Real-time Imaging and Reconstruction of the Small Bowels Based on Golden Ratio Radial and Regularized SENSE MRI

L. Brix[1,2], S. Ringgaard[2], B. Stausbøl-Grøn[2], B. Ginnerup Pedersen[2], Y. Berber[3], M. Ries[3], and T. Sangild Sørensen[4,5]
[1]Department of Clinical Engineering, Aarhus N, Region Midt, Denmark, [2]MR-Centre, Aarhus University Hospital, Skejby, Aarhus N, Region Midt, Denmark, [3]Laboratoire IMF, Centre National de la Recherche Scientifique/Universite Bordeaux 2, France, [4]Department of Computer Science, Aarhus University, Denmark, [5]Institute of Clinical Medicine, Aarhus University, Denmark

Background: Real-time MRI of the bowels may yield an increase in information compared to conventional imaging techniques in several areas: identification of regions of interest (i.e. terminal part of ileum), detection of functional bowel stenosis, recognition of reduced or altered motility and information about bowel movement physiology. Therefore, most vendors of MRI scanners offer 'real-time imaging' protocols, acquiring 4-5 frames per second for immediate display. However, this frame rate is prone to motion artifacts, temporal blurring and an incorrect representation of the tissue under investigation. Non-Cartesian sampling strategies have shown to be more useful for real-time applications due to their ability to reconstruct images with higher spatial and temporal resolution in combination with parallel imaging methods [1]. One particularly interesting sampling strategy is to use a constant azimuthal profile spacing of 111.25° (180°/the *Golden Ratio*) [2]. Sampling radial profiles based on the Golden Ratio allows reconstruction using an arbitrary number of profiles while maintaining an even distribution of profiles in *k*-space. Therefore, the temporal resolution can be set by the operator during reconstruction and does not need to be determined before data acquisition [1]. The purpose of this project was to implement a real-time data acquisition and reconstruction system that could produce images from the small bowels to a satisfactory frame rate for the visualization of peristaltic motion and motility in absence of degrading image artifacts.

Methods: A Philips Achieva 1.5T MRI system was programmed to acquire radial *k*-space profiles based on a constant azimuthal profile spacing of 111.25°. A 2D balanced dynamic sequence was applied to a healthy volunteer after ingestion of ice water and data was acquired using a 5 channel cardiac coil (TR = 3.1ms, TE = 1.53ms, flip angle = 50º, matrix size = 128x128, resolution = 2.34x2.34x5mm^3). The sequence was used to acquire a single coronal slice plane at the anterior part of the bowels. Raw *k*-space data was streamed from the scanner in real-time using the RealTI software (RTTech, Bordeaux) to an external workstation for off-line but *interactive* reconstruction by regularized SENSE using the parallel processing facilities of an Nvidia® GTX 280 graphics card [1]. The temporal resolution and artifact level were interactively chosen by the operator (much like window/level settings) to get the best compromise between true real-time temporal resolution with "limited" frame rates (approx 10 frames/sec) and sliding window reconstructions with frame rates approaching a few ms/frame. The combination of Golden Ratio radial sampling and sliding window reconstruction is unique because *k*-space is always close to being uniform sampled independent of the number of profiles used for reconstruction (Figure 1). Reconstructed images were inspected by two experienced radiologist with special knowledge of bowel anatomy and function.

Results: We successfully reconstructed images using as few as 34 profiles per image yielding a true temporal resolution of 9.5 frames/second. However, due to the relatively slow movement of the bowel the combination of 128 profiles per image and a sliding window of 20 profiles giving 50 frames/second yielded images with improved SNR, showed no visual temporal blurring and constituted better cine display (Figure 2). However, a small amount of banding artifacts was present in all image series due to intestinal gas.

Discussion: This project demonstrates that data acquisition based on the Golden Ratio gives the operator a unique possibility to interactively reconstruct images with an optimal compromise between a true temporal resolution and a sliding window reconstruction in real-time. In this context, due to the almost uniform distribution of profiles, independent of the number of acquired profiles, Golden ratio based sliding window reconstruction has better *k*-space covering compared to its Cartesian counterpart. By utilizing the parallel capabilities of a standard graphics cards image reconstruction time is no longer the limiting factor since it is shorter than the actual acquisition time. Thus, the technique has the potential to acquire and reconstruct MRI data on-line hereby sampling data and presenting the images to the operator in real-time.

