the virtual heart

a hierarchical continuum approach towards computational cardiology

- cardiac disease
- acute excitation-contraction
- chronic dilation-hypertrophy
- cardiac repair

http://biomechanics.stanford.edu
based on active adaptive continuum theories and modern finite element technologies, we develop tool sets for the computationally guided patient specific design of cardiac therapies.
action potentials in the heart

spontaneous re-excitation

stable resting potential

arrhythmias fibrillation heart failure

re-entry and ventricular fibrillation

\( \tau = 125 \text{ ms} \)

\( \tau = 500 \text{ ms} \)

\( \tau = 570 \text{ ms} \)

\( \tau = 700 \text{ ms} \)

\( \tau = 750 \text{ ms} \)

\( \tau = 850 \text{ ms} \)

\( \tau = 925 \text{ ms} \)

\( \tau = 975 \text{ ms} \)

\( \Phi \text{ [mV]} \)

-80 - 70 - 60 - 50 - 40 - 30 - 20 - 10 - 0 - 10 - 20
excitation of real hearts

from CT to finite element model

electrophysiology
excitation of real hearts

validation - computational EKG
**mal-adaptive growth**

\[
F^g = \mathbf{\vartheta}^\perp \mathbf{I} + [\mathbf{\vartheta}^\parallel - \mathbf{\vartheta}^\perp] \mathbf{n}^{\text{myo}} \otimes \mathbf{n}^{\text{myo}}
\]

<table>
<thead>
<tr>
<th>healthy cardiomyocyte</th>
<th>cardiomyocyte death</th>
<th>concentric hypertrophy</th>
<th>eccentric hypertrophy</th>
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<tbody>
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<th>physiological loading</th>
<th>heart attack</th>
<th>pressure overload</th>
<th>volume overload</th>
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<tr>
<td>( p, \lambda^{\text{myo}} )</td>
<td>( \mathbf{E}^{\text{myo}} )</td>
<td>( \mathbf{\vartheta}^\perp(p) )</td>
<td>( \mathbf{\vartheta}^\parallel(\lambda^{\text{myo}}) )</td>
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**growth and remodeling**
hypertrophied, normal and dilated heart

growth and remodeling
volume overload-induced dilation

- ejection fraction ↓ from 68.16% to 23.33%
- end-diastolic volume ↑ from 37.12mm$^3$ to 133.16mm$^3$

validation - mouse infarct models
volume overload-induced dilation

surgically implanted epicardial markers and transmural bead set

4d coordinates from in vivo biplane videofluoroscopic marker images

krishnamurthy, ennis, itoh, bothe, swansons-birchill, langer, rodriguez, criscione, miller, ingels

validation - ovine infarct models
volume overload-induced dilation

end-diastolic volume ↑ by 22±10%, sphericity ↓ by 5%

cheng, nguyen, malinowski, langer, liang, daughtes, ingels, miller [2006]
polydimethylsiloxane

freely jointed chain
discrete network of chains

filament sliding theory
starling's law of the heart

polydimethylsiloxane

cardiomyocytes

freely jointed chain
discrete network of chains

filament sliding theory
starling's law of the heart

muscular thin films for cardiac repair

böl, reese, parker, kuhl [2008]
vertical fibers
model verification

muscular thin films for cardiac repair
coiling strip
longitudinal fibers

muscular thin films for cardiac repair
tissue engineered patches for cardiac repair

**challenge** dimensional upscaling
stackable **fully tunable** sheets

substrate stiffness
fiber orientation
contractility
graft geometry

NSF-EFRI engineering of cardiovascular cellular interfaces and tissue constructs
pruitt, heilshorn, kuhl, wu, zarins

muscular thin films for cardiac repair
... people involved in this work...

oscar abilez (vascular surgery), markus böl (tu braunschweig, germany), wolfgang bothe (cardiothoracic surgery), anton dam (computational biomechanics), sarah heilshorn (materials science), neil ingels (palo alto medical foundation), gaurav krishnamurthy (computational biomechanics / cardiothoracic surgery), craig miller (cardiothoracic surgery), james norman (paediatrics /microsystems), kevin kit parker (disease biophysics group, harvard), beth pruitt (microsystems), rebecca taylor (computational biomechanics / microsystems), joe ulerich (computational biomechanics), jonathan wong (computational biomechanics), joe wu (radiology), chris zarins (vascular surgery)