Gastric Emptying of Cold Beverages in Humans: Effect of Transportable Carbohydrates

Xiaocai Shi, William Bartoli, Mary Horn, and Robert Murray

Eight healthy subjects, aged 39.0 ± 2.4 years, consumed four 6% carbohydrate-electrolyte solutions containing either one (glucose or fructose) or two transportable carbohydrates in single (glucose + fructose) or bound (sucrose) forms. Solution osmolalities ranged from 250 to 434 mOsm/kg H₂O. The test solutions were ingested at rest in the amount of 6 ml/kg of body weight at a temperature of 12 °C. Gastric emptying rate was measured by repeated aspirations via a nasogastric tube using the modified George double-sampling technique. The intragastric temperature was determined by a temperature probe attached to the nasogastric tube. There were no significant differences in gastric emptying rates and gastric volumes among the solutions. Intragastric temperature dropped from 36.5 °C to 23.3 ± 3 °C immediately after beverage ingestion but recovered to above 30 °C within 5 min. These data suggest that the gastric emptying rate of the specified beverages is not affected by the number and type of carbohydrates or by solution osmolalities within the tested range. Within 5 min after ingestion, cold beverages are warmed to above 30 °C in the stomach. This infers that the effect of cold solution temperature on gastric emptying rate is likely to be small and transitory.

Key Words: gastric emptying, fluid replacement and gastric temperature

The gastric emptying and intestinal absorption characteristics of fluid are two important determinants of the rate of rehydration in humans. Although there is a considerable amount known about the gastric emptying and intestinal absorption characteristics of carbohydrate beverages, there are gaps in this knowledge base. Evidence derived from research on fluid and solute absorption in the gut suggests that (a) both the type and the number of transportable carbohydrates can influence the rate of fluid absorption in the proximal small intestine; and (b) fluid absorption is enhanced by solutions containing multiple transportable carbohydrates compared to isocaloric solutions containing only one transportable carbohydrate (27). However, little is known about how gastric emptying is affected by the presence of more than one transportable carbohydrate in the beverage.

Gastric emptying is affected by many factors including ingested volume, energy density, osmolality, pH, drink temperature, exercise intensity, and mode of

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exercise. Most of these factors have been well documented (5). A rapid gastric emptying rate of fluid and carbohydrate is related to a large ingested volume and a low carbohydrate concentration in the beverage. When the same volume of fluid with the same carbohydrate concentration is ingested, there is some evidence that carbohydrate type in the beverage may affect the rate of gastric emptying. For example, when a solution containing two transportable carbohydrates was examined, a 7.5% maltodextrin and fructose solution tended to be emptied faster than a solution of maltodextrin and glucose in exercising subjects, although the difference was not statistically significant (24). This is probably due to the different gastric emptying rates for glucose, maltodextrin, and fructose (28). The data from these studies partially reflect the effect of adding a second transportable carbohydrate to a carbohydrate beverage on gastric emptying. There is no study that systematically investigates the gastric emptying rate of carbohydrate-electrolyte solutions containing single and multiple (free and bound) forms of transportable carbohydrates in humans.

Therefore, considering that gastric emptying is one of the critical steps in assuring rapid fluid, carbohydrate, and electrolyte replacement, and that the addition of a second transportable carbohydrate may affect gastric emptying, this study investigated how gastric emptying rate was affected by the presence of single and multiple transportable carbohydrates in single (glucose and fructose) and bound (sucrose) forms.

Beverage temperature is another factor influencing gastric emptying rate. Some limited data from animal and human studies indicated that change of beverage temperature decreased (6, 9) or had no effect (18, 30) on gastric emptying rate. These conflicting results make it hard to understand how the temperature of beverage affects gastric emptying rate. In this study, we were interested in the effect of the time course of temperature change on gastric emptying; therefore, we also measured the changes of intragastric temperature following cold beverage ingestion.

