Novel calcium-gelled, alginate-pectin beverage reduced energy intake in nondieting overweight and obese women: interactions with dietary restraint status

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ABSTRACT

Background: Foods containing strong-gelling fibers may provide a safe and efficacious strategy for reducing food intake by stimulating endogenous satiety signaling.

Objective: A novel, 2-part beverage, consisting of alginate-pectin and calcium components, that forms a stable, fibrous gel in the stomach was tested to determine its effects on subjective satiety and food intake in overweight and obese women.

Design: The investigation was a within-subjects, double-blind, placebo-controlled study. Subjects (n = 29) ingested a 2-part beverage twice per day (once before breakfast and once midafternoon) for 7 d. Three alginate-pectin formulations were tested: 1.0 g, 2.8 g, and control (no fiber). Subjective satiety and ad libitum food intake were measured on days 1 and 7 of each 1-wk treatment period with a 1-wk washout between testings.

Results: A significant reduction in food intake was observed at dinner for both formulations compared with the control formulation. The effects of the gel beverage differed as a function of rigid dietary restraint status. Women in the lower 50th percentile of rigid restraint consumed 12% less energy during the day and 22% less for the evening snack in the 2.8-g condition compared with the control condition. No effect was found for women in the upper 50th percentile of rigid restraint.

Conclusions: Consumption of a post-ingestion, calcium-gelled fiber beverage twice daily reduced energy intake in overweight and obese women with low rigid restraint scores. Use of foods designed to enhance satiety may be an effective adjunctive therapy for weight loss; however, more research is needed to determine how dietary restraint alters this response. Am J Clin Nutr 2007;86: 1595–602.

KEY WORDS Energy intake, satiety, calcium, alginate, pectin, dietary restraint

INTRODUCTION

The increasing prevalence of obesity in the United States (1–3) and worldwide (4–8) poses a significant threat to public health (9–13). Obesity results from a positive energy balance, and prevention and treatment efforts have focused on both the intake and expenditure sides of the energy balance equation. Medical approaches focus on reducing food intake by surgical (14) and pharmacologic (15) means. Although effective, these approaches are costly and not without risk of significant side effects (16–18). Recent advances in understanding the controls of food intake have made it possible to identify specific targets for reducing food intake that engage endogenous satiety mechanisms and that are potentially safer and less costly than medical approaches. One example is the use of low-energy-dense foods to maximize gastric feedback mechanisms of satiety, thereby reducing food intake (19–21) and enhancing weight loss (22). Use of low-energy food products that are specifically designed to engage gastrointestinal satiety mechanisms may be efficacious for enhancing weight loss or for preventing weight gain.

We report results from a study testing the effects of a novel low-energy, calcium-gelled, alginate-pectin beverage on food intake in overweight and obese women. The product was specifically designed to enhance satiety by forming a thick, stable gel in the stomach. We expect the gel to maintain some integrity as it passes through the upper gastrointestinal tract from anecdotal observation of the gel formed by simply mixing the 2 beverage components in a beaker at ambient temperature, from rheological measurements in an in vitro stomach model, and from examining physical appearance and measurement of flow characteristics of digesta recovered from fistulated Yucatan minipigs that consumed the beverage components (data not shown). In all cases, gel particles were present and contributed to the apparent viscosity of the resultant slurry. Samples that experienced minimal trituration (beaker) contained large gel particles that could be scooped up by the hand-full, whereas samples macerated in the pig digestive tract contained smaller but clearly visible particles. Assuming similar slurry formation in the human digestive tract, the dilution of digesta by this inert material could be expected to slow nutrient absorption and result in prolonged triggering of associated gut satiety signals. We hypothesized that the combination of these signals with gastric signals would enhance satiety and reduce energy intake. Our objective was to assess the effects of the gel beverage on subjective satiety and food intake during several meals. A secondary objective was to assess the effects of sustained consumption of the beverages during a 1-wk period and...
to evaluate the effect of timing of the beverage; thus, one beverage was ingested with a meal and the other beverage was ingested between meals. Finally, we sought to assess the possible modulating effects of subject characteristics related to eating, such as binge eating and dietary restraint, because previous studies showed that satiety responses may be altered by behavioral characteristics of the subjects (23–27).

