Intravascular Parallel Imaging: A Feasibility Study

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Introduction: MR based intravascular screening for timely identification and treatment of vascular diseases, such as atherosclerosis or venous thromboembolism, may play an import role towards reducing the morbidity and mortality of cardiovascular diseases. As demonstrated by established interventional modalities such as x-ray angiography or 3-D intravascular ultrasound, vessel screening typically requires the acquisition of coronal or sagittal slices covering the longitudinal course of the vessel. However with MR, high resolution imaging in those planes is challenging since device and respiratory motion, high blood flow rates and inhomogeneous coil sensitivities lead to low SNR images dominated by motion and flow artifacts. One way to overcome these problems is to decrease acquisition time. This can be achieved by using partially parallel acquisitions (PPA) [1,2]. PPA techniques reduce imaging time by replacing the spatial encoding normally performed using gradients with spatial information contained in the sensitivity patterns of the elements of an RF coil array. However, the design and construction of catheter based array coils is constrained by the catheter's (a) small size and (b) cylindrical surface. Therefore, only two different types of catheter arrays have been realized to date: the double loop array [3] and the opposed solenoid array [4]. Of those, only the second approach offers the spatial separation of the component coils and sensitivities that are prerequisite for PPA. Therefore, the aim of this work is to implement and evaluate the feasibility of partially parallel intravascular survey imaging using a two channel opposed solenoid phased array catheter coil.

Material & Methods: A catheter-based, opposed solenoid phased array coil was constructed by using two independent counter-wound solenoid coils connected to separate receive channels of a Siemens Magnetom Sonata 1.5T whole body scanner (Fig. 1). Connecting each coil to a separate receiver channel allows them to be used either independently or in a combined fashion for tracking or imaging applications, respectively [4,5]. Solenoid coils were wound from 30 AWG copper magnet wire. Each solenoid was 5F in diameter, had 5 windings per coil, and a length of 4.5mm. The gap between the solenoid coils was 1cm. Tuning, matching, and passive decoupling with crossed diodes was performed on the tip of the catheter using surface mount components. Micro-miniature coaxial cable was used to connect the coils to the scanner. The maximum outer diameter of the device (including components and insulation) was 11F. The ability to acquire longitudinal images using PPA with this catheter coil configuration was tested in both uniform phantom and porcine imaging experiments. The catheter probe was placed in a saline filled vessel phantom for *in vitro* studies. The device was advanced up to the abdominal aorta through a 14 F introducer sheath in the proximal femoral artery during porcine imaging experiments. The auto-calibrating PPA method, GRAPPA [6], was chosen for parallel imaging because: (i) GRAPPA is reported to provide robust reconstruction even in imaging situations where the signal is very low but non-zero as commonly occurs in intravascular applications, and (ii) GRAPPA does not require additional coil sensitivity mapping procedures which could lead to misregistration errors under the influence of significant motion. Several different sequence types including gradient echo-, spin 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) was acquired and compared to each other. When using GRAPPA, 12-24 additional calibration lines at the center of k-space were acquired for determination of reconstruction parameters. Slice orientation and phase encoding direction was parallel to the longitudinal axis of the catheter coil array.

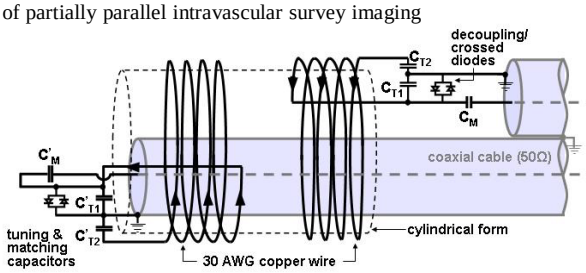

Figure 1: Electrical schematic of the opposed solenoid array.

