Published in final edited form as:
Magn Reson Med. 2010 February 25; 63(3): 797–802. doi:10.1002/mrm.22152.

Tapering improves the forward-looking properties of the interventional loopless antennae

D. Qian[1,2], **A. M. EL-Sharkawy**[1], and **P. A. Bottomley**[1,2]

[1] Russell H. Morgan Department of Radiology and Radiological Science, Johns Hopkins University, School of Medicine, Baltimore, Maryland, United States

[2] Department of Electrical and Computer Engineering, Johns Hopkins University, Baltimore, Maryland, United States

Introduction

The loopless antenna is an intravascular detector comprised of a cable whose central conductor is extended to form a whip tuned to a quarter wavelength (λ/4) in the medium (1). It has maximum sensitivity at the whip-cable junction, declining to near zero at the distal tip of the whip. Interventional MRI detectors are commonly uniformly insulated to improve biocompatibility, mechanical stability, and reduce heating. However, uniform insulation increases the resonant whip length of loopless antennae, lowering sensitivity near the tip vs. uninsulated antennae. Poor tip visibility at MRI could result in vessel perforation, and limit applications where tip visibility and tracking is important, such as in the brain. Here we report that the distal sensitivity of the 3T insulated loopless antenna can be improved several-fold by redistributing the whip insulation via tapering. Tapering utilizes the large difference in dielectric constant between the insulation (ε ~3) and the sample (ε ~80) to increase the current sensitivity near the tip.

The distal distribution of the absolute signal-to-noise ratio (SNR) along the transverse plane of no-insulation, uniform-insulation, and tapered-insulation loopless antennae are determined by the numerical electromagnetic (EM) method-of-moments (MoM) at 3T and experimentally validated in a saline phantom. The SNR gain is demonstrated in a porcine aorta specimen.

Methods

The loopless antennae are formed from 2.2mm diameter UT-85-C cable with an 0.5mm inner conductor whip, and cable dielectric ε =2.2. The whips of two antennae are insulated with ε =3 polyethylene (PET) heat-shrink tubing: one with a standard uniformly thick 0.5mm layer, the other with a tapered layer of 1mm at the junction decreasing linearly from 1mm at the junction to 0.025 mm at the tip. The third is left un-insulated. The sample is a 0.35% bio-analogous saline phantom with conductivity σ =0.63 S/m and ε=80.

The whip lengths of the three antennae are numerically tuned to resonate in the sample by computing the impedance using *FEKO* EM MoM Software (South Africa) iterating the whip length for zero reactance. This yields resonant whips' lengths of 4cm, 16 cm, and 10 cm for bare, uniform-insulation, and tapered whips, respectively. The absolute SNR in $\sqrt{\text{Hz}}$/ml is computed from the scaled ratio of the circularly polarized RF field excited by a 1A current, to the root of the loaded antenna resistance.

Experiments are conducted on three antennae of identical geometry to that numerically computed, inserted in 0.35% saline. Each antenna is tuned for 3T and matched to 50Ω. SNR is measured on a Philips 3T scanner in MR images acquired with a gradient-echo sequence at fully relaxed conditions and from separate noise scans. The scanner noise figure is measured and accounted for. Finally, MRI of a pig aorta specimen is performed 1cm from the tip of the uniform and tapered-insulation antennae, for comparison.

Results

The computed current distribution of the three loopless antennae shows that the tapered antenna has the highest current sensitivity along the entire whip length even when normalized by its length (λ/4). The absolute experimental SNR of all antennae agree with the computed SNR within 10%, demonstrating that all of the losses are fully and correctly accounted for by the analysis, and that the experimental antennae are performing as best as can be theoretically expected [Fig 1]. At 1cm from tip, the tapered antenna has an SNR four times higher than the uniformly insulated antenna. This translates into a 16-fold gain in the sensitive field-of-view, defined as the area of contours exhibiting the same SNR [Fig 1]. Sagittal scans displayed with the same contrast level shows much higher SNR at the antenna tip for the tapered-insulation vs. the uniform-insulation antenna [Fig 2]. In the pig aorta, images acquired 1cm from the tip of the tapered antenna reveal the vessel outline, but the uniform-insulation antenna shows no anatomy [Fig 3].

Discussion

Numerical EM SNR analysis accurately predicts loopless detector SNR performance, making it an ideal tool for optimizing detector design. Tapering the whip insulation provides large gains in distal SNR and the forward-looking properties of the loopless antenna at 3T without compromising its small cross-section profile. This adds key value to its utility in interventional MRI.