SUBJECTS AND METHODS

Subjects

Healthy, premenopausal, nonsmoking, overweight or obese [body mass index (BMI; in kg/m²): 25–35] women between the ages of 20 and 40 y were recruited through media advertisements and flyers. Subjects were screened by self-report questionnaires and anthropometric assessment to ensure that they were in good health, did not have an eating disorder, were weight stable, were not dieting to lose weight, were not depressed, and were willing to consume the foods used in the study. Screening questionnaires included the Beck Depression Inventory (28), the Eating Attitudes Test (29), the Eating Inventory (30), and the Binge Eating Scale (31). Subjects were asked to taste samples of the test beverages to ensure they would be willing to consume the beverages during the study. They were also instructed to consume comparable meals before each test day, to abstain from alcohol for 2 d before each session, to refrain from consumption of any foods after 2200 the evening before each session, and to discontinue use of any vitamin or calcium supplements. This study was approved by the Health Sciences Institutional Review Board of the University at Buffalo, and subjects gave written consent before participation.

Study design

The study was a within-subjects, placebo-controlled, double-blind design with 3 formulations tested. Subjects received one formulation for 7 d with a 1-wk washout between test weeks. Subjects consumed the test beverage twice daily: one dose before breakfast and a second dose 2.5 h after lunch for a total of 14 doses consumed per 7-d treatment session. Order of treatment was counterbalanced with 5 subjects randomly assigned to each of 6 possible treatment sequences with the use of a random numbers generator.

Calcium-alginate beverage

Each dose provided 40 kcal and was packaged in 2 parts. The alginate-pectin blend [alginate (≈1:1: Manugel LBA and GHB; ISP, Wayne, NJ) 1.0 or 2.8 g and a 15:85 blend of pectin (USP-L220; CP Kelco, Atlanta, GA)] and matched control beverages were formulated in a fruit-flavored aqueous solution (237 mL) sweetened with sucralose. The other part was a 118-mL, fruit-flavored beverage also sweetened with sucralose that provided ≈500 mg elemental calcium as the lactate salt (Purac, Lincolnshire, IL) or no calcium. Subjects consumed sequentially one 237-mL and one 118-mL bottle on each occasion the dose was to be consumed. The reaction of the alginate-pectin blend with the calcium occurs in the stomach on ingestion. The cross-linking of polysaccharide chains is fast and yields a thick, stable gel. In this form, it would be unpalatable to subjects and easily distinguishable from the control beverage. The 237-mL alginate-pectin mixtures and the 118-mL calcium salt mixture were formulated as separate beverages that, when taken together, constitute a single treatment. The corresponding control beverages were formulated to match the active beverages for flavor and color but without the alginate-pectin blend or calcium. Neither beverage alone was expected to be effective in forming a stable gel; therefore, neither beverage was tested as a separate treatment. Bottles were numbered with arbitrary 4-digit numbers by the manufacturer to maintain the study blind.

Test sessions

Subjects were asked to report to the laboratory for meals (breakfast, lunch, and dinner) on days 1 and 7 of each test-session week. Test sessions began between 0700 and 0900. Subjects first completed a short questionnaire to ensure they consumed the evening meal and were not ill in the previous week. Immediately before breakfast, they were asked to consume the appropriate 237-mL (1.0 g, 2.8 g, or control) beverage, followed by the 118-mL calcium (or control) beverage. They were asked to consume each beverage over a 3-min interval and were given timers to help pace their consumption. Subjects then consumed breakfast and returned for lunch 4–5 h later and dinner 9–10 h later. They were given a cooler (with ice packs) that contained one dose of the test beverage (237-mL and 118-mL components) and a bottle of spring water and were instructed to consume the test beverage 2.5 h after the end of the lunch meal. They were given written instruction reminding them to consume the 237-mL beverage first, followed by the 118-mL beverage and to pace their consumption over 3 min for each beverage. They were asked to refrain from drinking water for 30 min after consumption of the test beverage. Subjects were also instructed not to consume any foods or beverages between breakfast and lunch and between lunch and dinner, except the bottled water and the test beverages provided. Subjects were asked to assess subjective sensations of hunger, fullness, nausea, thirst, and the desire to eat on 100-mm visual analog scales (VASs) before and after each meal and hourly between meals. They were given another cooler after the dinner meal, containing snacks for the evening and enough water and test beverages for a 5-d period. They were told to consume as much or as little of the evening snacks as they desired and to return the leftovers the next morning. They were instructed to consume the test beverages each morning, immediately before breakfast, and in the afternoon (2.5 h after lunch) for the following 5 d and to return the empty containers to the laboratory on day 7. Subjects were also asked to record in a daily diary the time each bottle was consumed and any unusual events or sensations they experienced that day. Returned coolers were immediately checked by study personnel. Empty bottles were counted, and the 4-digit numbers were recorded on a check-in sheet. Any reports of unusual events or symptoms were immediately followed up in a telephone interview conducted by the study coordinator and reviewed by the study physician. The protocol for day 7 was the same as day 1 with the exception that participants were not given test beverages to consume after the test day was completed.

