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Initiation and maintenance of re-entrant cardiac propagation: a computational vulnerability study

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Introduction

- Numerous works have addressed atrial arrhythmogenicity of a given electrophysiological model using different methods to initiate and maintain re-entrant activity.
- No common procedure to test atrial fibrillation vulnerability in silico has yet been defined.

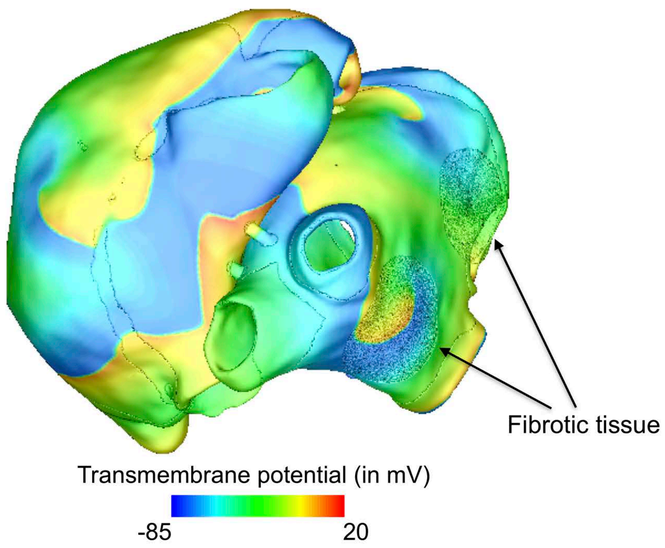
Methods

Atrial model

- Tetrahedral mesh with 0.33 mm of average edge length (11,205,866 elements)
- Fibre orientation given by a semi-automatic rule-based algorithm [1]
- Courtemanche atrial fibrillation remodelled in 9 regions with different conduction velocities [2]
- With fibrotic tissue (wF) and without fibrotic tissue (noF) in circular left atrium regions with radius of ~7 mm
- Monodomain model

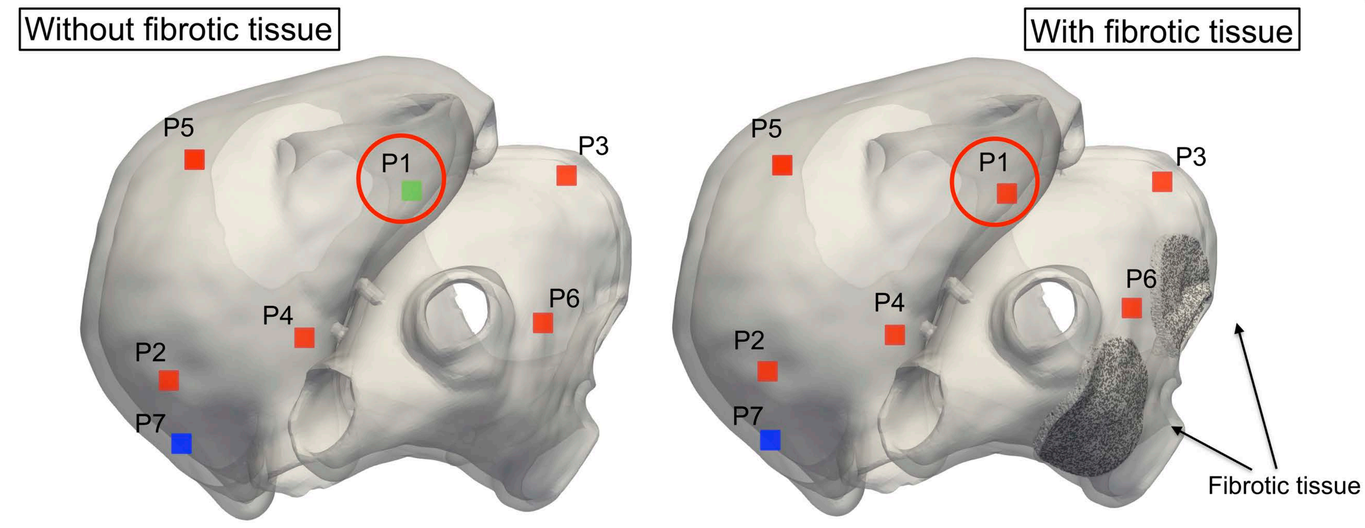
Arrhythmia initiation

- S1-S2: Continuous beating from the sinus node and rapid extrastimulus pacing from the rim of one of the four pulmonary veins (PVs) [3].
- Phase singularity distribution: Placing phase singularities in the atria, estimating an activation time map solving by the Eikonal equation and using this as initial state for the monodomain simulation [4].



