14 - final project - manuscript review

ME338A - Final project - Paper review - due in class Thu, March 11, 2010, 11am

Constitutive modelling of passive myocardium

A structurally-based framework for material characterization

Gerhard A. Holzapfel & Ray W. Ogden

Philosophical Transactions of the Royal Society A 2009,367:3445-3475.

This final project will demonstrate that during the past 10 weeks, you have learned to read state of the art continuum mechanics literature. Gerhard Holzapfel and Ray Ogden, two leading scientists in continuum biomechanics, have recently published a manuscript that introduces a new continuum mechanics model for passive cardiac muscle tissue.

1 Read the publication and try to understand what it is all about. You do not necessarily need to understand **all** the equations. You can briefly glance over section 6, it is not relevant for this final project.

2 Summarize the manuscript in less than 200 words.

3 Ogden & Holzapfel use a slightly different notation than we have used in class, i.e., they do not use dots to indicate scalar products. Rewrite equations (3.1) to (3.14) in our tensor notation, i.e., use the dot for scalar products when appropriate.

4 Rewrite equations (3.1) to (3.14) in index notation. For each equation, state in brackets whether it is a scalar, vectorial, or second order tensorial equation.

5 In section 4, Ogden & Holzapfel review existing constitutive models for passive cardiac tissue. They discuss three transversely isotropic models (4.1), (4.2), and (4.3) and three orthotropic models (4.5), (4.7), and (4.8). Summarize these six models in a table. For each model, list the first author, the year it was published, the invariants it is based on, and the parameters that are needed.

6 Figure 4 illustrates the deformation state of simple shear. Calculate the Green Lagrange strain tensor $\boldsymbol{E} = \frac{1}{2} [\boldsymbol{F}^{\mathrm{t}} \cdot \boldsymbol{F} - \boldsymbol{I}]$ from the deformation gradient given in (5.9) and sketch the deformed configuration in the fs-plane.

7 Equation (5.38) is the key equation of the paper. It introduces the free energy function for myocardial tissue. Describe its three terms and explain the required material parameters.

8 Most soft biological tissues are incompressible and anisotropic. How are incompressibility and anisotropy handled in this constitutive formulation?

9 Review the publication with the help of the attached spreadsheet. Use common sense to answer the questions you cannot answer based on your current continuum mechanics knowledge. There are no wrong answers, and we will not take off points as long as you can justify your opinion.

Instructions

Please rate this manuscript on a scale of 1-5, with 1 indicating greatest degree or best, and 5 indicating least degree or poor. You must also provide comments to the authors in prose. It is not acceptable to merely fill out numbers, and return the review.

Manuscript title ____________________

Authors ____________________

Summary (required brief summary of the context)

____

Presentation	(best) 1	2	3	4	5 (poor)
is clearly written	☐	☐	☐	☐	☐
title is appropriate	☐	☐	☐	☐	☐
abstract is appropriate	☐	☐	☐	☐	☐
figures and tables are adequate	☐	☐	☐	☐	☐
problem statement is clear	☐	☐	☐	☐	☐
provides appropriate detail	☐	☐	☐	☐	☐
describes limitations	☐	☐	☐	☐	☐
references are adequate	☐	☐	☐	☐	☐

Comments (required in addition to the number ratings above)

____

Significance	(best) 1	2	3	4	5 (poor)
represents important advance	☐	☐	☐	☐	☐
addresses importand and realistic problem	☐	☐	☐	☐	☐
is likely to scale up to realistic problems	☐	☐	☐	☐	☐
provides new evidence for existing technique	☐	☐	☐	☐	☐

ME338A Continuum Mechanics Review Form

Comments (required in addition to the number ratings above)

____

Originality	(best) 1	2	3	4	5 (poor)
novel approach or combination of approaches	☐	☐	☐	☐	☐
has not been published before	☐	☐	☐	☐	☐
points out differences from related research	☐	☐	☐	☐	☐
reformulates a problem in an important way	☐	☐	☐	☐	☐

Comments (required in addition to the number ratings above)