The images in this project may improve the diagnosis and documentation in a number of bowel disorders and illnesses and it may replace a variety of fluoroscopic motility examinations. Its potential includes real-time information in identification of regions of interest, e.g. the terminal ileum in patients with or suspected of having Crohn's disease. The technique also has the potential to identify functional bowel stenosis and reduced or altered bowel motility. Real-time information about bowel movement physiology is also possible and gives rise to a new way of imaging the gastrointestinal system.

Conclusion: Acquisition of the bowels, by radial *k*-space read-out based on Golden Ratio distributed profiles, enable off-line interactive real-time reconstruction. The technique allows the operator to optimize and compromise between a true or sliding window temporal resolution and artifact level in bowel imaging in a healthy volunteer. This study is a step toward using MRI for imaging moving organs and overcoming some of the inherent problems with MRI being a time-consuming and static imaging modality. Future prospects are to make the acquisition and reconstruction system completely on-line hereby presenting the acquired and reconstructed images to the viewer in real-time while preserving the freedom to choose an arbitrary number of *k*-space profiles and if desired combine the reconstruction with a sliding window reconstruction. Thus, it is possible to adapt the technique to the anatomy under investigation.

[1] Sørensen TS et al. *IEEE Trans Med Imaging* 2009, 28(12):1974-85
[2] Winkelmann S et al. *IEEE Trans Med Imaging* 2007, 26:68-76

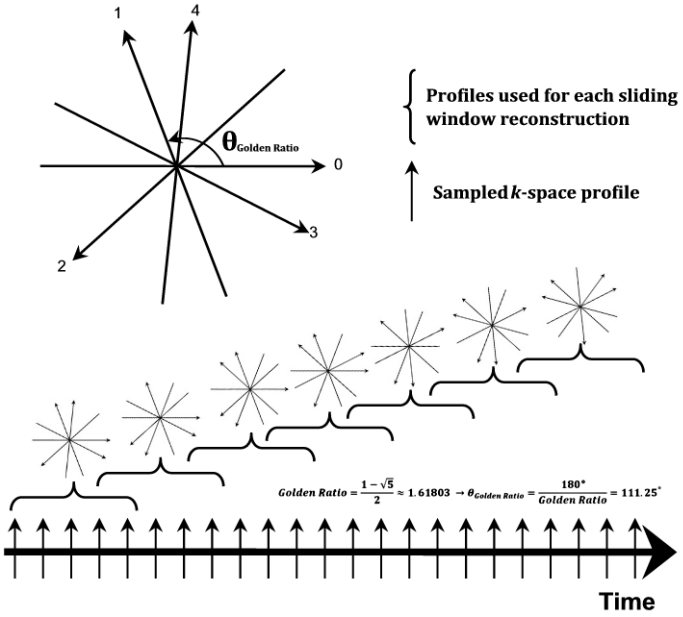

Figure 1: The Golden Ratio offers a high flexibility in choosing a random number of profiles for each reconstruction. In this project an optional sliding window reconstruction could be applied in which *k*-space profiles from former reconstructions were used for image generation.

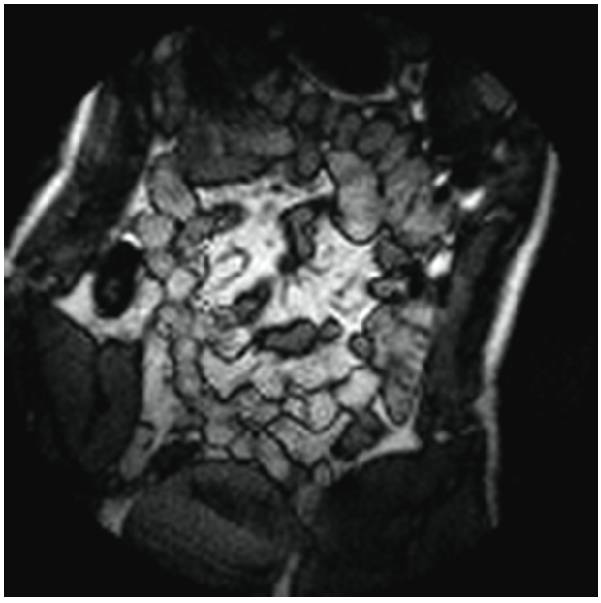

Figure 2: Coronal slice of the bowels. The image is reconstructed from 128 profiles and a frame rate of 50 images per second.