TECHNISCHE UNIVERSITÄT DRESDEN

Utilization of a Computational Cardiac Electromechanics for Mechano Electric Feedback

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1 Goals

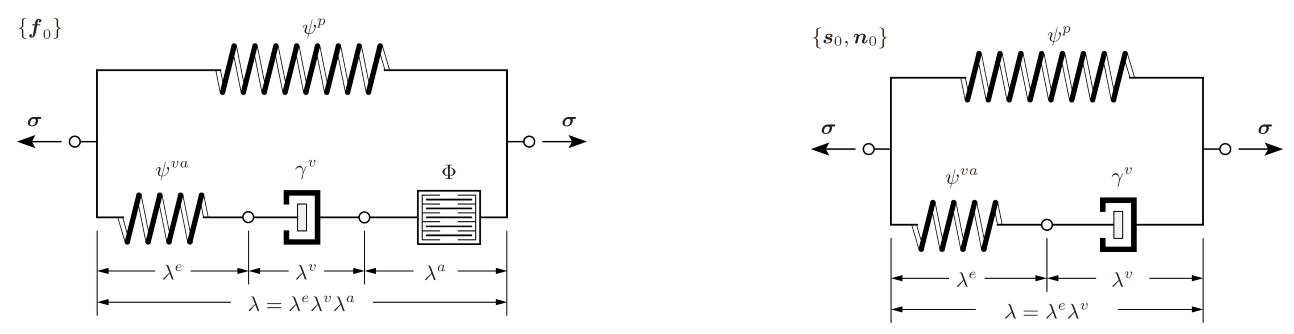
- modelling the electromechanics of the myocardium
- generation of patient-specific heart models
- validation of the developed numerical schemes
- simulating arrhytmias and its termination (commotio cordis and premature ventricular contraction)

2 Cardiac Electromechanics

coupled governing equations

- state variables $\{\varphi(\boldsymbol{X},t), \Phi(\boldsymbol{X},t); \boldsymbol{\mathcal{I}}_{va}(\boldsymbol{X},t), \boldsymbol{\mathcal{I}}_{e}(\boldsymbol{X},t)\}$
- quasi-static equilibrium $J\ \mathrm{div}\left[J^{-1}\hat{\boldsymbol{\tau}}\right] + \boldsymbol{B} = \boldsymbol{0}$
- electrical equilibrium $\dot{\Phi} = J \mathrm{div}[J^{-1}\hat{\mathbf{q}}] + \hat{F}^{\phi}$

rheology for electro-visco-elasticity of the myocardium

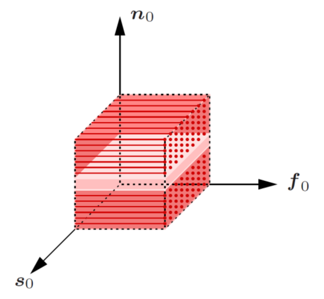


$$\psi(\boldsymbol{g};\boldsymbol{F},\boldsymbol{F}^e) = \psi^p(I_1, I_3, I_{4f}, I_{4s}, I_{8fs}) + \sum_{\mathrm{i=f,s,n}} \psi^{va}(\lambda^e_{\mathrm{i}})$$

$$\lambda_{\mathrm{f}} = \lambda^e_{\mathrm{f}}\lambda^v_{\mathrm{f}}\lambda^a_f \quad \lambda_{\mathrm{s}} = \lambda^e_{\mathrm{s}}\lambda^v_{\mathrm{s}} \quad \lambda_{\mathrm{n}} = \lambda^e_{\mathrm{n}}\lambda^v_{\mathrm{n}}$$

$$\boldsymbol{F}^a := \boldsymbol{1} + (\lambda^a_f - 1)\boldsymbol{f}_0 \otimes \boldsymbol{f}_0$$

$$\boldsymbol{F}^v := \boldsymbol{1} + (\lambda^v_{\mathrm{f}} - 1)\boldsymbol{f}_0 \otimes \boldsymbol{f}_0 + (\lambda^v_{\mathrm{s}} - 1)\boldsymbol{s}_0 \otimes \boldsymbol{s}_0 + (\lambda^v_{\mathrm{n}} - 1)\boldsymbol{n}_0 \otimes \boldsymbol{n}_0$$



- the orthotrophy along fibre, sheet and normal directions
- multiplicative decomposition of total deformation into elastic, viscous and active parts

Aliev & Panfilov model for excitation of the myocardium

ionic source (*electrically normalized*)

$$f^{\phi} = f^{\phi}_e(\phi, r) + f^{\phi}_m(\boldsymbol{g};\boldsymbol{F},\phi)$$

