Interventional MRA With No Strings Attached: Wireless Active Catheter Visualization

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Introduction:

Active instrument visualization strategies for interventional MRA require vascular instruments to be equipped with some kind of RF coil or dipole RF antenna for MR signal detection. While such visualization strategies reward with a number of potential advantages, i.e. high instrument to background contrast (1, 2), positional feedback from the device (3) as well as potential for intravascular MR imaging (1), active strategies still require the vascular instruments to be connected to the scanner with either coaxial cable, or alternatively, with laser fibers (4, 5). Such connections increase instrument complexity, compromise instrument handling and, in the case of wires, are a potential source of RF heating. In order to eliminate some of the mentioned disadvantages while maintaining superior instrument contrast inherent to active visualization strategies, the purpose of this study was to implement self-resonant RF coils into vascular catheter systems that inductively couple their signal to surface coils and thus enable wireless active instrument visualization.

Methods

6F Catheters were designed containing 100-mm-long self-resonant RF resonators at the distal instrument tip to enable wireless active instrument visualization (Fig. 1). The resonators consisted of longitudinal single-loop coils that were tuned with ceramic chip capacitors to the Larmor frequency of the MRI scanner. Scanning was performed on a 1.5 T SIEMENS Sonata system with the body coil serving as transmitter. Up to eight channels of body and spine phased-array coils were employed for simultaneous visualization of the anatomy and inductive signal coupling of the instrument coils. The signal amplification of the catheter coils was determined in NaCl phantoms by systematically increasing the excitation flip angle. Measurements were performed to determine SNR and instrument to background CNR as a function of the flip angle. *In vivo* experiments were performed on fully anaesthetized domestic pigs (n = 5) weighing between 80 and 125 kg. The instruments were inserted through the right iliac artery and guided through the vasulature under real-time Cartesian and projection reconstruction TrueFISP imaging (TR/TE 2.6/1.3 ms, FOV 400 x 400, matrix 256 x 135, slice 10 mm, flip angles varying between 1-90°) with frame rates of up to 9 fps. Subsequent to selective catheterization, time-resolved 3D contrast-enhanced selective intra arterial angiograms were acquired to verify individual catheter positions.

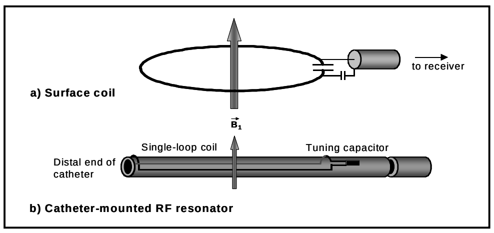

Fig. 1: Wireless signal coupling between two RF coils and its application to active catheter visualization. (b) Distal end of catheter equipped with RF resonator that is amplifying the local B_1 signal that can be wirelesssly picked up by a surface coil (a).

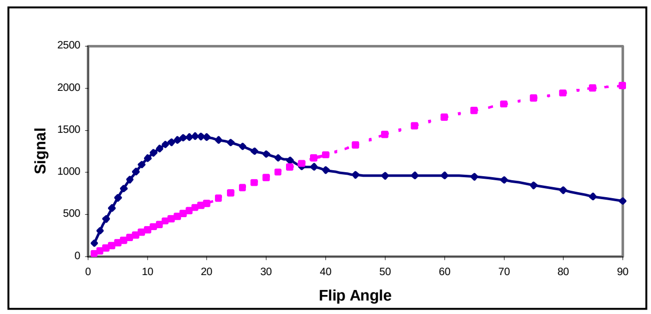

Fig. 2: Catheter (solid line) and background signal (dashed line) as a function of the excitation flip angle in a phantom. Note: Low flip angles already result in high catheter signal while background signal is still limited.

Results:

The catheter mounted resonators enabled visualization of the instrument tip and curvature over 10 cm with robust signal in both, phantom and in vivo experiments. In the phantom experiments, low excitation flip angles of around 2-5° already resulted in strong signal amplification and thus good instrument visibility (Fig. 1). Maximal instrument signal (Fig. 2) as well as instrument to background CNR (CNR = 200) was achieved with flip angles in the range of 10-20°. A flip angle of 35° resulted in identical signal of instrument and background (CNR = 0). Even higher flip angles resulted in progressively negative CNR, i.e. instrument displaying darker than surrounding blood.

In the in vivo experiments, the inherent contrast of the TrueFISP sequence, depicting blood with hyperintense signal, enabled vessel visualization without the administration of contrast. Instrument to background contrast could be adjusted by simply varying the excitation flip angle of the imaging sequence (Fig. 3). The in vitro data was fully supported by the in vivo experiments. Here also best instrument to background contrast was achieved with flip angles in the range of 10-20° (Fig. 3). The real-time TrueFISP sequences allowed for active guidance of the catheters with a frame rate of up to 9 fps (Fig. 4). Subsequently to successful catheter guidance, time-resolved CE selective angiograms were acquired in the abdominal aorta, and in the renal, splenic, mesenteric, and hepatic arteries of the pigs.

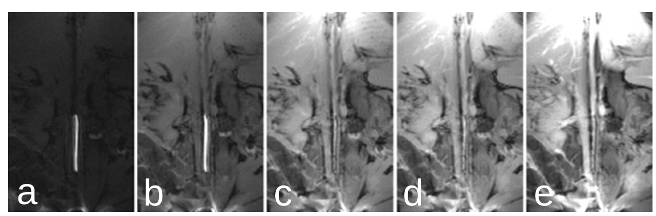

Fig. 3: Variation of excitation flip angles and resulting changes in instrument to background signal in vivo. TrueFISP images acquired with the inductively coupled catheter in the abdominal aorta of a pig. Phased array surface coils were employed as outside RF receivers. Flip angles of 1° (a), 18° (b), 35° (c), 50° (d), 90° (e), are shown representatively (300 x 185 mm image portions). Image window and level were kept constant for comparison.

Discussion:

The proposed instrument visualization strategy provides simple and reliable catheter visualization with several inherent advantages: unlike the signal characteristic of an intravascular dipole antenna, which is inherently faint at the antenna tip, active wireless visualization of catheters with self-resonant loop coils enables reliable visualization of the vascular instrument curvature to the very tip. Additionally, due to inductive signal coupling, no wire connection compromises instrument handling, and, although not explicitly measured, instrument RF heating is not expected.

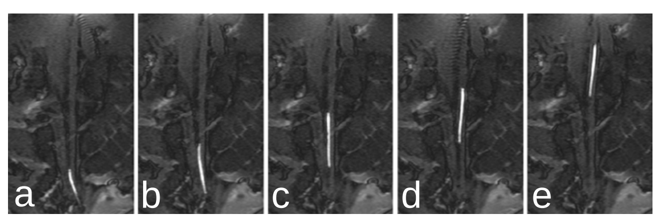

Fig. 4: *In vivo* wireless active catheter guidance from the left iliac artery into the abdominal aorta of a pig. Five out of 120 frames are shown. Note the flip angle of 18° allows for high instrument to background contrast.

References:

1. Quick HH, et al., MRM 2003; 49:129
2. Lederman RJ, et al., Circ. 2002; 19:1282
3. Elgort DR, et al., JMRI 2003; 18:621
4. Wong EY, et al., JMRI 2000; 12:632
5. Weiss S, et al., ISMRM 2001; p. 544