Methods

Eight healthy subjects (6 males and 2 females), with no history of gastrointestinal problems, participated in this study. Subjects were 39.0±2.4 years and 79.3±6.7 kg body weight. The study was explained to the subjects, and they signed an informed consent form, consistent with guidelines established by the American College of Sports Medicine. Subjects who had never inserted a nasogastric tube before this study participated in a practice session, where they were given instructions and suggestions on how to successfully insert the tube.

Twenty-four hours prior to each test, subjects abstained from alcohol and caffeine ingestion, and did not perform any strenuous exercise. The night before each experiment, subjects were encouraged to eat a pasta-containing meal to minimize gastric residue and were instructed to drink at least 32 oz. of water to assist in emptying as much of their previous meal as possible. Subjects reported to the laboratory after a 12-hour fast and were allowed to drink as much water as they wanted prior to arriving at the laboratory.

The modified George double-sampling technique (2, 12) was used to measure gastric volume and is summarized below. The calculations for gastric volume, gastric emptying rate, and gastric secretions are described in a previous paper (23). Upon arrival at the lab, the subject inserted a nasogastric tube (AN13, adult 12 FR or
AN 11 pediatric, 10 FR gastric sump tube, H.W. Anderson Products, Chapel Hill, NC) through the nasal passage and into the stomach. The nasogastric tube was lightly coated with a viscous solution of lidocaine hydrochloride (Barre-National, Baltimore, MD) to reduce the irritation of placing the tube. Another tiny aspirating tube was attached to the nasogastric tube and a temperature probe (IT-18 type, Physitemp Instruments, Clifton, NJ) was inserted through this tiny aspirating tube for monitoring intragastric temperature. Subjects inserted the nasogastric tubes themselves and were then seated for the remainder of the test.

The subjects’ stomachs were rinsed repeatedly with distilled water via infusion and aspiration until the aspirated fluid remained clear. As much fluid as possible was then aspirated from the stomach. The proper location of the tube in the stomach was verified by infusing 180 ml of water and then immediately aspirating all fluid. If all 180 ml were aspirated, the tube was marked to provide a reference for positioning for future tests. After the rinsing was completed, the subjects rested for 10 min to allow for emptying of any residual fluids that had escaped from aspiration.

Subjects ingested a mean volume of 48.1 ± 40 ml (6.0 ml/kg body weight) of the test beverage as quickly as possible (usual time required <1.0 min). Beverages were served at 12 °C for a better comparison with data from the previous human studies (1, 23). Beverages contained 60 g/L of glucose (G), fructose (F), sucrose (S), or glucose + fructose (GF; 30 g/L each), plus 19 mmol/L of sodium, 3 mmol/L of potassium, and 25 ppm phenol red (Adrich Chemical, Milwaukee, WI), a molecule that is not absorbed across the gastric membrane. Solution osmolarities for G, F, S, and GF were 434 ± 3, 421 ± 5, 250 ± 1, and 423 ± 5 mosmol/kg H₂O, respectively. Using a 60-ml syringe, the stomach contents were mixed by repeated aspiration and infusion for approximately 1 min after the beverage was ingested. This procedure helped assure that the ingested beverage was thoroughly mixed with the residual gastric contents. Prior to collecting each gastric sample, approximately 20 ml of fluid was aspirated into a 60-ml syringe to remove the dead-space volume in the nasogastric tube prior to taking a gastric sample. The sample collection involved 1 min of mixing the gastric contents via aspirating and infusing, aspiration of a 5-ml sample, infusion of 10 ml of “stock” solution, 1 min of mixing, and collection of a second 5-ml sample. The “stock” solution contained the beverage being tested with 500 ppm of phenol red. The time that the sample was collected was recorded for use in calculating gastric emptying rate. Samples were collected in this fashion every 10 min for 30–40 min.

