CCI Journal Club

What are all these models, and do we really need them?

Translating cardiac mechanical modeling into clinical applications

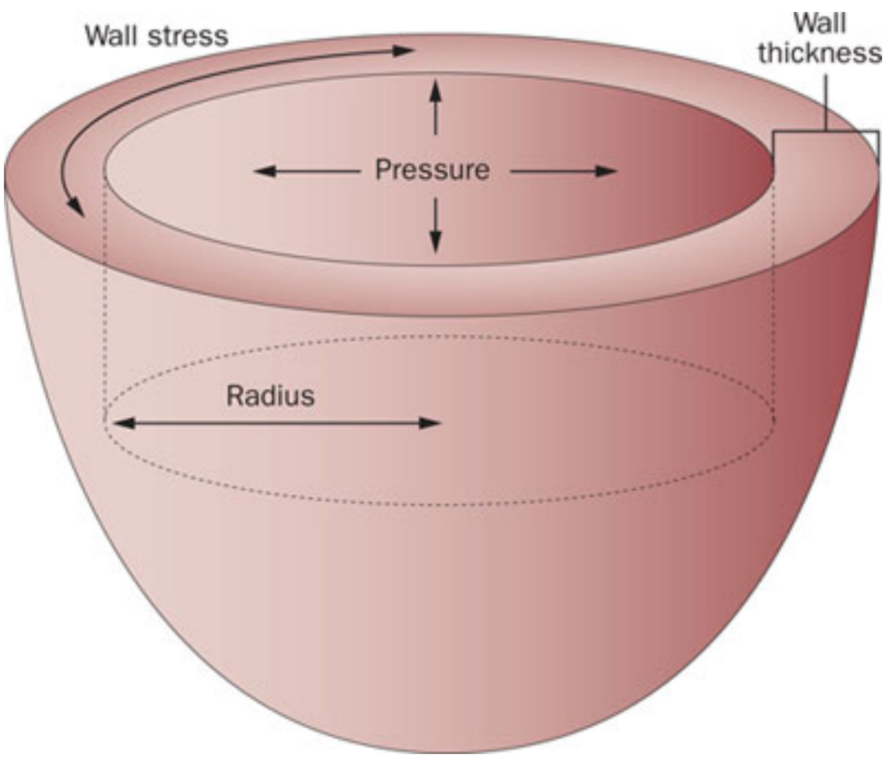
Henrik Finsberg
PhD student

March 27, 2017

CENTER FOR CARDIOLOGICAL INNOVATION

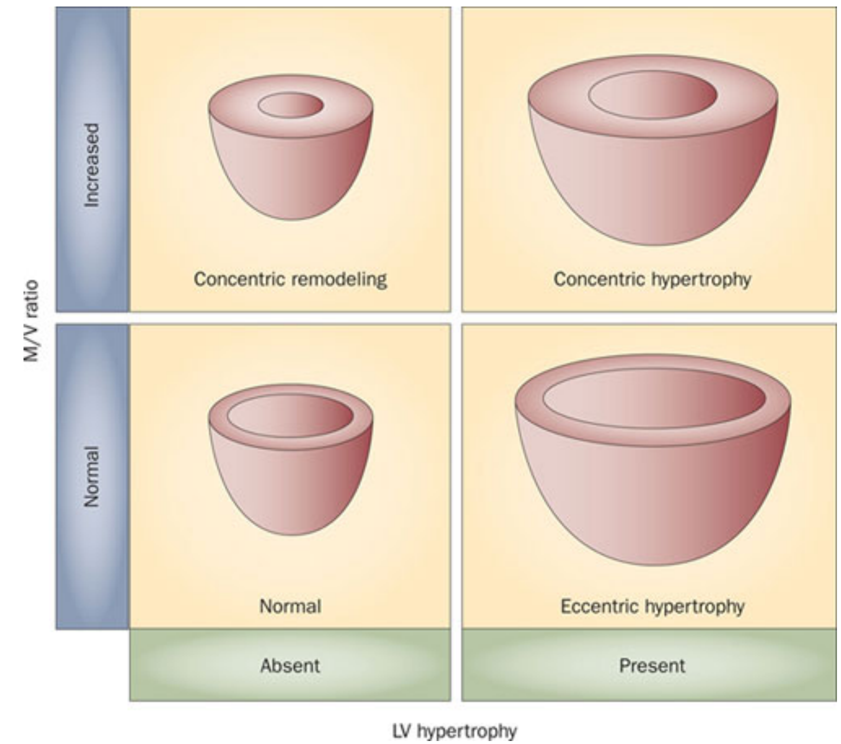
Centre for Research-based Innovation

The Law of Laplace is one of the earliest examples of models used to understand cardiac physiology



Gjesdal, 2011

Gjesdal, 2011

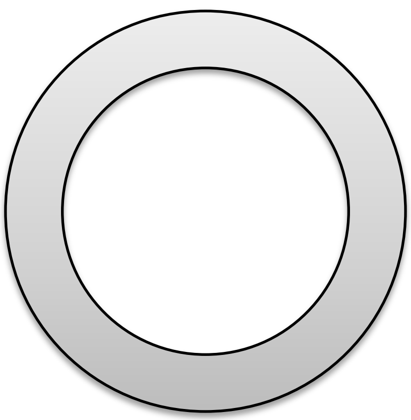


$$\text{wall stress} = \frac{\text{pressure} \times \text{radius}}{2 \times \text{wall thickness}}$$

Woods, 1892

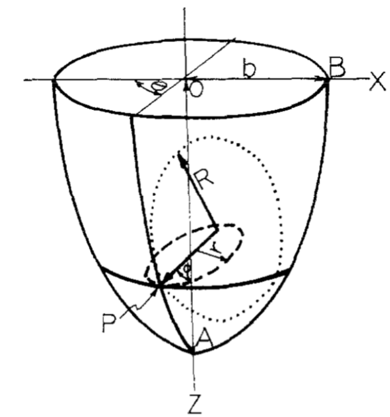
Geometrical models have developed from simple spheres to truncated ellipsoids to patient specific geometries