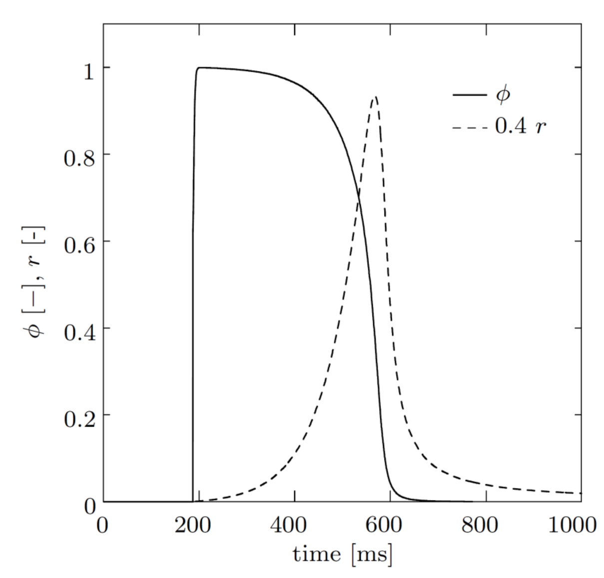
purely electrical part

$$f^{\phi}_e = c\phi(\phi-\alpha)(1-\phi) - r\phi$$

$$\dot{r} = \left[\gamma + \frac{\mu_1 r}{\mu_2 + \phi}\right]\left[-r - c\phi(\phi - b - 1)\right]$$

mechano electric feedback

$$f^{\phi}_{\lambda_f} = G_s\langle\lambda_f - 1\rangle(\phi_s - \phi) \quad f^{\phi}_{\dot{\lambda}_f} = G_s\langle\dot{\lambda}_f\rangle(\phi_s - \phi)$$



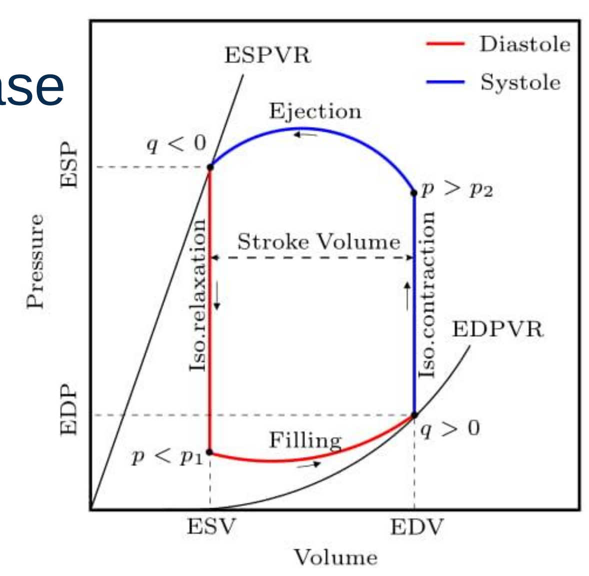
hemodynamics of the ventricles

- blood pressure is modelled as a function of the deformation state (the ventricle cavity volume $\mathcal{V}$)
- windkessel model for the ejection phase

$$\dot{\hat{p}}_{\mathrm{v}} = \frac{1}{C_{ap}}\left(1 + \frac{R_c}{R_p}\right)q + R_c\,\dot{q} - \frac{\hat{p}_{\mathrm{v}}}{C_{ap}R_p} \qquad q := -\dot{\mathcal{V}}$$

