

1 Simulation Outline

1.1 Overview

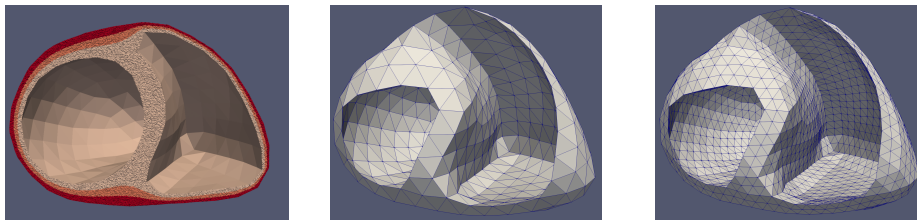
This repository contains simulations of ventricular pacings, performed on the same geometry. It consists of signals of three source models (transmembrane voltages (TMVs), extracellular potentials (EPs) on the epicardium and endocardium, and EPs on the pericardium (pericardial potential (PP))) for both physiological and pathological cases. Three different pacings were considered (left ventricle lateral (lvL), right ventricle lateral (rvL), and right ventricle septal (rvS)). Geometries and transfer matrices are also provided.

Table 1 lists the simulations, Figure 1 depicts the heart geometry in different resolutions and Figure 2 depicts the three different stimulus points. The naming convention follows the rule: **origin-of-pacing**, **type-of-scar**, and **location-of-scar**, separated by underscores, so `lvLateral_blockLine_lvAnterior` is the simulation with a pacing on the left ventricle lateral wall, which has a line of block on the left ventricle anterior side of the heart.

1.2 Geometries

1.2.1 Used Surface Meshes

A triangular surface mesh of the two ventricles with mean edge length of 12.415 mm (resolution (Res) 0) was used as the basis model of the heart. This model was one and five times linearly subdivided to obtain finer mesh resolutions on the same geometry. Res 1 has therefore a mean edge length of 6.208 mm, Res 5 a mean edge length of 0.388 mm. For the simulations, a volume mesh of tetrahedrons with mean edge length of 0.530 mm, was derived from the surface mesh of Res 5 to ensure that the surface vertices existed on the volume mesh.



(a) Volume mesh used for simulations (red: epi-layer, orange: mid-layer, amber: endo-layer). (b) Surface mesh with mean edge length 12.42 mm (Res 0), used for reconstructions. (c) Surface mesh with mean edge length 6.26 mm (Res 1), used for reconstructions.

Figure 1: Heart geometries used for simulations and reconstructions.

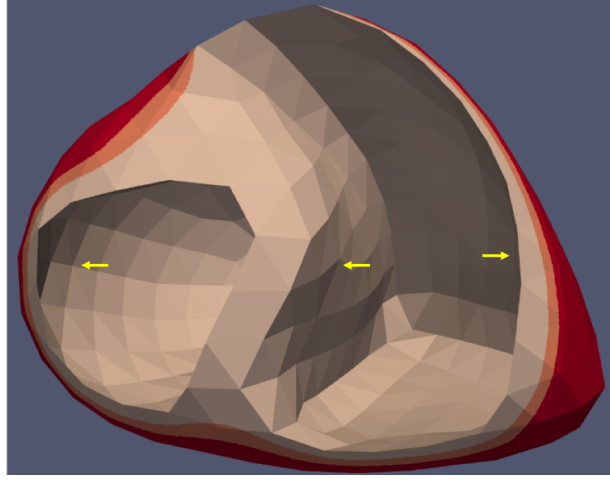


Figure 2: The three stimulus points, indicated by arrows. From left to right: lvL, rvS, rvL

1.2.2 Pathological Geometries

Two types of pathological geometries were created in this work:

- Lines of block (LOBs) (six geometries)
- Scar Patches (two geometries)

The epi-endocardial LOB geometries are depicted in Figure 3, the transseptal LOB geometries in Figure 4, and the scar patch geometries in Figure 5.

