Quantitative assessment of small bowel motility by nonrigid registration of dynamic MR images

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INTRODUCTION

MRI of the small bowel is established in the clinical management of enteric disorders. Evaluation of bowel motility is of increasing interest, both for assessing segmental diseases such as Crohn's disease, and potentially for the diagnosis or follow-up of chronic intestinal motility disorders [1,2]. However clinical assessment of small bowel motility is most often performed visually, which is both subjective and purely qualitative. Quantitative assessment methods have been proposed to analyze peristaltic and segmental motility in rats [3], with limited work in humans [4]. Postprocessing of dynamic MRI of the small bowel is challenging because of the complexity of motion patterns and intensity changes due to through-plane motion of the bowel loops and due to flow (in-plane or through-plane flow) in the bowel lumen. Here we propose to quantify motility based on a nonrigid registration technique which includes a model of those intensity changes over time. This allows a robust and automated estimation of the bowel wall displacements which can be used to extract various parameters such as amplitude and frequency of constrictions or changes in bowel cross-sectional diameter or area.

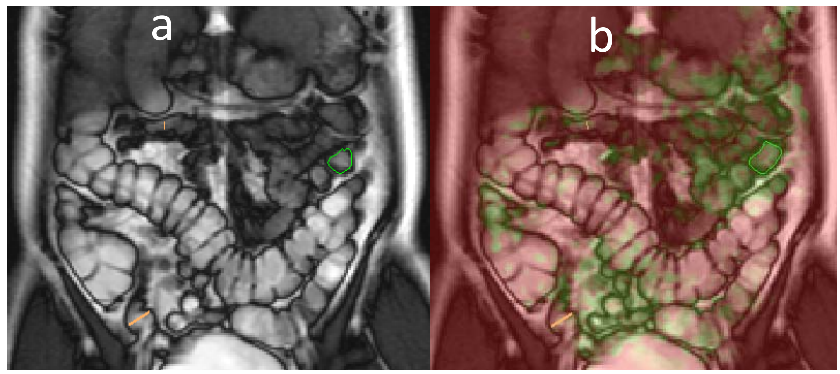

Fig.1. Example lines (marked in orange) and polygon ROI (green contour) defined in various small bowel regions (a). Parametric map showing the standard deviation over time of the Jacobian: regions with high motility appear in green and low motility in red (b). Here the polygon ROI received grade 1 (normal motility) by the expert whereas the line ROIs received grade 4 (not moving at all).

METHODS

Registration: Displacements $u_x(x,y,t)$ and $u_y(x,y,t)$ in the time series of 2D slices are estimated by an algorithm which jointly registers the 2D images ρ using a sum-of-squared-differences (SSD) cost function and creates a model of intensity changes c over time. The following optimization problem is solved:

$$\underset{u_x,u_y,c}{\arg\min} \left\| \left(T_{u_x,u_y}\rho + c\right) - \rho_{ref} \right\|^2 + R(u_x, u_y, c),$$

where $T_{ux,uy}$ denotes the image transformations associated with displacements u_x and u_y, and ρ_{ref} is a reference image (chosen as the closest to the median image of the time series) ; $R(u_x,u_y,c)$ is a regularization term imposing smoothness on both the displacement field (u_x,u_y) and the map of intensity changes c.

MRI protocol: 10 patients with known or suspected Crohn's disease were recruited for this study which was approved by the local ethics committee. Dynamic MRI data were acquired on a 1.5 T Siemens Avanto scanner (Erlangen, Germany) with a T2 True FISP sequence (6 to 16 coronal slices, 1.8 mm spatial resolution, 700 ms per frame, 15 sec breath-held acquisition of each slice).

Validation of the registration was done by comparing manual with automated measurements of bowel wall displacement. Specifically, 2 observers placed markers delineating the bowel wall on one image (from a single time frame), in each of 5 datasets. The markers are lines where the bowel appears like the longitudinal cross-section of a cylinder, and polygon ROIs where it appears as a transverse cross section. The algorithm then propagated these markers to all other time frames using the registration displacement fields. The observers themselves then drew the markers on each time frame of the dataset, manually delineating displacement of the bowel wall. In total 400 measurements were made (4 ROIs x 20 frames x 5 patients). Agreement between manual measures of displacement and displacement measured via automated propagation of the same ROIs was tested using linear regression.

Validation of automated motility assessment: Two expert clinical radiologists then assessed the magnitude of peristalsis within various small bowel segments in 5 new datasets, placing 10 ROIs (10 ROIs x 5 patients = 50 automated motility measurements in total) and grading motility (grade 1=moving normally to 4=not moving at all). Comparison was then made to various quantitative measures extracted from the same ROIs using the proposed algorithm. For instance Fig. 1 shows the standard deviation of the Jacobian associated with image deformations over time (i.e. the ability of a structure to contract or expand).

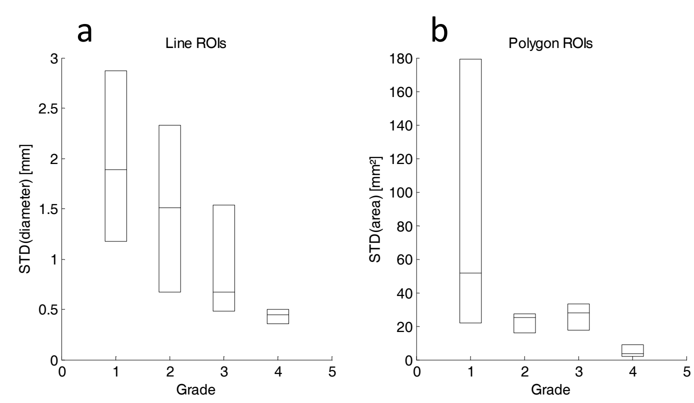

Fig.2. Agreement between expert radiologist grading (1=normal to 4=akinetic) and automated small bowel motility measures (5 patients, 50 ROIs in total): standard deviation over time of cross-sectional diameters (lines) (a) and cross-sectional areas (polygon ROIs) (b). Horizontal lines indicate the maximum, the median and the minimum of each group.

RESULTS

Registration: Good agreement was found between manually measured bowel wall displacements and automated measurements (correlation coefficient CC>0.94 for lines, CC>0.99 for polygons).

Automated motility assessment: Fig. 2 shows the standard deviation over time of small bowel cross-sectional diameters (lines) or areas (polygon ROIs) which can be used as an indication of the amount of motion. These measures were obtained automatically using the displacements given by the registration algorithm and were in good agreement with expert grading of the motility.

CONCLUSION

The good agreement between manually drawn ROIs and automatically propagated ROIs demonstrates the ability of the algorithm to realign small bowel structures and thereby quantify their motility accurately. Quantitative assessment of small bowel motility by the proposed technique was also in good agreement with expert radiologist grading.

The algorithm presented here has several advantages compared to existing registration techniques based on other cost functions such as mutual information: i) it allows more general intensity changes over time in the image (e.g. local changes due to through-plane motion or flow) as these changes are modeled explicitly and are no longer limited to a one-to-one mapping of the histogram; ii) it remains computationally simple as it uses an SSD cost function.

REFERENCES

[1] Froehlich *et al.*, JMRI 2005, 21:370-375 ; **[2]** Froehlich *et al.*, Eur Radiol 2010, 20:1945-1951; **[3]** Ailiani *et al.*, MRM 2009, 62:116-126 ; **[4]** Patak *et al.*, Gut 2007, 56:1023-1025.