Meals

The study was designed to assess the effects of the calcium-alginate beverages on food intake during the course of the day. We varied the timing of the beverages to examine effects on intake at subsequent meals. The first beverage was consumed immediately before breakfast. Food intake at breakfast was standardized. Subjects were given a choice of bagels or cereal and...
yogurt for their breakfast and were served this same breakfast, along with other meal-appropriate foods, such as juice, milk, coffee, or tea, on each of the days in the test session and were encouraged to consume all of the meal. Foods presented for lunch, dinner, and evening snack were more varied and designed to allow subjects to choose from a variety of foods. Lunch and dinner meals were served as individual, buffet-style meals that allowed subjects ad libitum selection from a variety of meal-appropriate foods, such as sliced meats, bread, cheeses, and fruit at lunch, and hot entrees, including meats (roast beef or chicken breast) and vegetables for dinner. All foods were commercially available products and provided varying amounts of energy and macronutrients, allowing subjects to vary intake of energy, fat, protein, and carbohydrate. Subjects were presented with more food than they were likely to consume and instructed to consume as much or as little as they desired. In addition, subjects were asked to choose from a variety of take-home snacks and beverages, such as potato chips, cookies, chocolate bars, juice, milk, fruit, and fresh vegetables, to be consumed in the evening after dinner.

All foods were weighed on an electronic scale to the nearest 0.1 g before and after consumption to determine the amount consumed. Energy and macronutrient composition of the foods were obtained from the manufacturer’s food label or from a standard reference for unlabeled food (32), such as fresh produce.

Data analyses

Statistical power analyses were conducted with the use of NQUERY (version 4.0; Statistical Solutions, Saugus, MA). We used estimates of mean intake (and SDs) at lunch and dinner and for the daily total reported by Rolls et al (33) in a study that used procedures similar to our research protocol. The analyses were conducted with the use of the paired t test procedure for a one-sided t test, and α was adjusted to correct for multiple comparisons because we intended to compare means between 3 conditions (adjusted α = 0.0167). We determined that a sample size of 30 subjects yielded power estimates of 0.81, 0.86, and 0.94 to detect a 15% reduction in food intake at lunch, at dinner, and for total daily intake, respectively. We also conducted post hoc power analyses from the current study to compare with these initial calculations.

Outcome data were analyzed with the use of the STATISTICAL ANALYSIS SYSTEM (SAS; version 9.1; SAS Institute, Cary, NC). The mixed model procedure was used to test for treatment differences, with treatment condition (1.0 g, 2.8 g, or 0.1 g before and after consumption to determine the amount consumed. Energy and macronutrient composition of the foods were obtained from the manufacturer’s food label or from a standard reference for unlabeled food (32), such as fresh produce.

**RESULTS**

Thirty-five women were enrolled in the study, and 29 completed all test sessions (Table 1). Withdrawals were due to job conflicts (n = 2), personal conflicts (n = 1), lack of childcare (n = 1), and age, BMI; and scores on the Beck Depression Inventory, Eating Attitudes Test, Binge Eating Scale, and the 3 factors of the Eating Inventory, including global, flexible, and rigid restraint (35), were entered as covariates in the mixed models as main effects and in interaction terms to determine whether baseline characteristics of the subjects modulated the effects of beverage ingestion on food intake or subjective satiety. The covariates were tested as continuous and binary variables (with a 50th-percentile cutoff). None of the continuous variables were found to be significant. With the use of a 50th-percentile split, trends for an interaction of global restraint score and condition were found for total daily energy intake (P = 0.059) and intake at evening snack (P = 0.059). The only statistically significant interactions with condition were for rigid restraint, reported in “Results.” The interactions were further examined with the use of the SLICE command in SAS to test for an effect of condition within each rigid restraint group. P < 0.05 was considered to be statistically significant for interaction terms and the effect of condition in the SLICE procedure. Tukey’s post hoc test was used to compare least-squares means when main effects of condition were found. When significant effects of condition were found within rigid restraint groups, adjusted P values were used to compare least-squares means between the 3 conditions [adjusted P = 1 − (1 − P)α]. Data given in the text, figure, and tables are least-squares means (±SEMs) from the mixed models, unless stated otherwise.

### Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>33.4 ± 6.5</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>83.0 ± 5.7</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>164.6 ± 4.4</td>
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<tr>
<td>BMI (kg/m²)</td>
<td>30.6 ± 2.2</td>
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<tr>
<td>Beck Depression Inventory (score)</td>
<td>4 ± 3.2</td>
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<tr>
<td>Eating Attitudes Test (score)</td>
<td>7 ± 7.7</td>
</tr>
<tr>
<td>Binge Eating Scale (score)</td>
<td>11.9 ± 7.3</td>
</tr>
<tr>
<td>Restraint (global score)</td>
<td>10.7 ± 4.0</td>
</tr>
<tr>
<td>Rigid restraint</td>
<td>3.4 ± 1.7</td>
</tr>
<tr>
<td>Flexible restraint</td>
<td>3.1 ± 1.6</td>
</tr>
<tr>
<td>Disinhibition</td>
<td>7.7 ± 3.9</td>
</tr>
<tr>
<td>Hunger</td>
<td>6.0 ± 3.7</td>
</tr>
</tbody>
</table>

1 All values are x ± SD; range in parentheses; n = 29.
starting the test meal sessions for similar reasons (n = 2). Fourteen additional subjects were eligible to participate but withdrew before starting the test meal sessions for similar reasons (n = 9) or for inability to comply with test beverage consumption (n = 5).

Some exceptions to the study protocol occurred as a result of subjects’ scheduling conflicts or noncompliance with the study protocol. On 8 occasions subjects had more than 1 wk off between test sessions (2 or 3 wk), one subject required a shorter washout week between test sessions (5 d), and there were 16 instances of subjects having a nonstandard length of test week (from 5 to 8 d). In addition, one subject mistakenly consumed the afternoon test beverage before lunch and another forgot to consume the afternoon test beverage. Two subjects missed a test day (all meals), and one missed an evening snack. All subjects were included in the analyses, and the total sample size was 29, with the exceptions noted above for missing data.

Energy and macronutrient intake

Consumption of the calcium and alginate-pectin beverages between lunch and dinner significantly reduced energy intake at dinner. Subjects consumed ≈10% less energy in both active-gel conditions compared with the control condition (Table 2). No interaction between condition and day was found. The suppression of food intake at dinner was evident on both days that food intake was measured with an average reduction for the 2 fiber conditions of 9% on day 1 and 12% on day 7 compared with the control condition (data not shown).

Approximately two thirds of the reduction in caloric intake observed at the dinner meal (Table 2) was accounted for by the significant reduction in carbohydrate intake at that meal in both conditions. Indeed, significant reductions in carbohydrate intake were observed at breakfast, lunch, and for the day. At breakfast, subjects consumed ≈5% less carbohydrate in the 2 experimental conditions compared with the control condition. Subjects consumed ≈11% less carbohydrate in the 1.0-g condition than in the control condition at lunch and ≈6% less carbohydrate during the day in both gel-beverage conditions than in the control condition (Table 2). The reduction in overall energy intake in each condition for the day, amounting to ≈8.5% of that consumed in the control condition, was not enough to reach statistical significance.