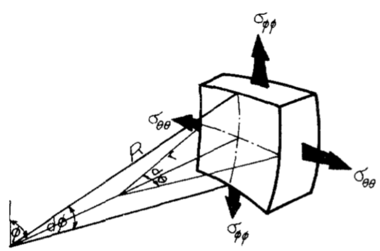
Sphere



Woods, 1892

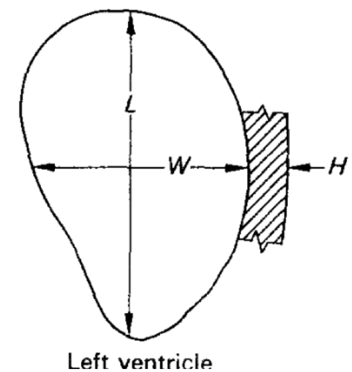
Ellipsoidal

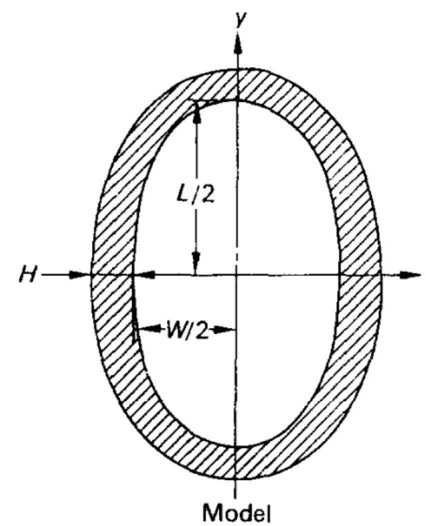




Wong 1967;
Mirsky, 1969;

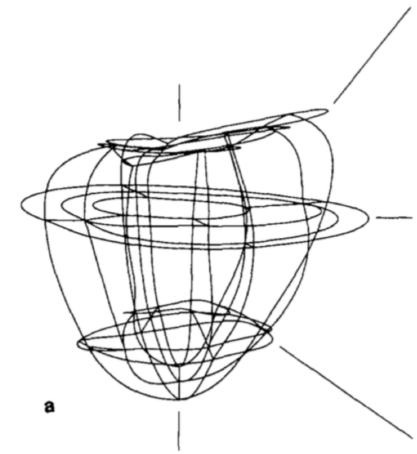
Axisymmetric

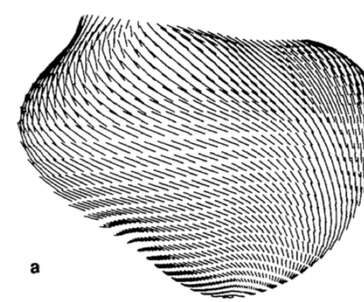




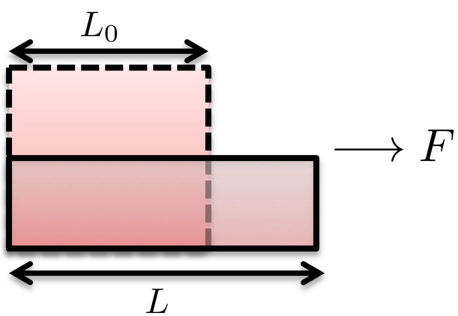
Streeter, 1970;
Ghista 1973

Patient specific

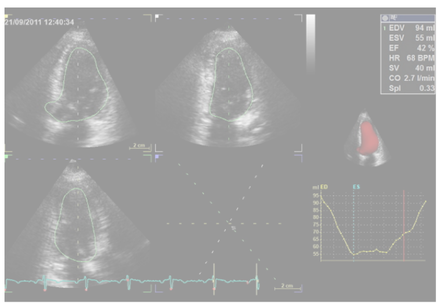




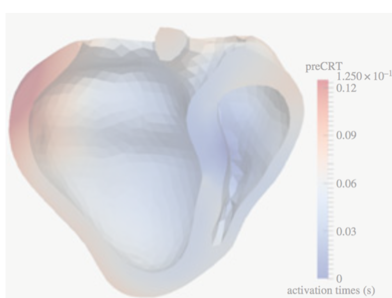
Hunter, 1988;
McCulloch, 1987

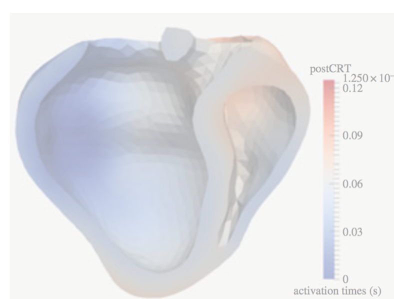


What is a model, and where does it comes from?

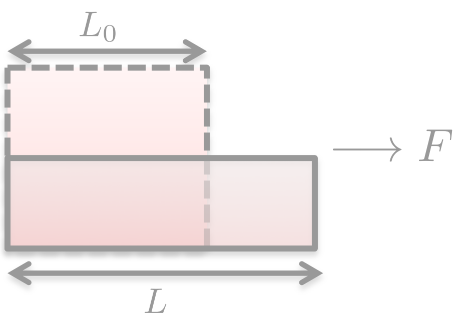


How can we make a model patient specific?

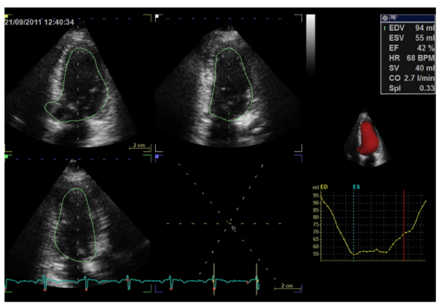




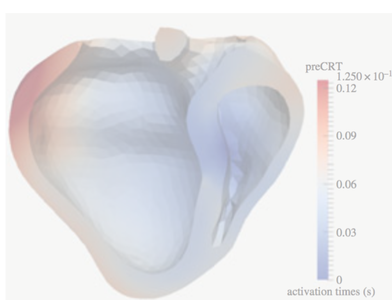
What can we use models for?

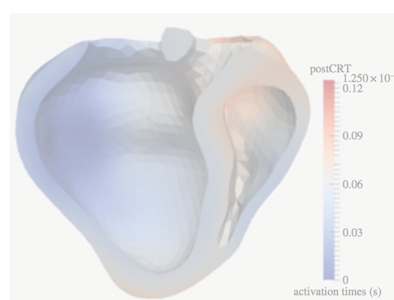


What is a model, and where does it comes from?

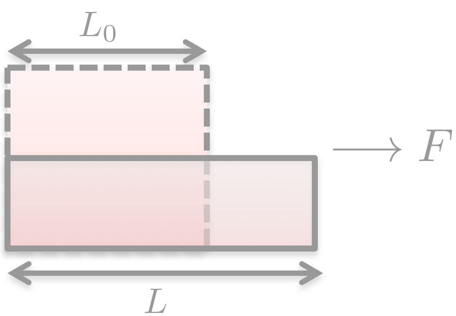


How can we make a model patient specific?