For the final sample, 60 ml of the test beverage with no phenol red was infused. This was done to ensure that there would be enough volume for mixing with the gastric residue and to collect a final sample. If the volume that was aspirated at 30 or 40 min was low, then the 60 ml of test beverage was infused and the test was stopped after a final 5-ml sample was collected. Only a few samples were collected at 40 min, so only the 30 min values are presented in the results.

The gastric samples were filtered through a 25-mm filter with 0.005-mm pores (German Science, Ann Arbor, MI) to remove particulate matter. Two 1.0-ml aliquots of the filtered sample were diluted to 10 ml with 1.5% phosphate buffer (sodium phosphate, tribasic dodecahydrate, Adrich Chemical, Milwaukee, WI). Spectrophotometric analysis of the samples and “standards” containing known concentrations of phenol red was done at 559 nm using a Varian dms 300 spectrophotometer (Varian Instrument Group, Palo Alto, CA). The remainder of the gastric sample was frozen for later analysis of osmolarity and carbohydrate content.
Osmolality was determined using a Fiske 2400 multi-sample osmometer (Fiske Associates, Norwood, MA). Glucose, sucrose, and fructose concentrations were determined using a Waters HPLC (Waters Corporation, Milford, MA; 17). Intragastric temperature was monitored each minute during the test using a BAT-12 temperature monitor (Physitemp Instruments, Clifton NJ).

**Statistical Analysis**

Statistical evaluation of the data was performed using ANOVA for repeated measures. The Tukey and Scheffe F test were used to isolate specific differences when significant effects were found from the ANOVA. Significance level was set at $p < .05$. Values are presented as mean ± standard error (SE).

**Results**

There were no statistically significant differences for the changes in gastric volume and gastric emptying rate among the four test solutions over time (Figure 1). Gastric emptying rate decreased over time from $29.5 ± 3.3$ to $15.9 ± 1.1$ ml/min (Figure 1). Gastric secretion volumes (Table 1) were consistent during the test period (~3–4 ml/min), and there were no significant differences among solutions. This finding is consistent with previous studies (10, 21, 23).

![Figure 1](image-url)  
Figure 1 — Changes in gastric emptying rate and gastric volume during 30 min ($n = 8$).  
$F =$ fructose; $G =$ glucose; $S =$ sucrose; $GF =$ glucose and fructose. Values are means ± SE.
Table 1  Gastric Secretion Volume (in ml)

<table>
<thead>
<tr>
<th>Solution</th>
<th>10 min</th>
<th>20 min</th>
<th>30 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>6% F</td>
<td>35.72 ± 10.52</td>
<td>39.45 ± 4.26</td>
<td>31.04 ± 6.34</td>
</tr>
<tr>
<td>6% G</td>
<td>34.38 ± 11.51</td>
<td>41.02 ± 3.19</td>
<td>18.57 ± 1.45</td>
</tr>
<tr>
<td>6% S</td>
<td>29.64 ± 5.46</td>
<td>32.82 ± 3.80</td>
<td>21.28 ± 3.70</td>
</tr>
<tr>
<td>3% F &amp; 3% G</td>
<td>34.24 ± 9.11</td>
<td>32.36 ± 2.15</td>
<td>31.79 ± 6.95</td>
</tr>
</tbody>
</table>

Note. Values are Means ± Standard Errors.

Figure 2 — Changes in test beverage and gastric osmolality during 30 min (n = 8). F = fructose; G = glucose; S = sucrose; GF = glucose and fructose. Values are means ± SE. *G significantly differs from F solution at all points. *G significantly differs from GF solution at all points but test beverage. 'S significantly differs from all at all points, p < .05.

