

# Imitation of Radiofrequency ablation scars with laser system for MR guided ablation of Atrial Fibrillation

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## INTRODUCTION:

Atrial Fibrillation (AF) is among the most common cardiac arrhythmias with a high risk of mortality and morbidity [1-2]. There are several minimally invasive catheter approaches that are performed under imaging guidance. These methods imitate the linear and transmural cuts and sutures along the atrial walls as in the widely accepted surgical Cox Maze procedure to block undesired currents. Cryotherapy, microwave ablation, radiofrequency (RF) ablation, and laser ablation are common techniques used in these procedures. Catheter delivery of RF energy to the cardiac chamber is widely used and approved as safe and successful [4]. The operation is commonly performed under x-ray, which suffers from poor soft tissue contrast. In addition, the surgeon has to decide whether the local ablation is successful by looking at the simultaneous ECG data, which makes the operation technically difficult and time consuming. Due to the long exposure times, x ray burns may occur. MR imaging during RF ablation is possible with proper matching and tuning circuits [3]. However, during the operation RF and ECG catheters may cause artifacts in the image for some orientations. On the other hand, fiber delivery of laser energy has no MR compatibility issues and is used with MR guidance in the field. It is not widely used in treatment of AF, since there is a risk of perforating the myocardial wall. Several diffusing tip designs have been proposed to emit light in cylindrical symmetry [7] to produce a more even effect, but, due to its orientation with respect to the cardiac chamber, common RF delivery methods cannot be applied directly. Here, we propose a novel multiple fiber scheme for delivery of laser beam that imitates the scars created with RF probes under MR guidance. This scheme imitates the ablation pattern of RF delivery and as such is expected to have quick adaptation by physicians. As a preliminary demonstration, we used a 3-fiber scheme supported by real-time MR thermometry maps of the ex-vivo and in-vitro ablation zones during laser delivery.

## THEORY:

The main principles of creating ablation lesions by both RF and laser energy delivery are similar, but with important differences. The high current density at the tip of the RF probe encounters high impedance. However, this resistive effect takes place within a 1-mm range [5]. The rest of the energy is dissipated through heat conduction. The unipolar electrode tip creates half spherical lesions inside the tissue. In case of laser delivery, absorption of laser light by tissue is the main mechanism of energy transfer, leading to localized heating. For our wavelength of operation (980 nm) the penetration depth is about 3 mm. The beam from a fiber has Gaussian shape, creating narrow and deep lesions (Figure 1b). We assumed that the tissue characteristics are both temporally and spatially linear (negligible variations in absorption, scattering coefficients during the initial period of ablation). Virtually any desired lesion pattern can be obtained by changing the number of fibers, their orientations and wavelengths. A simple approach is to place three fibers in the orientation shown in Figure 1c, where the impulsive absorption ( $J/cm^3$ ) responses spatially add up and create a half circular lesion in the xz plane. The rest of the energy is then dissipated in a spherical geometry deeper into the tissue. Since the temperature distribution is related intimately with the absorbed energy, MR thermometry images and sections of ablated lesions on both phantoms and tissues are compared with simulation results.

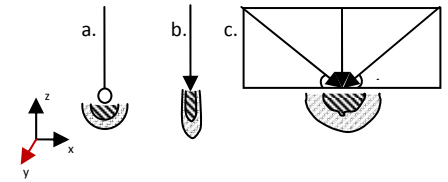


Figure 1 – a. Unipolar RF electrode lesion b. Single fiber excited lesion c. Our design

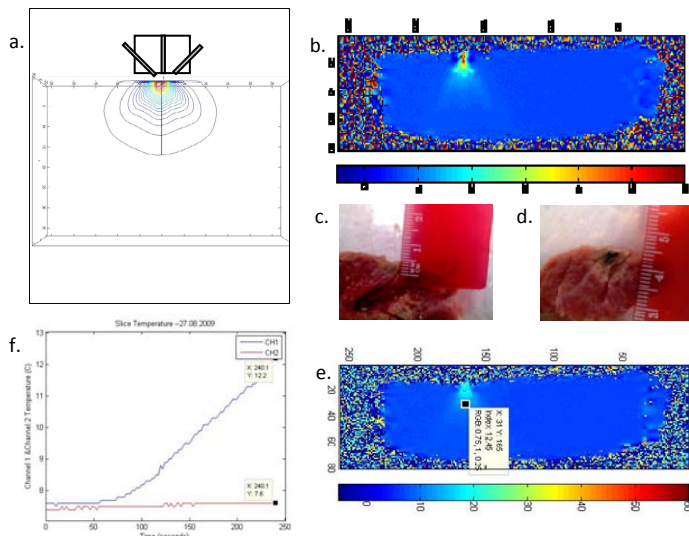


Figure 2 - a. Simulation Results for 1um wavelength fiber excitation. b. MR Thermometry image of the excited slice (ex-vivo tissue) after 3.49min laser delivery c. The slice in the xz plane of the tissue ablated with 5W 3.49 minutes of RF delivery. d. The slice in the xz plane of the tissue ablated with total of 5W 3.49 minutes of laser delivery. e. MR Thermometry image of the slice after 3.49min laser delivery where the non-reference temperature sensor probe is inserted (gel) (12.4°C at 3.49min). f. Temperature measurement of the sensor (e) with respect to time (12.4°C at 3.49min).

## ACKNOWLEDGEMENTS:

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## REFERENCES:

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## SIMULATIONS and RESULTS:

Monte Carlo Simulations of photon transport equations for a single fiber are implemented and combined with a MATLAB-based code to predict 3D distribution of the three-fiber system in Figure 1c. Experimentally, three fiber-coupled diode lasers operating at a central wavelength of 970 nm and providing a maximum of 10 W average power each were used. The fibers were extended into the scanner room and placed in their positions. Tissue samples were placed inside saline water to inhibit charring at the tip and to simulate, to some extent, the cooling effect of blood. Two optical temperature sensors (Neoptix, CA) were placed, one 1-cm posterior to the fiber holder (to prevent excess heating due to the incoming laser light), and the other to a reference point, where no heating occurs. The samples were imaged with a 3T Siemens Magnetom Trio inside a head matrix. GRE (TR = 80ms, TE = 20ms, number of slices = 5 with data acquisition time of 5.25 sec/slice, 200 Hz-px BW with a measurement number of 40) sequence was applied. The simultaneous temperature mapping was done based on the PRF shift method [6]. The simulation results were then compared with gel and tissue experiment results (Figure 2) including the temperature measurements of the sensor.

## CONCLUSION AND DISCUSSION:

In this preliminary work, it is shown that we are able to create lesions with a novel fiber-based laser ablation scheme, where the lesion pattern imitates the commonly used RF energy delivery techniques. The real-time MR thermometry images are consistent with local temperature measurements. In addition, the lesion patterns as determined both from thermal maps, and slices of ablated tissue are mutually consistent and in agreement with numerical simulations. The preliminary results are promising. Several fiber diffuser tip designs have been reported for use in tumor ablation operation, however the geometry of the designs is not suited AF treatment due to high risk of perforating the myocardial wall. Spherical laser energy induced lesions as described here are deeper, potentially minimizing recurrence of AF after the treatment and may compensate the deficiencies of the RF ablation. This approach has full MR compatibility: no distortion in the phase images occurs, and real-time MR thermometry maps during the operation can easily be recorded. Efforts are under way to develop a more compact scheme, such the fibers can be packaged to 1-2 mm diameter to be inserted through the veins. Different orientations and fiber tips are being explored to obtain beam profiles closer to a perfect spherical distribution.