Focusing electrical current at depth for ablation

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Abstract: During ablation, current must penetrate deeply into tissue to deposit energy; to achieve this, electrodes must be spaced further apart, affecting more tissue than necessary. We propose a strategy to focus current at depth using multiple surface electrodes and an optimal current-drive strategy. Simulation results in 2D show promising improvements.

1 Introduction

Catheter ablation is a minimally invasive procedure to destroy abnormal tissue. This study is motivated by the use of radiofrequency catheters to apply electrical energy to arrhytmogenic sites on the endocardium, as a therapeutic technique for atrial fibrillation (AF).

Current catheters have two electrodes through which current is applied, and modern designs typically use advanced features such as open saline irrigation which cools the surface of the heart muscle[2]. To be effective current must penetrate sufficiently deeply into the tissue so energy reaches the entire ablation site. However, in order to penetrate sufficiently deeply, electrodes must be spaced further appart, and thus the width of the region to which current is applied is large.

This study is motivated by the need to achieve deep current penetration, while still maintaining a narrow width of application. Our proposed approach is to use multiple surface electrodes and calculation of an optimum pattern to produce current in a region of interest.

2 Methods and Results

Using EIDORS[1], a model of an homogeneous half space with 11 surface electrodes is created and the 2D plane vs. depth along the electrodes shown for an inner region (Fig. 1). A region of interest (ROI) is identified (green box) in which it is desired to have uniform current density magnitude, $|\vec{J}|$. On each side of the ROI, a region ROIx is identified in which it is desired to have zero current density, $\vec{J} = 0$.

Using these 11 electrodes, $11 \times 10/2 = 55$ pair-drive current patterns are possible. For each pattern, i, the forward model is solved to calculate $\vec{J}_i$ throughout the model. The magnitude $|\vec{J}_i|$ is shown for a few patterns.

In order to calculate an "optimal pattern", $\mathbf{c}$, we seek the value of current to be appled through each pattern, c_i. Thus if patterns 1,2 and 5 apply positive current through electrode #1, the optimal pattern will apply $c_1 + c_2 + c_5$ through this electrode. A Jacobian (sensitivity) matrix, $\mathbf{J}$ is calculated via vertical concatenation of each vector component of $\vec{J}$.

Vector $\mathbf{c} = \left(\mathbf{J}^t\mathbf{W}\mathbf{J} + \lambda\mathbf{I}\right)^{-1}\mathbf{J}^t\mathbf{W}\mathbf{d}$ is then calculated, where λ is a small Tikhonov regularization factor, $\mathbf{W}$ is a weighting of each element's importance (currently uniform) and $\mathbf{d}$ is 1 in ROI and 0 in ROIx (other areas are ignored).

Fig. 1 shows three bipolar patterns (with the classic depth-width trade-off) and the "optimized" pattern for the identified ROI. A clearly more uniform current in the ROI has been achieved, in this simplified, 2D model.

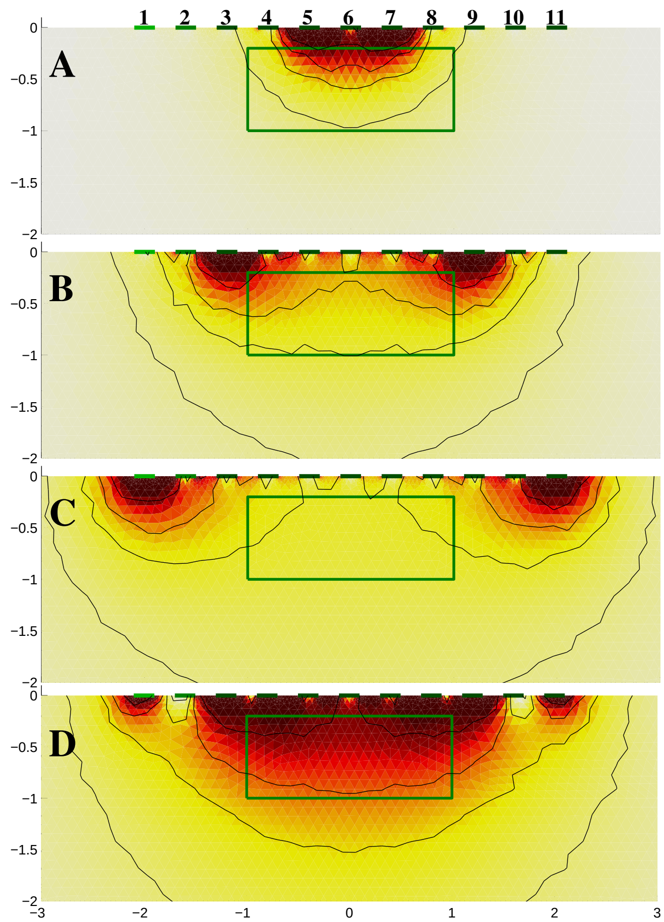

Figure 1: Current density vs. depth for four different current drive scenarios (darker colours indicate higher current). Contours indicate 5%,10%,15% and 25% of maximum. Electrodes: A) 5→7, B) 3→9, C) 1→11, D) optimized pattern (all electrodes).

3 Discussion

Previous data[3] show that bipolar ablation is feasible in vivo. However, current technology used in circular catheters is limited to ablation within the atria. The present model has the potential to improve ablation technology with linear ablation catheters, resulting in an increase ablation lesion size and depth with wide clinical applicability.

These simulation results are promising and suggest that it may be possible to achieve improved ablation performance using multiple electrodes with optimized current patterns.

References

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