The gastric osmolality of solutions F, G, and GF decreased gradually, as would be expected with the addition of gastric secretions. Not surprisingly, solution G retained a significantly higher osmolality over time than solutions F and GF. Solution osmolality was significantly lower in solution S compared with other solutions, and the gastric osmolality of solution S was relatively constant over time and was significantly lower than all other solutions (Figure 2). Solution carbohydrate concentration significantly decreased over time. The gastric osmolality of solution S remained relatively constant over time when the sucrose concentration decreased gradually over time. The fructose concentration (solution F) was significantly lower than the glucose concentration (solution G) at 10, 20, and 30 min, and was also lower than the sucrose concentration (solution S) at 30 min (Figure 3).

Within the first 2 min following ingestion, the intragastric temperature decreased from 36.5 °C to 23.3 °C (Figure 4). The temperature reached 30 °C within 5
Figure 3 — Changes in gastric carbohydrate concentration during 30 min \((n = 8)\). F = fructose; G = glucose; S = sucrose; GF = glucose and fructose. Values are means ± SE. *Test beverage significantly differs from other time points. †F significantly differs from G. ‡F significantly differs from G and S. \(p < .05\).

Figure 4 — Changes in gastric temperature during 30 min \((n = 8)\). F = fructose; G = glucose; S = sucrose; GF = glucose and fructose. Values are means ± SE.

min post ingestion, and then gradually climbed to 35 °C over the next 15 min. There were no differences for intragastric temperature among the four solutions.

**Discussion**

In this study, 6% carbohydrate-electrolyte solutions were examined to determine the effect on gastric emptying of ingesting either one (glucose or fructose) or two transportable carbohydrates in free (3% glucose and 3% fructose) or bound (6% sucrose) form. In brief, there were no significant differences in gastric emptying rate
over time among the four solutions (Figure 1), suggesting that at a 6% carbohydrate level, neither the type of carbohydrate (monosaccharide or disaccharide) nor the number of transportable carbohydrates affects the gastric emptying rate in humans. The practical nature of this finding is that a rehydration solution with multiple types of carbohydrate enhances intestinal absorption of fluids (27) without affecting gastric emptying rate.

The effect of carbohydrate type on gastric emptying has been reported in previous studies (8, 11, 19, 20, 24, 28). A study (8) that assessed the gastric emptying rates of carbohydrate solutions containing single transportable carbohydrates indicated that galactose solutions emptied faster from the stomachs of resting subjects than glucose solutions, and that fructose solutions emptied even faster than galactose solutions. In another study (13), starch solutions emptied from the stomach of subjects at the same rate as did isocaloric glucose solutions, but maltodextrin and fructose solutions emptied faster than glucose solutions (13, 28). The inhibitory effect of glucose on gastric emptying that has been reported in animal studies depends on nutrient-specific feedback (16) that is mediated by afferent nerves from the small intestine (32) and by feedback from sodium-glucose cotransporters (25, 26).

In this study, we did not observe an inhibitory effect of glucose on gastric emptying. This is consistent with previous findings (8, 28) that an inhibitory effect of glucose on gastric emptying was not observed in humans who consumed 5% or 10% glucose solutions. However, gastric emptying slowed significantly when the concentration of glucose was raised above 10%, compared with a fructose solution (28).

Some early studies (4, 7, 15) demonstrated that the rate of gastric emptying is influenced by the osmolality of the ingested solution, with hypertonic solutions emptying more slowly than iso- or hypotonic solutions. The mechanism proposed to explain this delay is that beverage hypertonicity shrinks osmoreceptors in the duodenum, and the volume change creates a signal to delay gastric emptying (14, 15). However, other studies (3, 23, 31) have suggested that osmolality does not affect gastric emptying rate, and that beverage osmolality accounts for less than 5% of the variance in mean gastric emptying rate (23). For example, Vist and Maughan (31) added 50 mmol/L of sodium to glucose and fructose solutions (3.64%) to manipulate the osmolality of the test solutions. The increased osmolality did not affect the gastric emptying rate. Brouns et al. (3) also found that drinks with different carbohydrate content emptied at different rates, despite being iso-osmotic, and that drinks with different osmolalities emptied at the same rate when carbohydrate content was similar. This similarity in gastric emptying rate, despite differences in beverage osmolality, is not surprising, as research has demonstrated that the gastric emptying rates for maltodextrin and glucose solutions are related to the concentration of carbohydrate in the solutions and not the osmolality (11). This has been also supported by our data showing that 6% monosaccharide solutions with an average osmolality of 426 mOsm are emptied at the same rate as an isocaloric sucrose solution with an osmolality of 250 mOsm (Figure 1). The osmolality of the sucrose solution remained relatively constant over time, although the sucrose concentration slightly decreased. This observation suggests that some sucrose is hydrolyzed in the stomach, but that the increase in the number of osmotically active particles in the stomach was offset by the addition of gastric secretion.

