The Bazooka Coil: A Novel Dual-Purpose Device for Active Visualization and Reduction of Cable Currents in Electrically Conductive Endovascular Instruments

C. M. Hillenbrand[1], A. Reykowski[2], E. Y. Wong[1], S. Rafie[1], W. Nitz[2], J. L. Duerk[1]

[1]Radiology, University Hospitals of Cleveland/Case Western Reserve University, Cleveland, OH, United States, [2]Siemens Medical Solutions, Erlangen, Germany

Introduction: Interventional magnetic resonance imaging is a rapidly growing field, with particular potential resulting from the recent advent of magnets with shorter lengths and wider bores. Much of the recent interest has been directed toward using exclusively MRI for vascular interventioal procedures. Therefore, visualization and tracking of endovascular devices (e.g., guidewires, catheters, stents), in combination with real-time MR imaging, has become a top priority in this emerging research field. Several techniques which incorporate an RF antenna in a catheter or guidewire have been introduced [1-3]. Some authors have demonstrated passive visualization of interventional instruments based on signal voids and/or susceptibility artifacts caused by the instrument [4,5]. Disadvantages of this approach are the dependence of the appearance on the MR sequence, the imaging parameters, the field strength, and the device orientation. Other investigators have focused on use of the conventional catheters and guidewires found in x-ray fluoroscopy (particularly nitinol guidewires) because of their familiar steerability, stiffness etc. While nitinol is not ferromagnetic and therefore suited for MRI, it is electrically conductive and may give rise to local heating if a sufficient length is used; specifically, resonating RF waves may develop along the conductor/guidewire [6,7]. These resonances cause induced electric voltages and currents to travel along the guidewire as standing waves during RF transmission. The same concerns are raised for catheter-based antennas due to the long coaxial cable connecting the antenna to the MR receiver [8,9]. In order to reduce the potential risk of standing RF waves in intravascular MR procedures and to improve the visibility of any conducting intravascular instrument (active antennas or conventional guidewires), we developed a novel device based on inductively coupled, cylindrically shaped standing wave barriers surrounding the interventional instrument outside of the body. This device can be used with any conductive wire structure (guidewire, catheter antenna etc.) which is small enough in size to be fed through the inductively coupled wave guide. Furthermore, this device allows one to extract an MRI signal from the intravascular device during receive mode, permitting device visualization and guidance, respectively. We designed, built and tested this device's feasibility for decoupling and signal reception in vascular phantoms and a porcine animal model.

Material Methods: The dual purpose device, here loosely referred to as the "bazooka coil", consists of a bazooka balun-style RF trap [10] with a hollow inner conductor (Fig.1). Any conductive interventional instrument fed through the lumen of this inner conductor will inductively couple to the trap. With the trap properly tuned, cable currents traveling on the interventional device will be minimized at the location of the trap. This effectively shortens the length of the conductor and reduces the risk of possible RF heating. The efficiency of the trap device is a function of the bazooka geometry and the length of the inductive coupling section. The fact that the trap couples to the interventional instrument is also used for extracting an MRI signal during the receive phase: a low noise, low impedance preamplifier is connected to the trap via a matching section. A PIN diode in front of this preamplifier activates the bazooka trap during the transmit cycle and also protects the preamplifier from excessive RF. The preamplifier is followed by a conventional cable trap which prohibits shield currents on the receive line during transmit. The entire device can be regarded as an independent RF coil connected to the MRI system using a separate receiver channel. However, the resonant detuning circuit common to all MRI coils is replaced here by a resonant bazooka balun. The bazooka coil was tested on a Siemens Magnetom Sonata 1.5T whole body scanner. For phantom imaging experiments, either an active catheter probe or a conventional nitinol guidewire (Terumo, Tokyo, Japan) was placed in a vessel phantom filled with saline. TrueFISP images were acquired in order to study the signal characteristics of the wire/coil when fed and imaged through the resonant standing wave barrier. Tracking capabilities, specifically the active visualization of the whole profile of a nitinol guidewire via the device was tested in the aorta of a pig animal model by using an interactive TrueFISP protocol (TE/TR 3.5/7ms, matrix 256^2, FOV 350mm, SL 8mm).