____

Technical content	(best) 1	2	3	4	5 (poor)
evaluates effectiveness of techniques	☐	☐	☐	☐	☐
is supported with sound arguments	☐	☐	☐	☐	☐
is supported with theoretical analysis	☐	☐	☐	☐	☐
is supported with experimental results	☐	☐	☐	☐	☐
is technically sound	☐	☐	☐	☐	☐

Additional comments to the autors

____

Overall recommendation ☐ accept ☐ marginal ☐ reject

Your confidence in recommendation ☐ strong ☐ medium ☐ weak

Confidential commments to the editor

____

Confidential reviewer name ____________________

final project

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A

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Constitutive modelling of passive myocardium: a structurally based framework for material characterization

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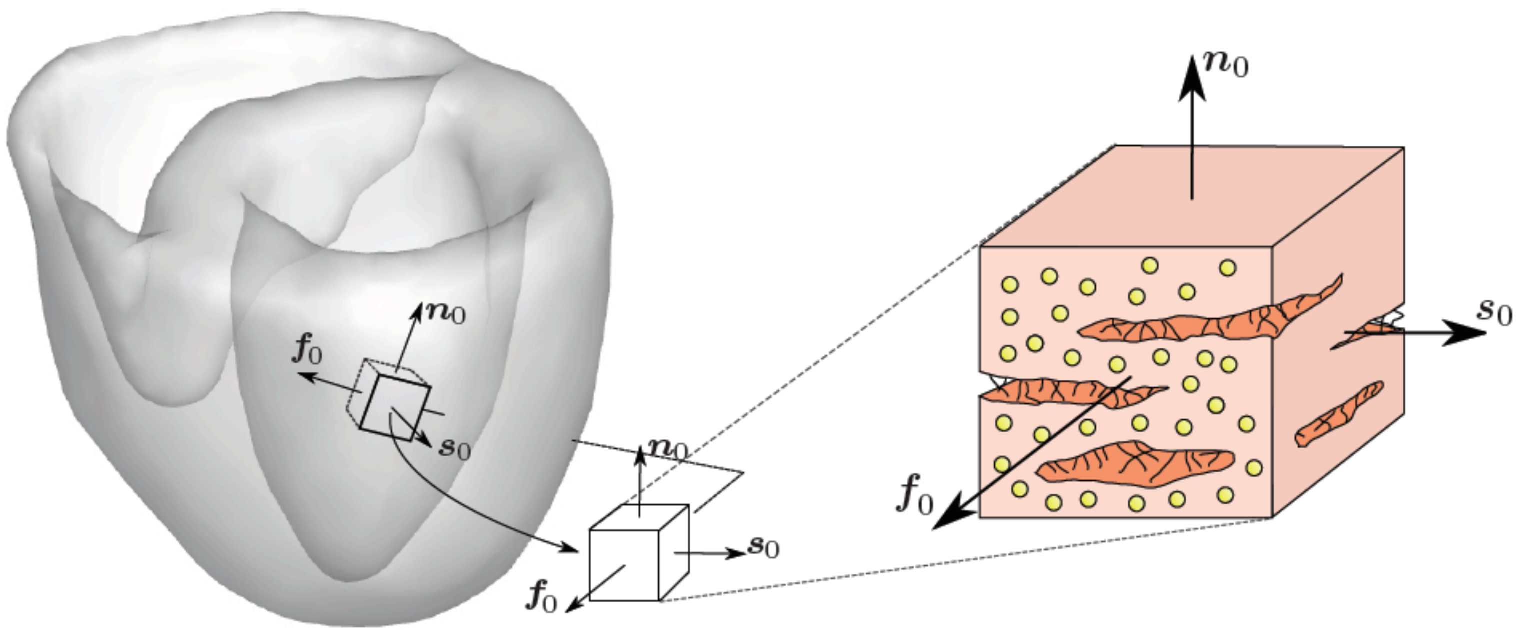
final project