Significant interactions with rigid restraint status were found for intake at the evening snack (P = 0.007) and for the total daily intake (P = 0.017) (Figure 1). The rigid restraint subscale of the Eating Inventory comprises seven, 1-point items. Scores for subjects ranged from 1 to 7, and 50% scored ≤2. Post hoc testing with the use of the SLICE command showed significant effects of condition for subjects classified in the lower 50th percentile for intake during the day (P = 0.01) and intake at the evening snack (P = 0.046). Subjects in the low rigid restraint category consumed less energy during the day (2541 ± 187 kcal; adjusted P = 0.013) and tended to consume less at the evening snack (536 ± 99 kcal; adjusted P = 0.07) in the 2.8-g condition than in the control condition (2875 ± 186 and 684 ± 98 kcal for daily intake and evening snack, respectively). When the 2 gel-beverage conditions were compared (Figure 1), intake during the day tended to be less with the 2.8-g condition than with the 1.0-g condition (2799 ± 186 kcal; adjusted P = 0.07), but no difference (adjusted P = 0.12) was found between the 2 gel-beverage conditions for the evening snack (668 ± 98 kcal in 1.0-g condition). No significant differences were noted for breakfast (499 ± 34, 476 ± 34, and 454 ± 34 kcal), lunch (855 ± 80, 804 ± 80, and 765 ± 81 kcal), and dinner (756 ± 63, 771 ± 63, and 707 ± 63 kcal) in the control, 1.0- and 2.8-g conditions, respectively. No interactions with day were found. The reduction in energy intake at snack and during the day was due in part to a significant reduction in energy intake from carbohydrates (Table 3). Subjects with low rigid restraint consumed ≈22% less carbohydrate at the evening snack and 12% less carbohydrate during the day in the 2.8-g condition than did subjects in the control condition. In the high rigid restraint group, SLICE analyses showed no significant effects of condition on energy intake (Figure 1). Differences in macronutrient intake between conditions at dinner, at evening snack, and for the daily total were found (Table 3). Subjects with high rigid restraint consumed less protein and fat in the 1.0-g condition than did subjects in the control condition at dinner and during the day. There was no evidence of lowered intake of macronutrients at the evening snack when subjects with high rigid restraint were found to consume more protein in the 2.8-g condition than in the control condition (Table 3). We compared

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Energy and macronutrient intake by test condition</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>1.0 g</td>
</tr>
<tr>
<td>Carbohydrate (kcal)</td>
<td>364 ± 14</td>
<td>345 ± 14</td>
</tr>
<tr>
<td>Protein (kcal)</td>
<td>65 ± 3</td>
<td>63 ± 3</td>
</tr>
<tr>
<td>Fat (kcal)</td>
<td>63 ± 8</td>
<td>65 ± 8</td>
</tr>
<tr>
<td>Total (kcal)</td>
<td>499 ± 20</td>
<td>479 ± 20</td>
</tr>
<tr>
<td>Lunch Carbohydrate (kcal)</td>
<td>294 ± 22</td>
<td>262 ± 22</td>
</tr>
<tr>
<td>Protein (kcal)</td>
<td>114 ± 7</td>
<td>112 ± 7</td>
</tr>
<tr>
<td>Fat (kcal)</td>
<td>366 ± 28</td>
<td>367 ± 28</td>
</tr>
<tr>
<td>Total (kcal)</td>
<td>807 ± 47</td>
<td>775 ± 47</td>
</tr>
<tr>
<td>Dinner Carbohydrate (kcal)</td>
<td>379 ± 21</td>
<td>329 ± 21</td>
</tr>
<tr>
<td>Protein (kcal)</td>
<td>127 ± 6</td>
<td>118 ± 6</td>
</tr>
<tr>
<td>Fat (kcal)</td>
<td>236 ± 14</td>
<td>220 ± 14</td>
</tr>
<tr>
<td>Total (kcal)</td>
<td>764 ± 37</td>
<td>689 ± 37</td>
</tr>
<tr>
<td>Snack Carbohydrate (kcal)</td>
<td>315 ± 36</td>
<td>324 ± 36</td>
</tr>
<tr>
<td>Protein (kcal)</td>
<td>36 ± 4</td>
<td>36 ± 4</td>
</tr>
<tr>
<td>Fat (kcal)</td>
<td>203 ± 27</td>
<td>203 ± 27</td>
</tr>
<tr>
<td>Total (kcal)</td>
<td>564 ± 58</td>
<td>571 ± 58</td>
</tr>
<tr>
<td>Daily total Carbohydrate (kcal)</td>
<td>1433 ± 64</td>
<td>1341 ± 63</td>
</tr>
<tr>
<td>Protein (kcal)</td>
<td>342 ± 12</td>
<td>329 ± 12</td>
</tr>
<tr>
<td>Fat (kcal)</td>
<td>868 ± 49</td>
<td>855 ± 49</td>
</tr>
<tr>
<td>Total (kcal)</td>
<td>2716 ± 110</td>
<td>2594 ± 109</td>
</tr>
</tbody>
</table>

