

Towards clinical MRI measurements of gastric function and emptying for a standardised liquid nutrient meal: validation of data acquisition and analysis.

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Introduction. MRI allows comprehensive, non-invasive assessment of gastric function (emptying, motility, mixing and dilution of meals) to differentiate normal from abnormal function in diseases such as functional dyspepsia and gastro-paresis [1]. However adoption of MRI has been slow, primarily due to labour-intensive image analysis and long scan times. The aim of this study was to determine a data acquisition and analysis protocol which provides accurate information and is applicable in routine clinical investigation of gastric function and emptying.

Methods. This study was approved by the local Ethics Committee and all subjects gave written informed consent. 10 healthy volunteers (5 male, mean, age 21 yrs) attended after an overnight fast. The 400ml liquid nutrient test meal (200 ml Fortisp Vanilla (Nutricia Clinical) with 200 ml water) was doped with 0.5 mmol/l Gd-DOTA (Dotarem®, Guerbet, France) to improved image segmentation. In pilot studies this meal was large enough to trigger dysfunction and symptoms but, small enough to be completely consumed by 85% of patients. Subjects were scanned before and 0, 5, 10, 15, 30, 75, 90, 120 mins after meal consumption. A 1.5 T Philips Achieva scanner with a 16-element SENSE XL torso coil acquired forty contiguous, 5 mm, transverse slices (thin to reduce partial volume effects) in a single breath-hold using a multi-slice, balanced turbo field echo (TrueFISP) sequence (chosen to outline visceral organs) with in-plane resolution 2.0 x 1.77 mm², FOV 400x320 mm², TE/TR 1.5/3.0 ms, SENSE 2.0. FA was set to 80° to maximise contrast between stomach contents and walls whilst remaining within the SAR limits.

Data Analysis: Total gastric (TGV; liquid + air) and liquid content (LGV; meal + secretions) volumes were measured using customized software (IDL®, Research Systems Inc, Boulder, Co, USA) optimized for measuring the volumes of the gastric contents. Liquid and air in the stomach were defined using an intensity based, region growing algorithm. This identified pixels within a range of intensity levels connected to a user defined starting point (seed), with gaps filled using a morphological closing filter. The observer placed the initial seed point, chose the appropriate minimum (liquid) or maximum (air) intensity levels and performed adjustments needed to define the regions of interest fully. This was performed slice by slice and intensity levels defined for t=0 were used for all other time points for that subject. TGV and LGV were then fitted to a model of gastric emptying using Matlab® (The Mathworks, Inc) to allow characterisation of the filling relaxation and emptying of the stomach:

$$V(t) = V_0 \left[f \left(1 + \frac{kt}{t_{empt}} \right) \exp \left(\frac{-t}{t_{empt}} \right) + (1-f)(1-Gt) \right]$$

The novel model included a term allowing for a late, linear phase of gastric emptying where the emptying rate becomes more linear, probably due to nutrient feedback control of gastric emptying from the small bowel for this meal. A simplified version of this model (with f=1) of gastric emptying [2] was also fitted to the data over the initial hour of emptying. T50 (time to empty half the initial volume (V₀)) was calculated from both model fits. Three observers measured TGV and LGV from the images, and data were fitted to both models. Coefficient of inter-observer variance (CV) was calculated for each volume and for the fitted model parameters.

Results. The doped liquid nutrient test meal was well delineated by the optimised bTFE sequence. Observers took 60-90min to complete the analysis for a single volunteer (all time points) which is considerably faster than manual segmentation and reduced the number of 'clicks' needed by the observer from >500 to <100 per time point. Figure 1 shows association of inter-observer CV with TGV. Similar results were found for LGV. Table 1 presents mean CV for all model parameters. One volunteer was excluded from fitting due to late acquisition of the t=0 time point. Figure 2 shows an example emptying curve with fits to both models.

