Fast T1 mapping for the assessment of intragastric distribution, dilution and mixing

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Introduction: Quantitative assessment of postprandial intragastric distribution, dilution and mixing is of major importance for a detailed understanding of transport and emptying mechanisms in the gastrointestinal (GI) tract. MRI studies have shown that the distribution of the fat phase in the stomach effects gastric motor activity and emptying and that in high-viscosity meals secretion and dilution appear to have a control mechanism to preserve normal gastric emptying (1, 2). In gastric MRI, distribution, dilution and mixing has so far been analyzed only in a semi-qualitative way. Either by comparing the altered signal intensity in the gastric contents due to a released paramagnetic marker (3) or by changes in 1/T2 of a guar gum test meal (2). Using paramagnetic marker, quantitative determination of intragastric distribution can be achieved by detecting T1 relaxation times, due to the one-to-one relation of T1 and marker concentration. Existing standard MRI sequences for quantitative T1 measurements are not applicable to abdominal imaging due to their long acquisition times. To avoid artifacts from breathing and intestinal motion, fast mapping of T1 values is crucial for a dynamic assessment of distribution, mixing and dilution processes in the human stomach. The aim of this study was to develop and evaluate a fast T1 mapping technique for the use in gastric MRI.

Methods: All measurements were performed using a 1.5T whole-body MRI scanner (1.5T Intera, Philips Medical Systems, Best, The Netherlands). Based on the idea of Christensen et al. (4) fast T1 mapping was achieved by applying two consecutive T1-enhanced fast field echo sequences (T1-FFE) using different flip angles. Flip angles were optimized for maximum T1 precision over a T1 range from 150 to 500ms. This T1 range corresponds to concentrations of 300-1200µM of the paramagnetic contrast agent Gd-DOTA (DOTAREM®, Laboratoire Guerbet, France) within a normal glucose test meal. Optimum flip angles were calculated to be α_1=6° and α_2=36°. In order to destroy any residual transverse coherencies at the end of repetition time maximized spoiling gradients were applied along slice selection and measurement direction with minimum duration of 2.1ms. For the given T1 range a minimum of 10 startup cycles for α_1 and 15 for α_2 were used to reach steady state of the longitudinal magnetization avoiding ringing and blurring artifacts due to k-space weighting. For optimum slice excitation profile a sinc-gauss excitation pulse with a time-bandwidth product γGDT of 136 rad was applied. T1-FFE sequence parameters were as follows: 1 slice, Δz=10mm, TR/TE=8.7/4.3ms, Tscan=1.5s, flip angles=6°, 36°, FOV=400x325mm^2, matrix=128x82, phase increment=150°. The sequence was first evaluated in vitro and then applied to healthy volunteers.

In vitro: Different concentrations (300µM, 400µM, 500µM, 600µM, 700µM, 800µM, 900µM, 1000µM, 1100µM and 1200µM) of Gd-DOTA homogenously mixed with 10% glucose solution were prepared in small bottles. Each bottle was placed in the center of a send-receive head coil and T1 values were determined using a standard MR spectroscopy sequence. Six bottles with concentrations of 300µM, 400µM, 500µM, 800µM, 1000µM and 1200µM were chosen for validation of the fast T1 mapping sequence. Four rectangular surface coils were placed around the bottles for signal detection. To correct for inhomogeneous B1 excitation, a B1 map was determined using the double angle method (5). Mean T1 values of the Gd-DOTA concentrations were calculated within a region of interest of 10x10 pixels.

In vivo: Two healthy volunteers participated in this pilot study. After placing the volunteers in supine body position in the MRI scanner subjects were asked to drink 300ml of 10% glucose labeled with 1000µM of Gd-DOTA. After drinking, T1 mapping of the gastric region was continuously performed for 22s during breathold. This scan sequence was repeated every minute over a period of 30 min. After 15 min volunteers were again asked to drink 100ml of unlabeled 10% glucose to decrease intragastric Gd-DOTA concentration. Six rectangular surface coils placed around the abdomen were used for signal detection. Calculated T1 values were not corrected for inhomogeneous B1 excitation because no feasible B1 map could be acquired using a standard B1 mapping sequence (acquisition time ~3min).