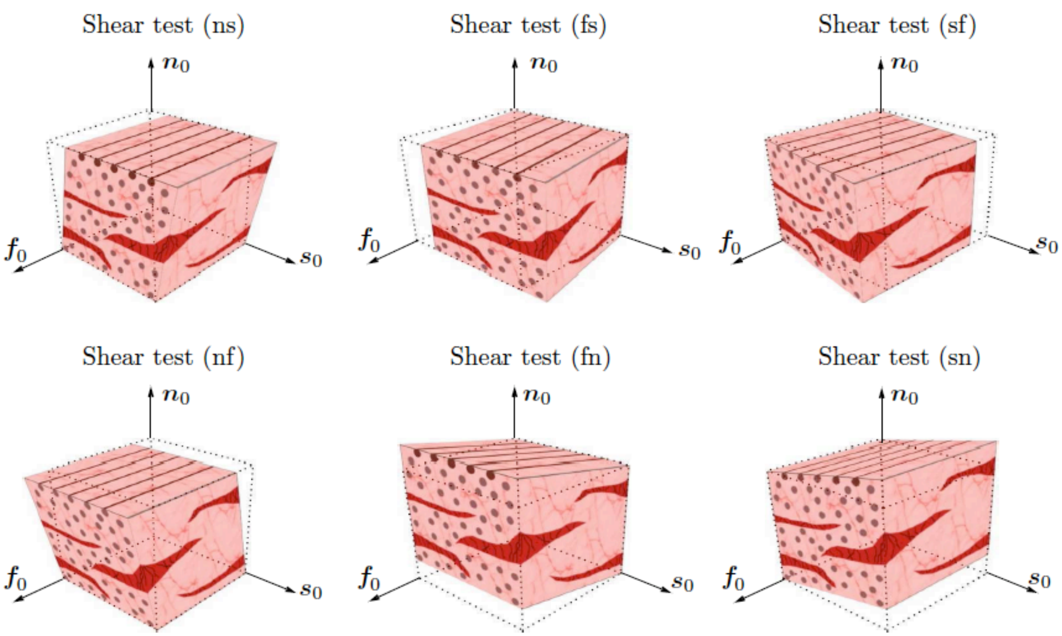
passive - *in vitro* measurement vs *in silico* prediction

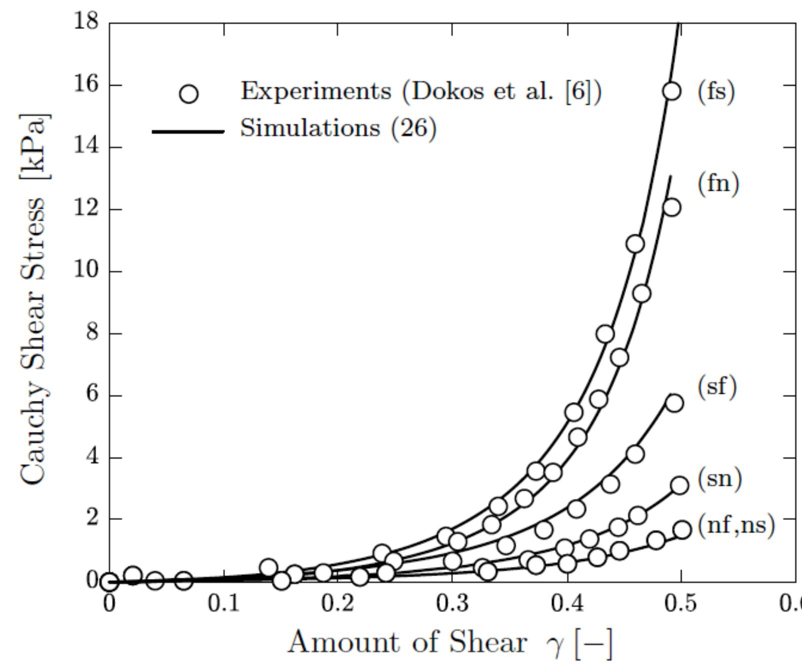
$$\bar{\Psi}(\boldsymbol{g};\bar{\boldsymbol{F}},\boldsymbol{M},\boldsymbol{S}) = \frac{a}{2b}\exp[b(\bar{I}_1-3)] + \sum_{i=f,s}\frac{a_i}{2b_i}\{\exp[b_i(\bar{I}_{4i}-1)^2]-1\} + \frac{a_{fs}}{2b_{fs}}[\exp(b_{fs}\bar{I}^2_{8fs})-1]$$



dokos, smaill, young, le griece [2002], holzapfel, ogden [2009], göktepe, acharya, wong, kuhl [2009]

