Wireless Active Catheter Visualization: Passive Decoupling Methods and Their Impact on Catheter Visibility

H. H. Quick[1], M. O. Zenge[1], H. Kuehl[1], G. M. Kaiser[2], S. Aker[3], H. Eggebrecht[4], S. Massing[1], M. E. Ladd[1]

[1]Department of Diagnostic and Interventional Radiology, University Hospital Essen, Essen, Germany, [2]Department of Transplantation Surgery, University Hospital Essen, Essen, Germany, [3]Department of Pathophysiology, University Hospital Essen, Essen, Germany, [4]Department of Cardiology, University Hospital Essen, Essen, Germany

Introduction:

Wireless active catheter visualization recently has been introduced as a high-contrast instrument visualization strategy for interventional MRA. Due to inductive signal coupling, the method does not require any electrical (wire) or mechanical (optical fiber) connection between instrument and MR scanner (1). The concept is based on catheter integrated self-resonant RF resonators that are tuned to the resonance frequency of the scanner and inductively couple their signal to outside surface RF coils. While providing excellent and robust instrument to background contrast (1), no means to detune the catheter coil in RF body coil transmit mode has been implemented, which might lead to localized RF increases around the "high-Q" resonators. The purpose of this study was to integrate and evaluate different strategies for passive (and thus wireless) decoupling of catheter mounted RF resonators.

Theory:

Two modes can be differentiated with wireless active catheter visualization. 1) In body coil RF transmit mode, low flip angle excitation pulses of a fast imaging sequence are amplified in the immediate vicinity of the resonant *high-Q* catheter RF coil, resulting in locally increased effective flip angles. The background gives relatively little signal at these low excitation angles, resulting in a positive contrast between catheter coil and background. 2) In RF receive mode, the resonant catheter coil picks up the MR signal in its immediate vicinity, resulting in a B_1 field vector that can be inductively coupled to a surface RF coil. The catheter coil thus acts as a local signal amplifier, additionally increasing the catheter to background contrast. With passive decoupling, the RF resonators can be detuned in transmit mode, leaving only the receive mode for instrument signal amplification.

Methods

Three different 6F catheters were designed containing 120-mm-long self-resonant RF resonators at the distal instrument tip to enable wireless active instrument visualization (Fig. 1). In catheter "I", the resonator consisted of a longitudinal single-loop coil that was tuned with a ceramic chip capacitor to the Larmor frequency of the MRI scanner. Catheter "II" and "III" additionally were passively decoupled with miniaturized crossed diodes according to the decoupling schemes displayed in Fig. 1. 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 signal detection. The signal amplification of all three catheter coils was determined *in vitro* 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 = 2) weighing 65 and 75 kg. The instruments were inserted through the right iliac artery and guided through the vasculature under real-time Cartesian and radial TrueFISP imaging (TR/TE 2.6/1.3 ms, FOV 400 x 400, matrix 256 x 135, slice 5 mm, flip angles varying between 1-90°) with frame rates of up to 5 fps.

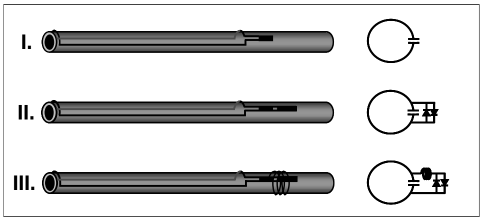

Fig. 1: Distal end of three different catheters equipped with RF resonators: I: tuned, no decoupling; II: tuned and decoupled with crossed diodes; III: tuned and decoupled with secondary resonant RF circuit. Electrical diagrams are shown on the right.