LOBs on the epicardium were created using solutions of Laplace's equation. This ensures that the LOBs are in the middle between the two ventricles. The trajectory inside the volume mesh was determined by following gradient streamlines to each endocardium (again, using solutions of Laplace's equation). Figure 6 depicts solutions to Laplace's equation. Figure 6 shows the solutions to Laplace's equation.

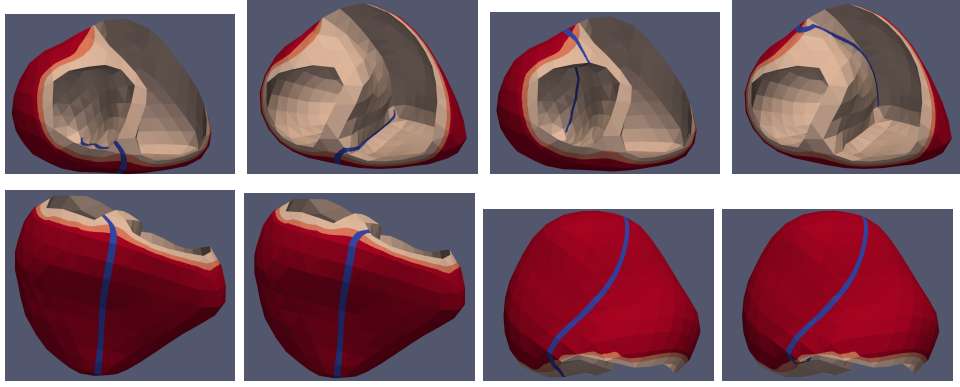
Transseptal LOBs were created by interpolating the intermediate points between the LOB on the endocardium.

Scar patches were created by choosing a seed point on the epicardium and including all points within geodesic distances of 20 mm and 40 mm, respectively.

1.3 Monodomain Simulations

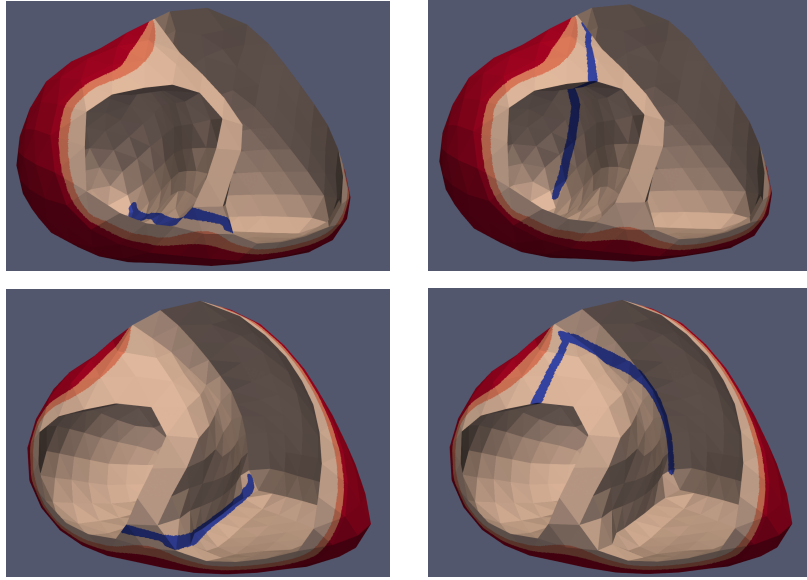
1.4 General Parameters

The simulations were performed using standard models. This included the Ten Tusscher et al. ionic model of 2006 [4], different cell model variants for endo-, epi- and mid-layer, and realistic fiber angles of $\alpha = \pm 60^\circ$ for



(a) Epi-endocardial scar on the left ventricle posterior side. (b) Epi-endocardial scar on the right ventricle posterior side. (c) Epi-endocardial scar on the left ventricle anterior side. (d) Epi-endocardial scar on the right ventricle anterior side.