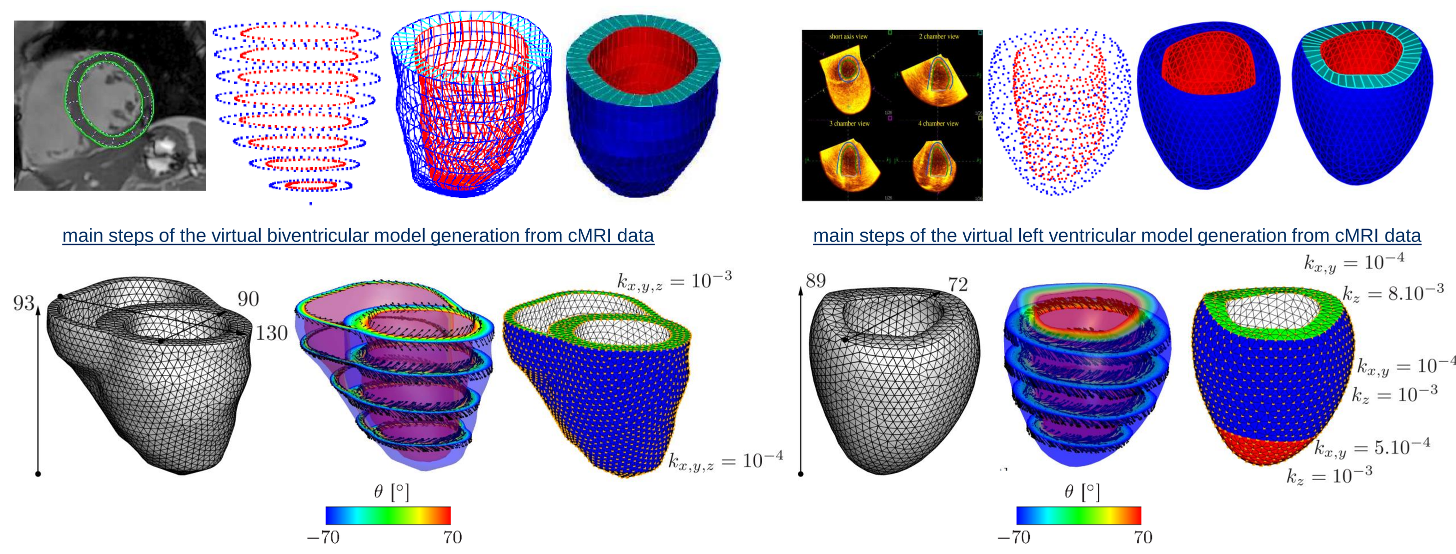
- filling and isovolumetric phases

$$\dot{\hat{p}}_{\mathrm{v}} = \bar{\kappa}(1-\theta) \qquad \theta := \frac{\mathcal{V}}{\mathcal{V}_0}$$



