RF-safe intravascular imaging using a self-visualizing transformer line

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Objective:

Intravascular MR-imaging may provide a local SNR gain possibly relevant for some interventional and diagnostic applications like high resolution intravascular imaging. However, regular signal transmission lines are not RF-safe due to possible RF heating of leads by resonant excitation of common mode currents. This safety issue prohibits intravascular MR imaging coils from being used in humans. Concepts to build RF-safe transmission lines to accomplish this task were so far mainly explored for interventional device visualization and localization [1,2]. In this work, we demonstrate RF-safe intravascular imaging on a 1.5T scanner with a new intravascular imaging instrument based on the combination of a self-expanding intravascular imaging coil, a glass fiber reinforced plastic (GFRP) guide material for delivery of the imaging coil through a standard catheter, and an MR-visible and RF-safe transformer line for MR signal transmission.

Material and Methods:

A GFRP material obtained in a miniature pultrusion process (micro-pultrusion) functions as an RF-safe shaft for the delivery of the imaging coil through a standard catheter. The material has an extremely high flexural and shear modulus [3,4], which stabilizes the catheter and makes it very suitable for this application. The outer diameter of the shaft is 800µm.

The expandable imaging coil at the tip of the shaft was made using a 354µm nitinol tube holding a 150µm copper wire within the 230µm lumen (Fig.1). The size of the imaging loop was 3.8cm², and the whole assembly has a diameter of 4-5F in the folded state. The loop was tuned in its expanded state in tap water using a 0201 SMD capacitor (muRata, Kyoto, Japan). An SMD 0201 PIN diode MA4SPS552 (M/A-COM, Lowell, MA, USA) was used for passive decoupling during transmission.

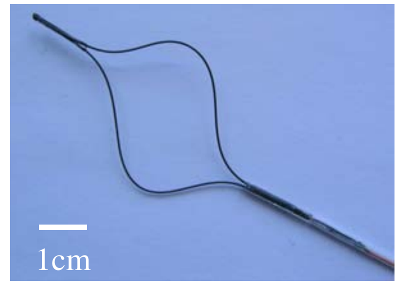

Fig. 1: Self-expanding intravascular imaging coil.

The imaging coil was connected to a low profile transformer-based transmission line attached to the GFRP shaft. The line is based on a new distributed matching principle and allows for imaging and active visualization of the entire intravascular imaging instrument. Low impedance cable segments provide a power matching of individual transformers thus completely avoiding the need for lumped capacitors thereby creating transmission lines of very small diameters. The two shields of a 390µm diameter triaxial cable (Tyco Electronics Corp.) with an impedance of 8.8Ohm at 63.8MHz were used. This low impedance matches the transformers over a distance of only ~30cm, i.e., each cable segment between two transformers turns the load of one transformer Z into its complex conjugate Z*. The line is proximally matched to 50Ohm using a short cable and a series capacitor. Due to this matching method, the entire transmission line becomes resonant for differential mode currents. Consequently, small imperfections of the shields allow reception of differential mode spin signal allowing for active visualization over the entire length. This effect can be used for guidance of the instrument without additional micro-coils for tracking.

To assess the imaging performance, the device was tested in a phantom and a pig study, and the local SNR gain was analyzed at different locations in combination with a standard 140mm diameter surface coil.

Results and Discussion:

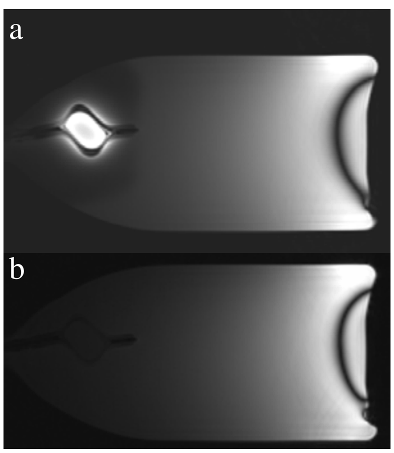

Fig. 2: Local SNR gain 120mm away from a 140mm diameter surface coil (a). Effectiveness of the passive decoupling (b).

The lowest common mode resonance of the transmission line was measured as 134MHz in tap water, which is comparable with previous devices equipped with transformer-based cables and suggests that this line is equally RF-safe for usage in an MR scanner (Philips Achieva 1.5T, Philips Medical Systems, Best, The Netherlands).

Fig. 2a shows an exemplary image obtained with the intravascular coil positioned 120mm from the center of a 140mm diameter surface coil (SSFP, matrix 256, slice thickness 4mm, flip angle 45°). The intravascular imaging coil had a mean SNR of 220 in a 6.4cm³ region centered at the coil. The SNR at the center of the intravascular coil was 370 compared with ~20 of the surface coil at this position, and with 300 at the center of the surface coil. The effectiveness of the passive decoupling is demonstrated in Fig. 2b, which does not show any SSFP artifact from a local flip angle gain, which was observed without passive decoupling (not displayed). Note, that, for both Fig. 2a and 2b, inductive coupling was minimized by orientating the dipole moment of the intravascular coil perpendicular to that of the surface coil.

Fig.3 shows the active visualization of the transformer line itself with the imaging coil in its folded state. The differential mode signal reaches an SNR of 170 in the most distal cable section close to the imaging coil and an SNR of 22 in the most proximal cable section. This differential mode signal was shown to be independent of the catheter position with respect to the z-axis of the scanner. The first and second transformer produced an SNR of 380 and 150, respectively. Note, that, since the signal is received via a separate channel, very low SNR down to e.g. ~5 would still allow for visualization and tracking of the device.

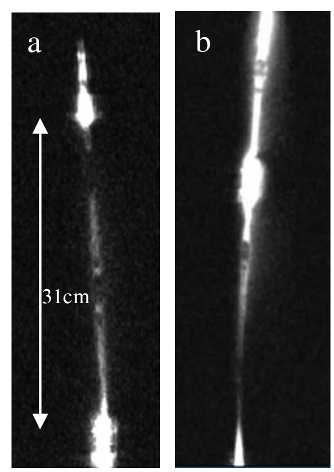

Fig. 3: Visualization of the transformer line at the tip section (a) and at a distance of 60cm from the tip (b).

Conclusion and Outlook:

Intravascular imaging was demonstrated using a self-expanding receive loop at the distal end connected via a self-visualizing, RF-safe transformer line based on distributed matching. The phantom and animal experiments indicate a significant SNR gain with respect to the local SNR produced by the imaging. A potential clinically relevant application for this technology may be lesion monitoring during tissue ablation e.g. in electrophysiology interventions or vessel wall imaging during maintained blood flow.

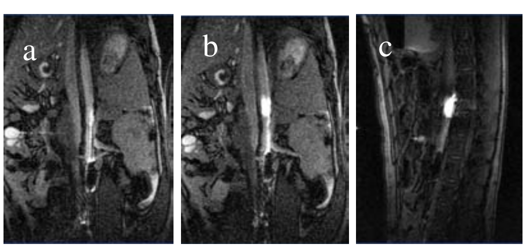

Fig. 4: In-vivo images obtained with the RF-safe intravascular imaging device ((a) folded state, (b,c) coronal and sagittal realtime images with the device in the expanded state).

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