Results: Figure 2 shows a comparison of standard- and GRAPPA TrueFISP images from a vessel phantom using sequence parameters suited for intravascular imaging [4]: TE/TR 6/12ms, FOV 55mm, SL 3mm, matrix 128^2. 12 reference lines were acquired for GRAPPA. Figures 2a and b show the component images of the catheter coil array, demonstrating localized sensitivities for each element. Comparison of figure 2c and d reveals equivalent overall image quality for both standard and GRAPPA acquisitions. No artifacts from the PPA reconstruction appeared. Decreased signal to noise ratio (SNR) was observed in GRAPPA images outside the region of interest where coil sensitivity was lowest. These signal losses do not affect the overall image quality in the area of interest around the device. Figure 3 shows a similar comparison from porcine imaging experiments using TSE. The actual slice orientation is depicted in the axial image in figure 3a. TSE imaging parameters were TE/TR 12/521ms, FOV 55mm, SL 4mm, matrix 128^2, ETL 11, and 22 calibration lines. Even in this case, GRAPPA showed very good performance at nearly half of the measurement time required by the standard image. SNR differences were less than 41.4% predicted by the decreased acquisition time and use of parallel imaging, suggesting a successful trade-off in acquisition time and motion artifact immunity. Finally, figure 3d shows a porcine vena cava acquired with GRAPPA and the coil located within the aorta.

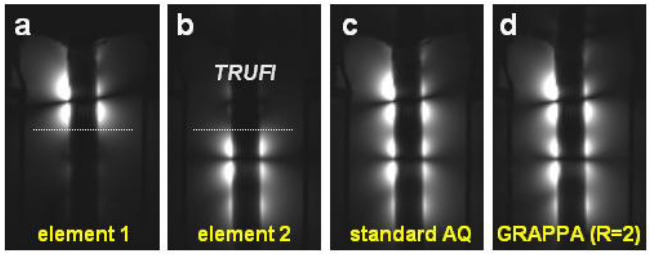

Figure 2: Comparison of standard and parallel imaging acquisition in a vessel phantom using a TrueFISP sequence.

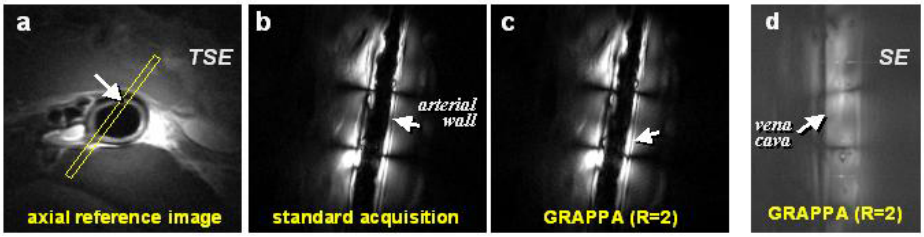

Figure 3: Intravascular imaging from the abdominal aorta of pigs: (a) axial reference image showing the slice position of images (b) and (c). (b) standard and (c) GRAPPA images depicting two layers of the arterial wall. (d) Another GRAPPA image from a different pig depicting the course of the vena cava.

Discussion & Conclusion: This work describes, to our knowledge, the first demonstration of intravascular parallel imaging. We developed a suitable catheter-based opposed solenoid phased array coil, and conducted parallel imaging in planes parallel to the device's longitudinal axis. Our imaging results from phantom and porcine experiments revealed robust intravascular imaging using the auto-calibrating GRAPPA method, at imaging times nearly half that of non-accelerated imaging sequences. SNR provided by our coil and GRAPPA was deemed sufficient for depiction of vessel wall structures in intravascular imaging applications. Currently, we are limited to acceleration factors of 2 due to the actual number of coil elements integrated on the prototype catheter - extension to more than 2 solenoid coils is technically possible, however. We expect further increases in imaging speed and hence further improvements in intravascular imaging quality from a larger number of coils. This will have the positive side effect of improved tracking capabilities from multiple markers incorporated into a single device [5], and facilitate improved cardiovascular imaging in the future.

References: [1] Sodickson DK et al, MRM 38: 591-603 (1997); [2] Pruessmann K. et al, MRM 42: 952-62 (1999); [3] Quick HH et al., MRM 45:138-46 (2001); [4] Hillenbrand C et al, Proc. ISMRM 11: 1186 (2003); [5] Dumoulin CL et al, Proc. ISMRM 11: 314 (2003); [6] Griswold MA et al., MRM 47: 1202-10 (2002).