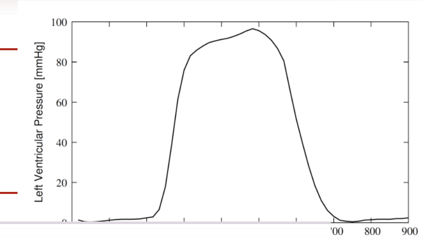
passive - *in vitro* measurement vs *in silico* prediction

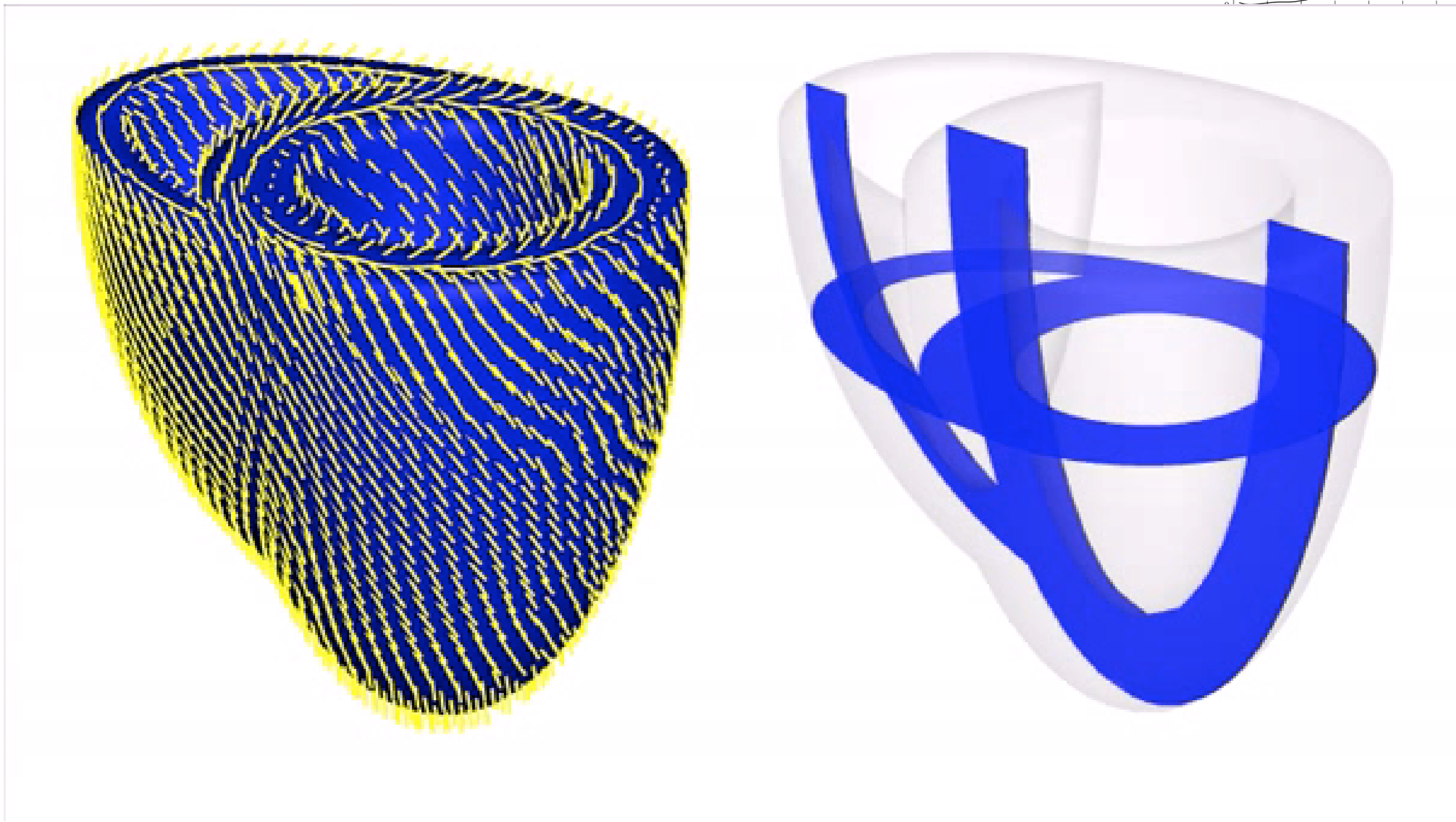




dokos, smaill, young, le griece [2002], holzapfel, ogden [2009], göktepe, acharya, wong, kuhl [2009]