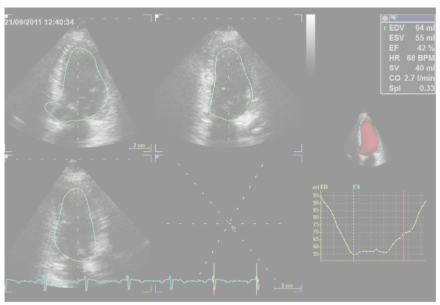




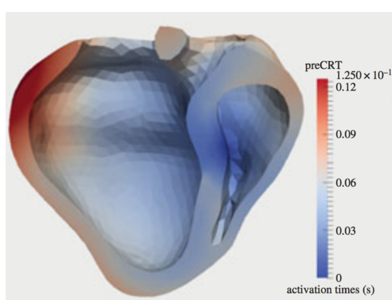
What can we use models for?

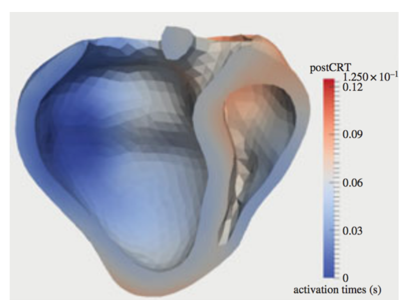


What is a model, and where does it comes from?



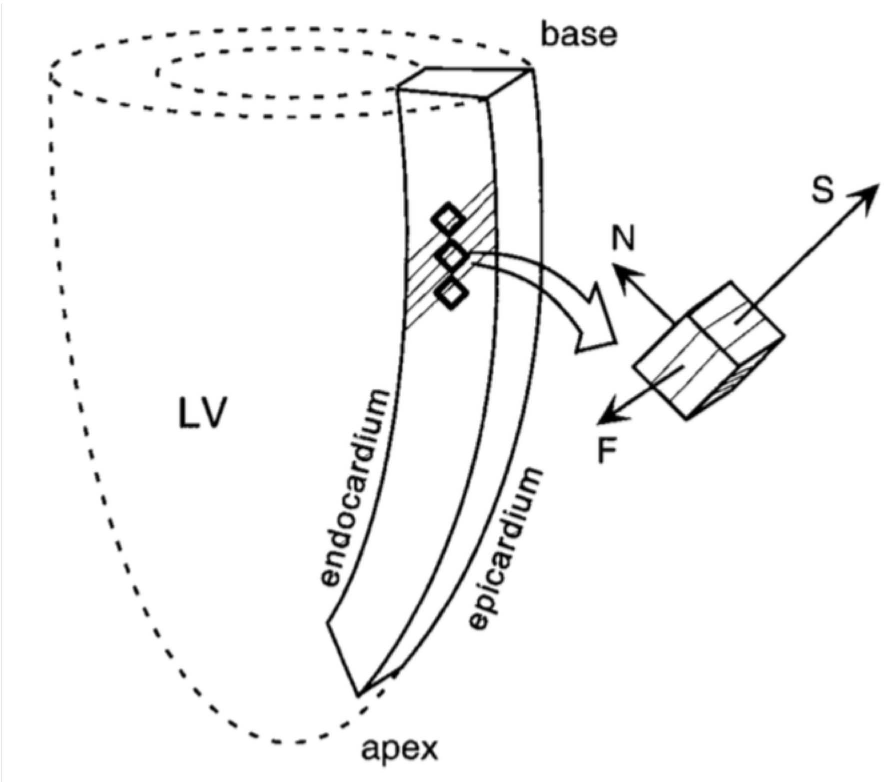
How can we make a model patient specific?

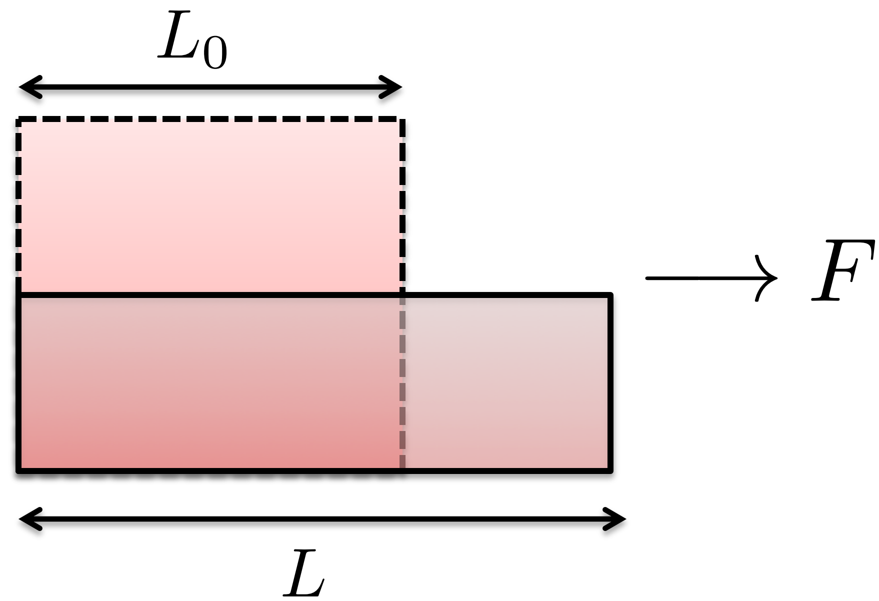




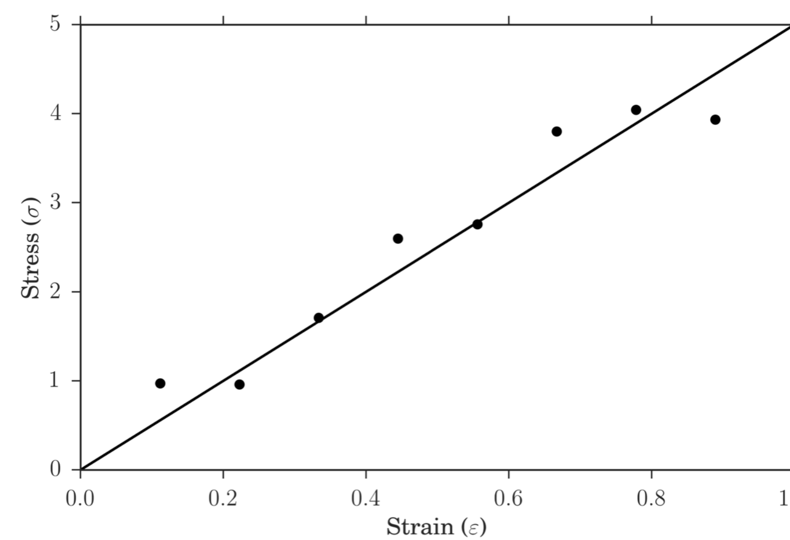
What can we use models for?