Results

Phase singularity distribution



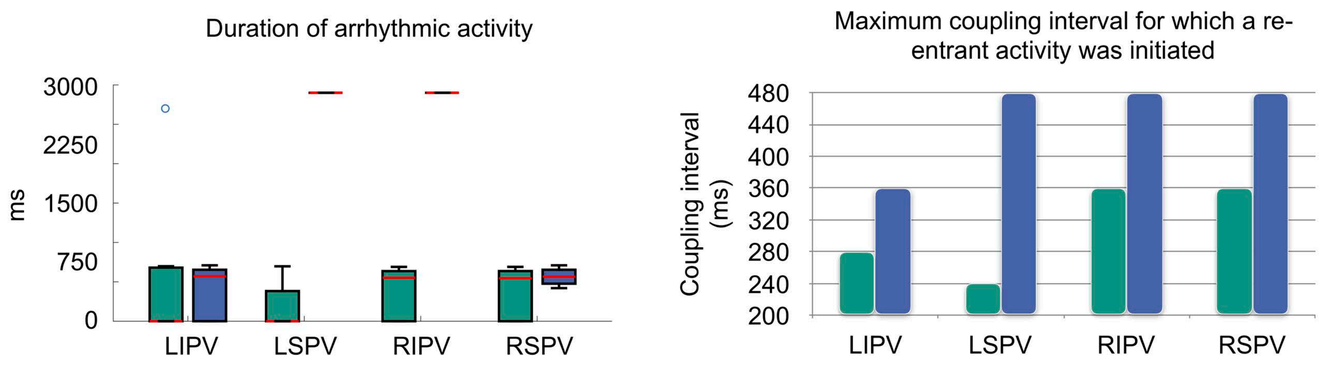
Duration of arrhythmic activity with phase singularity placed at this point:

- < 2000 ms
- = 2500 ms
- = 5000 ms

Duration (in ms) of re-entrant activity starting from initial states with 3 phase singularities set in points P2, P3, P6. The simulation time window was 5000 ms.

Points \ Setting	noF	wF
P2, P3, P6	5000	5000

S1-S2



Duration (in ms) of arrhythmic activity with extrastimulus pacing from different rim of the four pulmonary veins with coupling intervals (CI) between the sinus rhythm and the first pulmonary vein in the range of 200-480 ms. The simulation time window was 2900 ms.

CI \ PV	LIPV		LSPV		RIPV		RSPV	
	noF	wF	noF	wF	noF	wF	noF	wF
200	698	710	697	2900	690	2900	690	710
240	656	670	656	2900	655	2900	654	670
280	2700	630	0	2900	610	2900	613	630
320	0	590	0	2900	572	2900	571	590
360	0	550	0	2900	530	2900	520	540
400	0	0	0	2900	0	2900	0	500
440	0	0	0	2900	0	2900	0	460
480	0	0	0	2900	0	2900	0	420

LIPV: Left inferior pulmonary vein
LSPV: Left superior pulmonary vein
RIPV: Right inferior pulmonary vein
RSPV: Right superior pulmonary vein

Conclusion

- The inclusion of fibrotic tissue in the atrial model increased the inducibility time window with the S1-S2 protocol. Therefore, initiation of re-entrant cardiac propagation with the S1-S2 protocol is easier in the atrial model including substrate modification.
- Initiation of re-entrant drivers is not different taking into account the inclusion or not of fibrotic tissue in the atrial model using the phase singularity distribution method.
- Maintenance of re-entries generated with the S1-S2 method is in most of the cases longer in the atrial model including fibrotic tissue.
- No re-entrant activity was sustained for the whole simulation time window with the S1-S2 protocol using the atria model without fibrotic tissue.
- Maintenance of re-entries generated with the phase singularity method is equal in the atrial model including fibrotic tissue exception for one point.
- Both protocols show a greater vulnerability to arrhythmic activity of the atrial model with fibrotic tissue areas.

[1] Wachter A. et al., Mesh structure-independent modeling of patient-specific atrial fiber orientation, CDBME, 2015.
[2] Loewe A. et al., Influence of chronic atrial fibrillation induced remodeling in a computational electrophysiological model, Biomed Tech, 2014.
[3] Roney C. H. et al., Variability in pulmonary vein electrophysiology and fibrosis determines arrhythmia susceptibility and dynamics, Comp. Biol., 2018.
[4] Jacquement. V., An eikonal approach for the initiation of reentrant cardiac propagation in reaction-diffusion models, IEEE Trans Biomed Eng, 2010.

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