A New Intravascular Loopless Monopole Antenna (ILMA) for MR Imaging

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Introduction:

In recent years, intravascular MR coil, which utilizes a special coil placed neighboring to the target artery, has been proposed to improve the local signal-to-noise ratio (SNR) and spatial resolution of vessel wall images. Especially the intravascular coil has identified its advantage in detecting atherosclerotic plaques [1]. At present, there are two types of intravascular MRI receivers: loop coil and loopless antennae [2]. The intravascular MR detectors mentioned in previous report are usually rigid and bulky, therefore are difficult to be inserted into small diseased vessels. Also the corresponding signal sensitivity of those small-loop coils falls off very rapidly. In this study, a novel long intravascular loopless monopole antenna (ILMA) design with a thin, non-shielded flexible guide-wire is presented. The guide-wire of ILMA, which was made of a flexible copper wire instead of conventional coaxial-cable, allowed a thinner volume to be applied into small vessels and enabled an enhanced longitudinal coverage. In vitro and in vivo test were carried out to assess the feasibility of the ILMA, including SNR, spatial resolution, and longitudinal coverage.

Materials and Methods:

Based on monopole antenna theory [3], the design of ILMA was shown in Fig 1. The guide-wire, made of copper wire, was 23.11 inches long, 0.0118 inch in diameter, and was connected to a tuning/matching circuit for obtaining high gain of signals. In the tuning/matching circuit, represented in Fig.1, there are three adjustable capacitors, C_1, C_2, C_3, respectively. C_1 serves for the Q-factor adjustment after tuning the resonant peak at 127.72MHz, C_2 is used to tune the resonant frequency roughly close to the expected Larmor frequency, and C_3 offers the fine-tuning near the Larmor frequency. To evaluate the sensing function of the proposed ILMA antenna, MR imaging was carried out by in vitro and in vivo experiments, via the tuning circuit to connect with a 3T whole-body MRI system (General Electric Medical System, Milwaukee, WI). A tube-flow phantom (3mm in inner diameter) was used to simulate the blood flow, and the average flow volume was set to 13.4mL/min. Scanning parameters were: sequence: GRE T2*, repetition time (TR) = 320.0 ms, echo-time (TE) = 11.0ms, Flip angle=15°, slice thickness =5.0 mm, FOV=8×8cm, Matrix=320×256, Phase FOV=1.0 and NEX=2; A cucumber of regular shape was employed to test the spatial resolution and the longitudinal coverage capability of the proposed ILMA, and the corresponding scan parameters were: sequence: GRE T2*, repetition time (TR) = 200.0 ms, echo-time (TE) = 11.0ms, Flip angle=25°, slice thickness =6.0 mm, FOV=8×8cm, Matrix=320×256, Phase FOV=1.0 and NEX=4. Finally, a healthy New Zealand white rabbit, approximately 4 Kg in weight, was used to evaluate the abdominal artery wall, and the scanning parameters were: sequence: Double IR FSE, repetition time (TR) = 800.0 ms, echo-time (TE) = 12.8ms, slice thickness =2.0 mm, FOV=8×7cm, Matrix=256×224, and NEX=4. The SNR of MR images were estimated by: $SNR = (S-N)/SD$. Where S is the signal amplitude of the region of interest (ROI) in the image, N represent noise and SD stands for the standard deviation of noise in the ROI.

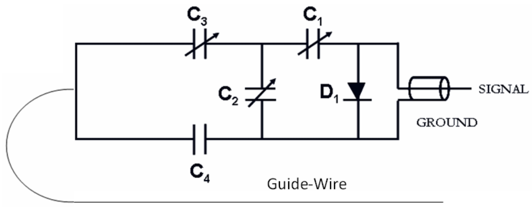

Fig.1 Schematic representation of the proposed ILMA.

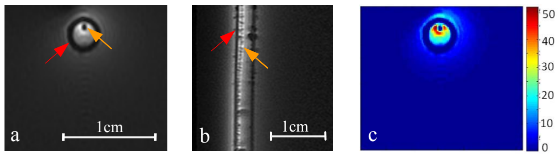

Fig.2. Validation in a tube-flow phantom at 3T. (a) The axis image. (b) The sagittal image. (c) The SNR map of (a). The red arrow indicates the outside diameter of the perfusion tube, and the yellow arrow indicates the position of ILMA.

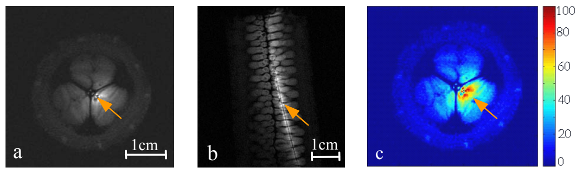

Fig.3. Imaging of a cucumber at 3T. (a) The axis image. (b) The sagittal image. (c) The SNR map of (a). The yellow arrow indicates the position of ILMA.

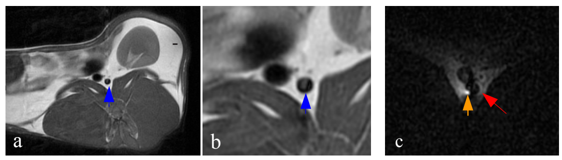

Fig.4. High-resolution axial image of the artery wall. (a) The scout image acquired with a knee coil. (b) The magnified image of (a). The blue arrow indicates the abdominal aorta of the rabbit. (c)The partial vessel wall cross-sectional image. The yellow arrow indicating the position of ILMA, and the red arrow pointing to the partial vessel wall of abdominal aorta.

Results:

From the acquired phantom MR images, the wall of phantom is clearly visualized with a high-resolution by using the ILMA, as shown in Fig.2a and 2b. The red arrow indicates the outside diameter of the perfusion tube, and the yellow arrow indicates the position of ILMA. Fig.2(c) shows the SNR map of Fig. 2(a). The ILMA based cucumber MR images are shown in Fig.3. (a and b), and the position of guide-wire is represented by the arrow in yellow. Fig. 3(b) demonstrates a clear sagittal image with at least 3.937inch longitudinal coverage. Fig. 3(c) shows the SNR map of Fig.3. (a). For the in vivo study, the scout image was acquired with an 8-channel knee coil (Extremity Coil, General Electric Medical Systems) for obtaining the anatomical orientation of the rabbit, as shown in Fig. 4a, and the blue arrow indicates the abdominal aorta of the rabbit. Although the images from the knee coil have high SNR, the abdominal aorta wall can not be distinguished from the tissues around it. Fig.4. (b) shows the magnified image of Fig. 4(a). Fig.4(c) demonstrates the partial vessel wall (0 to 6 o'clock position) high-resolution cross-sectional image by using ILMA, with the yellow arrow indicating the position of ILMA, and the red arrow pointing to the partial vessel wall of abdominal aorta.

Conclusion & Discussion:

As has been demonstrated, this study reports a new non-shielded MR imaging ILMA, which is different from the previous coaxial cable based catheter coil and loopless dipole antenna. The results suggest that the proposed ILMA can provide a larger longitudinal coverage for multi-slice vessel wall imaging with an acceptable SNR. It is worth mentioning that the flexible clinical-size guiding wire used in ILMA could be even thinner and thus easier to be manufactured, as it does not have any shielded wire at all. As a result, this type of antenna is convenient to be inserted into small vessels. In this study, since the guide-wire was touching the vascular wall (7 o'clock position), the signal of the vessel wall was overwhelmed locally, leading to a signal loss at partial artery wall. Although only the partial artery wall was observed in this study, it is believed that the loopless monopole based intravascular antenna can reveal more reliable diagnostic information on atherosclerosis in further study.

References:

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