A model is a set of equations describing some phenomena based on experimental observations, physical laws and assumptions





$$\sigma = \frac{F}{A} \quad \varepsilon = \frac{L - L_0}{L_0} \quad \sigma = D\varepsilon$$



To capture anisotropy of the myocardium, more complex models have to be developed

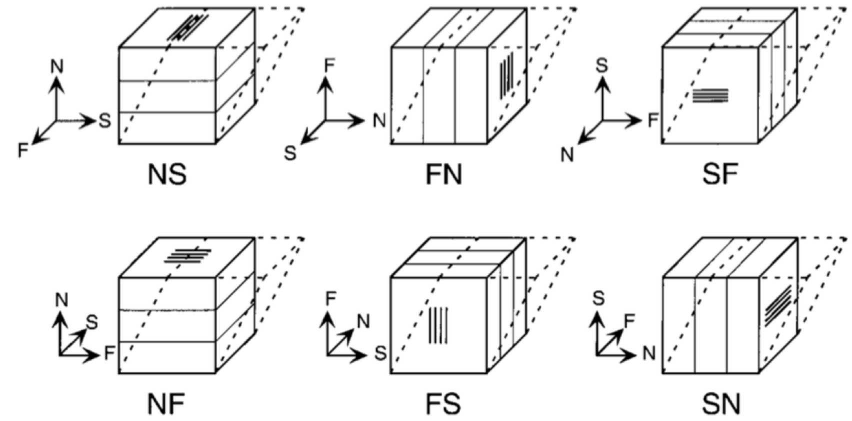
$\Psi =$

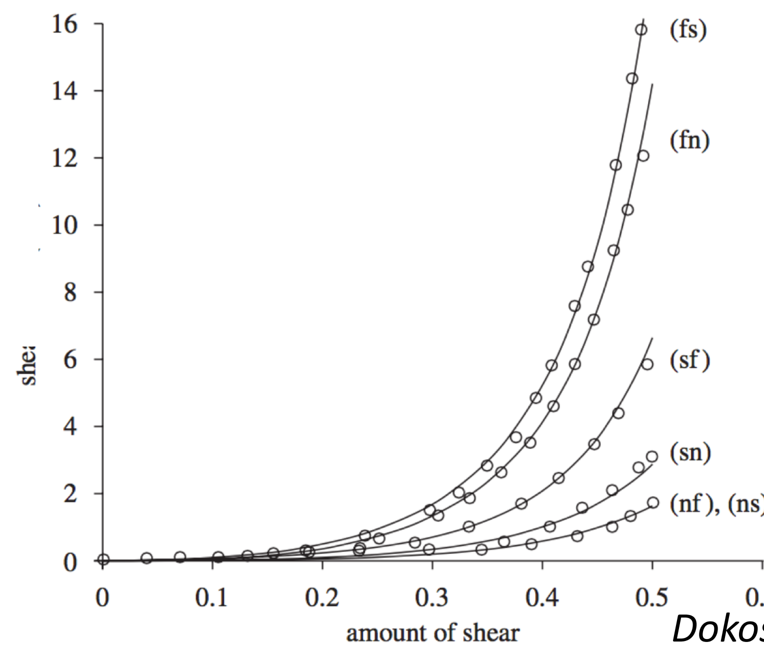
Contribution from Extracellular matrix

$+$ Contribution from Fibers

$+$ Contribution from Sheets

$+$ Contribution from Fiber-Sheets





Dokos, 2002

Holzapfel and Ogden, 2009

To capture anisotropy of the myocardium, more complex models has to be developed

$$\Psi =$$

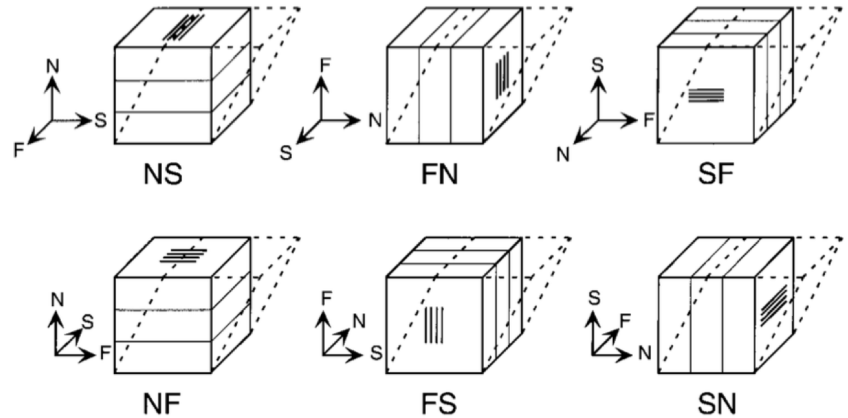
$$\frac{a}{2b}\left(e^{b(I_1-3)}-1\right)$$ Extracellular matrix

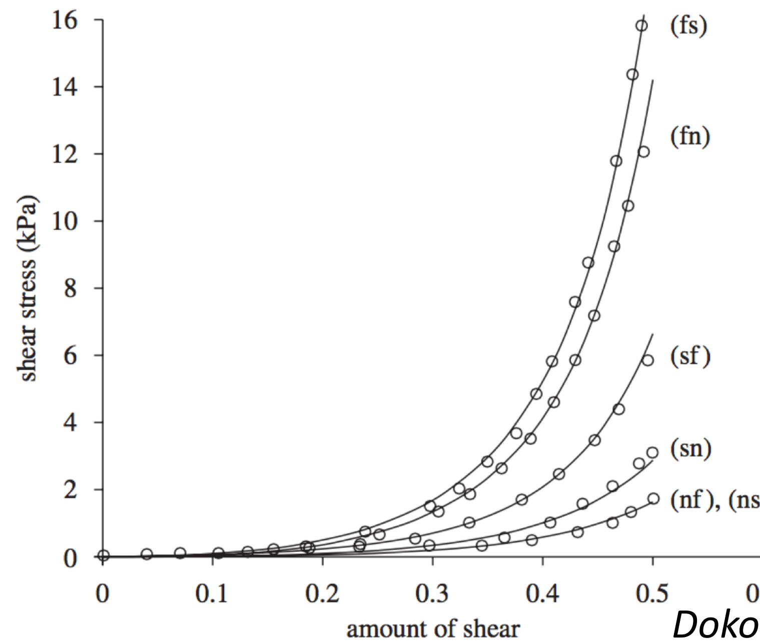
$$+\frac{a_f}{2b_f}\left(e^{b_f(I_{4f}-1)^2}-1\right)$$ Fibers

