Electromechanical Model of the Human Heart Left Ventricle That is Personalized By Electrocardiography Data

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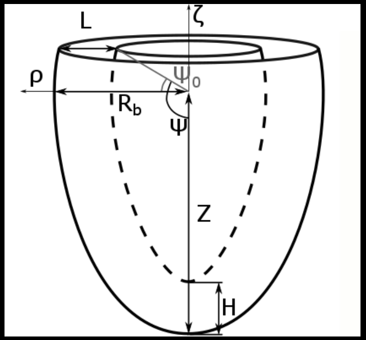
Ural Branch of Russian Academy of Science

Ural Federal University named after the first President of Russia B.N.Yeltsin

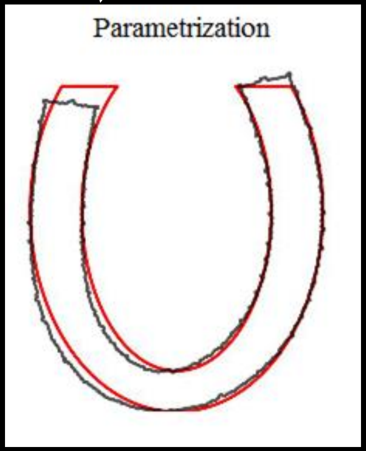
3D MODEL

ECHO data

LV contour

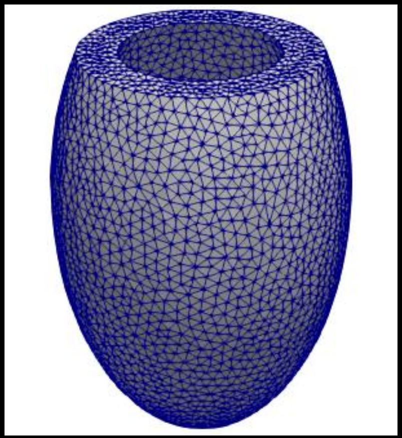


Scheme with parameters used to construct 3D geometry



Parameters	Values
Rb, мм	27.8
L, мм	8.4
Z, мм	52.7
H, мм	8.0
e	0.97
ψ0, град	-47.5

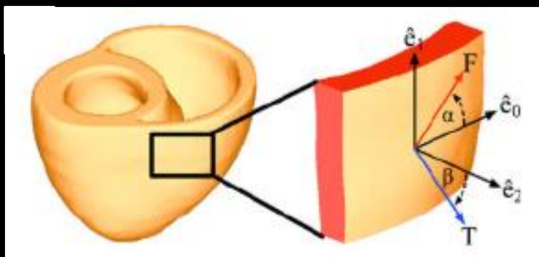
The LV geometry parameters of one patient.

