The Feasibility of Asymmetrical Loopless Antennas for Therapeutic Ultrasound Catheter Cardiac Ablation Therapies

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INTRODUCTION: Recently, the use of MRI compatible ultrasonic catheters has been developed to treat ventricular tachycardia[1]. With these catheters, magnetic resonance thermometry (MRT) has been proposed for treatment monitoring, however, as denoted in the previous study there are limitations in obtaining thermal maps for the beating heart. To overcome these limitations, an intracardiac RF loop coil has been developed for the treatment monitoring of RF atrial ablation[2]. These local coils are beneficial to MRT as they provide greater SNR in phase difference images (SNR in phase difference images is directly proportional to SNR in magnitude images[3]). This increase in SNR can then enable faster image acquisition and artefact reduction. However, a combined imaging and treatment catheter has not yet been developed. In this study we propose the use of therapeutic ultrasound as a therapy delivery technique combined with a local asymmetrical loopless antenna for treatment monitoring. Asymmetrical designs address the challenges associated with local coils, that being of a compact design and a therapy delivery tool at the distal end. *The objective of this study was to demonstrate the feasibility of asymmetrical loopless antennas combined with therapeutic ultrasound for use in cardiac catheter ablation therapies.*

METHODS: To determine the optimal proximal and distal whip lengths that would enable ultrasound transducers to be used at the distal end of a catheter, simple simulations were performed. A method of moments (MoM) calculator was used (FEKO, Stellenbosch, South Africa), to determine the intrinsic SNR[4]. We simulated such loopless antennas as well as a-2-cm-loop coil and a 28-cm surface coil at both 1.5 T and 3.0 T field strengths. Our model consisted of a 20.0 × 20.0 × 20.0 × cm cuboid filled with blood. Two wire segments (whips) of varying lengths were placed in the centre of cuboid along with a port at various locations along the wire segments. The simulated magnetic field was taken 2 cm away from both the 2-cm loop coils and loopless coils and 10 cm away from the 28-cm surface coils.

Based on the simulations, a catheter design that gave rise to adequate SNR and transducer placement was constructed. It was determined that a 10 mm distal whip length and 80 mm proximal whip length gave rise to adequate SNR while allowing the functionality of an ultrasonic catheter for therapy delivery. A transducer and whip holder was rapid prototyped which enabled an air-backed 11 MHz 2.5 mm by 5.0 mm lead-zirconium-titanate (PZT) transducer to be placed approximately 10 mm from the distal end. The catheter was then aligned along the main magnetic field and Spoiled Gradient Echo (SPGR) sequences were used to determine overall SNR at various locations along the catheter shaft (axially). Imaging parameters include: FOV = 30 cm, TR/TE = 50/5.8 ms, flip angle= 30º, slice thickness = 5 mm, acquisition matrix = 256 × 256, NEX=1, total slices = 30, BW= 32 kHz. Fast gradient echo (FGRE) pulse sequences were used as MRT methods to detect temperature increases during heating experiments. Imaging parameters include: FOV = 20 cm, TR/TE = 39/20 ms, flip angle= 35º, slice thickness = 6 mm, acquisition matrix = 128x128, total slices = 1, scan time = 60-120 seconds dynamic scan (5 seconds per image). During all heating experiments, maximum acoustic power (4 W) was applied to both the phantom and ex vivo porcine samples for a duration ranging from 30-60 seconds.

RESULTS: It was determined that a 10 mm distal whip length and 80 mm proximal whip length would be best suited for such a catheter. There is a 37 % decrease in SNR when compared to the optimal case (43 mm proximal and distal whips[4]) and 118 % SNR increase when compared to a simulated 20 mm loop coil. The 28 cm loop represented a surface coil located 10 cm above the imaging region. The surface coil showed decreased SNR when compared to all loopless antennas. Figure 1 shows the SNR calculation for different simulated asymmetric loopless antennas. SNR measurements taken axially along the length of the catheter are illustrated in Figure 2. These SNR measurements show that the region of highest sensitivity is located at the port of both whips. This is also the location where the therapeutic ultrasound transducer is placed. Heating experiments then show reliable temperature maps in Figure 3. These MRT images are acquired simultaneously with the asymmetrical loopless antenna while the attached ultrasound transducer causes the temperature rise.