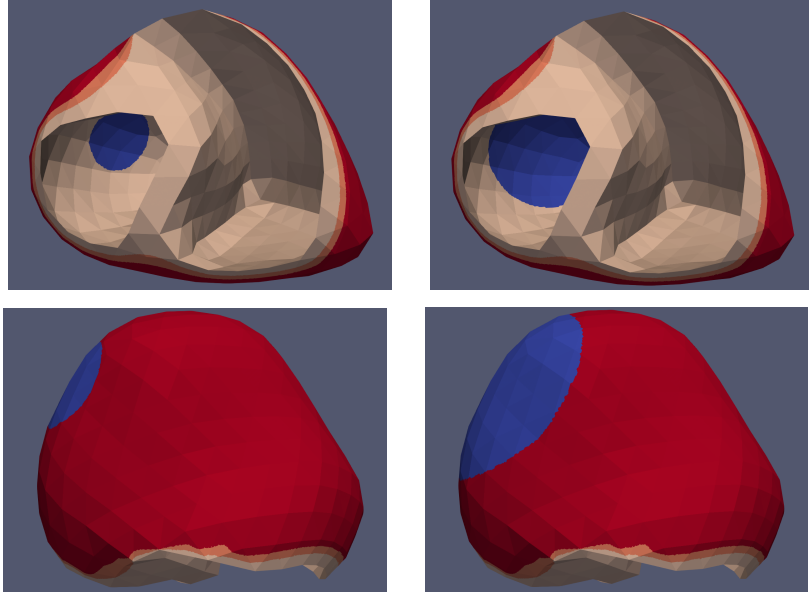
Figure 3: Overview of epi-endocardial scar geometries.



(a) Transseptal scar on the anterior side.

(b) Transseptal scar on the posterior side.

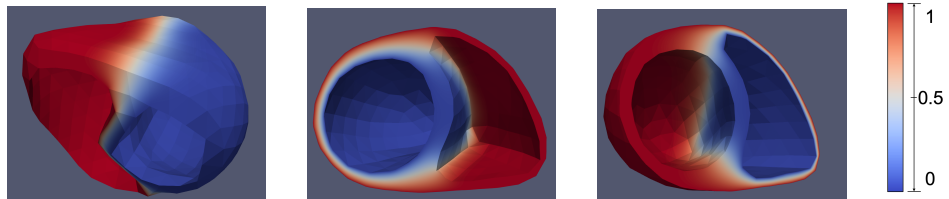
Figure 4: Overview of transseptal scar geometries.



(a) Small patch on the left ventricle.

(b) Large patch on the left ventricle.

Figure 5: Overview of patch geometries.



(a) Solution of Laplace's equation from the left ventricle endocardium to the right ventricle endocardium.

(b) Solution of Laplace's equation from the epicardium to the left ventricle endocardium.

(c) Solution of Laplace's equation from the epicardium to the right ventricle endocardium

Figure 6: Solution of Laplace's equations, used to compute gradient streamlines.

endo- and epicardium [1]. All simulations were conducted using the monodomain model and performed on a volumetric heart model with mean edge length of 0.530 mm. A conduction velocity (CV) of 0.6 m/s in fiber direction and 0.3 m/s in transversal direction was obtained by adjusting the fiber anisotropy ratio k and the conductivity ratio κ .

Following the example of [2], the adjustment of CV and action potential duration (APD) was performed on a box ($\approx 50 \text{ mm} \times 25 \text{ mm} \times 8 \text{ mm}$). The mean edge length of the box (0.527 mm) was comparable to the original mean edge length in the heart model (0.530 mm).

Action Potential Duration Gradient As a simple test case for non-invasive repolarization time (RT) or APD estimation, we decided for a linear, apicobasal APD gradient of $\pm 25\%$. For that reason, $g_K := g_{Kr} := g_{Ks}$, a constant regulating the potassium currents I_{Ks} and I_{Kr} , was adjusted. As g_K and the APD have a nonlinear relationship, a least squares fit was used to obtain a polynomial function to determine the value of g_K on each mesh point.

