SD)

Intake measure	Preload ^a	Gender		BMI classification		Timing of preload ingestion	
		Female (n = 38)	Male (n = 30)	<25kg/m ² (n = 44)	\geq 25kg/m ² (n = 24)	Pre-breakfast (n = 41)	Pre-evening meal (n = 27)
Energy (Kcal)	Alginate	1694.5 \pm 405.1	2001.8 \pm 501.1	1802.5 \pm 400.7	1880.7 \pm 587.6	1759.8 \pm 375.1	1936.9 \pm 581.8
	Control	1799.8 \pm 416.1	2174.0 \pm 467.6	1949.9 \pm 444.3	1992.4 \pm 534.7	1916.3 \pm 452.6	2038.7 \pm 505.8
Carbohydrate (g)	Alginate	218.8 \pm 55.8	251.8 \pm 98.0	237.1 \pm 64.5	226.7 \pm 100.3	223.5 \pm 51.5	248.4 \pm 106.7
	Control	237.9 \pm 49.9	263.4 \pm 85.7	249.2 \pm 65.5	248.9 \pm 75.6	235.9 \pm 56.9	269.2 \pm 80.5
Sugar (g)	Alginate	92.7 \pm 43.0	86.8 \pm 37.7	95.8 \pm 39.5	79.6 \pm 41.2	92.6 \pm 40.9	86.1 \pm 40.4
	Control	102.5 \pm 39.1	95.7 \pm 38.9	104.6 \pm 39.5	90.1 \pm 36.6	100.6 \pm 41.4	97.8 \pm 35.5
Fat (g)	Alginate	59.7 \pm 18.9	66.7 \pm 17.4	63.5 \pm 18.3	61.4 \pm 18.9	62.3 \pm 18.6	63.4 \pm 18.5
	Control	64.9 \pm 18.6	75.9 \pm 20.3	70.0 \pm 20.8	69.4 \pm 18.9	69.0 \pm 21.5	71.0 \pm 17.7
Saturated fat (g)	Alginate	20.7 \pm 7.8	23.4 \pm 6.0	21.9 \pm 7.4	21.8 \pm 6.8	21.7 \pm 7.2	22.2 \pm 7.2
	Control	22.5 \pm 7.6	27.6 \pm 7.5	24.9 \pm 8.1	24.6 \pm 7.8	24.8 \pm 8.5	24.7 \pm 7.1
Protein (g)	Alginate	59.2 \pm 17.7	79.3 \pm 29.2	65.7 \pm 18.4	72.5 \pm 34.7	64.2 \pm 16.0	73.9 \pm 34.7
	Control	65.3 \pm 16.0	85.0 \pm 22.2	70.8 \pm 18.6	79.8 \pm 24.9	69.1 \pm 17.6	81.5 \pm 24.4

^a For the main effect of preload type, mean daily intake of energy, carbohydrate, sugar, saturated fat and protein was significantly greater in the control condition ($p = 0.019$, $p = 0.007$, $p = 0.004$, $p = 0.004$, $p = 0.004$ and $p = 0.003$, respectively). There was no significant interaction between preload and either gender, BMI classification or timing of preload ingestion for energy or any nutrient.