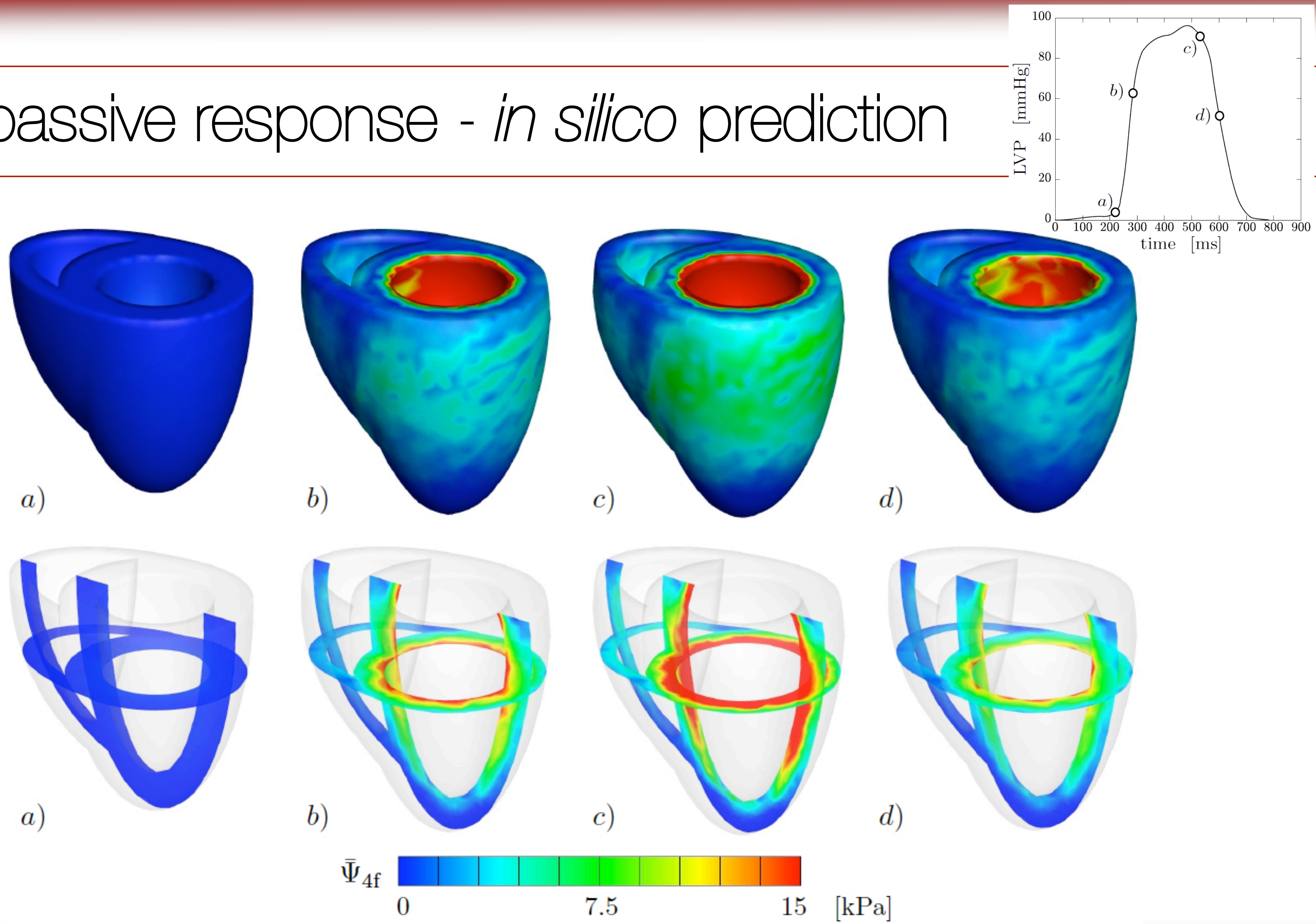
passive response - *in silico* prediction





göktepe, acharya, wong & kuhl [2009]