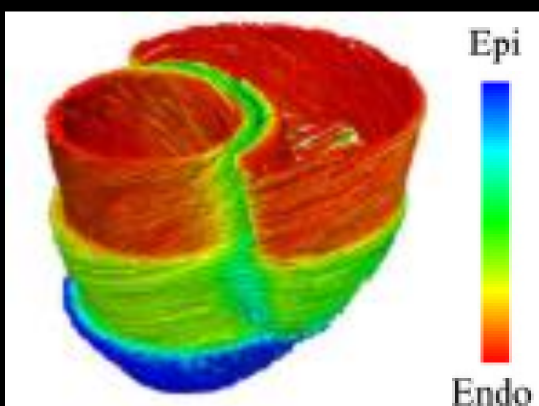


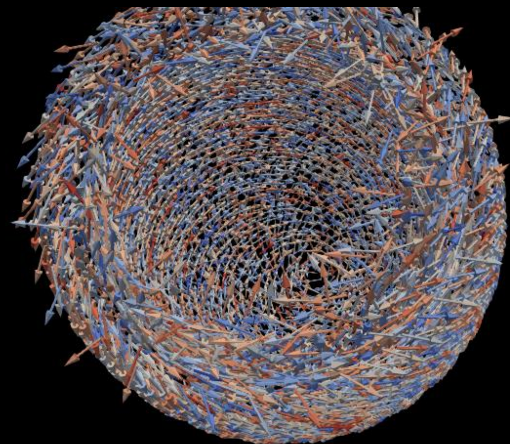
3D model of the left ventricle

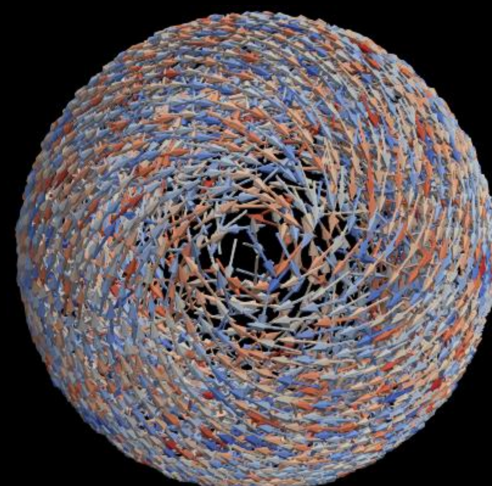
Pravdin, S. F. et al., Biomedical engineering online, 12(1), 54 (2013)

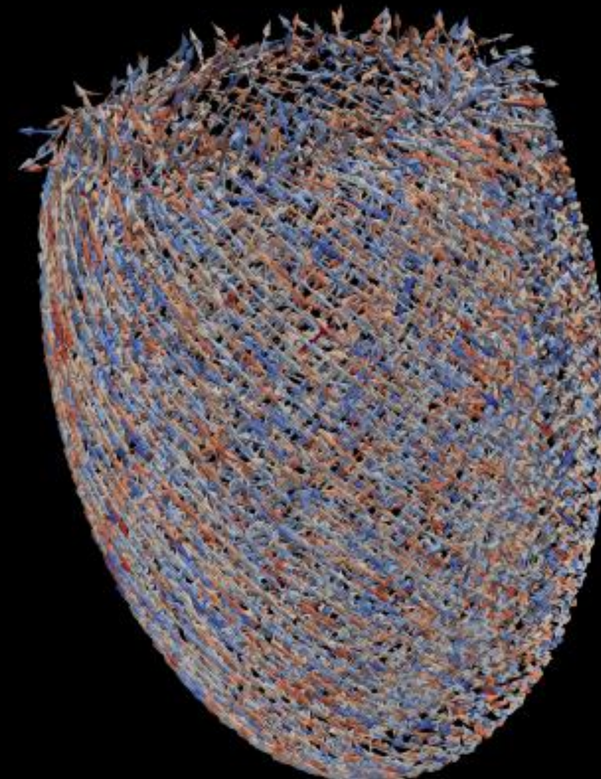
INTRODUCTION OF ELECTRICAL AND MECHANICAL ANISOTROPY USING VECTOR FIELD OF FIBER ORIENTATION







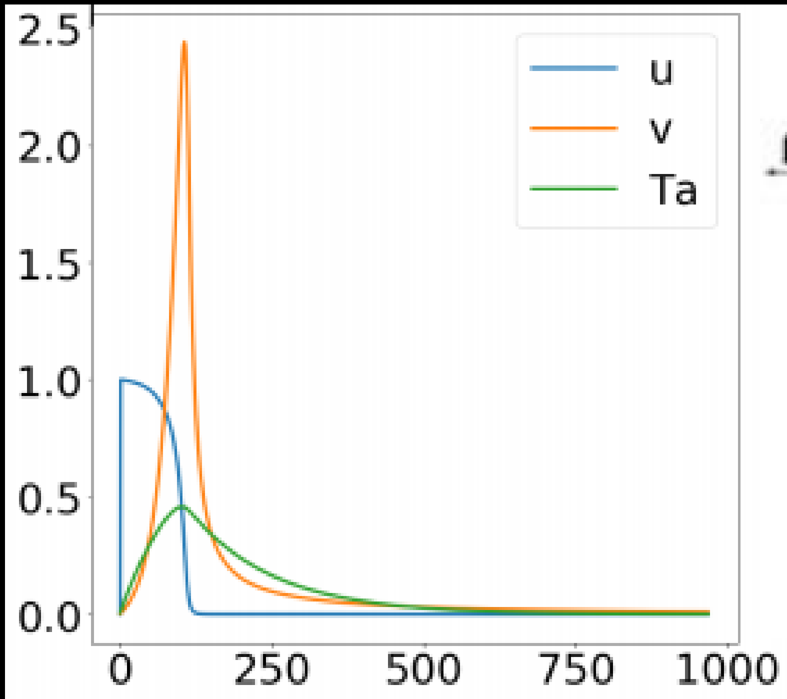




A Novel Rule-Based Algorithm for Assigning Myocardial Fiber Orientation to Computational Heart Models **2012**