1 Subjects (n = 29) completed three 1-wk test conditions, in counterbalanced order, with a 1-wk washout period between conditions. In each condition, subjects consumed 1 of 3 beverages (control, 1.0 g, or 2.8 g) before breakfast and in the midafternoon for 7 d. Food intake was measured on days 1 and 7 of each 1-wk test period. Data are collapsed across day (1 and 7) because the effects of day were not significant. Values in the same row with different superscript letters are significantly different, P < 0.05 (Tukey’s post hoc test).

2 For main effect of condition in mixed model.

3 Least-squares x ± SEM (all such values).

4 Total energy intake and intake for macronutrients were derived from nutrition facts labels for individual foods consumed; therefore, the total energy consumed at each meal or during the day is not equal to the sum of the energy consumed from each macronutrient.

5 Includes energy from gel or control beverages (80 kcal/d).
the baseline characteristics of the subjects with high and low rigid restraint with the use of t tests and found no significant differences between groups for binge score, disinhibition, hunger, age, BMI, Beck depression score, or Eating Attitudes Test score (P > 0.20 for all; data not shown).

**Post hoc power analyses**

Differences in the least-squares means for intake in the 2.8-g and control conditions (adjusted for the effects of session) and estimates of the SD of the differences between least-squares means from the mixed models were used to perform post hoc statistical power analyses. One-tailed tests with an adjusted α of 0.0167 was used in the analyses. We had originally based our sample size (n = 30) on statistical power calculations by using data from a previous study (33) that showed adequate power (≥0.80) to detect a reduction in food intake of 15% at lunch, dinner, or for the total daily intake. The statistical power to detect a 15% reduction in intake in the current study was high (0.97 for lunch, 0.92 for dinner, and >0.99 for total daily intake), indicating that failure to find an effect on total daily intake in the combined sample of 29 women was not due to a lack of statistical power. The effect was much greater in the group with low rigid restraint. Despite the smaller sample size (n = 10), the power to detect a 15% reduction in total daily intake was 0.97. Power to detect a 15% reduction in intake at lunch, dinner, and evening snack was much lower in the group with low rigid restraint (0.57, 0.42, and 0.24, respectively).

**Subjective satiety**

Four-factor interactions were not significant in models testing the effects of condition, day, time, and rigid restraint status on subjective ratings of hunger, fullness, prospective consumption, and appetite score. Significant 2-factor and 3-factor interactions were found; however, the results were inconsistent. For example, subjects with low rigid restraint reported lower ratings of hunger in the morning in the 2.8-g and control conditions than did those in the 1.0-g condition on day 1, but subjects with high rigid restraint reported greater fullness immediately before lunch in the 2.8-g condition than did subjects in the 1.0-g and control conditions on both days. Because the interaction effects involving restraint status and condition were generally small in magnitude and inconsistent, they are not discussed in further detail here.

**Nausea and adverse events**

Ratings of nausea were low and ranged on average from 2.6 to 8.3 mm (100-mm scale) during the course of the day (data not shown). No significant effects of condition, restraint status, day, or interactions between variables were found at any time point before meals or during the morning or afternoon.

Fourteen incidents of adverse events were reported by 8 subjects. All events were deemed not to be serious by the study physician and included reports of mild stomachache, increased frequency of bowel movements, loose stool, and increased flatulence. Three events were deemed to be temporally unrelated to ingestion of the beverages. Of the remaining 11 reports, 3 were reported after ingesting the control beverage, 4 after ingesting the 1.0-g fiber beverage, and 4 after ingesting the 2.8-g fiber beverage.