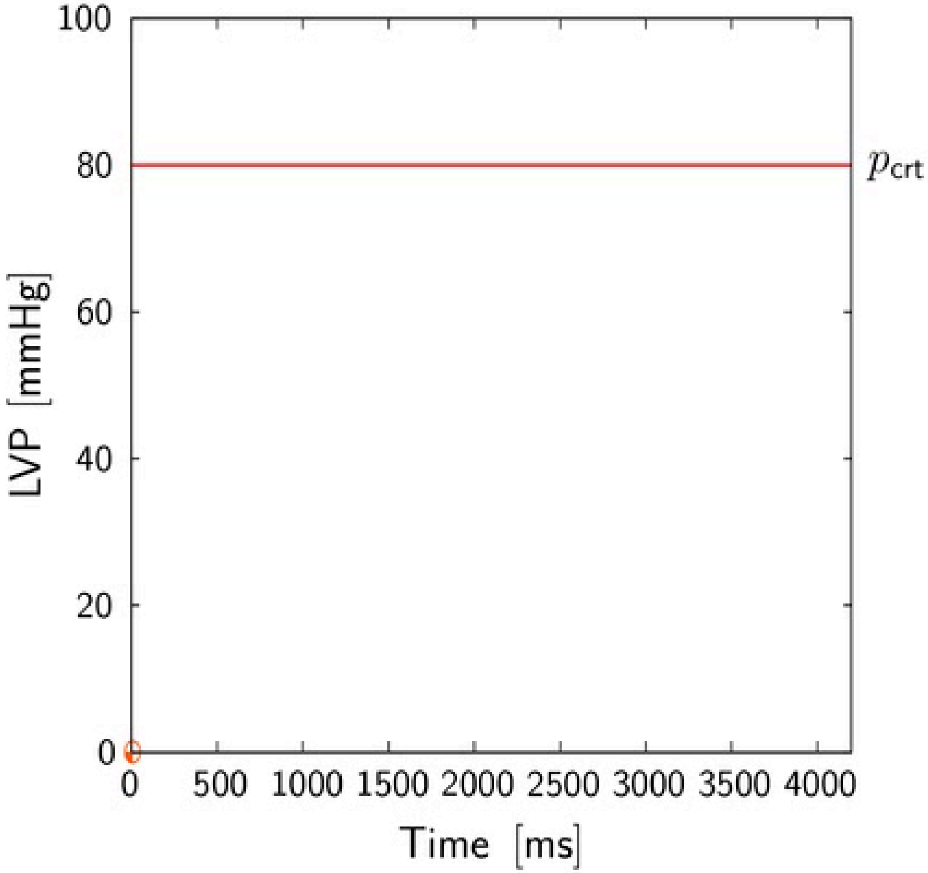
passive response - *in silico* prediction