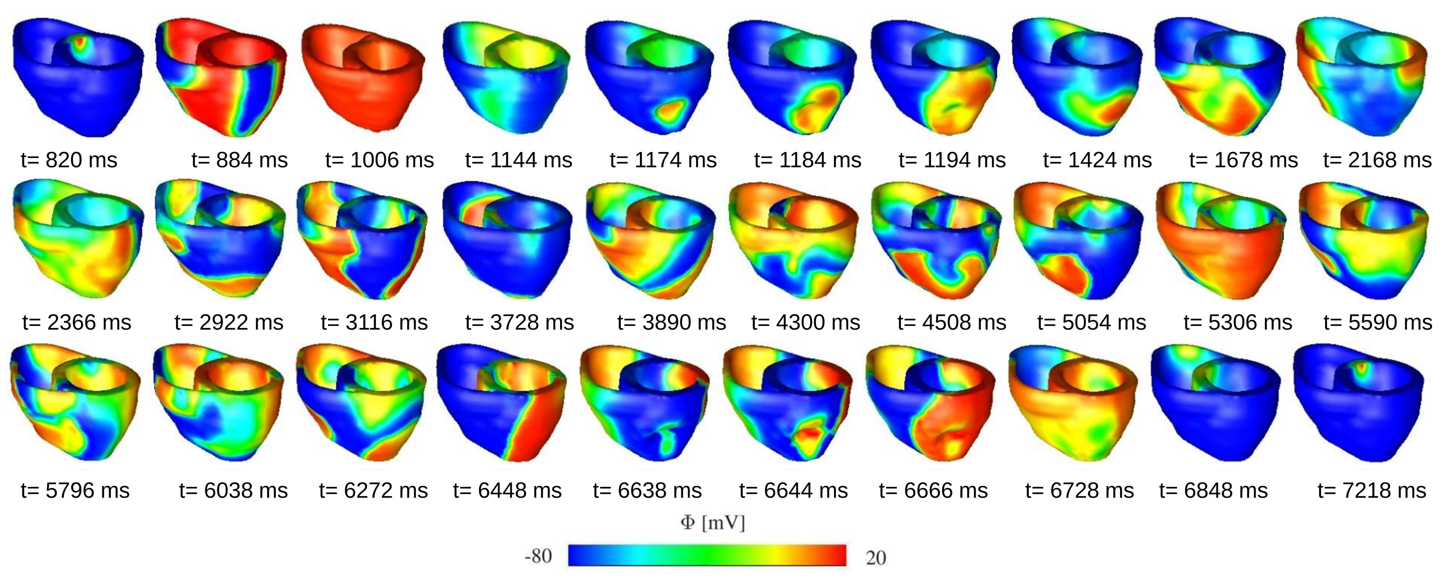
3 Patient specific heart geometry

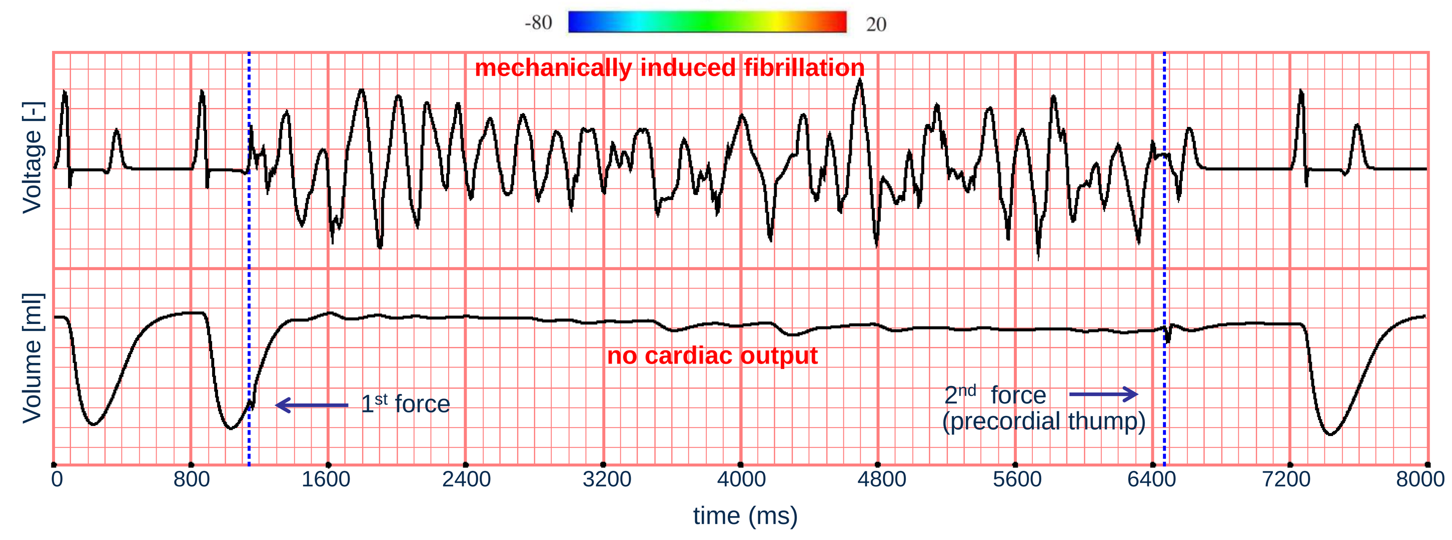
generation of patient specific heart geometry



4 Numerical examples

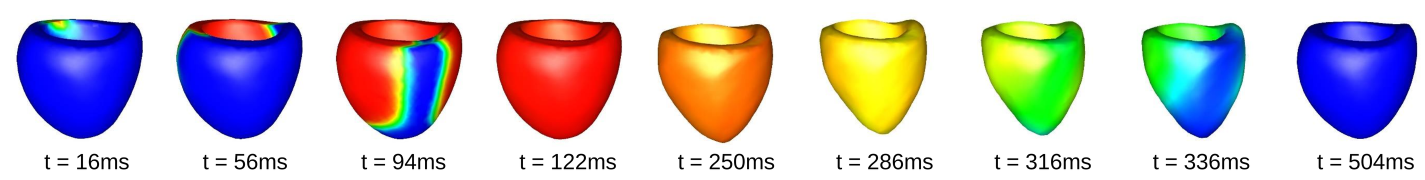
commotio cordis and precordial thump



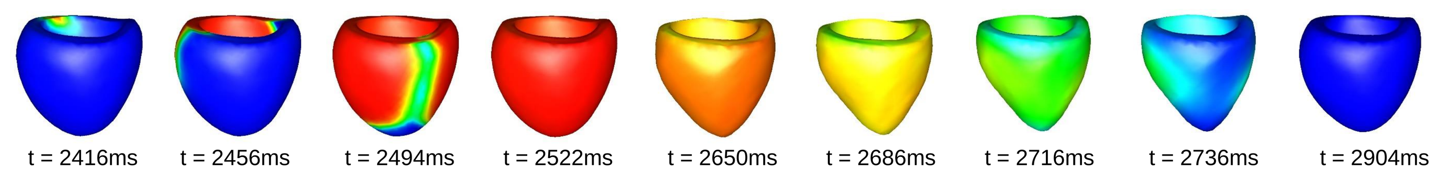


premature ventricular contraction induced by hemodynamic disturbance

normal healthy cycle



the cycle with reversed T-wave



premature ventricular contraction