Computer Simulations Outcomes of Left Atrial Arrhythmia Induction are Highly Sensitive to Scar and Fibrosis Determination

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Abstract

Personalized computational models used to guide ablation heavily depend on late gadolinium enhanced images for scar and gray area estimation. The estimation has a high degree of uncertainty, but it is unclear how sensitive the simulation outcome is to the specific scar. In this work, we study the sensitivity of the simulation outcome on the scar.

Two personalized left atrial models were generated for a de-novo and a redo atrial. In control setting scar and gray area were obtained by thresholding LGE-MRI images at 70%, and 60% of the maximum myocardial intensity, respectively. This was compared against segmentations, generated by dilating, or eroding the control segmentation by one pixel, and increasing or decreasing the threshold by 5%. The outcomes were normal capture without further activity, extra beats with additional activity but not sustained, sustained arrhythmia with activity until the end of the simulation, and no capture.

We found normally captured beats were not affected in redo cases but did change in de-novo ablation. However, extra beats were likely to change to arrhythmia when adding or subtracting scar. Sustained arrhythmia was sensitive to a reduction in scar size.

This reiterates that attention is need when determining appropriate thresholds for scar and gray area.

1. Introduction

Personalized computational models are being used to guide ablation [1]. While detailed cardiac meshes can readily be obtained from magnetic resonance imaging (MRI), gray area and scar are often obtained by threshold segmentation of the late gadolinium enhanced MRI (LGE-MRI). The determination of the segmentation threshold is an active field of research [2, 3] with many different methods. This leads to small differences in scar and gray area distribution and content. While it is clear that it does impact scar visualization and estimates, it is unclear whether the outcome of computer simulation will change.

Therefore, we study how small changes in scar segmentation affect the prediction of simulations.

2. Methods

First, we describe the mesh generation than the computational settings.

2.1. Mesh Generation

At random, two patients were selected one from a de-novo ablation and one from a redo atrial ablation. Magnet resonance angiography (MRA) images were manually segmented with CorView (University of Utah) to obtain the endocardial surface. The MRA was chosen over the LGE-MRI because of its smaller voxel size of $0.625 \times 0.625 \times 1.25mm$, where the LGE-MRI has a voxel resolution of $0.625 \times 0.625 \times 2.5mm$. Before the endocardial surface was extracted the segmentation was resampled to $0.625 \times 0.625 \times 0.625mm$. The epicardial surface was generated by inflating the endocardial surface by $1.5mm$. The resulting mesh was smoothed and converted into a tetrahedral mesh with tetGen. Then the myocardial fiber orientation was projected to each geometry form a mesh with known fiber orientation.

The scar was obtained from the LGE-MRI. First, the left atrium was segmented, then the LGE-MRI was masked to contain the atria only. From the masked image, a threshold segmentation at 70% and 60% maximum intensity were performed, resulting in scar the gray area, respectively. From this segmentation, the modified segmentations are derived. The first two modifications are dilatation and erosion by a single voxel in the image plane. Two further modifications were generated by reducing or increasing the segmentation threshold by 5%. All segmentation were projected in the computational model after the LGE-MRI was rigidly registered to the MRA.

2.2. Simulations

For the resulting two different geometries with each five different scar and gray area simulation of activation were

Region	Normal	Gray Area	Scar
Longitudinal [m/s]	0.3552	0.0554	0.0000
Transversely [m/s]	0.1332	0.0554	0.0000

Table 1. Conductivities for the different tissue regions

Ion channel	g_{Na}[%]	g_{to}[%]	g_{CaL}[%]	g_{K1}[%]	g_{Kr}[%]
Normal	1.0	0.8	0.2	0.9	1.6
Gray Area	0.8	1.0	0.3	0.5	1.0
Scar	0.0	1.0	0.0	0.0	1.0

Table 2. Ion Channel Modifications in Percent of Original

performed. For the numerical simulation, the opensource software openCARP was used. The software implements the finite element methods to solve the diffusion part of the monodomain equation which was used in this work. The conductivity's used are listed in Tabel 1. For the ion exchange at the cell membrane, the Courtemanche model[4] has been modified according to Table 2

To induce atrial fibrillation or flutter, eighth S1 paced beats with a cycle length of 600ms were followed by a premature S2. The S2 ranged from 160ms to 300 ms in 10ms steps. Each simulation was continued two seconds after the S2 beat or until electrical activity ceased.

The simulation was then examined to classify the outcome in one of four possible classes. The first class "Normal capture" is if the last S2 is captured and propagated normally without any reentry. For the second class, "Extra Beat" one or two additional beats followed the S2 beat, but activity ceased before reaching the 2sec end of the simulation. If the activity was sustained until the end of the simulation the outcome was called "sustained activity". Finally, if the S2 did not propagate we called it "no capture".

