Brief Communication

Osmolarity Does Not Affect the Gastric Emptying Rate of Oral Rehydration Solutions

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ABSTRACT. Background: The objective of this study was to determine the effect of either carbohydrate or osmolarity on gastric emptying rate in normal healthy subjects. Methods: In total 12 test drinks were ingested as a single 8 mL/kg per body weight bolus on an empty stomach. Six of these drinks had a different carbohydrate content, increasing stepwise from 46 to 90 g/L, but all with the same osmolarity (539 mOsm/kg). The other six drinks all contained 60 g carbohydrate/L but differed stepwise in osmolarity because of the use of maltodextrins with a difference in chain length (243 to 374 mOsm/kg). Results: The results show a significant negative relation between carbohydrate content and gastric emptying in the six drinks with a uniform osmolarity but progressively increasing carbohydrate content. The six drinks, which had the same carbohydrate-energy content but different osmolalities, emptied all at the same rate from the stomach. The delivery of carbohydrate-energy per minute from the stomach to the small intestine was the same for all drinks. Conclusions: From these data we conclude that the rate of gastric emptying of carbohydrate-containing solutions is triggered by the carbohydrate-energy drink content or by the delivery rate of carbohydrate-energy to the gut. Osmolarity in the range studied had no effect. (Journal of Parenteral and Enteral Nutrition 19:403–406 1995)

Over the last two decades numerous studies have been performed to determine the rate of gastric emptying of liquids, in particular of rehydration drinks for athletes. These are reviewed in several papers.1–4 From these studies it appeared that plain water has a very fast gastric emptying rate and that solutions that contain ≤30 g/L of glucose or ≤60 to 80 g/L of disaccharides and oligosaccharides do not or only slightly reduce gastric emptying rate. Higher quantities of carbohydrate in solutions were always emptied significantly slower, compared with water. Frequently the effect of delayed gastric emptying has been attributed to result from increased osmolarity and/or energy density of the drink. However, by increasing carbohydrate (CHO) content, more substrate is delivered to the gut, which exerts, when being hydrolyzed, an osmotic effect. Therefore it is impossible to conclude which of the two factors is dominant in controlling the rate of gastric emptying.

Until now no systematic study has been done on the single role of osmolarity or energy density based on CHO content on gastric emptying.

The aim of the present study, therefore, was to determine the rate of gastric emptying from two series of drinks: one with different osmolalities, but with similar energy content, and one with different energy contents, but with similar osmolarity.

METHODS

Subjects and Experimental Design

Ten male volunteers, all with no history of gastrointestinal (GI) abnormalities, took part in this study. Subject characteristics were as follows: age, 22.6 ± 2.6; weight, 70.8 ± 7.1 kg (mean ± SD). All subjects were familiar with gastric intubation and testing and were asked to participate in 12 gastric emptying experiments of which a full explanation was given and informed consent was signed. Approval for the study was obtained from the Ethical Committee of the University of Limburg, Maastricht, the Netherlands.

Daily Protocol

After a 10-hour fast, subjects came to the laboratory at 8 am. Meals on the day before the experiment as well as the fasting time were standardized so that the influence of intestinal contents on gastric emptying was assumed to be equal in all tests.

At 8:30 am a nasogastric tube was placed and the stomach was emptied from any residue, rinsed, and emptied again. Thereafter a recovery test was performed to check the accuracy of the placement of the catheter. This procedure is described in detail by Beckers et al. After this procedure, the subjects remained seated and the test drink was infused. The treatment consisted of a bolus infusion (8 mL/kg body weight) of the test drink, via the nasogastric tube in seated position. Separate experiments were performed with an interval of at least 1 week.

Test Drinks

The 12 test drinks were tested blind and at random in a counterbalanced design in two separate experiments by the same subjects. Composition characteristics of the test drinks are given in Table I; drinks 1 to 6 in experiment 1, followed immediately by drinks 7 to 12 in ex-
Gastric Sampling and Calculation

Samples from the stomach were taken by syringe from the nasogastric tube at 0, 10, 20, 30, 40, 60 minutes. Determination of total gastric volume and gastric emptying were performed using the double sampling technique of George as modified, described and validated by Beckers et al. Samples were analyzed for phenol red concentration by spectrophotometry at 660 nm after the sample (0.1 mL) was diluted with (0.9 mL) NaOH/NaHCO₃ buffer (0.25/0.50 mmol/L).

As an overall measure of gastric emptying rate, $t_{90}^{16}$ was calculated from a simple exponential curve fit, $t = 3.25(t_{90})$ using Biomedical Computer Programs (BMDP 9).^{11}

Statistics

Analysis of variance for repeated measures, (one-factor ANOVA) was used to assess within-treatment effects over time as $t_{90}$, Fischer LSD post hoc test was used to indicate differences between the different drinks. The level of confidence was set at $p < 0.05$. Regression analysis was performed to indicate the correlation between osmolarity, CHO content, and gastric emptying rate.