J. D. Bayer,[1] R. C. Blake,[1] G. Plank,[2] and N. A. Trayanova[1]

MATHEMATICAL MODEL OF CARDIAC ELECTROPHYSIOLOGY AND ACTIVE TENSION



Axis_X - time(ms)
Axis_Y - arbitrary units

$$
\begin{cases}
\frac{\partial u}{\partial t} = \Delta u - ku(u-a)(u-1) - uv, \\
\frac{\partial v}{\partial t} = (\epsilon_0 + \frac{\mu_1 v}{u+\mu_2})(-v - ku(u-a-1)), \\
\frac{\partial T_a}{\partial t} = \epsilon(u)(k_{T_a} u - T_a).
\end{cases}
$$

u - transmembrane potential;

v - reverse conductivity

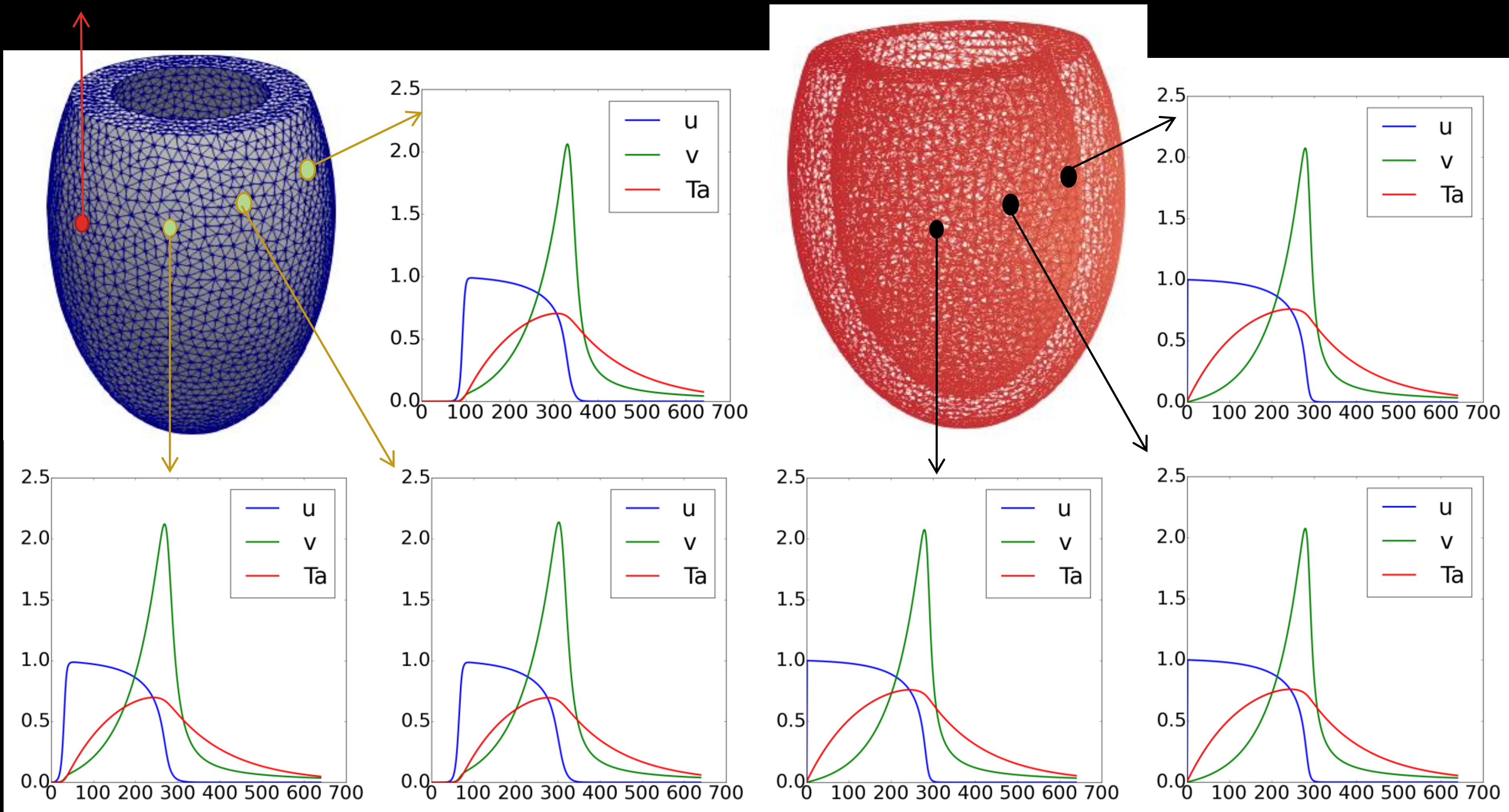
T_a - active tension

Aliev R. R., Panfilov A. V., Chaos, Solitons & Fractals, 7, 293-301(1996)

Two activation sequences

Point of activation

Activation of the entire volume



Axis_X - time(ms), Axis_Y – arbitrary units

PASSIVE AND ACTIVE MECHANICAL MODEL

$$\mathrm{div}[\mathbf{J}^{-1}\mathbf{T}] = 0$$

$$\mathbf{T}_{\mathrm{pas}}(\mathbf{F},\mathbf{M}) = (\frac{\lambda}{2}\ln(\det(\mathbf{F}^T\mathbf{F})) - \mu)+$$