$$+\frac{a_s}{2b_s}\left(e^{b_s(I_{4s}-1)^2}-1\right)$$ Sheets

$$+\frac{a_{fs}}{2b_{fs}}\left(e^{b_{fs}I_{8fs}^2}-1\right)$$ Fiber-Sheets

$$\sigma = J^{-1}\frac{\partial\Psi}{\partial\mathbf{F}}\mathbf{F}^T$$



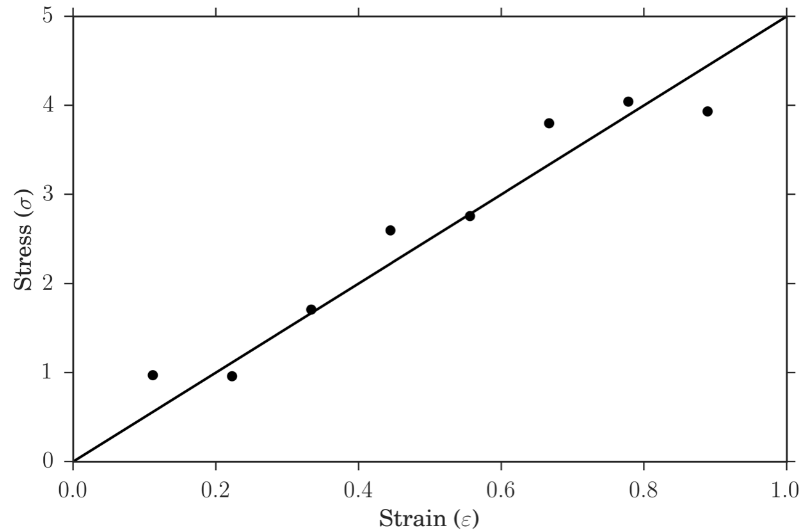


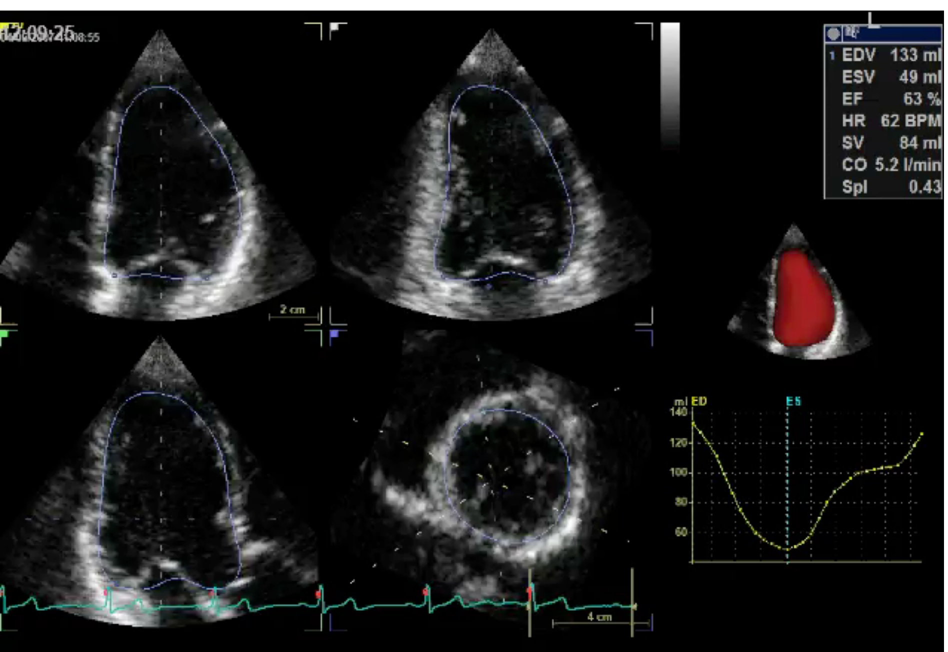
Dokos, 2002

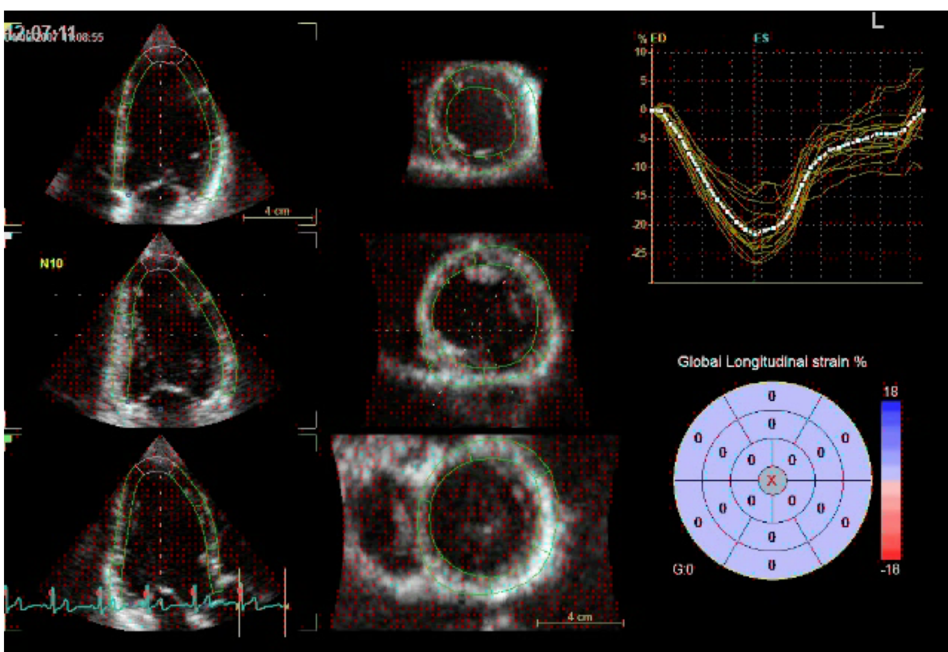
Holzapfel and Ogden, 2009

Models depend upon parameters which need to be determined

$$\sigma = D\varepsilon$$

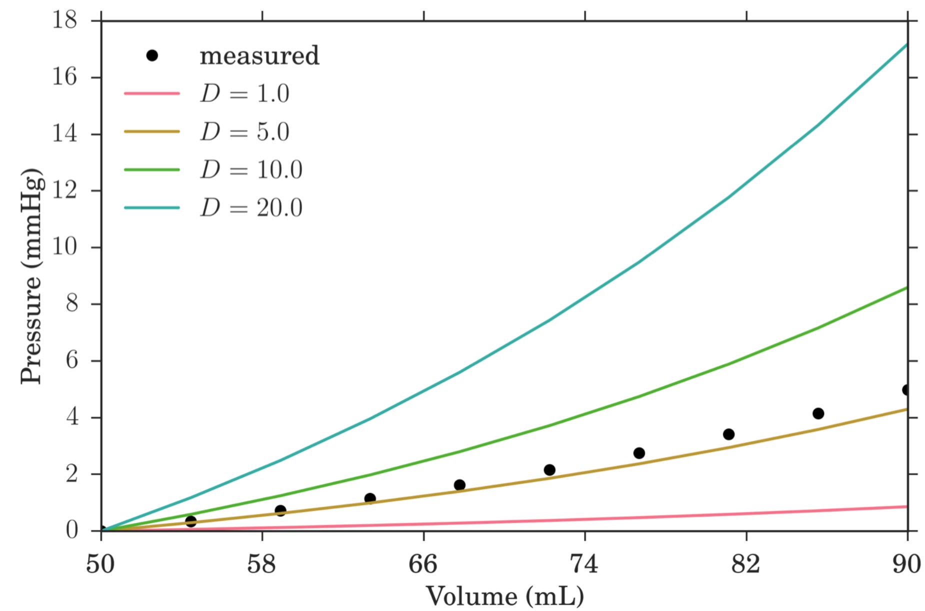






Data assimilation is a technique for estimating parameters based on clinical observations

