Assessment of Motion patterns in free breathing MRI of the abdomen using continuously tagged imaging

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Introduction The entire abdomen is subject to complex motion patterns [1,2], comprising of breathing, heart and peristaltic motion. Insight into the contribution of each source is important to motility research and motion correction. This study proposes the use of continuously tagged imaging for motion assessment during free breathing, non-triggered, non-gated, dynamic MRI of the entire abdomen.

Data acquisition Tagging was originally developed for cardiac imaging and is linked to the cardiac motion cycle using ECG triggering [3-5]. In the present work each tagging prepulse is followed by a fast 3D read-out, this is repeated in a dynamic series resulting in a continuous registration of tag patterns and the motion associated with the tag patterns. Hence, tagged dynamic data can be acquired without any assumption or demand on the motion of interest. A delay must be inserted between the tagging prepulse and dynamic readout to allow motion to deform the tag pattern or tag sheets. The sampling duration is defined by the sum of this delay and the readout duration itself. The readout sequence must be fast to enable high sampling rates and avoid T1-decay of the tag pattern. After approval of the Institutional Review Board a free breathing dynamic set of 150 dynamics was acquired in one healthy consenting volunteer with a delay of 50 ms between tagging prepulse and readout. The readout duration was as short as 85 ms by using a combination of parallel and half-Fourier imaging, such that the sampling rate was 7 Hz. The voxel size was 3 mm isotropic, the FOV was 400x400 with 6 slices.

Motion extraction Tag patterns per dynamic were determined automatically using a scale-space based algorithm [6] (Figure 1) to render high detail deformation fields (Figure 2). Accumulating the difference in deformation over time resulted in a velocity map (Figure 3), in which heart pulsation and breathing motion can be recognized (Figure 4).

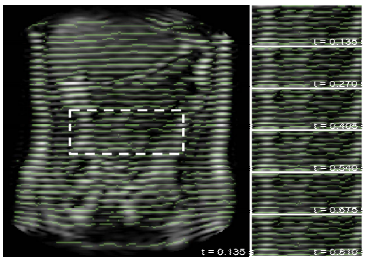

Figure 1: Coronal 2D slice of the tagged dynamic set during free breathing with the tracked lines indicated in green. Figure 1b shows a crop of the first 5 dynamics as indicated in figure 1a.

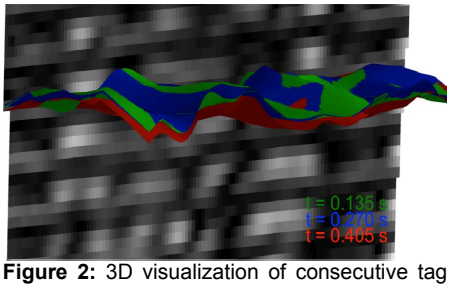

Figure 2: 3D visualization of consecutive tag sheets in the temporal dimension. Motion information can be gathered not only from the deformed shape of a single sheet, but also from the relative difference between two sheets in time, indicating a change in velocity.

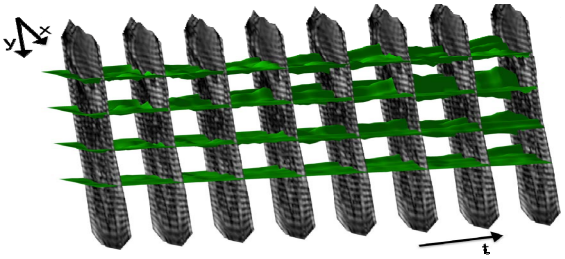

Figure 3 3D visualization of the velocity accumulation as calculated from the evolution of the tag sheets in time. From left to right 8 dynamics are shown along the time axis. Variation in velocity is calculated from the relative distance between consecutive tag sheets. Note that the accumulated velocity can exceed the tag spacing.