$$\mu\mathbf{F}\mathbf{F}^T+$$

$$2\vartheta\eta(tr(\mathbf{F}\mathbf{M}\mathbf{F}^T) - 1)\mathbf{F}\mathbf{M}\mathbf{F}^T$$

$$\mathbf{T} = \mathbf{T}_{\mathrm{pas}} + T_{\mathrm{a}}$$

λ, μ - Lame constants

η - passive stiffness of myofibrils

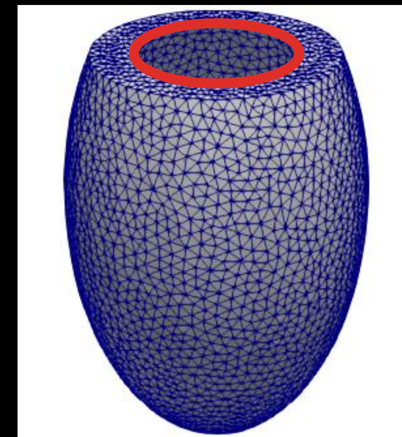
$\mathbf{F}$ - jacobian transition from the initial position to the current;

$\mathbf{M}$ - tensor of fiber anisotropy after deformation.

- deformed structural tensor.
- the left Cauchy-Green tensor.
- 3rd invariant of the strain tensor.
- The fiber stretch squared

Göktepe S. et al., Comput. Mech., 45, 227–243 (2009)

Implementation



number of elements - 7040

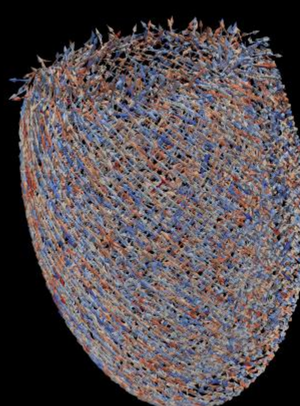
Boundary conditions:
The vertical movement of the epicardial ring is fixed on the base

Initial conditions:
Pressure =(конечно диастолическое)
u=1 (in point of activation)
u=0 (any point)
v=0
T_a=0