When considered together, research shows that (a) three 6% carbohydrate solutions (glucose, maltose, or maltodextrins) with osmolalities ranging between 243 and 374 mOsm do not significantly affect the gastric emptying rate (3); (b) four
6% carbohydrate solutions (glucose, sucrose, maltodextrin, and glucose + sucrose) and water with osmolalities that ranged from 1 to 349 mOsm exhibited similar gastric emptying rates (23); and (c) there were no significant differences in the gastric emptying rates among water, 4% (1% glucose + 3% fructose), and 6% (3.1% glucose + 0.6% sucrose + 2.3% fructose) carbohydrate solutions when solution osmolalities ranged from 0 to 403 mOsm (22). However, significant difference in gastric emptying was found between 6% (3.1% glucose + 0.6% sucrose + 2.3% fructose) and 8.2% (2.5% glucose + 0.2% sucrose + 3.5% fructose + 2% maltodextrin) carbohydrate solutions with similar osmolalities (403 vs. 412 mOsm) (22). Based on these studies, it can be concluded that neither carbohydrate type nor osmolality (in a range of 1–424 mOsm) influences the gastric emptying rate when solution carbohydrate level is at or lower than 6%.

The effect of beverage temperature on gastric emptying rate has not been extensively investigated. A study on rats (9) reported a decrease in gastric emptying with increasing beverage temperature, while another study on dogs (30) showed that meal temperature did not alter the initiation of gastric emptying. Human studies have also reported conflicting results. Costill and Saltin (6) found that gastric emptying rate decreased when solution temperature increased, whereas McArthur and Feldman (18) reported that solution temperatures that ranged from 4 °C to 58 °C did not affect gastric emptying. Sun et al. (29) studied the effect of meal temperature on the rate of gastric emptying and indicated that only the cold meal had a significantly slower gastric emptying rate than the control meal. These results supported a previous study (1) that indicated that gastric emptying was reduced during the first 5 min after ingesting a cold drink (12 °C) compared with a control drink (37 °C), but that temperature did not have a significant effect on the subsequent gastric emptying rate. The intragastric temperature after ingesting a cold drink (4 °C) showed a dramatic decrease within a minute, and then returned to 30 °C within 5 min and to body temperature within 15 to 20 min (18, 29). We found similar results in the present study in that the gastric emptying rate was higher within the first 10 min than during the next 20 and 30 min when intragastric temperature was almost back to normal. However, the decrease in gastric emptying rate more closely parallels the decrease in gastric volume and is not proportional to the changes in gastric temperature. Therefore, these results imply that gastric volume is more important than beverage temperature for regulating gastric emptying.

In conclusion, 6% carbohydrate-electrolyte solutions containing either one or two transportable carbohydrates in single or bound forms emptied at similar rates in humans at rest. Differences in carbohydrate type, number of transportable carbohydrates, and beverage osmolalities within the range of 250 to 434 mOsm/kg H₂O did not influence gastric emptying rate. Intragastric temperature quickly returned to near normal within 5 min after beverage ingestion, suggesting that if a cold beverage does affect gastric emptying, the effect is likely to be small and transitory.

References


