

Measurement of Lagrangian strain and Eulerian flow in the abdomen using Continuously Single Shot Tagged Magnetic Resonance Imaging

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Introduction Continuously tagged imaging (CTI) extends the tagged imaging technique from periodic to non-periodic motion [1,2]. This study presents a method to extract Lagrangian strain and Eulerian flow from the deformed tag planes without the use of the initial, non-deformed tag plane locations. The method is demonstrated in a numerical phantom simulation and applied to assess in-vivo low frequent bowel motion [3,4].

Methods Continuously tagged imaging was designed for intrinsically non-periodic motion [5,6]. No gating or ECG-triggering is used and each deformed tag pattern is acquired in one full read out and then refreshed. This different approach from conventional cardiac tagged imaging results in a different type of motion capture which is schematically illustrated in figure 1. Here, a conventional triggered tagged acquisition and a continuously tagged acquisition are both simulated in a numerical Shepp-Logan phantom. The single frame outtakes (figure 1b-c) show how the CTI acquisition remains typically small (figure 1b) since the tag pattern is refreshed after each readout whereas the triggered acquisition gradually increases in amplitude with elapsed time since tagging preparation (fig1c). The temporal reslice of the same simulated acquisition conveys a more subtle difference (figure 1d-f). In the CTI acquisition the paths of constant tag phase are detached from tissue path lines; the motion capture has changed from the Lagrangian to the Eulerian frame. We propose the extraction of Lagrangian strain and Eulerian flow from CTI data without the use of the initial tag positions tagged data acquired in the abdomen.

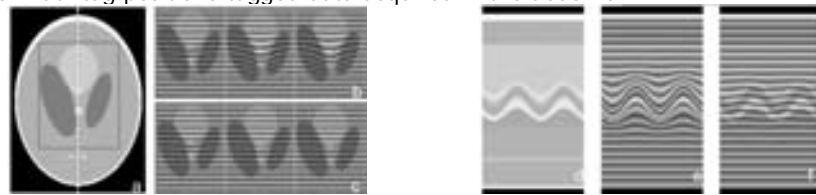


Figure 1: simulated visualization of the difference between triggered tagged and continuously tagged imaging.

Without the initial tag positions, strain information can still be obtained by calculating the local thickening of the taglines. This information is still observed in the reference frame of the imaged object and therefore designated as Lagrangian strain. By tracking the taglines in consecutively acquired frames, we do not sample motion of single tissue points but rather the rate of motion at fixed points in the scanner frame; this motion can be designated as Eulerian flow. These two measures were validated in the numerical phantom simulation shown in figure 1. Furthermore one healthy volunteer was scanned in a Philips 3T Intera 2 hours after lunch for 8 minutes during free breathing to assess low frequent bowel motion. Scan parameters: voxel size 3x3x3mm, TR/TE=2.9/1.8ms. FOV=400x400x36mm, dynamic scan time 98ms. A 100 ms delay was used between tag preparation and read out sequence.

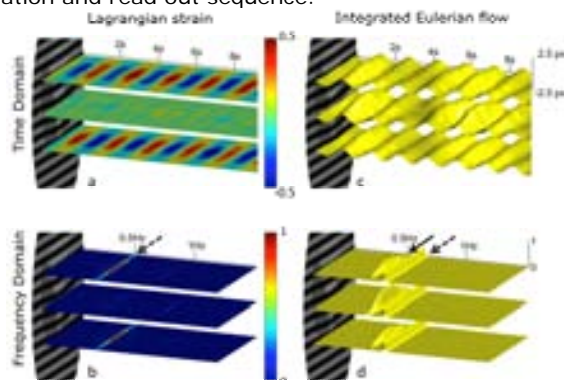


Figure 2: Lagrangian strain and Eulerian flow reconstructed from a simulated CTI acquisition in a Shepp Logan Phantom.

Results Figure 2 shows 3D visualizations of the Lagrangian strain and Eulerian flow at three tagplane locations in the Shepp-Logan phantom simulation. In both the time and frequency domain it shows that Lagrangian strain is insensitive to rigid motion whereas the Eulerian flow captures both rigid and non-rigid motion. In figure 3, the same visualization is applied for the in-vivo acquisition. In the time domain, it can be seen that the Eulerian flow clearly captures both heart and breathing rate, whereas the strain is less pronounced and dispersed over the FOV. In the frequency domain, the Eulerian flow data is largely confounded to three components corresponding to the breathing frequency, its higher harmonic and the heart rate frequency. The Lagrangian strain shows spectral activity near the breathing frequency at several locations in the FOV but also displays activity at lower frequencies, in the typical range of 'slow waves', the base frequencies of gastric and small bowel motility [3,4].

Conclusion Lagrangian strain and Eulerian flow can be extracted without the use of initial tag positions which can considerably ease post processing techniques and decrease sensitivity to errors caused by B0 inhomogeneity and water fat shift artefacts. With this highly non-invasive method bowel motion can be studied during free breathing for long periods of time, enabling non-invasive low frequent motility assessment with broad coverage i.e. inside and outside the gastrointestinal tract. The method should be further validated with longer in-vivo experiments using reference measurements such as manometry.

References [1] A. M. J. Sprengers, M. P. van der Paardt, F. M. Zijta, M. W. A. Caan, R. M. Lamerichs, A. J. Nederveen, J. Stoker, *J Magn Reson Imaging* **2012**, DOI 10.1002/jmri.23637. [2] K. M. Moerman, A. M. J. Sprengers, C. K. Simms, R. M. Lamerichs, J. Stoker, A. J. Nederveen, *Med Phys* **2011**, 38, 1248–1260. [3] E. Husebye, *Neurogastroenterology and Motility* **1999**, [4] E. M. Quigley, *Gastroenterol. Clin. North Am.* **1996**, 25, 113–145. [5] M. P. van der Paardt, A. M. J. Sprengers, F. M. Zijta, R. Lamerichs, A. J. Nederveen, J. Stoker, *J Magn Reson Imaging* **2013**, DOI 10.1002/jmri.24094. [6] K. M. Moerman, A. M. J. Sprengers, C. K. Simms, R. M. Lamerichs, J. Stoker, A. J. Nederveen, *Med Phys* **2012**, 39, 1793–1810.

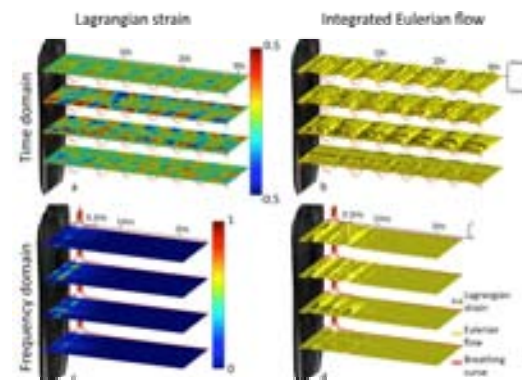


Figure 3: Lagrangian strain and Eulerian flow reconstructed from a CTI acquisition in one healthy volunteer.