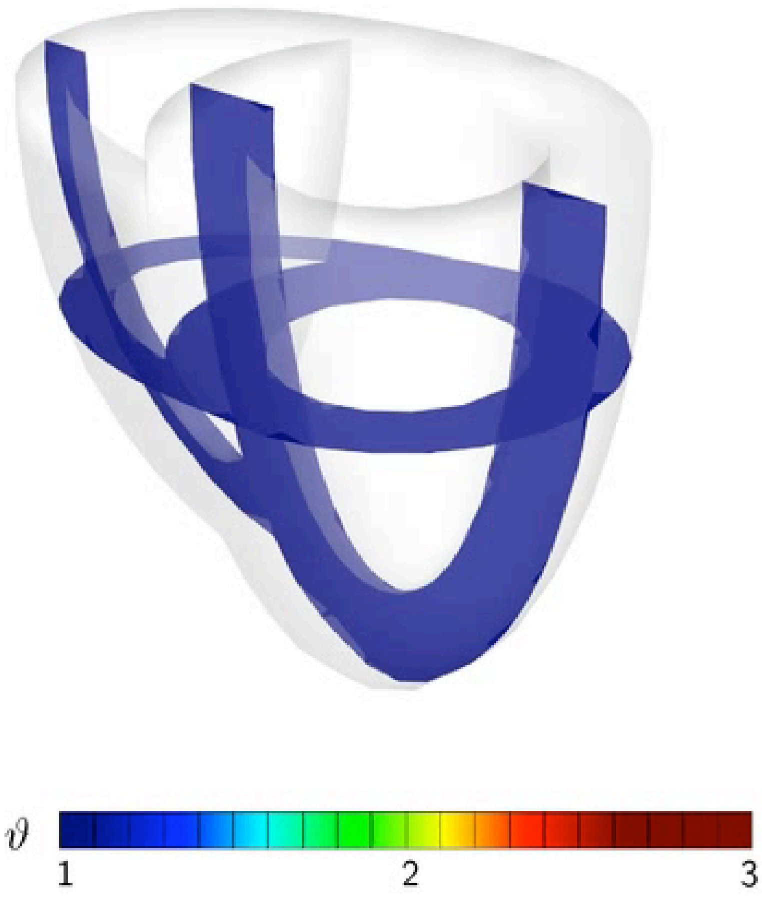


göktepe, acharya, wong, kuhl [2009]

intro to the heart - tue 03/09/10

hypertrophic wall thickening





linear hyperelasticity

$$\mathbb{E} = \lambda \boldsymbol{I} \otimes \boldsymbol{I} + 2\,\mu \mathbb{I}^{\text{sym}} \qquad \boldsymbol{\sigma} = \mathbb{E} : \boldsymbol{\epsilon}$$

$$\mathbb{E} = \begin{bmatrix} \lambda + 2\mu & \lambda & \lambda & 0 & 0 & 0 \\ \lambda & \lambda + 2\mu & \lambda & 0 & 0 & 0 \\ \lambda & \lambda & \lambda + 2\mu & 0 & 0 & 0 \\ 0 & 0 & 0 & \mu & 0 & 0 \\ 0 & 0 & 0 & 0 & \mu & 0 \\ 0 & 0 & 0 & 0 & 0 & \mu \end{bmatrix}$$

two Lame parameters λ and μ .

volumetric deviatoric decomposition

$$\mathbb{E} = 3\,\kappa \mathbb{I}^{\text{vol}} + 2\,\mu \mathbb{I}^{\text{dev}} \qquad \boldsymbol{\sigma} = \mathbb{E} : \boldsymbol{\epsilon}$$

$$\mathbb{E} = \begin{bmatrix} \kappa + \frac{4}{3}\mu & \kappa - \frac{2}{3}\mu & \kappa - \frac{2}{3}\mu & 0 & 0 & 0 \\ \kappa - \frac{2}{3}\mu & \kappa + \frac{4}{3}\mu & \kappa - \frac{2}{3}\mu & 0 & 0 & 0 \\ \kappa - \frac{2}{3}\mu & \kappa - \frac{2}{3}\mu & \kappa + \frac{4}{3}\mu & 0 & 0 & 0 \\ 0 & 0 & 0 & \mu & 0 & 0 \\ 0 & 0 & 0 & 0 & \mu & 0 \\ 0 & 0 & 0 & 0 & 0 & \mu \end{bmatrix}$$

two parameters $\kappa = \lambda + \frac{2}{3}\mu$ and μ.

relations between elastic constants

	E,ν	E,μ	λ,μ	κ,μ
E	E	E	$\frac{\mu[3\lambda+2\mu]}{\lambda+\mu}$	$\frac{9\kappa\mu}{3\kappa+\mu}$
ν	ν	$\frac{E-2\mu}{2\mu}$	$\frac{\lambda}{2[\lambda+\mu]}$	$\frac{3\kappa-2\mu}{6\kappa+2\mu}$
μ	$\frac{E}{2[1+\nu]}$	μ	μ	μ
λ	$\frac{E\nu}{[1+\nu][1-2\nu]}$	$\frac{\mu[E-2\mu]}{3\mu-E}$	λ	$\kappa-\frac{2}{3}\mu$
κ	$\frac{E}{3[1-2\nu]}$	$\frac{E\mu}{3[3\mu-E]}$	$\lambda+\frac{2}{3}\mu$	κ