Spectral analysis Regions of interest were manually segmented in the liver, stomach, abdominal wall and left upper quadrant of the small intestine area. The analysis of Fourier spectra of the velocity within the ROIs revealed harmonics at 0.2 Hz and 0.8 Hz and their respective higher harmonics, originating from respiratory and cardiac motion respectively. Motility related contributions are difficult to localize and obscured by the pronounced breathing pattern.

Conclusion It was shown that the continuously tagged imaging method is able to measure broad sets of motion patterns occurring in the abdomen during free breathing. The combination of one single tagging prepulse per dynamic readout and a fast TFE sequence enables the sampling of non-periodic motion up to a dynamic sample rate of 7 Hz. For detailed spectral analysis of motility, a higher spectral density is required, i.e. longer scan duration. The motion information gathered with this method can be utilized for both diagnostic and motion correction purposes.

References[1] L.A. Szarka et al. Am J Physiol Gastrointest Liver Physiol 296 (2009) G461-75.[2] E. Husebye, Neurogastroenterology & Motility 11 (1999) 141-161.[3] E.R. McVeigh, Magnetic Resonance Imaging 14 (1996) 137-150. [4] S.E. Fischer et al. Magnetic Resonance in Medicine 31 1994) 401-413.[5] L. Axel et al Radiology 172 (1989) 349.[6] Sprengers et al. ISMRM 2010 nr 2660

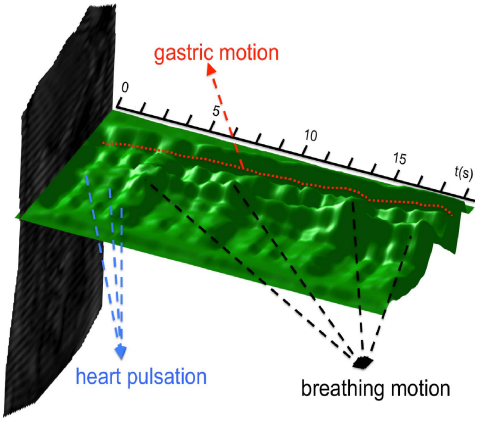

Figure 4: 3D visualization of the velocity as a function of time for one set of tag sheets placed at the same position in the scanner at consecutive points in time. From the motion pattern composed of the accumulation in velocity breathing, heart pulsation and a gastric wave in the stomach area can be allocated.

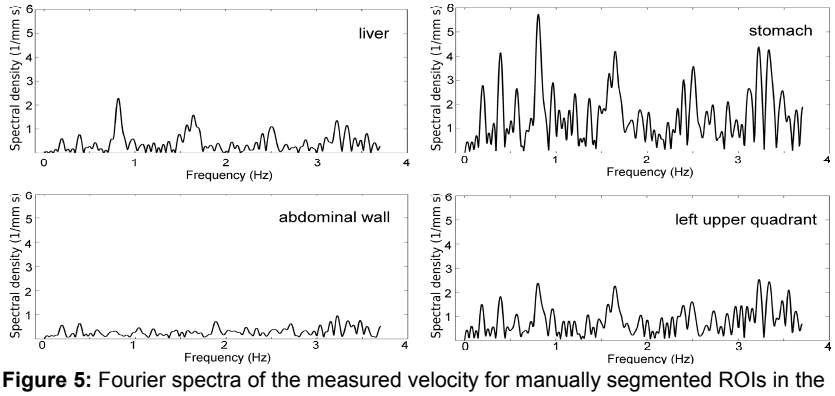

Figure 5: Fourier spectra of the measured velocity for manually segmented ROIs in the liver, stomach, abdominal wall and left upper quadrant of the small intestine area. Peaks around 0.2 Hz and 0.8 Hz and their higher harmonics (breathing and heartbeat) are visible for all ROIs except the abdominal wall region where heartbeat is less pronounced. The left upper quadrant of the small intestine and the stomach feature a slightly broader and more dispersed spectrum of velocity rates, most likely due to gastric and small bowel activity. The difference in spectral power also indicates the ratio of motion activity between the abdominal wall, liver, stomach and left upper quadrant of the small intestine.