CARDIAC CYCLE

ACTIVATION OVER THE ENTIRE VOLUME OF THE LEFT VENTRICLE

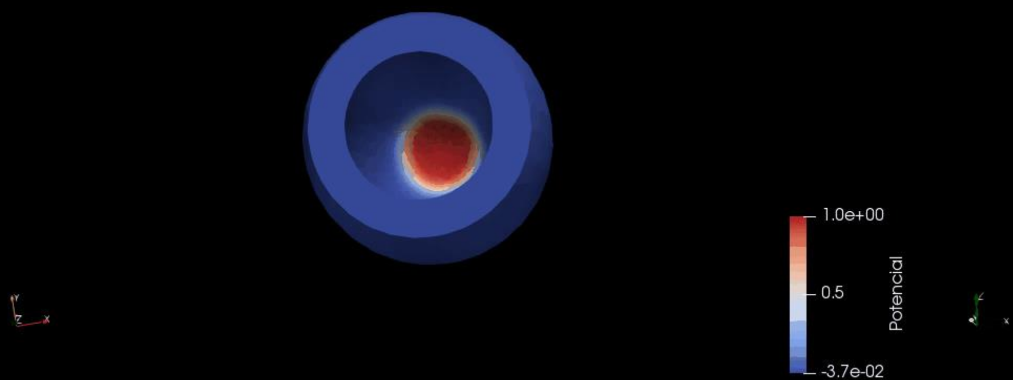
T=1000ms - simulation time

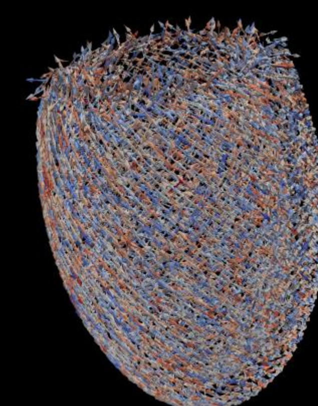


Ejection fraction 66.5%

CARDIAC CYCLE
T=1000MS

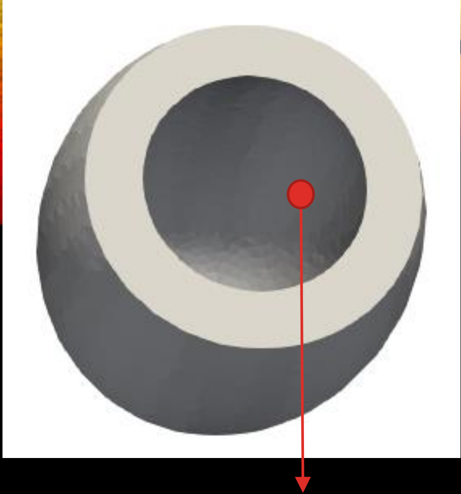
Point of activation



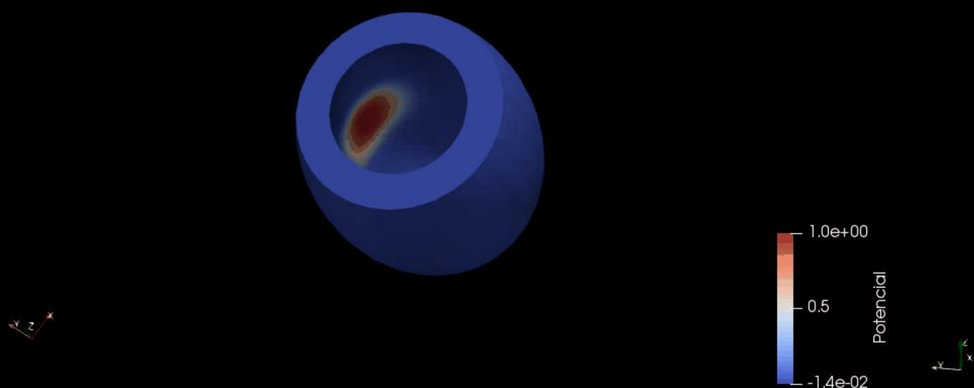


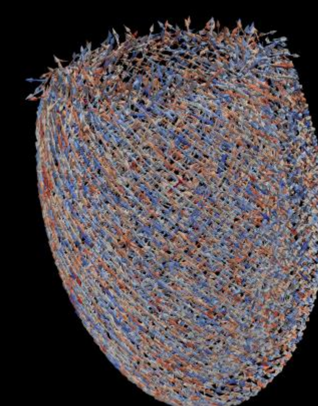
Ejection fraction 64.03%

CARDIAC CYCLE
T=1000MS



