Oral Carbonation Attenuates Feeling of Hunger and Gastric Myoelectrical Activity in Young Women

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Summary  We previously reported that carbonated water ingestion induced fullness and gastric motility. In order to determine whether such satiating effects occur through oral carbonic stimulation alone, we conducted modified sham-feeding (SF) tests (carbonated water ingestion (CW), water ingestion (W), carbonated water sham-feeding (CW-SF), and water sham-feeding (W-SF)), employing an equivalent volume and standardized temperature of carbonated and plain water, in a randomized crossover design. Thirteen young women began fasting at 10 p.m. on the previous night and were loaded with each sample (15˚C, 250 mL) at 9 a.m. on separate days. Electrogastrography (EGG) recordings were obtained from 20 min before to 45 min after the loading to determine the power and frequency of the gastric myoelectrical activity. Appetite was assessed using visual analog scales. After ingestion, significantly increased fullness and decreased hunger ratings were observed in the CW group. After the load, transiently but significantly increased fullness as well as decreased hunger ratings were observed in the CW-SF group. The powers of normogastria (2–4 cpm) and tachygastria (4–9 cpm) showed significant increases in the CW and W groups, but not in the CW-SF and W-SF groups. The peak frequency of normogastria tended to shift toward a higher band in the CW group, whereas it shifted toward a lower band in the CW-SF group, indicating a different EGG rhythm. Our results suggest that CO2-induced oral stimulation is solely responsible for the feeling of satiety. Moreover, different gastric-contraction rhythms (slow or fast) were induced by oral carbonic stimulation alone and carbonated water ingestion.

Key Words  carbonated water, oral stimulation, appetite, electrogastrography, sham-feeding

Carbonated water, a non-caloric beverage with carbon dioxide dissolved in plain or mineral water, has been widely consumed due to its cool and refreshing feeling, as well as its unique oral irritation (1–3) and thirst-quenching effect (4). In addition to its consumption as a daily beverage, reports have indicated that it has therapeutic effects on gastrointestinal symptoms, such as dyspepsia (5–7).

Since carbonated water is an effervescent beverage, it induces a perception of fullness through gastric antral distention (8). This type of satiating effect may be useful for preventing overeating and weight gain. Indeed, we previously reported that carbonated water ingestion may induce greater fullness and gastric motility (9).

In addition to gastric distention due to the liberation of dissolved gas released from carbonated water (8), oral stimulation via the taste of carbonation (1, 2) and physical sensation through the generation of carbon dioxide (1–3), carbonated water may contribute to postprandial satiety. According to appetite research studies using the sham-feeding method, the oral sensation of solid food alone can increase the feeling of fullness (10) and gut satiety hormone levels (11–13) without gastric distention. Moreover, we previously found that tasting carbonated water suppressed the peripheral (toe) temperature in young women (14). These findings suggest the concept that oral stimulation of carbonated water may be the sole contributor to increased satiety; however, little is known about the extent of the effect of oral carbonic stimulation alone, and gastric motility may also be involved.

Accordingly, in order to determine whether satiety responses, such as enhanced fullness and gastric motility, can occur through oral carbonic stimulation alone, we conducted sham-feeding tests employing an equivalent volume and a standardized temperature of carbonated and plain water, in a randomized crossover design.

MATERIALS AND METHODS

Subjects. Thirteen young female volunteers participated in the study (mean±standard errors: age, 24.9±2.4 years; height, 157.2±5.3 cm; weight, 48.1±4.5 kg).
Oral Carbonation Influences on Satiety and Gastric Motility

20.6±0.2 y; height, 158.4±0.9 cm; body mass, 50.6±1.0 kg; body mass index, 20.1±0.4 kg/m²; percentage of body fat, 27.4±1.4%; systolic blood pressure, 92±3 mmHg; diastolic blood pressure, 53±2 mmHg). All of the subjects were non-smokers, free of any symptoms or medical history of gastrointestinal or other diseases that could affect appetite and gastric motility. The SHSE (School of Human Science and Environment) Research Ethics Committee of the University of Hyogo approved the study (No. 116), which was in accordance with the principles of the Declaration of Helsinki. All of the subjects provided written informed consent.

Experimental procedures. We conducted a randomized crossover design experiment with four conditions; carbonated water ingestion (CW), water ingestion (W), carbonated water sham-feeding (CW-SF) and water sham-feeding (W-SF). Each of the 4 tests was performed within 3 wk, including a washout of 1 to 13 d. For preparation of the experimental samples, carbonated water was made by adding carbon dioxide to mineral water, and the same type of mineral water was used for the water sample. The mineral content of the samples has been described in our previous report (14), and the gas pressure of the carbonated water was 3.25 kgf/cm². All of the samples were served at 15°C in a transparent plastic cup.

