Intravascular 3D-Parallel Imaging

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Introduction: Intravascular Ultrasound (IVUS) has recently made inroads on the 3D assessment of vessel wall anatomy [1]. 3D reconstructions of the entire vessel segment can be performed from cross-sectional IVUS images; these help the physician to identify locations of pathology, as well as to evaluate the progression or regression of atherosclerotic disease. Typical IVUS scan specifications are: a frame rate of 30 frames/sec, pullback speed of 0.5mm/sec, in-plane resolution 50-150 μm, and slice resolution of about 0.5-1.0 mm [1]. The real-time capabilities and the relative ease of use have made IVUS the method of choice for intravascular vessel characterization. However, IVUS is based on acoustic impedance, and can therefore not offer the variety of contrasts mechanisms available with MR. In many ways, MR image quality already seems superior to IVUS and the achievable in plane resolution is almost comparable [2]. To date, MRI has lagged behind IVUS in imaging speed; one method to achieve MR acceleration is through the use of partially parallel acquisitions (PPA) [3-6]. The feasibility of catheter based array coils as a prerequisite for PPA has already been demonstrated [7]. In this work we focus on the development of new PPA sequences that provide the imaging speed necessary to achieve IVUS like pullback speed performance.

Material & Methods: Catheter-based, opposed solenoid phased array coils (Fig. 1) were constructed with either two or three solenoid elements connected to separate receiver channels of a Siemens Magnetom Sonata 1.5T whole body scanner. The opposed solenoid coils were wound from 30 AWG copper magnet wire. Each individual solenoid was 5F in diameter, had 5 windings per coil and a length of 4.5mm. The gap between the individual solenoids was 1cm. Tuning, matching, and passive decoupling were performed on the tip of the catheter. The maximum outer diameter of the device was 11F. In order to speed up acquisition time by parallel imaging, we chose to apply 3D acquisitions with the acceleration implemented in the partition direction and not in the 2D phase encoding direction. The partition direction was along the coil/catheter long axis since the individual solenoid coils were arranged equidistantly along the catheter. Thus, cross-sectional images with a radially symmetrical sensitivity profile and a in plane resolution comparable to IVUS data sets can be achieved. Intravascular 3D-PPA acquisitions with this catheter coil configuration were tested in both *in vivo* and *in situ* porcine imaging experiments. All animal experiments were approved by our institutional animal care and use committee (IACUC). During porcine imaging experiments, the catheter device was introduced into the proximal femoral artery through a 14 F inducer sheath and then advanced to the abdominal aorta. Several different sequence types including gradient echo-, and SSFP-sequences were investigated. In each case, a full k-space image (standard acquisition) and a reduced k-space image (reduction or acceleration factor R=2 or 3) were acquired; reconstructed images were compared.

Results: Figure 2 shows *in situ* images of a standard- and accelerated (R=2) 3D-TrueFISP data set from the abdominal aorta in a pig. Imaging parameters were: TE/TR 6.6/13.2ms, α=55°, matrix 128^2, FOV 30mm, 32 slices, SL 2mm (64m partition thickness), and TA 54 sec for the full data acquisition (Fig. 2b) and 27 sec for the partially parallel acquisition (Fig. 2a). Comparison of figure 2a and b reveals essentially equivalent overall image quality for both standard and PPA acquisitions, as well as clear delineation of the vessel wall and surrounding tissue structures in both cases. Compromising artifacts from the PPA reconstruction were not observed. Decreased signal to noise ratio (SNR) was apparent in PPA images outside the region of interest where the coil sensitivity was lowest. SNR differences were less than 41.4% as predicted by the decreased acquisition time and use of parallel imaging, suggesting a successful trade-off in acquisition time and motion artifact immunity. Figure 3 shows images of an *in vivo* data set acquired using a 3D FLASH sequence, where saturation pulses were applied to suppress arterial flow. The imaging parameters were TE/TR 22/57ms, α=55°, matrix 128^2, FOV 58mm, 30 slices, SL 2mm, TA 1:24 min for the full data set and consequently 42 sec for the data set accelerated by 2. Even in this case, PPA showed very good performance at half of the measurement time required by the standard image.