Acknowledgments

Supported by NIH R01 grants EB007829, HL090728

References

1. Susil RC, et al. Magn Reson Med. 2003; 50:383–390. [PubMed: 12876715]

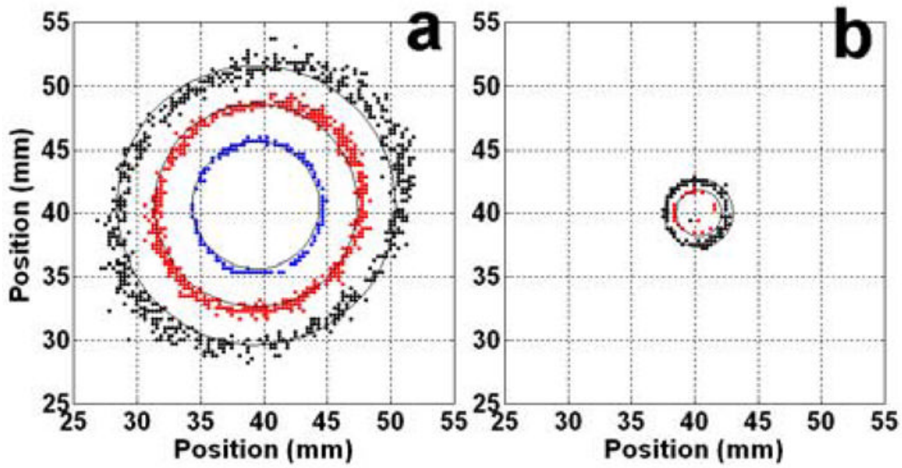

FIG 1.
Absolute SNR in axial plane 1cm from tip of (a) tapered-insulation antenna, and (b) uniform-insulation antenna (solid contours, computed; dotted, experimental SNR; black=65k, red=95k, blue=155k mL^{-1} $Hz^{1/2}$).

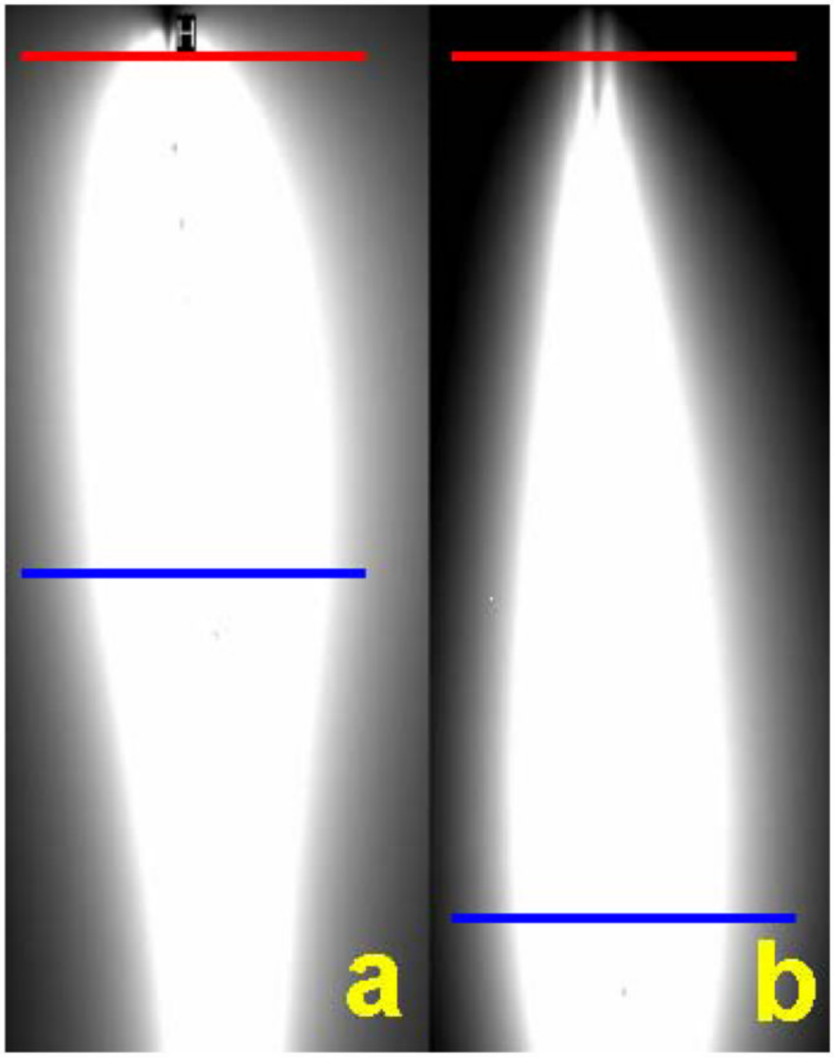

FIG 2.

Sagittal images of the tapered (a) and uniform antenna (b) whose image contrast are scaled similarly. Junction (blue line), 1cm from tip (red line).

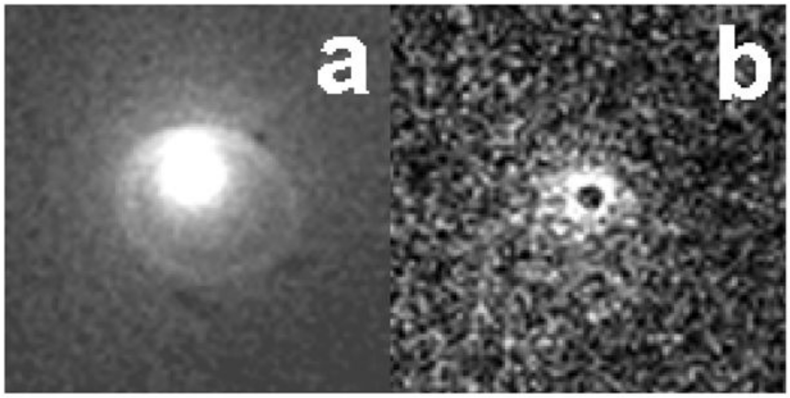

FIG 3.
Axial pig aorta images at 1 cm from the tip of (a) tapered-insulation antenna, and (b) uniform-insulation antenna.