$$\sigma = D\varepsilon$$



$$\text{minimize : (observations} - \text{simulations)}^2$$
$$\text{subject to : Newton's laws should hold}$$

Advances in medical imaging is key to make models more reliable

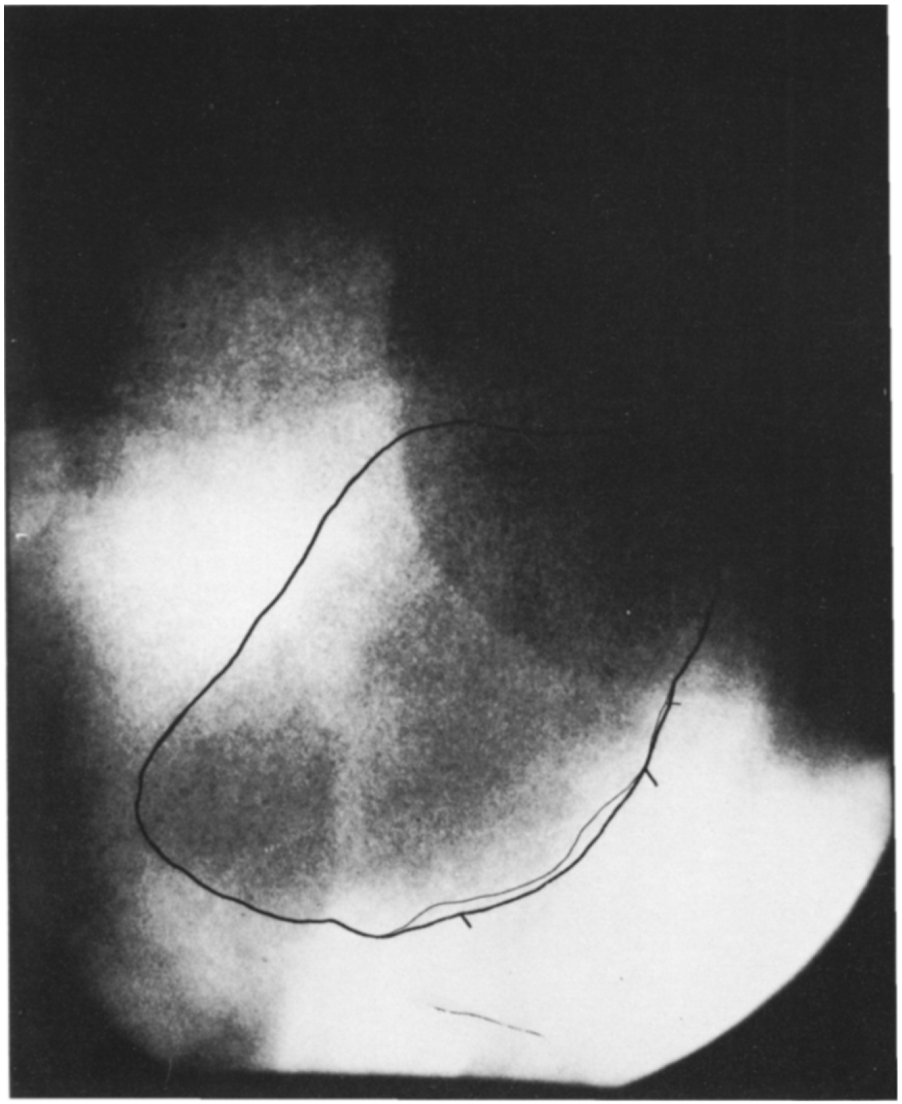
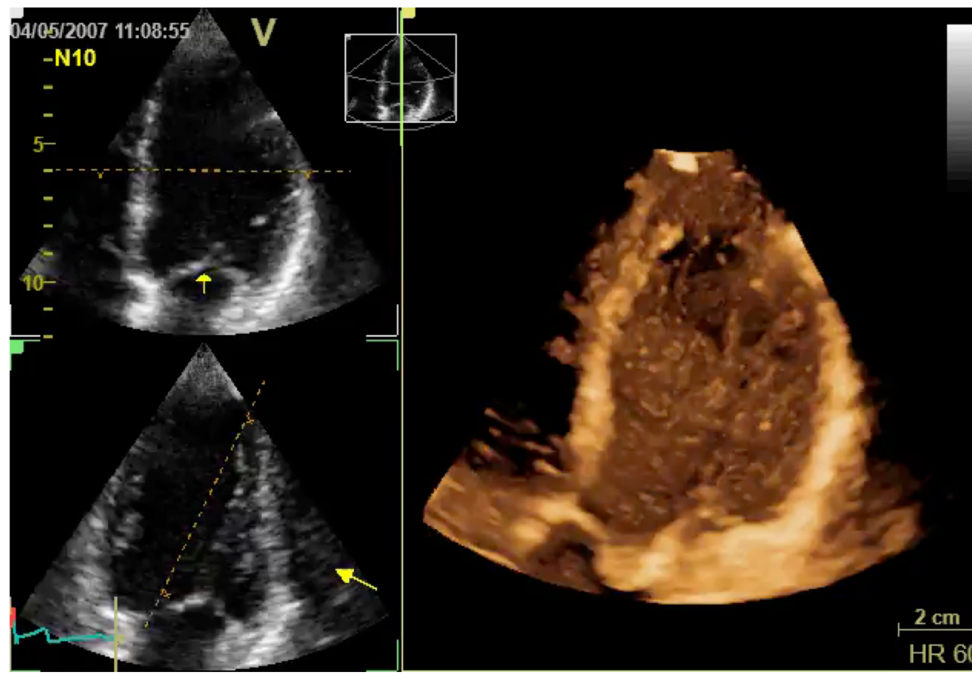


Fig. 1. An X-ray film of the left ventricle in anteroposterior projection.



