Visualizing and quantifying human fat digestion with IDEAL

Dian Liu[1], Helen Louise Parker[2], Jelena Curcic[1,2], Sebastian Kozerke[1], and Andreas Steingoetter[1,2]

[1]*Institute for Biomedical Engineering, University and ETH Zurich, Zurich, Switzerland,* [2]*Division of Gastroenterology and Hepatology, University Hospital Zurich, Zurich, Switzerland*

Introduction: The digestive processes from food intake to nutrient absorption in the gastrointestinal (GI) tract present complex and highly integrated mechanisms. MRI has recently evolved as a promising imaging modality to simultaneously assess the in vivo stability and luminal processing of food emulsion systems. Chemical shift-encoded imaging using IDEAL [1] potentially allows to visualize and quantify the spatial distribution of water and fat in the lumen of the GI tract during digestion [2], which is a key factor influencing the rate of fat and overall energy delivery. By optimizing the intragastric property and intestinal delivery of the lipid phase in the emulsion, the subsequent enzymatic and absorption processes involved in fat digestion can be slowed down or controlled, which alters the sensation of fullness and ultimately satiety [3]. This study aims at quantifying the influence of intragastric stability of fat emulsions on the dynamics and structure of gastric luminal content and the related fat emptying into the duodenum.

Methods: In vivo experiments were conducted on a 1.5T whole-body MRI scanner (Achieva, Philips Healthcare, Best, the Netherlands) with a standard 4-element coil array. Two different test meals designed to interact within the stomach in different ways were prepared: an acid stable (LE1) and an acid unstable fat emulsion (LE4). The test meals were isovolumetric (200 ml) with a fat fraction of 20% and droplet sizes of 0.6 µm.

Multi-echo data were acquired using a 6-point gradient-echo sequence with flyback gradients, TR 10ms, TE 1.25ms, dTE 1.54 ms, flip angle 10°, FOV 350x260mm^2, voxel size 2.0x2.3mm^2, scan duration 1.5s/slice. For each scan, 20 transversal slices with slice thickness 8mm were acquired in one breath hold to cover the complete stomach volume. Another 7 sagittal slices with slice thickness 6 mm were acquired in one breath hold to cover the superior part of the duodenum. Standard balanced SSFP scans with the same geometry as the corresponding multi-echo data and a scan duration 0.5s/slice were performed to acquire anatomical images. Eight healthy volunteers received the two test meals on two separate occasions in single-blind randomized order. Images were acquired in right decubitus position by performing the sequences every 10 to 30 minutes for 3 hours in total.

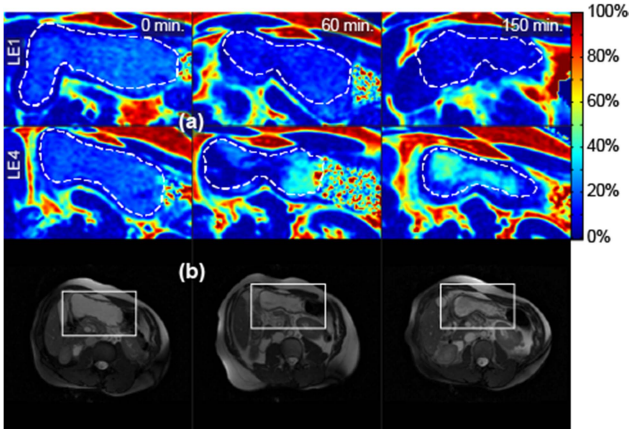

Figure 1: *Representative fat fraction maps of gastric content (dashed white line) of the two test meals (a) at three time points after meal intake and corresponding anatomical images (b). LE1 shows a dilution with water over time, whereas LE4 shows fat flocculation and subsequent re-emulsification.*

