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Short-term dietary supplementation with fructose accelerates gastric emptying of a fructose but not a glucose solution

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ABSTRACT

Objective: Short-term dietary glucose supplementation has been shown to accelerate the gastric emptying rate of both glucose and fructose solutions. The aim of this study was to examine gastric emptying rate responses to monosaccharide ingestion following short-term dietary fructose supplementation.
Methods: The gastric emptying rate of a fructose solution containing 36 g of fructose and an equicaloric glucose solution containing 39.6 g glucose monohydrate were measured in 10 healthy non-smoking men with and without prior fructose supplementation (water control) using a randomized crossover design. Gastric emptying rate was assessed for a period of 1 h using the [^{13}C] breath test with sample collections at baseline and 10-min intervals following drink ingestion. Additionally, appetite ratings of hunger, fullness, and prospective food consumption were recorded at baseline and every 10 min using visual analog scales.
Results: Increased dietary fructose ingestion resulted in significantly accelerated half-emptying time of a fructose solution (mean = 48, SD = 6 versus 58, SD = 14 min control; $P = 0.037$), whereas the emptying of a glucose solution remained unchanged (mean = 85, SD = 31 versus 78, SD = 27 min control; $P = 0.273$). Time of maximal emptying rate of fructose was also significantly accelerated following increased dietary fructose intake (mean = 33, SD = 6 versus 38, SD = 9 min control; $P = 0.042$), while it remained unchanged for glucose (mean = 45, SD = 14 versus 44, SD = 14 min control; $P = 0.757$). No effects of supplementation were observed for appetite measures.
Conclusion: Three d of supplementation with 120 g/d of fructose resulted in an acceleration of gastric emptying rate of a fructose solution but not a glucose solution.

Introduction

A rate-limiting step in the delivery, and thus absorption, of nutrients and fluid in the small intestine is the rate of gastric emptying. The regulation of gastric emptying is therefore perceived as an important factor in appetite control [1]. Gastric distension induced by an intragastric balloon to simulate the mechanical presence of food in the stomach has been shown to cause both satiation and satiety [2]. Therefore, a prolonged period of gastric distension as a result of delayed emptying may lead to a prolonged satiety period [3]. Slower emptying also delays the appearance of nutrients in the circulation that might contribute to satiety.

Carbohydrates, when ingested orally or directly administered into the stomach or small intestine, result in a reduction in subsequent food intake [4]. However, it has been suggested that the magnitude of this effect varies between different types of carbohydrates or sugars. With the recent rise in levels of obesity and its associated morbidities worldwide, research interests in carbohydrates and satiety have centered on the possible role of

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fructose in the pathogenesis of obesity and metabolic syndrome [5]. This has been motivated by the widespread use of fructose, either in the form of sucrose or high-fructose corn syrup, as an added ingredient in soft drinks and other sweetened beverages or foods, greatly increasing its dietary consumption [6,7]. Excessive intake of fructose and overconsumption of sugary beverages is suggested to contribute to the development of metabolic syndrome and obesity through altering feeding patterns and the promotion of weight gain [7]. The gastric emptying rate may play an important modulatory role in these outcomes.

A small compilation of research indicates that gastric emptying in humans may be influenced by patterns of previous dietary nutrient intake. Furthermore, there is evidence to suggest that these adaptive changes are macronutrient-specific [8,9] and rapid, with adaptations occurring in only a few days [3,9]. A high-fat diet for 14 d has been shown to accelerate gastric emptying of a high-fat test meal [10] but not a high-carbohydrate meal [8]. More recently, this adaptive response of the gastrointestinal (GI) system to the ingestion of high-fat meals has been reported to occur following only 3 d of high-fat diet [3]. Similarly, short-term dietary supplementation with 400 g/d of glucose for 3 d in healthy individuals has been shown to accelerate gastric emptying of a hyperosmotic glucose solution, but not of a protein solution [9]. The specificity of these effects of a high-glucose diet has not been extended to different monosaccharides, however. The emptying of a hyperosmotic fructose solution was equally accelerated following short-term supplementation with glucose solutions [11]. Whether these effects are replicated in response to short-term dietary supplementation with fructose is unknown. The aim of this study was to investigate the effect of 3 d of dietary fructose supplementation on the rate of gastric emptying of glucose and the rate of gastric emptying of fructose solutions as well as the accompanying subjective feelings of appetite.

Materials and methods

Participants

Ten healthy men completed this study (mean age = 27, SD = 6 y; height = 179.9, SD = 9.2 cm; body mass = 81, SD = 11 kg; body mass index = 25, SD = 3 kg/m^2; estimated body fat = 21%, SD = 8%). All volunteers were nonsmokers, had no history of GI symptoms or disease, were not consuming medication with any known effects on GI function, and had no other relevant medical conditions as assessed by a medical screening questionnaire. Verbal and written explanations of the experimental procedures were provided before participation. This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures were approved by the Ethical Advisory Committee of Manchester Metropolitan University's Faculty of Science and Engineering. Written informed consent was obtained from all participants.