Results:

The "Q-factors" of the three catheter resonators (I, II, and III) loaded with NaCl were determined to be 47, 39, and 31, respectively. All three catheter mounted resonators enabled visualization of the instrument tip and curvature over 120 mm in both phantom and *in vivo* experiments. Phantom signal measurements revealed very strong signal amplification already at low flip angles for catheter (I) *without* decoupling (Fig. 2). Catheters *with* decoupling (II and III) provided progressively increasing signal with increasing excitation flip angle. Both catheters provided higher signal than background signal, resulting in positive instrument contrast. The resonator with secondary decoupling circuit (III) provided less signal than the resonator with crossed diodes (II) (Fig. 2). The *in vitro* data was fully supported by the *in vivo* experiments. Catheter I showed high signal already at low excitation flip angles. Signal amplification for catheters II and III was not as high at low flip angles, but progressively increased with increasing flip angle (Fig. 3).

Discussion:

Passive decoupling strategies for wireless active catheter visualization provide a means to reliably detune the RF resonators in RF body coil transmit mode. RF energy deposition in the catheter resonators thus can be limited during transmit. By the same token, flip angle amplification is suppressed in transmit mode, leading to an altered instrument to background contrast behavior. While non-decoupled catheters provide strong signal with high instrument to background contrast at low flip angles, decoupled catheters provide high signal at higher excitation flip angles. The addition of passive decoupling strategies to the concept of wireless active catheter visualization potentially provides increased RF safety and broadens the range of applications, e.g. imaging with TrueFISP at high flip angles to display vascular background and the instrument simultaneously with high signal.

References:

1. Quick HH, et al., ISMRM 2004, 372.

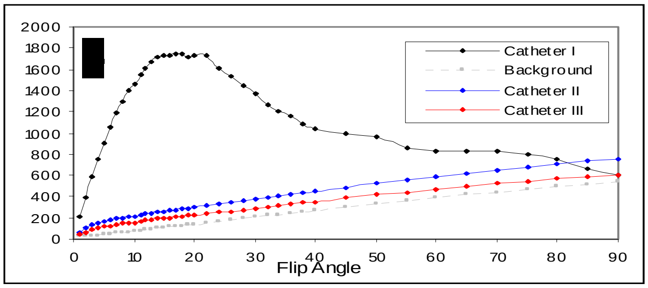

Fig. 2: Catheter signals (black, blue, and red) and background signal (grey) vs. excitation flip angle in a phantom. Note: All catheters provided higher signal than the background, resulting in positive instrument contrast. Catheter "I" (not-decoupled) provided significantly higher signal at low flip angles compared to the decoupled catheters "II" and "III".

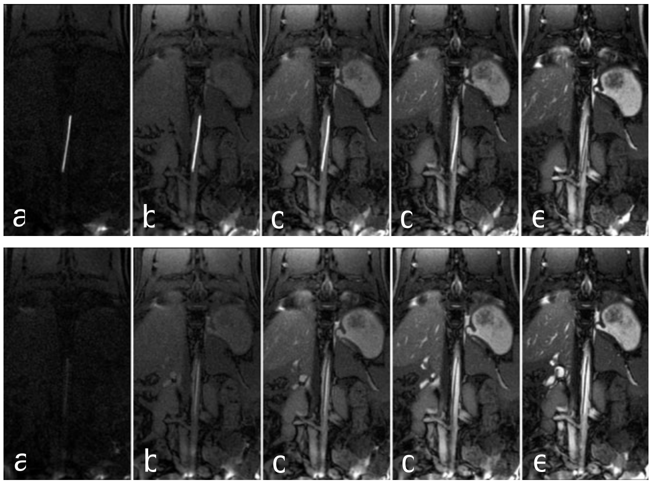

Fig. 3: Variation of excitation flip angles and resulting changes in instrument to background signal for catheter "I" (first row) and for catheter "II" (second row). Real-time TrueFISP images acquired with the catheters in the abdominal aorta of a pig. Phased-array surface coils were employed as outside RF receivers. Flip angles of 5° (a), 20° (b), 40° (c), 60° (d), 90° (e) are shown representatively (400 x 215 mm image portions). Image window and level were kept constant for comparison. Note: catheter "I" provides high signal at low flip angles, while catheter "II" provides progressively increasing instrument contrast with increasing flip angles.