3. Results

The different scar segmentation resulted in scar covering between 1 and 10% of the total mesh volume. While the gray area content varied between 9 and 31% (see Tab. 3). The scar distribution for the redo ablation is shown in figure 1

The simulations of the four modified scar segmentations show a dependency of the simulation outcome on the segmentation (Tab. 4). In the redo ablation, up to 13 of the 60 simulations worsen in the outcome, where in first time ablation this increased to 19 out of 60. Normal captured beats were not affected in redo cases but did change in de-novo ablation. Extra beats were likely to change to arrhythmia when adding or subtracting scar.

	Scar [%]	Gray Area [%]
Control	3	31
Plus One Pixel	8	31
Threshold -5%	10	31
Minus One Pixel	2	9
Threshold +5%	1	21

Table 3. Scar Content

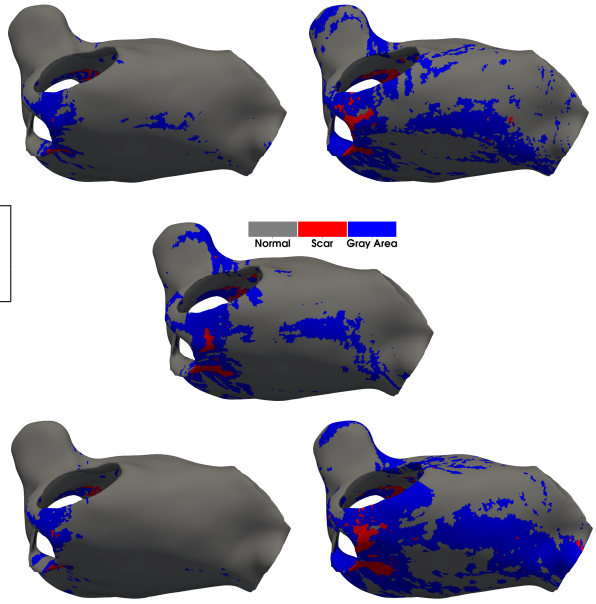

Figure 1. Difference in scar and gray area for different thresholds. *Top:* Left threshold -5 percent, right plus 5 percent, *middle:* control *bottom:* left minus 1 Pixel, right plus 1 pixel.

4. Discussion

First time ablations appear to be more robust towards an increase of the segmentation threshold. This could be related to more continuous scar and overall less scar in first time ablation. In contrast, redo ablations show previous ablation lines which can develop wholes when increasing the threshold. Wholes or partial lines are suspected to contribute to the need for redo ablation. Lowering the threshold, and thereby increasing the scar in some cases leads to a worse outcome, which is expected. For a few redo ablation, it improved the outcome, which could be explained by the assumption that the lower threshold might fill interruption in lines existing in higher thresholds.

5. Conclusions

The computational prediction of arrhythmia inducibility in the left atria depends on the segmentation of scar and gray area. Showing the importance of reliable scar segmentation methods, or more appropriate it might be needed

		Redo Ablation					First Time Ablation				
Control		Normal Capture 14	Extra Beat 16	Sustained Arrhythmia 18	No Capture 12	Total	Normal Capture 31	Extra Beat 17	Sustained Arrhythmia 2	No Capture 10	Total
Plus One Pixel	Normal Capture	14				14	18	1			19
	Extra Beat		1	1		2		3			3
	Sustained Arrhythmia		13	15		28	7	7	2		16
	No Capture		2	2	12	16	6	6		10	22
Threshold -5%	Normal Capture	14	2	1		17	19				19
	Extra Beat		1	1		2	3	7			10
	Sustained Arrhythmia		11	13	1	25	9	7	2		18
	No Capture		2	3	11	16	0	3		10	13
Plus One Pixel	Normal Capture	14	2	1		17	31	15	2	2	50
	Extra Beat		1	2		3		0			0
	Sustained Arrhythmia		11	11	1	23			0		0
	No Capture		2	4	11	17		3		10	13
Threshold -5%	Normal Capture	14	2			16	31	13	2		46
	Extra Beat		8	11		19		2		2	4
	Sustained Arrhythmia		6	7	1	14			0		0
	No Capture				11	11		2		8	10

No Change Worse Outcome Improved Outcome

Table 4. Simulation outcome for one redo ablation and one first time ablation. Arrhythmia induction was tested with S1-S2 pacing, where the S2 ranged from 300ms to 160ms. Four different positions for stimulation were explored resulting in 60 outcomes per test case. On top are the results from control settings, results from the modified settings are found on the right gray rows. The middle section shows the change observed from control. Green boxes indicate no change, red a worse outcome and cyan an improvement.

to include uncertainty of the scar segmentation in computational predictions.

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