Point of activation

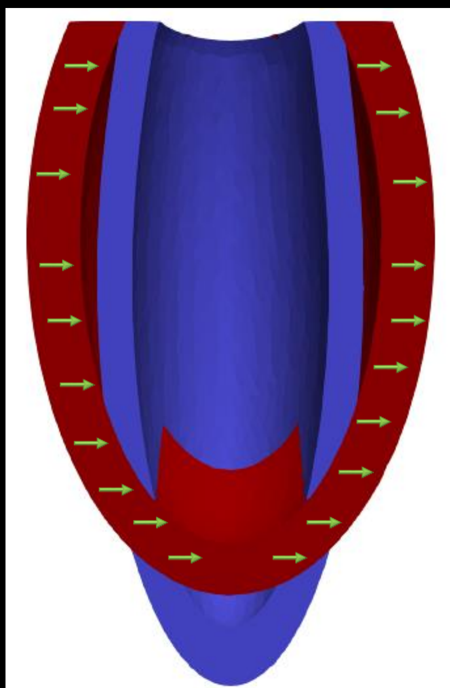


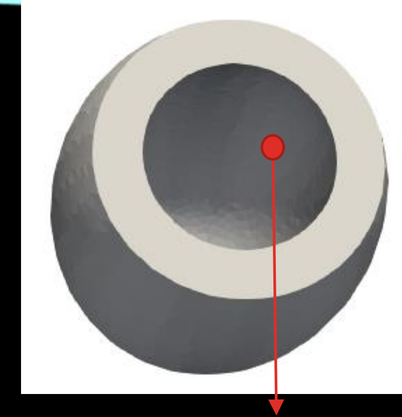


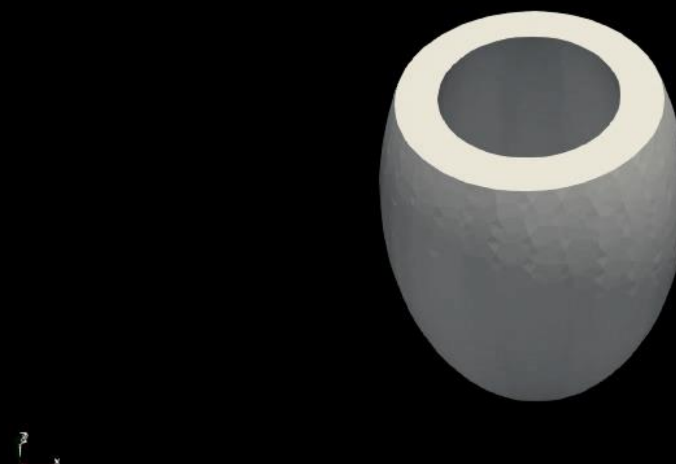
Ejection fraction 64.25%

EFFECT OF FIBER ORIENTATION. HORIZONTAL FIBER DIRECTION

T=1000MS



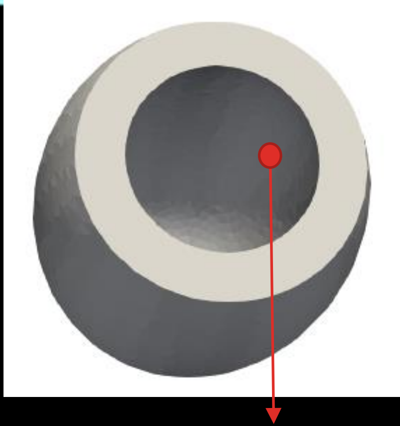




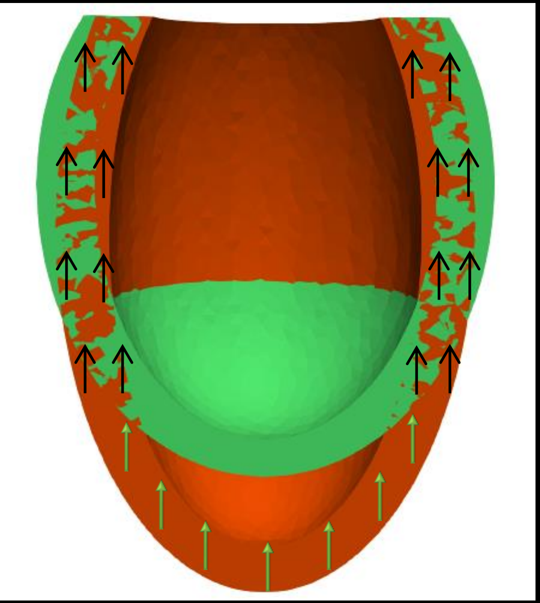
Ejection fraction - 32,119%

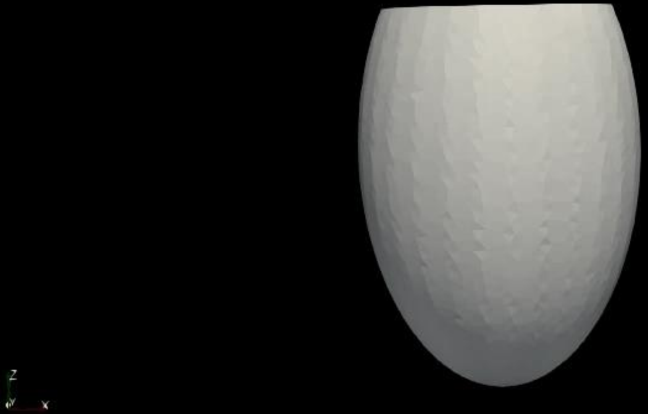
EFFECT OF FIBER ORIENTATION. VERTICAL FIBER DIRECTION