Preliminary trials

All participants reported to the laboratory for a preliminary familiarization visit. Anthropometric measurements of height to the nearest 0.1 cm using a wall-mounted stadiometer, body mass to the nearest 0.01 kg using electronic scales (GFK 150; Adam Equipment Co. Ltd., Milton Keynes, UK), and estimation of body fat percentage using a handheld bioelectrical impedance device (Omron BF306; Kyoto, Japan) were made. Furthermore, participants were familiarized with the gastric emptying assessment technique and the visual analog scale (VAS) to be used during the experimental trials. The VAS was composed of questions asking: "How hungry do you feel?" "How full do you feel?" "How much do you think you can eat?" [12] "How bloated do you feel?" and "How nauseous do you feel?" Respectively, horizontal lines 100 mm in length were anchored with "I am not hungry at all to I have never been more hungry," "not at all full to totally full," "nothing at all to a lot," [12] "not at all bloated to very bloated" and "not at all nauseous to very nauseous." Additionally, participants who had not previously participated in any studies in our laboratory involving fructose consumption completed a fructose tolerance test before further participation by consuming a 600 mL solution containing 36 g fructose. This procedure was used to ensure that no adverse effects would be experienced due to unknown malabsorption during supplementation and experimental trials.

Experimental protocol

Experimental trials were conducted in a single-blind, randomized, crossover fashion commencing between 0830 and 1000 following an overnight fast from 2100 with the exception of drinking 500 mL of water approximately 90 min before arrival at the laboratory. Participants reported to the laboratory on four occasions to complete four experimental trials: fructose with supplementation (FS), fructose with water control (FC), glucose with supplementation (GS), and glucose with water control (GC). Experimental trials were separated by a minimum of 7 d. Each experimental trial was preceded by a 3 d dietary and activity maintenance period during which participants were asked to record their diet and activity in the first trial and then replicate them in the remaining three trials. The purpose of this was to ensure standardization and consistency of macronutrient intake and metabolic status in the days leading up to each trial. In addition to their normal dietary intake, participants were asked to drink either four 500 mL bottles of water or four 500 mL solutions, each containing 30 g fructose daily over the 3 d. Participants were instructed to consume these drinks evenly throughout the day, between meals. Furthermore, participants were asked to refrain from alcohol consumption and strenuous physical activity in the 24 h preceding each experimental trial.

Upon arrival at the laboratory, participants were asked to completely empty the contents of their bladder into a container from which a 5 mL urine sample was retained for later analysis of osmolality by freezing point depression (Gonotec Osmomat 030 Cryoscopic Osmometer; Gonotec, Berlin, Germany). Body mass was subsequently recorded. Participants then ingested 595 mL of a fructose solution (36 g dissolved in 600 mL water) or an equicaloric glucose monohydrate solution (39.6 g dissolved in 600 mL water) containing 100 mg [^{13}C]sodium acetate (Cambridge Isotope Laboratories Inc., Andover MA, USA). Participants were given a maximum of 2 min to consume the test solution and instructed to consume it as quickly as they were able. Test-drink solutions were freshly prepared on the morning of the test and were given at room temperature. A 5-mL sample of the drink was retained for later analysis of osmolality. Ratings of appetite (hunger, fullness, prospective food consumption) [12] as well as ratings of bloatedness and nausea were assessed using 100-mm VAS, as described previously, at baseline and at 10-min intervals following drink ingestion for 60 min. Participants remained seated throughout the drink ingestion and 60-min sampling procedure. Following the last breath sample collection and completion of the VAS at 60 min, participants were asked again to completely empty their bladder into a container and a 5-mL urine sample was retained for osmolality analysis using the method aforementioned.

Measurement of gastric emptying

Gastric emptying was assessed using the [^{13}C]acetate breath method. This method of measurement has been shown to correlate closely to scintigraphy [13,14] and gastric aspiration [15]. Before ingestion of the test drink containing 100 mg [^{13}C]sodium acetate (Cambridge Isotope Laboratories Inc., Andover MA, USA), a basal end-expiratory breath sample was collected. Further end-expiratory breath samples were collected at 10-min intervals over 60 min after drink ingestion. Breath samples were collected into a 100-mL foil bag (Wagner Analyzen-Technik, Bremen, Germany) on each occasion by exhalation through a mouthpiece. Bags were then sealed with a plastic stopper and stored for later analysis.

Breath samples were analysed by non-dispersive IR spectroscopy (IRIS, Wagner Analyzen-Technik, Bremen, Germany) for the ratio of $^{13}CO_2$ to $^{12}CO_2$. The difference in the ratio of $^{13}CO_2$ to $^{12}CO_2$ from baseline breath to post-breath samples are expressed as delta over baseline (DOB). Half emptying time ($T_{½}$) and time of maximum emptying rate (T_{lag}) were calculated using the manufacturer's integrated software evaluation embedded with equations previously described [13]. Each participant's own physiological CO_2 production assumed as 300 mmol CO_2 per m^2 body surface per hour was set as default and body surface area was calculated by the integrated software according to a previously described formula [16] .

Statistical analysis

Differences in preingestion body mass, preingestion urine osmolality, and drink osmolality were examined using one-way repeated analysis of variance (ANOVA). Two-way repeated ANOVAs were used to examine differences in gastric emptying DOB values, and subjective appetite VAS scores. Sphericity for repeated measures was assessed, and where appropriate, Greenhouse-Geisser corrections were applied for $\varepsilon < 0.75$, and the Huynh-Feldt correction adopted for less severe asphericity. Significant F tests were followed by repeated one-way ANOVA and Bonferroni-adjusted pairwise comparisons as appropriate. Gastric emptying $T_{½}$ and T_{lag} data were examined with paired Student's t tests to test the