Gould, 1973

Advances in medical imaging is key to make models more reliable

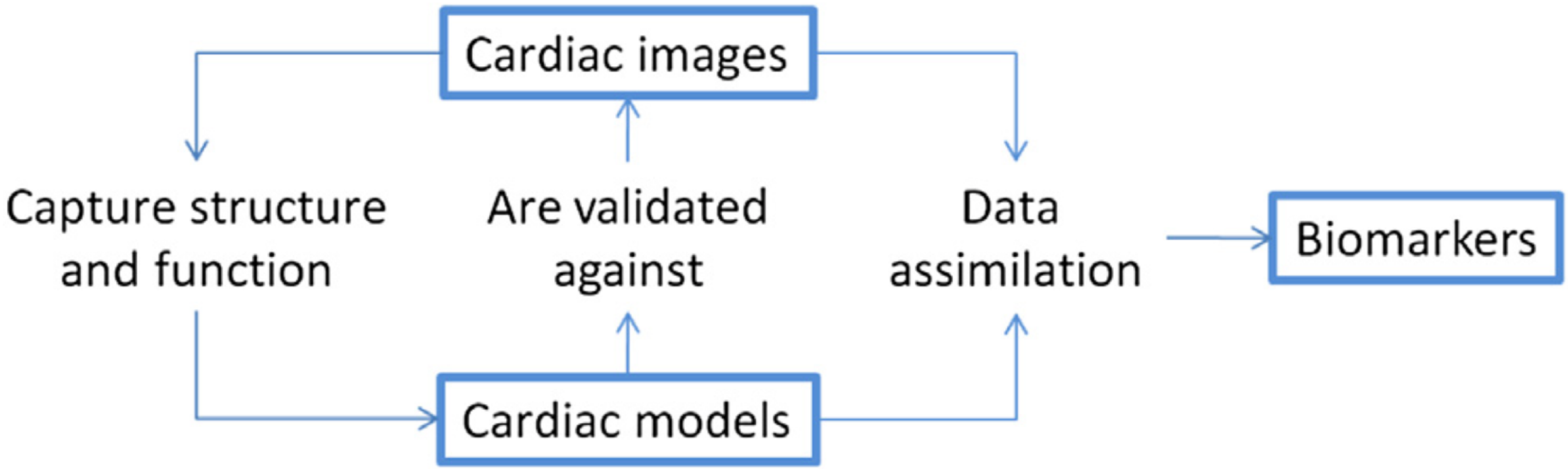


Fig. 1. Conceptual scheme of how cardiac images interact with computational models to generate novel insight and drive research progress.

Lamata, 2014

Models can be used for extracting biomarkers, and (in the future) make predictions

Biomarkers

Tool to gain insight into cardiac physiology

Short term predictions

Long term predictions

Models can be used for extracting biomarkers, and (in the future) make predictions

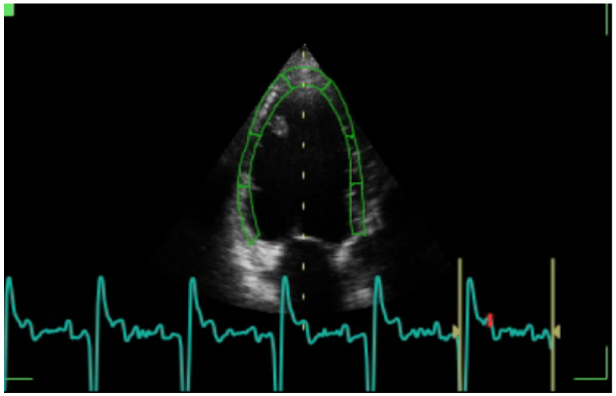
Biomarkers

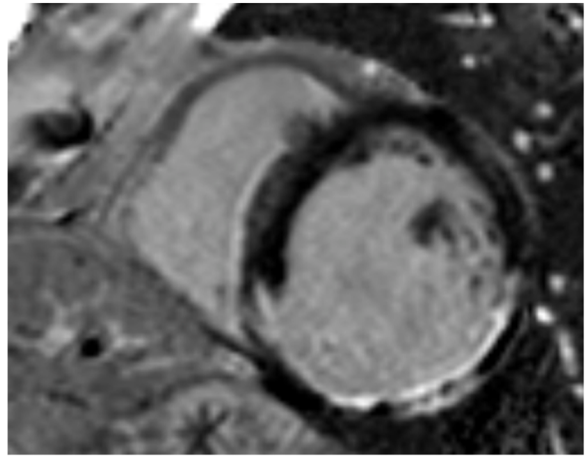
Tool to gain insight into cardiac physiology