Discussion and Conclusions: The doped nutrient meal showed excellent contrast on the optimised images, which allowed intensity based region growing segmentation to be used. Both models successfully parameterized the dynamic change in gastric volumes known to be related to gastric secretion and relaxation after the meal [2,3], however the more complex model was needed to describe the gastric volumes at later time points (>60 mins). The simplified model underestimated the T50 of the meal. The mean CV of volume measurements was below 5% for all volumes above 100ml. CV of fitted parameters were very small for V₀ and T50. Other parameters showed larger variation, however this remained below inter-subject variation of measured parameters. In conclusion optimised MRI with intensity based, image segmentation and fitting to a 5-parameter model allowed robust assessment of gastric function after a validated liquid nutrient meal using a protocol that is suitable for clinical practice. The model will allow changes in the filling, relaxation and emptying aspects of GI function to be characterised in disease states. Future work will also determine to what extent reduced data sets (eg only first 30 minutes) can be used to detect abnormal function in particular diseases (e.g. functional dyspepsia).

References [1] Marciani L. Neurogastroenterol Motil 2011;23:399-407. [2] Fruehauf H. et al. Neurogastroenterol Motil 2011;23:854-861. [3] Goetze O. et al. Neurogastroenterol Motil. 2009;2:725-42.

Acknowledgements: Funding from NIHR Biomedical Research Unit / University of Nottingham Pump Priming Award

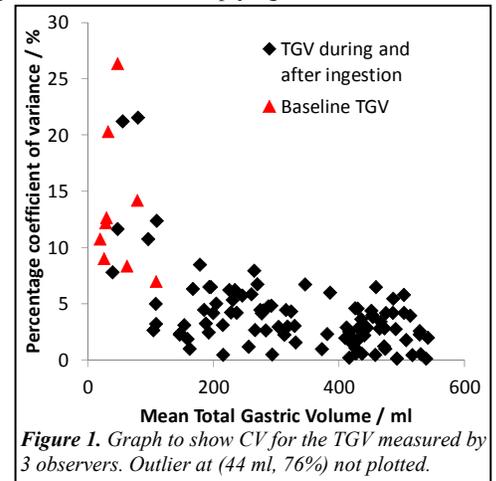


Figure 1. Graph to show CV for the TGV measured by 3 observers. Outlier at (44 ml, 76%) not plotted.

Model Parameter	Mean fitted parameter	Mean coefficient variance % (range)	Std dev / mean (all subjects) %
V ₀	486.0	3.3 (0.5-5.7)	8.0
k	1.95	50.3 (3.6-95.2)	71.9
t _{empt}	15.1	13.5 (2.2-45.5)	35.6
f	0.42	23.7 (1.5-60.9)	68.1
G	0.0041	19.3 (2.5-90.4)	46.0
T50	64.3	5.4 (1.8-14.0)	35.9
V ₀	488.1	3.1 (0.4-5.8)	8.0
k	0.87	40.8 (2.3-173.2)	36.8
t _{empt}	40.1	22.7 (4.1-63.5)	53.3
T50	53.4	8.3 (2.9-22.8)	28.5

Table 1. Summary of model parameters fitted to TGV data. Shaded region is parameters from simplified model fitted over the first 60 minutes only. Final column is the std dev/ mean value defined across all subjects using the mean fitted parameter from all three observers.

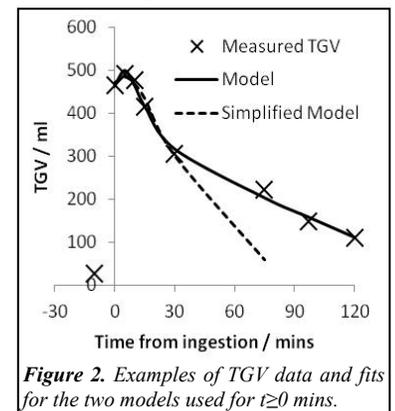


Figure 2. Examples of TGV data and fits for the two models used for t ≥ 0 mins.