Computational analysis of the myocardial structure
Shear-induced 3D reorientation of cardiac myofibers

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Background
Despite sensitivity of myofiber work to the myofiber orientation, experiments show cardiac myofiber shortening and metabolism is homogeneously distributed over the wall. This suggests myofiber orientation is regulated by mechanical load [1]. Studies concerning load bearing tissues suggest tissue fibers (e.g. collagen) align in between principal directions of deformation [3]. However, myofiber orientations in the cardiac left ventricle do not correlate to principal deformation directions [2]. Consequently, an alternative hypothesis is needed for the myocardial tissue.

Aim
We aim to test the hypothesis that myofibers adapt their orientation to minimize shear deformation during the cardiac cycle. Figure 1, shows a possible microstructural basis for this hypothesis.

Method
Model of reorientation
We hypothesize that shear deformation causes the unloaded myofiber direction \( \vec{e}_{f,0} \) to adapt towards the deformed myofiber direction \( \vec{e}_f \) a described by:

\[
\frac{\partial \vec{e}_{f,0}}{\partial t} = \frac{1}{\kappa} (\vec{e}_f (U) - \vec{e}_{f,0}) : \vec{e}_f = \frac{U : \vec{e}_{f,0}}{|U : \vec{e}_{f,0}|} ; \ U = \sqrt{F^T \cdot F} \quad (1)
\]

with \( \kappa \) a time constant and \( F \) the deformation gradient tensor. Since rigid body rotations are irrelevant to the adaptation process we have introduced deformation tensor \( U \) that does not include rigid body rotations. Due to removal of rotation, adaptation of the unloaded myofiber orientation is driven by (fiber-cross fiber) shear deformation.

Model of cardiac mechanics
Tissue deformation during the cardiac cycle is computed with a finite element (FE) model of left ventricular mechanics [5]. The FE model is coupled to a lumped parameter (LP) model of the circulation to enable simulation of a continuous series of cardiac cycles over time (figure 2).

Results

Conclusions
- Local reorientation of the myofiber to achieve minimal shear during the cardiac cycle was found to lead to a realistic overall myocardial structure.
- Reorientation was found lead to a significant homogenization of mechanical loading as well as to an increase in local and global cardiac output.

References