**DISCUSSION**

The novel, 2-part beverage tested in the current study is nonviscous before ingestion, but the acidic side-chain groups of the alginate undergo rapid cross-linking reactions with the divalent calcium ions to form a solid gel material on mixing in the stomach. Highly viscous fibers that form strong gels, although more likely to enhance satiety, are likely to be unpalatable. Thus, the delayed-activation beverage system tested in this study represents an alternative approach for the delivery of gels into the gastrointestinal tract that circumvents the aversive effects of orally ingesting a gelled substance.
Subjects completed three 1-wk test conditions, in counterbalanced order, with a 1-wk washout period between conditions. In each condition, subjects consumed 1 of 3 beverages (control, 1.0 g, or 2.8 g) before breakfast and in the midafternoon for 7 d. Food intake was measured on days 1 and 7 of each 1-wk test period. Values were determined from mixed model analyses with condition, day, rigid restraint status, and the interaction of condition and restraint entered as factors and adjusted for the effects of repeated testing (sessions 1–6). Data are collapsed across day (1 and 7) because the effects of day were not significant. Within a restraint category, values in the same row with different superscript letters are significantly different, adjusted P < 0.05. Adjusted P = 1 – (1 – P)\textsuperscript{1}.

1 Interaction of condition and rigid restraint status in mixed model.
2 Main effect of condition in mixed model.
3 Least-squares \( \bar{x} \pm SEM \) (all such values).
4 Comparison of least-squares means within restraint categories was conducted when a significant effect of condition was found with the Slice procedure (\( P < 0.05 \) for effect of condition within a rigid restraint category).
5 Includes energy from gel or control beverages (80 kcal/d).
6 Trend for a difference between least-squares means within a restraint category (0.05 < adjusted \( P < 0.10 \)).
7 Trend for a difference between least-squares means within a restraint category (0.05 < adjusted \( P < 0.10 \)).

The results show that ingesting the gel-forming beverage reduced food intake in weight-stable overweight and obese women without any meaningful change in subjective measures of appetite. In the total sample, dinner intake was suppressed by \( \approx 10\% \) in the 2 fiber conditions, with no evidence of energy compensation later in the evening. The effects, however, were mediated by dietary restraint status, and findings for the subjects with low rigid restraint showed evidence of a threshold response with \( \approx 12\% \) less food intake during the day in the 2.8-g condition than with the control condition, whereas intake in the 1.0-g condition was not less than the control condition and tended to be \( \approx 10\% \) greater than the 2.8-g condition. The effects were not attenuated during a 1-wk period. Intake suppression in the 2.8-g condition in the subjects with low rigid restraint, although not significant at each meal, appeared to be consistent across the day with reductions in food intake at breakfast, lunch, dinner, and evening snack, suggesting both short-term and longer-term effects on satiety.

The before-breakfast fiber beverages tended to reduce breakfast intake even though subjects were encouraged to finish the meal. The effect, however, was small in magnitude (\( \approx 45 \text{ kcal or 9\% of the control condition} \)) in subjects with low rigid restraint and 14 kcal (3\% of control condition) in subjects with high rigid restraint. The 4-h interval after consumption of the morning beverage may have been too long to affect intake at lunch. Alternatively, the smaller sample size of the group with low rigid restraint may have reduced our statistical power to detect the 84-kcal (10\%) reduction in lunch intake in the 2.8-g condition compared with the control condition. The shorter interval (2.5 h) in the afternoon resulted in reduced intake at dinner in the combined group of women but not in the group with low rigid restraint. In this group, the effects at dinner (\( \approx 50 \text{ kcal; 7\% reduction} \)) were not significant, whereas later effects at evening snack were clearly evident (\( \approx 141 \text{ kcal; 22\% reduction} \)).

The observed effects are postulated to result from stimulation of gastric and intestinal signals. Recent studies that used magnetic resonance imaging show that high-viscosity, gel-forming fibers form lumps in the stomach, increase gastric volume, and enhance gastric and intestinal signals. Recent studies that used magnetic resonance imaging show that high-viscosity, gel-forming fibers form lumps in the stomach, increase gastric volume, and enhance gastric and intestinal signals.
effects possibly because of delayed absorption of nutrients by gel lumps. Delayed absorption may cause stimulation of incretin responses that enhance satiety. We conducted exploratory analyses to examine the effects of meal in the statistical models; however, no significant main effects or interactions were found. Further work is needed to assess the time course of the effects of calcium-gelled alginates, with studies designed specifically for that purpose.