The participants were asked to maintain their usual lifestyle and body mass at least 1 wk before the test. On the day before the test, consumption of coffee, tea, spicy foods, and high-fat foods was prohibited. Each participant, in a fasted state that began at 10 p.m. the night previous to the test, was tested on 4 different days in a randomized order at approximately 9 a.m. On the first visit for the test, body mass and percentage of body fat were measured using a bioelectrical impedance analyzer (InBody 520, Biospace Co., Seoul, Korea) and with the subjects seated, blood pressure levels were measured two times using an electrical sphygmomanometer (HEM-907, Omron Co., Kyoto, Japan). On all of the test days, after a resting period, the electrode sensor for the electrogastrography (EGG) recording was attached to each subject, and the subject then rested for 10 min in a sitting-up 45° inclined position on a bed. After the resting period, EGGs were recorded from 20 min before to 45 min after the loading (only tasting or tasting and ingestion) in the sitting-up, 45° inclined position. Appetite sensations were evaluated 6 times; before (0 min) and immediately after ingestion (5 min) and at 15, 25, 35, and 45 min (completion), using visual analog scales (15, 16). In regard to the sample loading (250 mL of carbonated water or water), in the ingestion test, the participants were asked to take a small amount of the fluid samples each time and swallow after enough tasting. In the SF trail, the participants were asked to take a small amount of the fluid samples each time and taste enough, then to spit out the sample into a paper cup without swallowing. All loads were completed in 4 to 5 min using a stopwatch. The experiment room was kept at a temperature of 25–26°C, and the room was quiet and comfortable to minimize arousal stimuli. Each subject was separated by partition screens and requested to maintain her position during the data measurement period.

Appetite questionnaires. In order to evaluate appetite sensations (hunger and fullness), we used visual analog scales (VAS) (15, 16). 100 mm in length and anchored at each end, expressing the most positive (extreme) and most negative rating (not at all). Each questionnaire was constructed as a small booklet showing one question at time (15, 16).

EGG measurements and spectral analysis procedures. Mechanical movements of the stomach are regulated by gastric electrical activity, which consists of rhythmic normal waves (normogastria) at a frequency of 3 cycles per min (cpm) delivered from pacemaker cells (17–19). Normogastria controls the maximal frequency and the direction of contractions in the distal stomach (18). EGG is a technique for recording gastric myoelectrical activity using cutaneous electrodes placed on the anterior abdominal wall (18). Because of its non-invasiveness, EGG has gained popularity as a functional indicator of gastric motility. Detailed information about our EGG measurements and power spectral analysis method was provided in previous reports (9, 20).

Figure 1 shows an example of raw gastric myoelectrical signals (A) and the corresponding power spectrum (B). The raw gastric myoelectrical signal demonstrates a sinusoidal oscillation with a frequency of 3 cpm during the fasting or postprandial period (18). In general, signal amplitude (Fig. 1A) increases with meal/drink ingestion, and the increase in power with ingestion can be quantified by means of power spectral analysis (18, 20). In the normal state, the peak frequency is in the frequency band from 2 to 4 cpm (Fig. 1B) (18). We previously reported that the peak frequency shifted toward a higher band after hot water ingestion, indicating faster gastric motility. Conversely, the peak frequency shifted toward a lower band after cold water ingestion, indicating slower gastric motility (20). Thus, the peak frequency demonstrated the occurrence rate of the gastric normal wave.

An abnormal electrical activity in other gastric regions may replace the normogastria (18). Bradygastria appears when depolarizations occur at frequencies lower than the normal band (1–2 cpm), reflecting the reduction of contractile efficiency of the stomach (18). Tachygastria develops when an ectopic pacemaker generates an oscillatory pattern at frequencies higher than the normal band (4–9 cpm) (18). Usually, during tachygastria, the stomach is atonic (18). In healthy individuals, bradygastria and tachygastria have been reported to be present for very short periods of time; however, pathological conditions, such as diabetic gastroparesis (21), may be related to the rhythm disruption of normogastria.

Statistical analyses. All of the data values were expressed as means±standard errors. All of the statistical analyses were performed using SPSS 22.0 for Windows (IBM SPSS Inc., Tokyo, Japan). Where appropriate, the differences among 2 or 4 tests in terms of time
course changes in values for appetite ratings and the EGG parameters were analyzed using a two-way (sample and time) analysis of variance (ANOVA) with repeated measurements. Significant changes between before (0 min, at baseline) and after the loading in each test (CW, W, CW-SF, and W-SF) were identified by performing Dunnett’s test. Statistical significance was defined as $p<0.05$.