Discussion & Conclusion: In this study we were able to acquire long vessel segments in high resolution from the abdominal aorta of a pig by the use of catheter based array coils and 3D parallel imaging. With a dual array catheter coil and an acceleration factor of 2 we realized acquisition times of as low as 27 sec. The length of the covered segment was 64mm so that in this case a corresponding "pull-back speed" of 2.37mm/sec exceeds the comparative IVUS standard. A further increase in imaging speed can be traded for higher resolution in partition direction. Additional speed can be expected by using more coil elements and approaching higher acceleration factors. After optimization of our three-coil array we should achieve acceleration factors greater than 2. Additional work can apply to coil technology and fast parallel acquisitions to meet or exceed the other typical IVUS parameters of in-plane resolution, slice resolution and frame rate.

References: [1] Klingensmith JD et al., Am Heart J. 2003; 145(5):795-805; [2] Hillenbrand C et al, Proc. ISMRM 11: 1186 (2003); [3] Sodickson DK et al, MRM 38: 591-603 (1997); [4] Pruessmann K. et al, MRM 42: 952-62 (1999); [5] Griswold MA et al., MRM 47: 1202-10 (2002); [6] Kannengiesser S. Et al Proc. ISMRM 12, p 2149 (2004); [7] Hillenbrand C. et al, ISMRM 12, p 376 (2004).

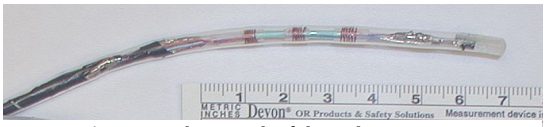

Figure 1: Photograph of the catheter array

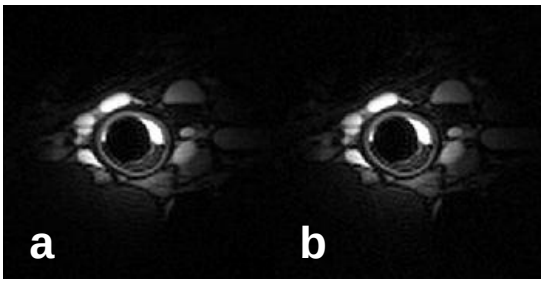

Figure 2: Intravascular 3D-TrueFISP imaging in situ. (a) GRAPPA image and (b) standard acquisition.

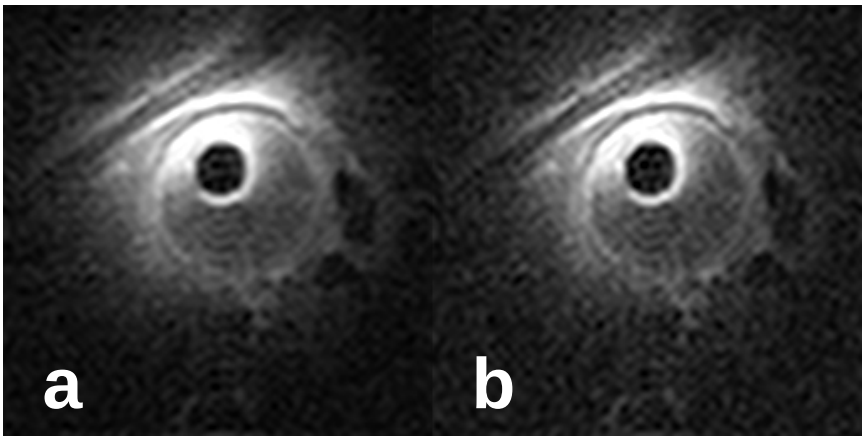

Figure 3: Intravascular 3D-FLASH imaging in vivo. (a) GRAPPA image and (b) standard acquisition.