RESULTS

Figures 1 and 2 present gastric emptying over time. Table II presents the $t_{90}$ emptying times as calculated from a semi-exponential curve fit, as well as the rates of carbohydrate and energy delivery from the stomach to the small intestine.

All drinks emptied semi-exponentially (Figs 1 and 2). The two drinks with the lowest carbohydrate (CHO) content emptied fastest. Drinks with a higher CHO content inhibited gastric emptying significantly ($p < 0.0001$) both over time and as $t_{90}$ (Table II, Figs 1 and 3).

Drinks 7 to 12 all with a CHO content of 60 g/L, but with different osmolarities, emptied at the same rate from the stomach (Table II, Figs 2 and 4). The delivery of carbohydrate-energy to the gut was the same for all drinks irrespective of the initial osmolarity or carbohydrate content.

These data showed that there are large interindividual differences between subjects in the rate of gastric emptying. Some subjects consistently empty fast whereas others empty slowly (Figs 3 and 4).

DISCUSSION

From a physiological and functional point of view, gastric emptying is influenced by a variety of factors reviewed by Brouns et al. and Costill; particle size, electrolyte content, osmolarity, fatty acids, pH, protein, volume, dietary fiber, energy density, heat stress and dehydration, meal temperature, and exercise intensity.

As far as CHO-electrolyte solutions used for oral rehydration are concerned, it is suggested that volume, osmolarity, acidity, and energy content are of major importance in the control of gastric emptying. Early studies by Hunt and Pathak, led to the hypothesis that specific receptors in the duodenum are sensitive to osmolarity. Hypotonic or Isotonic solutions containing sodium would lead to a water uptake of the receptor followed by receptor swelling, a signal to proceed with gastric emptying. This would explain that isotonic saline solutions appeared to empty faster from the stomach than water. Hyper- tonic drinks would lead to water flux out of the receptor and the receptor would shrink, a signal to delay gastric emptying. However, non hypersaline solutions composed of different types of CHO were shown to empty slower than
water in several studies. Thus osmolarity may be only one of a variety of factors that act in concert to regulate the rate of gastric emptying.

McHugh and Moran\cite{12} postulated in 1979 that not osmolarity but the caloric density of the test meal is of major importance. They based their statement on findings that starch and glucose in isocaloric solutions, but with largely different osmolarities, leave the stomach at the same rate. Same results were obtained by others.\cite{13,14} A progressive slowing of gastric emptying correlated with increasing calories, and this was not influenced by the macronutrient composition (CHO, fat, and protein) or the initial volume of the test meal.

These findings correlate with those of others who observed that caloric delivery of the stomach to the duodenum is constant despite large differences in substrate concentration or osmolarity of the meal.\cite{15,16,17} One factor, however, makes the interpretation of caloric density as prime factor to delay gastric emptying difficult. Increased caloric density is the result of a larger content of macronutrients. One may postulate that once these have entered the small intestine, rapid hydrolysis will occur and will lead to increased osmolarity of the luminal content which, in turn, will stimulate osmoreceptors to delay gastric emptying.

To overcome this problem as much as possible, we used carbohydrate solutions of which the maltose content was kept constant in 11 of the 12 drinks and the quantity of glucose and of short-chain glucose polymers was varied (Table I). Gastric emptying studies and constant perfusion with an isotonic short-chain polymer solution in the small intestine, have shown that osmolarity in the stomach or in the jejunal test segment does not change over time, which means that any increase due to hydrolysis is balanced by absorption and/or secretion of water.\cite{18,19} Thus by using isosmotic solutions with different caloric contents and additionally isocaloric drinks with different osmolarities, it was possible to study the influence of each factor on the rate of gastric emptying. The chosen range of CHO content (45 to 90 g/L) and osmolarity (240 to 370 mOsm/L) covers the composition of oral rehydration drinks normally used.

The results show that individuals vary widely in the rate of gastric emptying; however, these differences were consistent. Some subjects were fast emptiers, whereas others were slow. This observation is in line with many other studies. Because all subjects served as their own control in all treatments, this did not affect the final data. The data obtained showed that osmolarity does not affect gastric emptying. If osmolarity was of prime importance, then all drinks with the same osmolarity had to empty at about the same rate, which is not the case. The fact that drinks with different CHO content (and thus energy density) empty at different rates, despite being iso-osmotic and that drinks that are iso-energetic all empty at the same rate, despite different osmolarities, proves that CHO content (energy density) per se determines gastric emptying rate.

The observation that drinks 1 and 2 did not differ from each other may be explained by the fact that the carbohy-
drate content differed only 5 g/L. Another possibility is that the effect of drink volume on gastric emptying may overrule the inhibitory effect of carbohydrate if the latter is low. An analysis of the carbohydrate-energy delivery from the stomach to the duodenum showed that this delivery was the same for all drinks, irrespective of osmolarity and CHO content. This observation further underlines that it is the CHO delivery rate that determines the rate of gastric emptying.

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REFERENCES