1.4.1 Parameters for Pathological Cases

All LOBs were modeled passive tissue (CV of 0). For the scar patches, two different CVs were used: CV halved and CV of 0.

1.5 Extracellular Potentials

EPs on the epi- endocardial as well as the pericardial surface were calculated by solving Poisson’s equation using the finite element method (FEM), ensuring that EPs and TMVs induce the same body surface potentials (BSPs). PPs for points which did not exist in the volume mesh (e.g. in the opening of the valves) were linearly interpolated within tetrahedrons of the volume mesh.

1.6 Downsampling

Since high-frequency components cannot be represented on the coarse meshes, Laplacian blur downsampling from [3] was applied to obtain low-resolution ground truth signals for each model. Ground truth signals were extracted on the surface nodes from the volumetric model, which correspond to the surface model Res 5. Laplacian downsampling was performed to obtain ground truth signals for Res 0 and Res 1.

References

- [1] J. D. Bayer, R. C. Blake, G. Plank, and N. A. Trayanova. A novel rule-based algorithm for assigning myocardial fiber orientation to computational heart models. *Annals of Biomedical Engineering*, 40(10):2243–2254, 1 2012.
- [2] Dongdong Deng, Adityo Prakosa, Julie Shade, Plamen Nikolov, and Natalia A. Trayanova. Sensitivity of ablation targets prediction to electrophysiological parameter variability in image-based computational models of ventricular tachycardia in post-infarction patients. *Frontiers in Physiology*, 10:628, 5 2019.
- [3] Steffen Schuler, Jess D. Tate, Thom F. Oostendorp, Robert S. MacLeod, and Olaf Dössel. Spatial downsampling of surface sources in the forward problem of electrocardiography. In Yves Coudière, Valéry Ozenne, Edward Vigmond, and Nejib Zemzemi, editors, *Functional Imaging and Modeling of the Heart*, volume 11504 of *Lecture Notes in Computer Science*, pages 29–36. Springer International Publishing, 5 2019.
- [4] K. H. W. J. ten Tusscher and A. V. Panfilov. Alternans and spiral breakup in a human ventricular tissue model. *American Journal of Physiology. Heart and Circulatory Physiology*, 291(3):H1088–100, 1 2006.

Simulation name	Type of scar	Scar conductivity	Origin of stimulus
lvLateral	none	–	left ventricle lateral
rvLateral	none	–	right ventricle lateral
rvSeptal	none	–	right ventricle septal
lvRvLateral	none	–	left and right ventricle lateral
lvLateral_blockLine_lvAnterior	elongated	0	left ventricle lateral
lvLateral_blockLine_lvPosterior	elongated	0	left ventricle lateral
lvLateral_blockLine_rvAnterior	elongated	0	left ventricle lateral
lvLateral_blockLine_rvPosterior	elongated	0	left ventricle lateral
lvLateral_blockLine_transseptalAnterior	elongated	0	left ventricle lateral
lvLateral_blockLine_transseptalPosterior	elongated	0	left ventricle lateral
lvLateral_scarPatch_lvLateral_largeHalfCv	patch large	CV halved	left ventricle lateral
lvLateral_scarPatch_lvLateral_largeZeroCv	patch large	0	left ventricle lateral
lvLateral_scarPatch_lvLateral_smallHalfCv	patch small	CV halved	left ventricle lateral
lvLateral_scarPatch_lvLateral_smallZeroCv	patch small	0	left ventricle lateral
rvLateral_blockLine_lvAnterior	elongated	0	right ventricle lateral
rvLateral_blockLine_lvPosterior	elongated	0	right ventricle lateral
rvLateral_blockLine_rvAnterior	elongated	0	right ventricle lateral
rvLateral_blockLine_rvPosterior	elongated	0	right ventricle lateral
rvLateral_blockLine_transseptalAnterior	elongated	0	right ventricle lateral
rvLateral_blockLine_transseptalPosterior	elongated	0	right ventricle lateral

Table 1: Overview of performed simulations.