MRI assessment of the effects of the physical form of a meal on gastric emptying, gallbladder contraction, small bowel water content and satiety

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Background:
There is currently great interest in manipulating the physical form of food to enhance satiety. The stomach can "sieve" water from the solid component of a meal leading to faster decline in gastric volume. We hypothesised that if sieving was prevented by blending the meal to a soup, when compared to the same meal given a solid and liquid mixture: (a) gastric volumes would fall more slowly; (b) satiety would be enhanced; (c) the CCK duodenal response (as inferred from gallbladder contraction [1]) would be enhanced and (d) the small bowel secretion would be greater. To test these hypotheses we performed two related studies: a satiety study in quiet controlled conditions and a mechanistic study using serial, functional gastrointestinal MRI.

Aims: To investigate how blending a solid/liquid meal to a soup affects satiety, gastric emptying, gallbladder contraction and small bowel gastric content.

Materials and Methods: SATIETY STUDY: 22 healthy volunteers participated in this two-ways, randomised, crossover study. They attended in the morning, having fasted overnight. In quiet, controlled conditions they were fed either a roasted chicken and vegetables meal with a glass of water (241 kcal) or the same meal and water blended to a soup. The volunteers were asked to fill satiety questionnaires at fasted baseline and at intervals for 3 hours postprandially. MECHANISTIC STUDY: 18 healthy volunteers participated in this two-ways, randomised, crossover study. They attended in the morning, having fasted overnight. They were scanned in a 1.5T Philips Achieva MRI scanner at fasted baseline as detailed below. They were then fed the same meals as in the Satiety Study above and underwent serial scanning at intervals for 3 hours. A transverse Balanced TFE sequence (TE=1.2 ms, TR=2.4 ms, Flip Angle 45°, 20 contiguous slices 10mm thick, FOV=400X70%, reconstructed matrix 256X256, scan time 9 s) was used to measure volumes of the gastric lumen and of the gallbladder. This was done by manually tracing regions of interest on Analyze6. A coronal TSE (TE=320, TR= 8000, Fat sat SPIR, 24 contiguous slices 7mm thick, FOV=400X91%, reconstructed matrix 205X512, scan time 24 seconds) was used to measure volumes of water in the small bowel. This was carried out using in house software as previously described and validated by intubation studies in which measured values were shown to closely parallel infused volumes [2]. Briefly, a threshold level is set on the images based on the signal from the cerebro-spinal fluid, below which all image data is ignored. Bright water signal from other organs such the stomach, gallbladder, spinal fluid and bladder is easily identified and segmented out of the image, thus leaving only voxels containing water signal above the threshold in the small bowel. The volume of fluid in the small bowel at each time point is then calculated by integrating all such voxels. A coronal Dual Echo FFE (TE=2.3 ms and 4.6 ms, TR=156 ms, Flip Angle 80°, 24 contiguous slices 10mm thick, FOV=450X80%, reconstructed matrix 157X256, scan time 13 s) was also acquired as anatomical reference. These protocols were approved by the local Ethics Committee and volunteers gave informed written consent prior to experiments. Data are expressed as mean±SEM. The data was tested for normality and then 2-way analysis of variance and paired comparisons were used as appropriate.

Results: (mean±SEM) An example of MRI of the two meals in the stomach of a volunteer is given in Fig. 1. The soup meal reduced the subjects' sensation of hunger more than the solid meal ($p<0.02$, Fig. 2). The soup meal emptied from the stomach more slowly (gastric volumes at time T=30 min after the soup meal were 360±15 ml vs 265±8 ml for the solid meal, $p<0.0003$; at T=75 min they were 198±10 ml vs 256±22 ml respectively, $p<0.02$. The percentage gallbladder contraction (Fig. 3) was greater after the soup meal at time points T=30 min (58±2 % vs 48±2 % for the solid meal, $p<0.0002$) and T=75 min (44±2 % vs 32±2 % respectively, $p<0.0001$). Small bowel water content (Fig. 4) was initially higher for the solid meal (111±15 ml vs 70±8 ml for the soup meal immediately after feeding, $p<0.02$) whilst the soup meal induced greater secretion at later times (186±23 vs 124±16 ml for the solid meal at T=165 min, $p<0.007$).

Discussion: Blending the test meal to a soup abolished gastric "sieving" resulting in early emptying of the water phase of the mixed solid/liquid meal whilst the homogeneous soup meal emptied more slowly. This resulted in larger volumes remaining in the gastric lumen and enhanced stimulation of the duodenum with larger gallbladder contraction, a marker of CCK release [1]. The small bowel water content was higher for the soup meal at the later time points, implying that the soup also induced greater secretory stimulation. These gastrointestinal factors will have combined to induce an enhanced satiety after the soup meal. Serial, functional gastrointestinal MRI provided exquisite insights into the functional gastrointestinal response to altered physical form of meals.

References: [1] Froehlich F et al, Role of nutrient fat and cholecystokinin in regulation of gallbladder emptying in man. Dig Dis Sci 40:529-33, 1995. [2] Hoad CL et al. Non-invasive quantification of small bowel water content by MRI: a validation study. Phys Med Biol 52:6909-22, 2007.

Fig. 1

Fig. 2

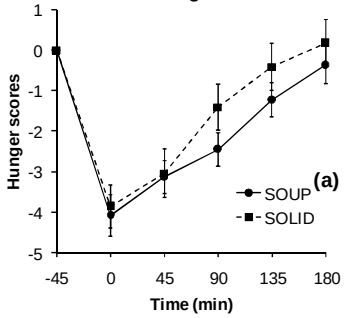

Fig. 3

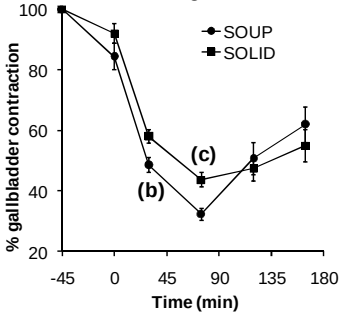

Fig. 4

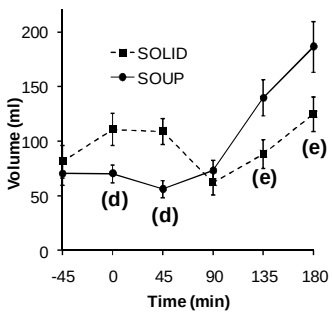

Figure Legends: Fig.1: An example of transverse Balanced TFE images of one subject on the two arms of the study, immediately after feeding. In the T_2 weighted images the solid/liquid meal (above) shows bright water surrounding dark solid chicken and vegetable chunks in the stomach. The soup meal (below) appears homogeneous with no sedimentation. **Fig.2:** The hunger scores. (a) 2-way RM ANOVA $p<0.02$. **Fig.3:** The % gallbladder contraction for both meals. (b) $p<0.0002$. (c) $p<0.0001$. **Fig. 4:** The small bowel water content for both meals. (d) $p<0.02$. (e) $p<0.007$.