T=1000MS



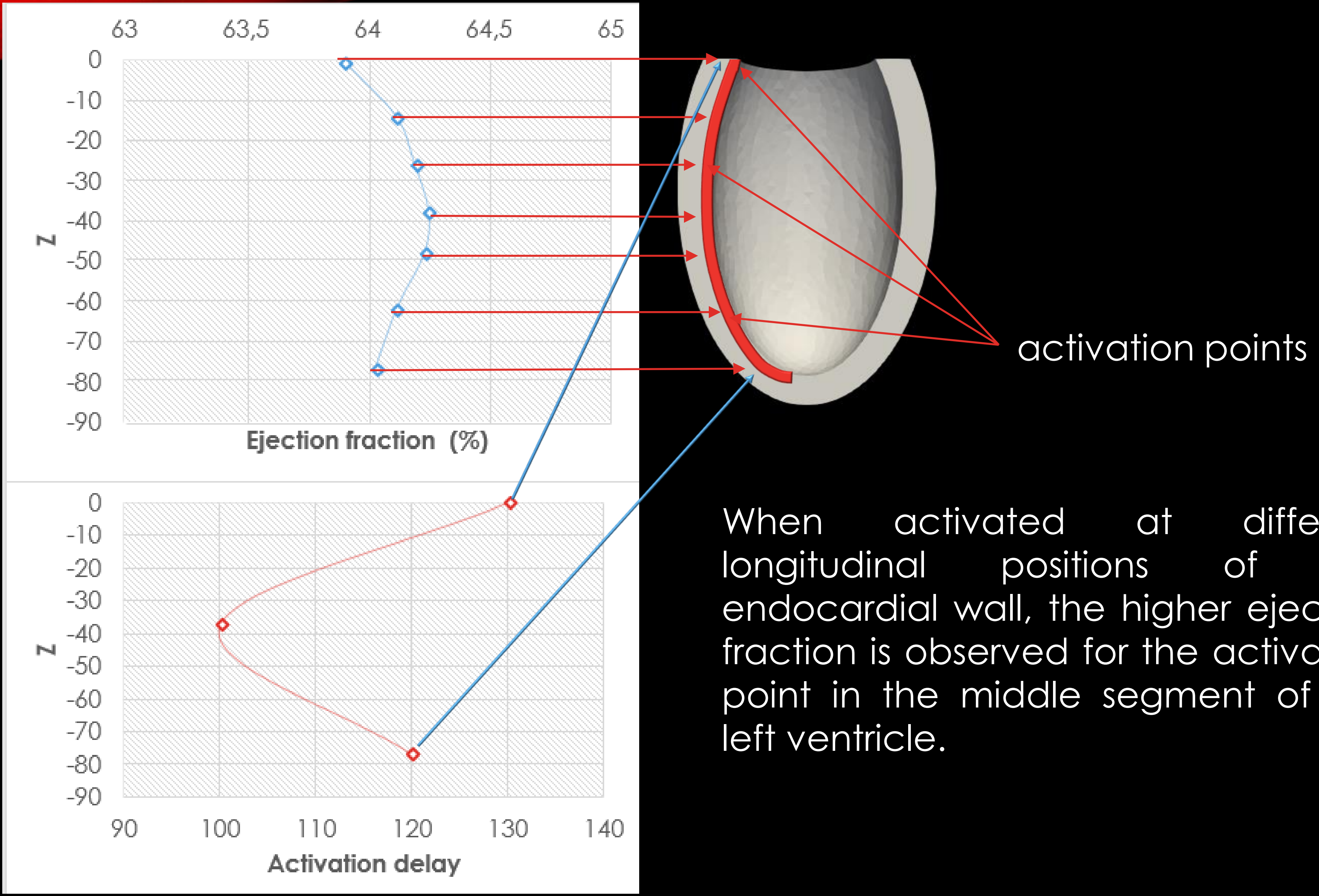
Point of activation





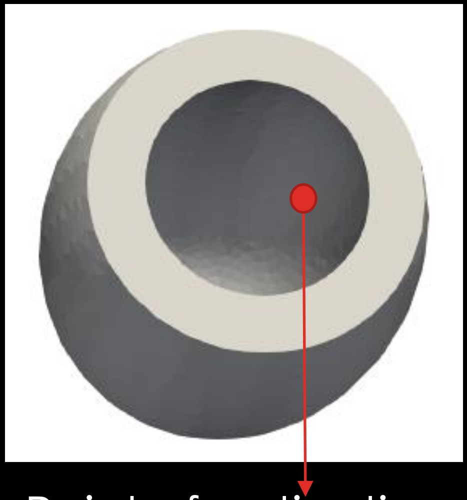
Ejection fraction - 39,52%

Ejection fraction dependence on activation points

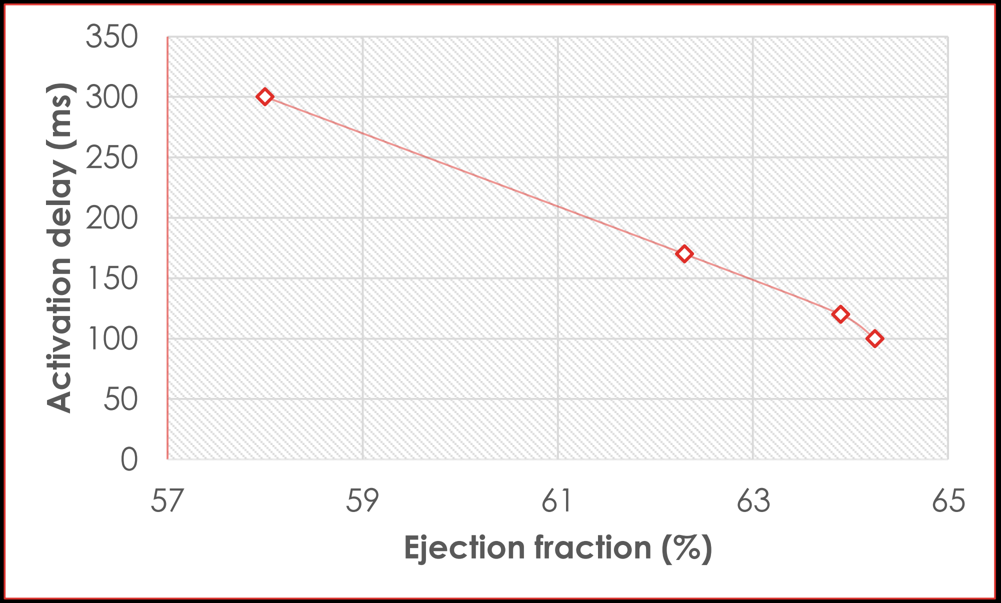


When activated at different longitudinal positions of the endocardial wall, the higher ejection fraction is observed for the activation point in the middle segment of the left ventricle.

Ejection fraction dependence on the conduction velocity



Point of activation



The higher conduction velocity the shorter the activation delay of the left ventricle, and the higher the ejection fraction.

CONCLUSIONS

- We developed an electromechanical model based on the personalized geometry of the human left ventricle, simulating correct ejection fraction
- The model reproduces effects of the myocardial fiber orientation, conduction velocity, and location of the activation points on the ejection fraction of the left ventricle
- In the future, the model will be used to compare the mechanical function in 49 patient geometry to evaluate dependence on left ventricular geometry.
- The model will be combined with a blood circulation model for more realistic simulations.

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Thank you for your attention

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