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transversely isotropic hyperelasticity

a **transversely isotropic material** is symmetric about an axis that is normal to a plane of isotropy. within this plane, the material properties are the same in all directions. the number of independent constants in the elasticty tensor reduces from 21 to five: C_{11}, C_{33}, C_{12}, C_{13}, C_{44}, here $\boldsymbol{n} = [0,0,1]^t$

$$\begin{pmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ & C_{11} & C_{13} & 0 & 0 & 0 \\ & & C_{33} & 0 & 0 & 0 \\ & & & C_{44} & 0 & 0 \\ & symmetric & & & C_{44} & 0 \\ & & & & & (C_{11}-C_{12})/2 \end{pmatrix}$$

orthotropic hyperelasticity

an **orthotropic material** is symmetric about two or three muturally orthogonal two-fold axes of rotational symmetry. its material properties are in general different along each axis. the number of independent constants reduces from 21 to nine: $C_{11}, C_{22}, C_{33}, C_{12}, C_{23}, C_{31}, C_{44}, C_{55}, C_{66}$

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ C_{12} & C_{22} & C_{23} & 0 & 0 & 0 \\ C_{13} & C_{23} & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{bmatrix}$$

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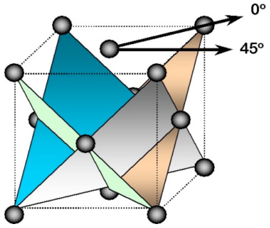
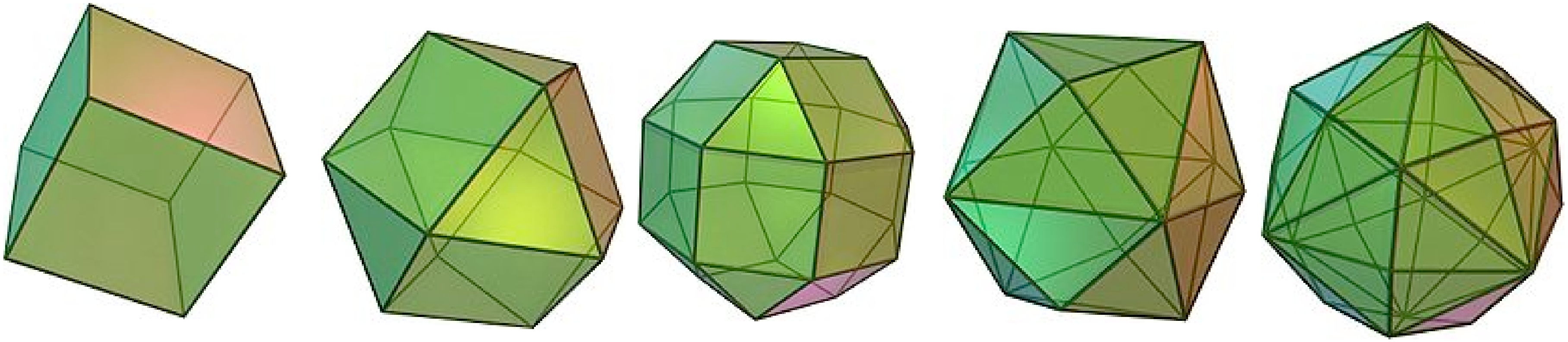
symmetry groups



the **symmetry group** of an object is the group of all isometries under which it is invariant with composition as the operation. it is a subgroup of the isometry group of the space concerned. a typical example are the symmetric lattices of fcc and bcc crystals.



example: double cork 1080

spins are referred to as **corked** or corkscrew when the axis of the spin allows for the snowboarder to be temporarily oriented sideways in the air, typically without becoming completely inverted. a **double-cork** refers to a rotation in which a snowboarder inverts or orients himself sideways **at two distinct times** during an aerial rotation.

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double mctwist 1260

the **mctwist** was invented in the early 1980s by skateboarder mike mcgill, and has since been adopted by snowboarders. to perform the trick, the rider does a front flip while at the same time spinning a backside 540. a variety of grabs are used to give the trick more style. in early 2010, shaun white debuted a new trick - the **double mctwist 1260**, which involves **two flips and three and a half spins.**

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