Results: Evaluations of the efficiency of our bazooka coil confirmed that currents on a test wire were reduced by >20dB with the device, thus shortening the effective wire length and reducing the risk of RF heating considerably. Here, the balun length was 17cm while the inner and outer diameters were 0.5 and 1.5cm, respectively. Imaging experiments in vascular phantoms revealed that the device was able to pick up the MR signal from any conductive structure fed through the hollow inner conductor. Figure 2b demonstrates inductive coupling into the bazooka balun; here signal from an opposed solenoid coil placed at the catheter tip and the coaxial cable are visualized. Single frames from a cine tracking experiment are shown in Figure 3. In this case, a nitinol guidewire was fed through the trap and advanced along the aorta. Combined images from a tracking movie acquired with the bazooka coil and the spine array are depicted in Fig. 3a. The enitre length (i.e. the profile) of the guidewire and surrounding tissues are clearly visible as a 5-10mm bright band within the aorta. The tip of the wire was identified faster and with higher accuracy by the interventionalist, when compared to experiments performed without the bazooka coil (Fig. 3b). Without the bazooka coil, the wire was visualized as a signal void (white arrows) which was not apparent in the image when the thin wire moved out of the slice plane.

Conclusion: We have successfully designed, built and introduced a device especially suited for interventional MRI. First, it reduces the formation of resonating RF waves on long conductors during transmission, thereby dealing with one of the main concerns of interventional intravascular MR. Second, the device is able to facilitate visualization of conductors and/or conventional interventional instruments under MR guidance without prior modifications to the instrument. This was confirmed in our *in vivo* experiments, where a conventional nitinol guidewire delivered a high-contrast signal over its entire length within the FOV and enabled depiction of the guidewire curvature and tip position. The use of a conventional interventional guidewire in combination with our bazooka coil retains the standard properties of the instrument (i.e. the "feel", the steerability), and allows the interventional instrument to act as an active RF antenna that is clearly MR visible. Since RF heating may be the most serious road block hampering the clinical use of vascular MR interventions, the bazooka coil is an important development for advancement of this field.

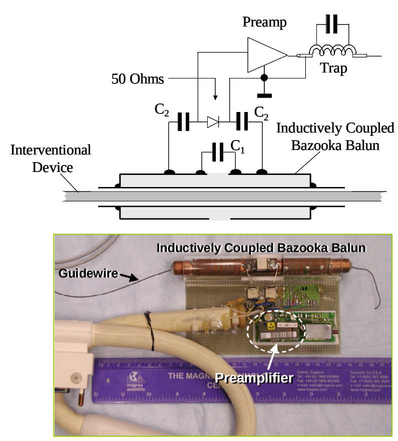

Fig. 1: Electrical schematic and photograph of the trap.

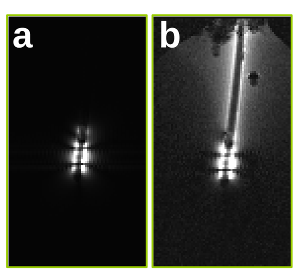

Fig. 2: MR signal reception with an intravascular antenna fed through the trap device. (a) Image acquired with the antenna, and (b) signal detected by the resonant trap circuit showing antenna at the tip of the catheter and the signal trace along the coaxial cable.

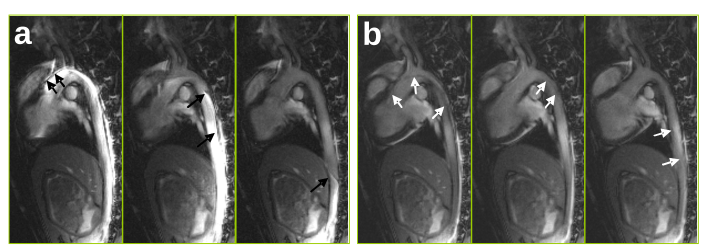

Fig. 3: Stills from an *in vivo* porcine guidewire (arrows) tracking experiment. (a) shows the whole profile of a nitinol guidewire actively visualized by the trap. The tip of the device is at any point in time clearly visible. (b) shows the same experiment repeated without the trap. The tip cannot be easily identified.

References: [1] Ocali, Atalar, MRM37:112-8(1997); [2] Ladd et al, MRM37:891-7 (1997); [3] Hurst et al, MRM24:343-57(1992); [4] Glowinski et al, MRM38:253-8(1997); [5] Bakker et al, Radiology 202:273-6(1997); [6] Liu et al., JMRI12:75-8(2000); [7] Konings et al., JMRI12:79-85(2000). [8] Ladd, Quick, MRM43:615-9(2000); [9] Atalar, ISMRM, p1006(1999); [10] Balanis, Antenna Theory, pp. 366.