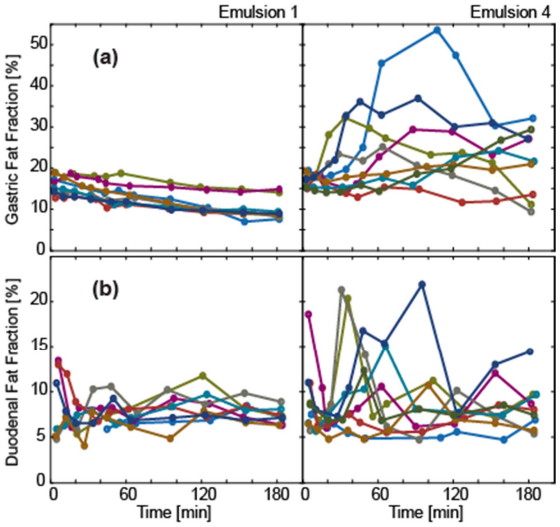

Figure 2: *Temporal development of mean fat fraction of luminal content for the two meals in the stomach (a) and duodenum (b) for each volunteer. LE4 exhibited larger inter-individual differences of fat processing than LE1.*

Hierarchical IDEAL [4] was used to reconstruct water and fat images and the resulting fat fraction maps were calculated by taking the ratio of the water and fat images. Gastric and duodenal content volumes were obtained by semi-automatically segmenting the anatomic images at each time point and applying the contours to the corresponding fat fraction maps. Gastric and duodenal fat fractions were defined as the mean fat fraction over the entire segmented content volume. The temporal development of fat fractions and the effect of the in vivo stability on the fat fractions were analyzed by linear mixed–effect modeling.

Results: The different intragastric stability of the fat emulsions resulted in different structuring of intraluminal content and different emptying patterns. LE1 remained stable, showed slow steady gastric content emptying patterns and was increasingly diluted with gastric secretion (Fig. 1). LE4 exhibited clear creaming and flocculation of fat, forming a region of high fat on top of gastric content, which resulted in bi-phasic content emptying patterns. The associated faster emptying of this phase with lower fat content caused a steep postprandial increase of fat fraction (FF) for LE4. This phenomenon varied considerably between individuals (Fig. 2a). As confirmed by the MR image data, the stomach was able to re-emulsify the flocculated fat and to eventually continuously decrease intragastric FF. Overall fat volume emptying was faster for LE4 (8.3±0.6 ml/hour) compared to LE1 (6.1±0.5 ml/hour). No temporal effect was detected for duodenal content volume or fat fraction for either lipid emulsion (Fig. 2b). However, short distinct increases in duodenal fat volume and FF were apparent for LE4 (Fig. 3), further confirming the observed gastric structuring and explaining the unsteady emptying patterns of LE4.

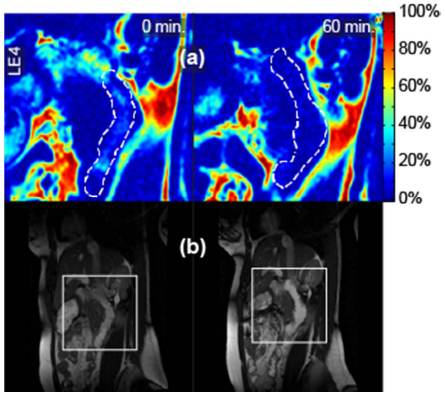

Figure 3: *Representative fat fraction maps (a) of duodenal content of the same volunteer as in Fig. 1 and corresponding anatomical images (b). At 60 min., high fat content was temporarily emptied through the duodenum.*

Discussion: IDEAL allowed the visualization and quantification of the effects of intragastric processing and structuring of lipid emulsions. Differences in the content emptying pattern, fat volume and fat distribution between acid stable and unstable emulsions were detected and quantified. Compared to the stable emulsion, the acid unstable emulsion was subject to different structuring by individual gastric secretion, which resulted in bi-phasic and significantly faster emptying of gastric content and highly variable gastric and duodenal fat fractions. The observed faster fat emptying of LE4 may be explained by the larger lipid droplet size of the re-emulsified emulsion compared to the small original droplet sizes of the emulsions. Previous data has confirmed that a reduction in droplet size of fat emulsions delays gastric emptying due to more effective lipase activity and increased intestinal feedback.

References: [1] Reeder S MRM 2004; [2] Liu D ISMRM 2013; [3] Radovic T Trans UEG 2013; [4] Tsao J MRM 2013.