RESULTS

Appetite feelings

Figure 2 shows the time course changes in appetite ratings among the 4 tests (CW, W, CW-SF, and W-SF). The time courses of the hunger and fullness scores differed among the 4 groups (sample×time, $p<0.001$, respectively). After the load, the lowest hunger and the highest fullness scores were shown in the CW group.

Each ingestion group (CW and W) showed significantly decreased hunger together with increased fullness scores as compared to baseline (0 min). The extent of these changes was greater in the CW group than in the W group (hunger: CW from 5 to 15 min, W at 5 min; fullness: CW from 5 to 35 min, W from 5 to 15 min, $p<0.05$ vs. 0 min).

In the CW-SF group, transient but significantly decreased hunger as well as increased fullness scores were observed (at 5 min, $p<0.05$ vs. 0 min). In the W-SF group, the hunger score increased toward the end of the test (at 35 and 45 min, $p<0.05$ vs. 0 min).

Fig. 1. An example EGG power spectrum analysis result: raw gastric myoelectrical signal (A), and the corresponding power spectrum (B), obtained from one subject.

Fig. 2. Hunger (A) and fullness (B) ratings. Data are expressed as means±standard errors. CW, carbonated water ingestion; W, water ingestion; CW-SF, carbonated water sham-feeding; W-SF, water sham-feeding. Sample effect, time effect and sample×time interaction were analyzed by 2-way repeated ANOVA. **$p<0.01$, *$p<0.05$, vs. 0 min (Dunnett’s test).

Fig. 1. An example EGG power spectrum analysis result: raw gastric myoelectrical signal (A), and the corresponding power spectrum (B), obtained from one subject.
Oral Carbonation Influences on Satiety and Gastric Motility

EGG parameters

Powers. Figure 3 shows the time course of the EGG powers among the 4 tests. The time courses of the normogastria and tachygastria powers differed among the 4 groups (sample×time, p < 0.028 and 0.022, respectively). After the loading, higher EGG powers were recorded for both ingestion (CW and W) groups, compared with both of the sham-feeding (CW-SF and W-SF) groups. Compared to the baseline, significantly increased powers were found in both CW (normogastria and tachygastria, at 25 and 35 min; p < 0.05 vs. 0 min) and the W groups (bradygastria, at 25 and 35 min; normogastria and tachygastria, at 25 min; p < 0.05 vs. 0 min). On the other hand, such significant changes did not appear in either of the sham-feeding groups.

Peak frequency. Figure 4A shows the time course changes in the peak frequency of normogastria among the 4 tests. The time courses of the peak frequency differed among the 4 groups (sample×time, p = 0.007). After the loading, the highest values were evident in the CW group. Moreover, immediately after ingestion, a tendency for an opposite pattern was observed, i.e., the values of the CW group tended to shift toward a higher band, but conversely, the values of the W group significantly shifted toward a lower band (p = 0.039, vs. 0 min).

A comparison of the CW and CW-SF groups showed significantly different time course changes (sample×time, p = 0.003). After the load, the higher peak frequency in the CW group than the CW-SF group would indicate that gastric motility becomes faster after ingestion. The lower shift of the peak frequency found in the CW-SF group would indicated that gastric motility becomes slower after sham-feeding (Fig. 4B).

A comparison of the two sham-feeding groups showed significantly different time course changes (sample×time, p = 0.029). After the loading, the peak frequency tended to be in a higher band in the W-SF group, but conversely, it shifted toward a lower band in the CW-SF group (Fig. 4C).
DISCUSSION

This study presents 3 major findings. First, even oral carbonic stimulation by carbonated water alone transiently, but significantly, increased fullness, and decreased hunger feelings were observed. Second, oral carbonic stimulation by carbonated water alone did not enhance the power of gastric motility (normogastria), despite the fact that remarkable augmentations were found after both carbonated water and water ingestion. Third, the peak frequency of normogastria shifted toward a higher band after carbonated water ingestion, but conversely, it shifted toward a lower band after oral carbonic stimulation alone, indicating different EGG rhythms.

Appetite feelings

Consistent with the findings of our previous report (9), using an equivalent amount and isothermal samples, the fullness rating was remarkably enhanced following carbonated water ingestion. The gas we previously estimated, released from 250 mL of carbonated water, was approximately 900 mL (9). Moreover, one study (8) that employed magnetic resonance imaging indicated that gastric shapes were enlarged after drinking 300 mL of carbonated beverage. Taken together, these findings and our present results indicate that greater fullness perception after carbonated water may be induced by gastric antral distention due to the liberation of dissolved gas.