The amount of fermentable, soluble fiber ingested in the beverage was fairly modest (1.0 or 2.8 g) compared with most high-fiber supplements. Higher intake of dietary fiber is associated with lower body weight (39–41). Fiber may be associated with reduced body weight because of its effects on satiety and food intake, but the bolus amount of fiber required to manifest a benefit may be larger than most persons are willing to ingest. Soluble, viscous fiber may be more effective for reducing food intake and enhancing satiety than are insoluble forms, an effect postulated to be due to slowing of gastric emptying and prolongation of nutrient absorption in the gastrointestinal tract [see reviews by Pereira and Ludwig (42) and Burton-Freeman (43)]. Recent findings, however, call into question the hypothesis that soluble fiber slows gastric emptying. Large [7.4 g (38)] or small [1.7 g (44)] amounts of psyllium or doses of guar gum ranging from 2.5 to 4.5 g (45) were shown to have no effect on the rate of gastric emptying. French and Read (46) showed that 12 g of guar gum added to a high-fat meal delayed the return of hunger despite a trend for an enhanced rate of gastric emptying.

Our findings uncovered an interaction between condition and dietary restraint. Dietary restraint, first introduced by Herman and Mack (47), is defined as the tendency to restrict food intake to control body weight. Herman and Polivy (48) postulated that restrained eaters develop anomalous eating patterns. Persons characterized as having high dietary restraint have been shown to report less hunger (49, 50), be less sensitive to the satiety value of dietary fat (51), more responsive to external cues (24), and less responsive to food palatability (52). Burton-Freeman (25) showed that restrained persons have a blunted cholecystokinin response to a preload, suggesting an aberrant endocrine response to the ingestion of food.

Three self-rating questionnaires have been developed to assess dietary restraint (30, 53, 54). We choose the Eating Inventory, developed by Stunkard and Messick (30) and later revised by Westenhofer et al (35), that delineates 2 types of dietary restraint: rigid restraint, characterized by a maladaptive, all-or-nothing approach to dieting and weight loss, or flexible restraint, characterized by a more graduated, adaptive approach. Studies show that higher scores for rigid restraint were correlated with a higher BMI and less successful weight loss, whereas higher scores for flexible restraint were associated with a lower BMI and greater weight-loss success (35). We found differential effects of the gel beverage on food intake as a function of rigid restraint status, whereas no interaction was found for flexible restraint, concordant with Stunkard’s thesis that rigid but not flexible restraint is related to aberrant satiety responses. Subscale scores were highly correlated ($r = 0.88$ for rigid and global restraint and $r = 0.79$ for flexible and global restraint). Thus, our finding for a trend for an interaction of global restraint and condition may have been due to our inability to distinguish between subtypes of dietary restraint because of our use of the short version of the Eating Inventory (30). Future studies are needed that use the long version of the Eating Inventory (35), to better classify subjects into subcategories and to examine relations between restraint and satiety.

In conclusion, the results show that ingesting calcium-gelled, algin-pectin twice per day reduced spontaneous food intake in overweight and obese women. The effect was more pronounced in women with low rigid restraint and evident only for the 2.8-g gel beverage. Further work is needed to determine whether longer-term consumption or increased frequency of consumption or both would reduce energy intake sufficiently to affect body weight. Foods containing strong-gelling calcium and algin-pectin that is activated in the stomach may be a useful adjunct to current behavioral approaches for weight loss or the maintenance of weight loss. The effects of foods designed to enhance satiety are likely to be modulated by dietary restraint and more successful for persons with low rigid restraint. It is unknown whether therapeutic approaches can be used to change a person’s dietary restraint style from rigid to flexible. Combining such efforts with satiety-enhancing foods or beverages is worthy of further investigation and may lead to substantial improvements to current treatment approaches for controlling body weight.

The author’s responsibilities were as follows—CLP (principal investigator) designed the study, performed the data analyses, prepared the manuscript for publication, and supervised subject recruitment, testing, and data collection; AEM: coordinated the study, recruited subjects, conducted subject testing, and performed data input; RJP: assisted in subject recruitment, subject testing, and writing the manuscript; JLN: an employee of McNeil Nutritional and contributed to the writing of the manuscript as well as the intellectual development and design of the study. He did not partake in any aspect of subject testing or data analyses. None of the other authors had any personal or financial conflicts of interest with the study sponsor.

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