Intra-cardiac Magnetic Resonance Imaging Catheter with Origami Deployable Mechanisms

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1 Background

Atrial fibrillation (AF) contributes to an estimated 750,000 hospitalizations and 130,000 deaths per year in the US [1]. Radiofrequency Ablation (RFA) therapy is a catheter-based minimally invasive treatment for AF. RFA electrodes embedded in the tip of a catheter are inserted from the femoral artery and maneuvered into the atrium (Fig. 1a & 1b). The abnormal tissue in the pulmonary veins of the atrium is ablated to electrically inactivate the sites causing irregular heart rhythm (Fig. 1c). Multi-parametric Magnetic Resonance Imaging (MRI) (e.g. T2-weighted, delayed contrast enhancement imaging) provides excellent soft tissue contrast and lesion visualization, which could serve as a roadmap for preoperative planning and intraoperative catheter navigation. With the use of an intra-cardiac (IC) MR imaging coil for real time visualization of the operation, electrophysiologists can monitor the ablated lesions, gaining greater control over the outcome of the procedure. In this study, we hypothesize that a specially designed catheter mechanism, which integrates a unique origami deployable mechanism for MR imaging, could enhance the safety and reliability of MRI guided RFA procedures.

![Fig. 1](image1.png)

Fig. 1 (a) Catheterization access from the femoral vein. (b) Illustration of typical EP therapy with catheters in the heart. (c) Catheter tip delivers a burst of high energy waves that cauterize the abnormal areas.

2 Methods

2.1 Mechanical design, fabrication, and optimization

The deployable mechanism is a modification of a previous design [3], displayed in Fig. 2a. The improvements of the new design (Fig. 2b) from the previous one include: multiple imaging coils enabling MR parallel imaging, ease of fabrication, imaging coils directly printed onto the catheter structure, and a low cost disposable design without the need of sterilization. The origami structure was constructed by micro-fabricating a 60 mm x 60 mm sheet of biocompatible polycaprolactone into an iso-area flasher pattern (Fig 2c), developed by Palmer and Schafer [2]. Copper circuits were printed in each corner of the catheter structure to form four square-shaped imaging coils. Through evaluation of geometric properties and mechanical strength of the structure, as well as the space required for placing tuning and matching electronics, an optimal shape design was determined. Laser-cutting and micro-fabrication techniques were used to miniaturize the prototype to an appropriate size to fit inside of the vessel in the stowed configuration (Fig. 3a) and expand inside the chambers of the heart in the deployed configuration (Fig. 3d).

2.2 Electronics for MR imaging

The imaging coils were connected to the tuning matching circuits (Fig. 4a) mounted on the catheter
structure, and then connected to the proximal end of the catheter through micro-coaxial cables. A network analyzer was used to tune the embedded circuit at 127.74 MHz (3T Larmor frequency) with -7.81 dB and matched to 50 ohm resistance (Fig. 4b). This provided an increase in the signal-to-noise ratio (SNR) at the resonant frequency of the MRI scanner, thus producing optimal image resolution and soft tissue contrast.

4 Interpretation

ICMRI catheter designs have been demonstrated to improve resolution and contrast visualization of soft tissue. The new ICMRI catheter integrated with origami deployable mechanisms improves the previous design with multiple imaging coils directly printed on the catheter origami structure using laser-cutting and micro-fabrication techniques, allowing for a low cost disposable design without the need of sterilization. The presented deployable mechanism could be an enabling technique for cardiac EP catheter designs and could also be applied to other medical applications that involve expandable and large surface structures.

Future work includes in vivo studies of the ICMRM catheter in swine models to further evaluate the hardware designs for MR imaging and MR-guided EP procedures.

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References