CONCLUSION: The results demonstrate the feasibility of using a combined asymmetrical loopless antenna with therapeutic ultrasound for catheter cardiac ablation therapies. These asymmetrical designs show a decreased SNR when compared to symmetrical loopless antennas, however, SNR measurements are still adequate which enables one to place a transducer on the device. These results suggest that such a catheter can provide a minimally invasive platform for both therapy delivery and treatment monitoring for cardiac ablation therapies.

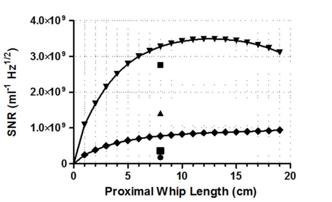

Figure 1: Simulation results showing SNR calculations for loopless antennas. The distal whip length is kept constant at 10 mm and varying proximal whip lengths (top curve at 3.0 T and bottom curve at 1.5 T) along with a 2 cm loop coil (square at 3.0 T, triangle at 1.5 T) and 28 cm surface coil (lower square at 3.0 T and circle at 1.5 T).

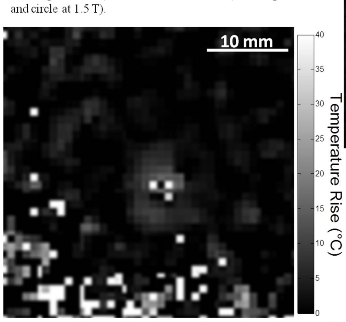

Figure 3: Ultrasound heating experiments in a phantom with MRT images acquired with the asymmetric loopless coil. The ultrasound transducer is directed upwards where the most significant heating occurs.

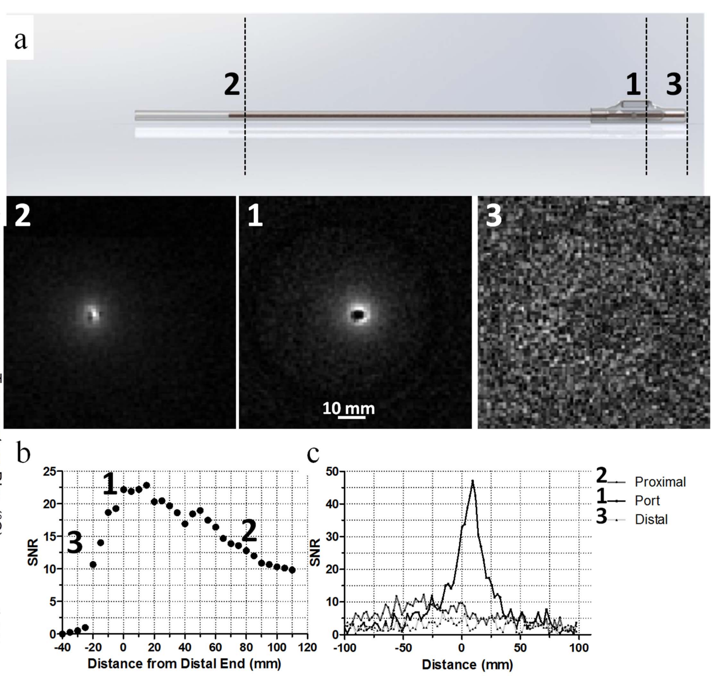

Figure 2: SNR measurements at the location indicated in. (a) Asymmetric loopless and therapeutic ultrasound configuration with 10 mm distal whip and 80 mm proximal whip and corresponding images axially through the dotted lines. (b) SNR measurements for axial images at the indicated locations. (c) SNR sensitivity profiles at the indicated locations.

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