Physiology & Behavior 176 (2017) 26–30

Contents lists available at ScienceDirect

Physiology & Behavior

journal homepage: www.elsevier.com/locate/physbeh

A tale of gastric layering and sieving: Gastric emptying of a liquid meal with water blended in or consumed separately

Guido Camps[a,*], Monica Mars[a], Cees de Graaf[a], Paul A.M. Smeets[a,b]

[a] Department of Human Nutrition, Wageningen University & Research, Wageningen, The Netherlands
[b] Image Sciences Institute, University Medical Center Utrecht, Utrecht, The Netherlands

ARTICLE INFO

Keywords:
Gastric emptying
Water
Liquid meal
MRI

ABSTRACT

Background: The process of gastric emptying determines how fast gastric content is delivered to the small intestine. It has been shown that solids empty slower than liquids and that a blended soup empties slower than the same soup as broth and chunks, due to the liquid fraction emptying more quickly. This process of 'gastric sieving' has not been investigated for liquid foods.

Objective: To determine whether gastric sieving of water can also occur for liquid foods.

Method: Two groups of men participated in a parallel design (n = 15, age 22.6 ± 2.4 y, BMI 22.6 ± 1.8 kg/m^2, and n = 19, age 22.2 ± 2.5 y, BMI 21.8 ± 1.5 kg/m^2) and consumed an isocaloric shake (2093 kJ, CARBOHYDRATES: 71 g, FAT: 18 g, PROTEIN: 34 g), either in a 500-mL version (MIXED) or as a 150-mL shake followed by 350 mL water (SEPARATE). Participants provided appetite ratings and were scanned using MRI to determine gastric emptying rate and volume at three time-points within 35 min post ingestion.

Results: Gastric emptying the percentage emptied in 35 min was significantly smaller for MIXED (29 ± 19%) than for SEPARATE (57 ± 11%, p < 0.001).

Conclusion: In the present study we show that gastric sieving can occur for liquid foods; water is able to drain from the stomach while a layer of nutrient rich liquid is retained. In indirect gastric emptying measurements, the behavior of labelling agents may be affected by the layering and confound emptying measurements.

1. Introduction

Gastric emptying is an important part of digestion, as the stomach acts as a gatekeeper distributing nutrients to the small intestine, in order to optimize digestion. The dynamics of stomach content flow and passage are still not completely understood. Gastric emptying was studied in relation to food qualities in animals, namely canines, in the seventies. This work showed that solids empty slower than liquids [1,2].

Subsequent work from the nineties showed congruent results in humans; the liquid fraction of the gastric content was dispersed quickly and drained quickly as well, with solid pieces being retained for longer periods in the stomach [3]. Additionally, Collins et al. showed differences in gastric content in the proximal and distal parts of the stomach. A subsequent study compared a solid meal given together with water versus a homogenized soup-like stimulus made out of the same ingredients [4]. In this study, the homogenized version yielded significantly higher feelings of fullness and slower gastric emptying. The authors attributed this to greater distension of the antral region by the homogenized version in combination with the slower emptying. Rolls et al. extended this by showing that subsequent intake can be reduced by incorporating water into a food dish, instead of serving water concurrently with the dish [5].

In 2012 it was shown - using MRI - that a possible mechanism for this greater satiety resulting from incorporated water is caused by the fact that when the solid and water fractions are not homogenized, the water sieves from the gastric content and empties quickly [6]. This gastric sieving can be prevented by blending the two fractions together to create a homogeneous caloric food. Additionally, emulsifiers have been used to manipulate the dispersion of fats throughout the gastric content and thereby manipulate gastric emptying [7].

Many commercial meal replacements in liquid form are currently available. Liquid meals are also often used in studies because they offer practical benefits over solid meals, for example when feeding must take place at standardised rates or through a tube. Although gastric sieving of water has been shown with solid and semi-solid foods, it has to our knowledge never been investigated using a liquid meal. MRI is optimal measurement method understanding gastric passage of liquid meals and

* Corresponding author.
E-mail address: guido.camps@wur.nl (G. Camps).

http://dx.doi.org/10.1016/j.physbeh.2017.03.029
Received 24 December 2016; Received in revised form 17 March 2017; Accepted 17 March 2017
Available online 23 March 2017
0031-9384/

Table 1
Energy content and nutrient composition of the shakes.

	MIXED	SEPARATE
Ingredients, per 100 g shake		
Protein powder, g	5.1	12.4
Cream, g	8.5	20.8
Dextrin-maltose, g	8.9	21.9
Vanilla sugar, g	1.3	3.3
Water, g	76.2	41.6
Total, g	100	100
Nutrients, 100 g shake		
Energy[a], kJ	418	1393
Carbohydrates, g	12	40
Of which mono- and disacharides	2.1	7
Fat, g	3	10
Of saturated	2.1	7
Protein, g	6	20
Fiber, g	0.5	1.7
Total ingested		
Shake weight, g	591	241
Amount of water served after shake, g	0	350
Shake energy, kJ (kcal)	2093 (500)	2093 (500)
Total volume, mL	500	500

[a] Nutrient composition of the shake resembles a mixed meal, with 50% of the energy load coming from carbohydrates, 30% from fats and 20% from protein.

the interaction with water consumption. Understanding this passage will help create novel experimental designs in the future.