Results: *In vitro*: The relation between T1 relaxation time and concentration of Gd-DOTA within 10% glucose is shown in Fig. 1. T1 values assessed by MR spectroscopy are in agreement with theory. Intensity coded T1 map of different Gd-DOTA concentrations is presented in Fig. 2. Calculated T1 values were similar to T1 values derived from MRS (300µM: 482±22 vs. 502±7ms, 400µM: 378±14 vs. 394±7ms, 500µM: 316±9 vs. 334±7ms, 800µM: 209±7 vs. 218±7ms, 1000µM: 172±6 vs. 177±7ms, 1200µM: 148±3 vs. 151±7ms).

In vivo: T1 maps of a defined gastric cross section were successfully generated over 30 min (Fig. 3). After drinking, calculated T1 values of the ingested test meal were lower compared to the in vitro results (proximal stomach: 115ms, distal stomach: 130ms). This was expected due to the missing correction for the inhomogeneous B1 excitation. However, there was a continuous increase in T1 values over the first 15 min (proximal stomach: 165ms, distal stomach: 170ms), probably due to gastric secretion. T1 values increased immediately after the ingestion of the additional 100ml glucose (proximal stomach: 180ms, distal stomach: 200ms).

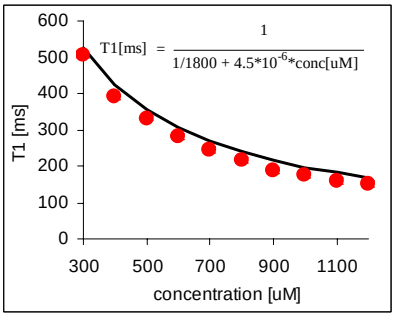

Fig. 1. Predicted (black curve) and measured (red dots) T1 relaxation times of different Gd-DOTA concentrations in 10% glucose.

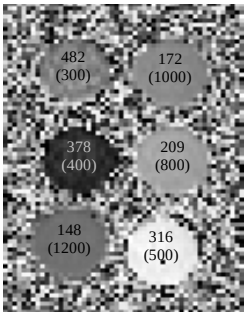

Fig. 2. T1 map with mean T1 values of specific Gd-DOTA concentrations (in brackets).

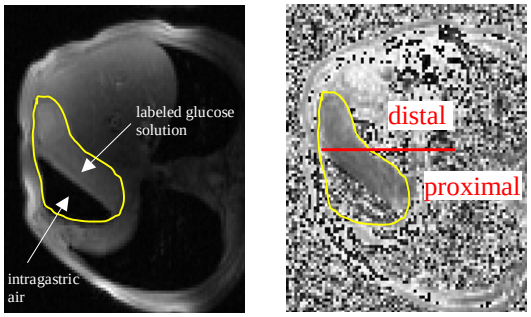

Fig. 3. Left: Oblique coronal MR image with outlined stomach wall (yellow). Right: T1 map of the stomach.

Discussion: A fast T1 mapping sequence for gastric MRI was evaluated in vitro and in vivo. Commonly used concentrations of Gd-DOTA within a typical test meal were quantified using this technique. Detected T1 values were in agreement with theory as well as spectroscopic measurements. T1 maps of gastric contents were acquired in volunteers and changes of intragastric Gd-DOTA concentration were successfully detected. To reduce image acquisition time and thus sensitivity to tissue and fluid motion and increase T1NR, an image matrix of 128x82 was chosen. Due to gradient hardware limitations, further reduction of TR was not possible without violating described constraints for spoiling and homogeneous slice excitation. For a complete and quantitative assessment of intragastric distribution and mixing processes in the stomach a stack of at least 20 T1 maps covering total gastric volume must be generated. To maintain T1 accuracy over the image stack interleaved image acquisition is needed. Moreover, a fast, motion insensitive B1 mapping technique as proposed by Yarnykh et al. (6) must be applied to allow for T1 value correction. The described MRI technique is feasible for the non-invasive assessment and quantification of gastric secretion as well as intragastric release of marked drugs models and distribution of labeled marconutrients.

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