Intriguingly, oral stimulation of carbonated water alone induced a transient feeling of satiety; implying that this response may occur in the cephalic phase. Carbonated water has sour (1, 2) and bitter tastes (2), and presents a unique stimulus to the oral cavity through carbonic acid and foaming (1–3). It has been reported that carbon dioxide activates transient receptor potential channel ankyrin 1 (TRPA1) and also that it is perceived as a tingling sensation in the oral cavity (3). Some animal experiments revealed that TRPA1 agonists, such as methyl syringate, altered gastrointestinal functions (22, 23) and suppressed the amount of food intake (22), suggesting that TRPA1 is responsible for appetite regulation. Moreover, the perception of coldness (15°C) may be related to the activation of transient receptor potential melastatin 8 (TRPM8) (24). It has been reported that menthol, the most representative agonist of TRPM8, reduces appetite sensation as well as food intake in humans (25). In addition, bitterness is known as a taste signal that anticipates non-nutritional components or toxins in foods (26). These findings (22–26), together with our present results raise the possibility that the transient fullness perception after oral carbonation may be explained by the activation of TRPA1 and TRPM8 induced by the taste of carbonated water and the physical stimulus of feeling coldness.

The EGG parameters

Mechanical gastric motility is regulated by gastric myoelectrical activity, and it consists of rhythmic slow waves (normogastria) at around the frequency of 3 cpm derived from pacemaker cells. Therefore, the calculation of the power of normogastria is thought to be a reliable indicator of gastric motility (18). In this study, oral carbonic stimulation alone did not affect any of the EGG powers, including normogastria. Interestingly, the peak frequency of normogastria shifted toward a lower band following oral carbonic stimulation alone, indicating slower gastric motility. There are only a limited number of previous studies related to the association of taste with gastric electrical activity. Wicks et al. (27) conducted a sham-feeding test and demonstrated that bitter taste per se delayed gastric emptying, and postprandially, increased the power of normogastria, but no data were shown related to the peak frequency of the normogastria. In addition, it is known that vinegar consumption delays gastric emptying (28, 29), but the effect of sourness perception on gastric motility has not been shown. Since delayed gastric emptying is associated with decreased normogastria (27), bitterness and sourness sensations might alter gastric motility.

Conversely, when carbonated water was ingested, the peak frequency of normogastria shifted toward a higher band, indicating faster gastric motility. In fact, in our previous experiment (9), this peak shift did not occur, even with the same amount of ingestion. This discrepancy between the previous (9) and the present results might be due to the different experimental protocols employed, such as drinking with enough tasting in the present study, or without tasting in the previous study (9).

The remaining question we must address is why a different gastric contraction rhythm (fast or slow) was observed between carbonated water ingestion and oral carbonic stimulation alone. Regarding the characteristics of carbonated water, such as bitterness, sourness, the taste of carbonation, feelings of tingling and the irritation due to foaming (1–3), these stimuli, either comprehensively or partly, could be involved in a pain-transmission pathway, since such stimuli are similar to toxic or pain signals and may influence gastric motility. Nevertheless, a large amount of gas liberated from carbonated water and generating stomach distention (8) may be stronger at triggering sympathetic activation than the stimuli induced by oral carbonic stimulation alone. According to the same line of research, after coffee ingestion (30), carbonated water (9) and spicy soup (31) enhanced gastric motility and sympathetic activation was found. The effect of remarkable gastric distention following carbonated water drinking might be stronger than the effect of oral stimuli. Recently, it has been reported that carbonated water has a thirst-quenching effect (4) and that there are cells that respond to the taste of carbonic acid (1, 3), suggesting the role of CO2 receptors or sour-sensing cells. Therefore, further research is needed to understand the role of oral CO2-induced irritation sensations in appetite and gastro-intestinal functions.

Limitations

The present study had some limitations. First, there was the gender limitation in addition to the small sample size. Second, the serum level of estradiol might be associated with appetite feeling, but we failed to adjust
for the estradiol cycle of our subjects. Third, due to taste characteristics of carbonated water, it was impossible to blind the samples; therefore, the results should be interpreted carefully. Fourth, while the EGG signals were related to the degree of gastric motility, these myoelectrical signals may not be concisely correlated to actual gastric motility. Finally, the role of the CO$_2$ receptors or sour sensing cells in the regulation of appetite remains unclear.

In conclusion, the present results suggested that oral carbonic stimulation by carbonic acid is solely responsible for the transient increase in satiety feeling. In addition, opposite rhythms (slow or fast) of normogastria were observed between oral carbonic stimulation alone and the ingestion of carbonated water. These new findings may have implications for dietetic treatment for populations who need weight control.

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REFERENCES