In this research we sought to determine whether gastric sieving of water can also occur with liquid meals. We hypothesized that the stomach empties more quickly when water is consumed separate from a liquid meal, as compared to when water is consumed as part of a liquid meal (mixed in). We also hypothesized that mixed consumption will suppress appetite more.

2. Materials and methods

2.1. Design

The design for this analysis is a two sample comparison between two treatments. Participants participated in one of two larger trials (Dutch Trial Register (NTR4573 (published: [8]) and NTR5507)).

2.2. Test products

An overview of the nutrient content of the test products can be found in Table 1.

The shake consisted of 50 g cream (Albert Heijn B·V, Zaandam, The Netherlands), 53 g Fantomalt (Nutricia®, Cuijk, The Netherlands), 30 g whey powder (Whey Delicious Vanilla, XXL Nutrition, Helmond, The Netherlands) and 8 g vanilla-sugar (Dr. Oetker®, Bielefeld, Germany). These ingredients were used to create a liquid shake either with 100 g of water or with 450 g of water (SEPARATE or MIXED). The shakes were mixed by adding the ingredients into a closed 600-mL beaker and whisking with an internal spherical whisk (diameter 3.5 cm). In case of the smaller shake, 350 g of water was consumed directly after finishing the shake.

2.3. Participants

Two groups of healthy men, SEPARATE (n = 15, age 22.6 ± 2.4 y, BMI 22.6 ± 1.8 kg/m^2) and MIXED (n = 19, age 22.2 ± 2.5 y, BMI 21.8 ± 1.5 kg/m^2), participated. There were no participants partaking in both trials. Participants were recruited via email. To be eligible, participants had to be male, healthy and 18–35 years old. Potential participants were screened to be of normal weight (BMI 18.5–25.0 kg/m^2) and willing to comply with the study procedures. By use of a questionnaire, potential participants were excluded if they had a self-reported hypersensitivity for any components which were present in the test products, if they were on a diet or had unexplained weight loss or gain in the past months, or if they reported any MRI contraindications. The procedures were approved by the Medical Ethical Committee of Wageningen University in accordance with the Helsinki Declaration of 1975 as revised in 2013. Written informed consent was obtained from all participants.

2.4. Study procedures

Participants were instructed to have a light meal the night before the session and not do any rigorous exercise or strenuous activities that day. Participants were instructed to fast for at least 3 h, only drinking water in that time and nothing during the last hour before each session. After arrival participants provided baseline appetite ratings, that is ratings of hunger, fullness, prospective consumption, desire to eat and thirst. These were orally scored from 1 to 100 points [9].

Subsequently participants were scanned for baseline stomach content (to confirm it was empty). After this, participants exited the scanner and consumed the shake (MIXED) or shake and water (SEPERATE).

Each participant consumed the shake within 2 min as instructed. After that, they were positioned in the scanner and provided appetite ratings via the intercom and underwent gastric MRI scans up to 40 min after ingestion. For MIXED scans and scores were obtained directly after ingestion, at 10, 20, 30 and 40 min. Data for 30 and 40 min were interpolated. For SEPARATE scans and scores were obtained directly after ingestion and at 15 and 35 min.

2.5. MRI

Participants were scanned with the use of a 3-Tesla Siemens Verio (Siemens AG, Munich, Germany) MRI scanner using a T_2-weighted spin echo sequence (HASTE, 24 6-mm slices, 2.4 mm gap, 1.19 × 1.19 mm in-plane resolution, effective TE of 87 ms with parallel imaging (grappa, factor 2), with breath hold command on expiration to fixate the position of the diaphragm and the stomach. The duration of one scan was approximately 19 s. Syngo fastView MRI software (Siemens AG, Munich, Germany, http://www.healthcare.siemens.com/medical-imaging-it/syngo-special-topics/syngo-fastview) was used to manually delineate gastric content on every slice. Gastric volume on each time point was calculated by multiplying surface area of gastric content per slice with slice thickness including gap distance, summed over the total slices showing gastric content.

2.6. Statistical analyses

AUC over 35 min was calculated for subjective ratings and gastric content using Graphpad Prism 5 (Graphpad Software, La Jolla, USA), following the trapezoidal rule. Change in appetite ratings was tested using an ANOVA with time, treatment and the interaction as fixed factors and subject as random factor and baseline measurement as a covariate. Post hoc LSD corrected test were performed in case of significant effects.

Differences between the AUC values were tested using a t-test. Emptying percentage of the gastric content in 35 min was calculated by correcting for baseline and dividing the content at 35 min by the starting volume. The difference between percentage emptied in this period was tested using a t-test. Significance level was set at p = 0.05. Data are expressed as mean ± SD. All tests were performed using IBM SPSS 22.0 (IBM, Armonk, USA).