Short term predictions

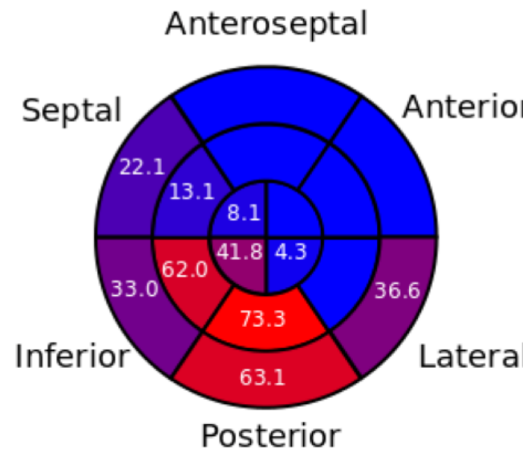
Long term predictions

Estimation of tissue stiffness





Myocardial Scar



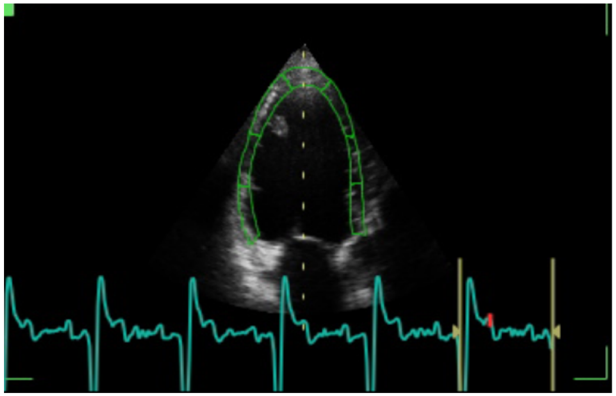
$\Psi =$

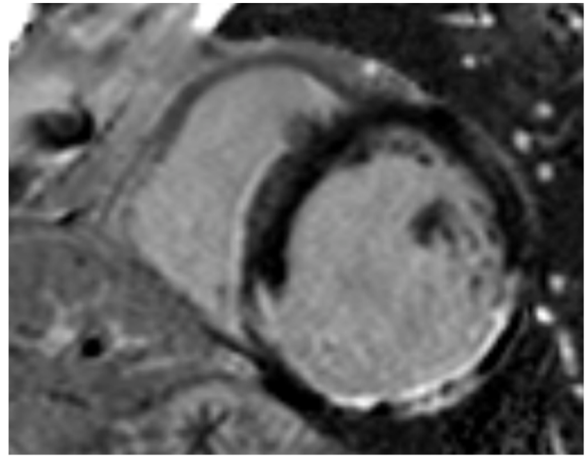
Contribution from Extracellular matrix

$+$ Contribution from Fibers

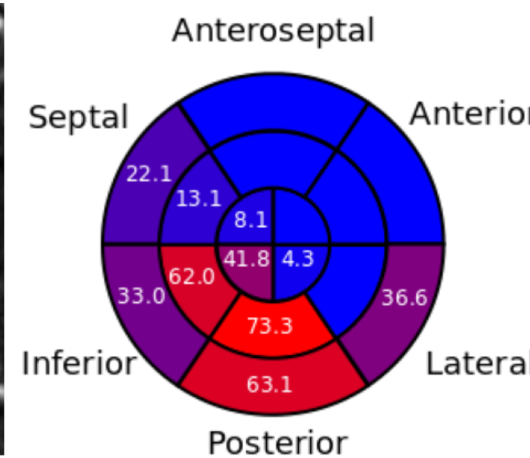
Balaban, 2017

Estimation of tissue stiffness





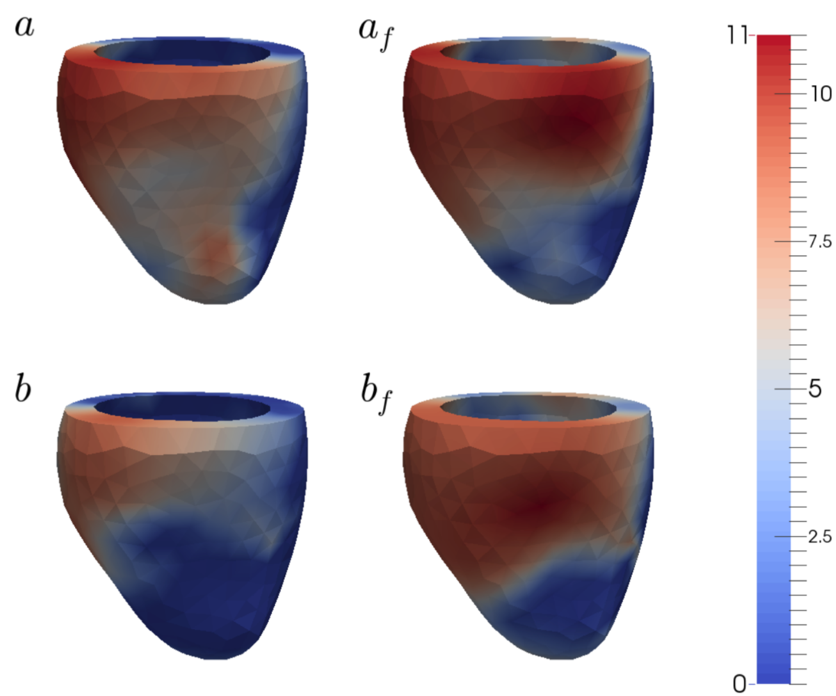
Myocardial Scar



$$\Psi =$$

$$\frac{a}{2b}\left(e^{b(I_1-3)}-1\right)$$ Extracellular matrix

$$+\frac{a_f}{2b_f}\left(e^{b_f(I_{4f}-1)^2}-1\right)$$ Fibers

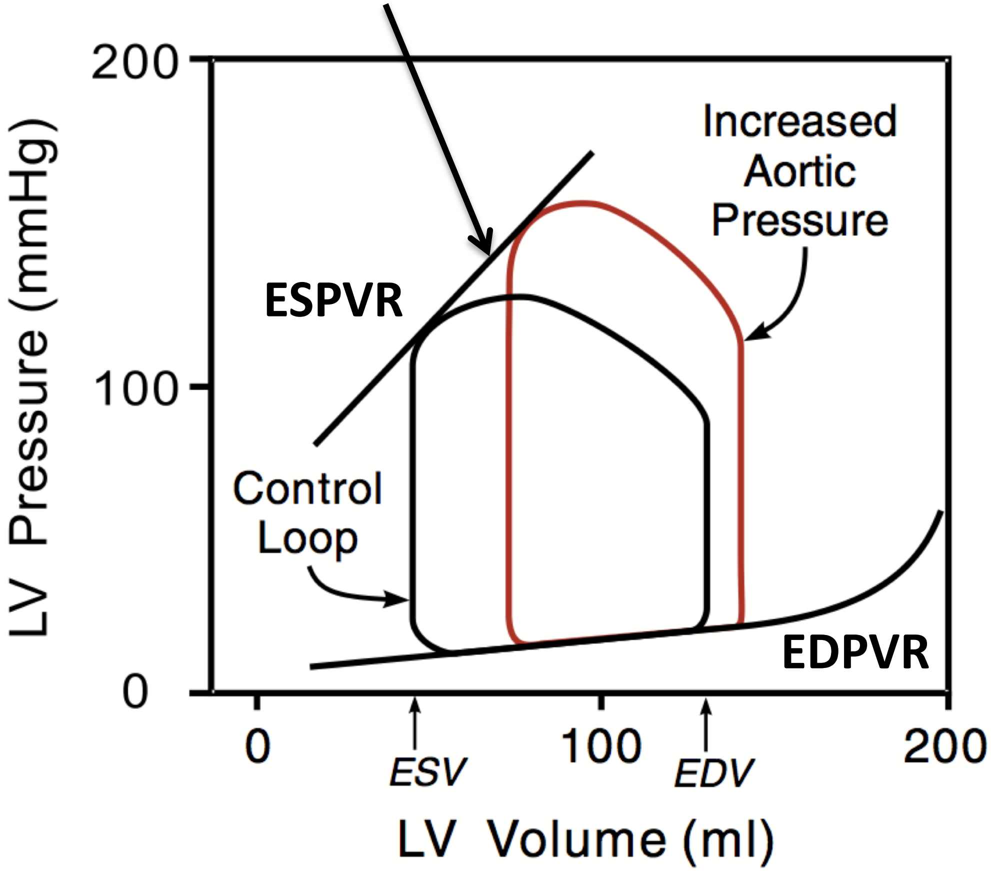


Balaban, 2017

Estimation of contractility

Katz: Myocardial Contractility is the ability of the heart to do work

Slope = Contractility $= E_{\mathrm{ES}}$

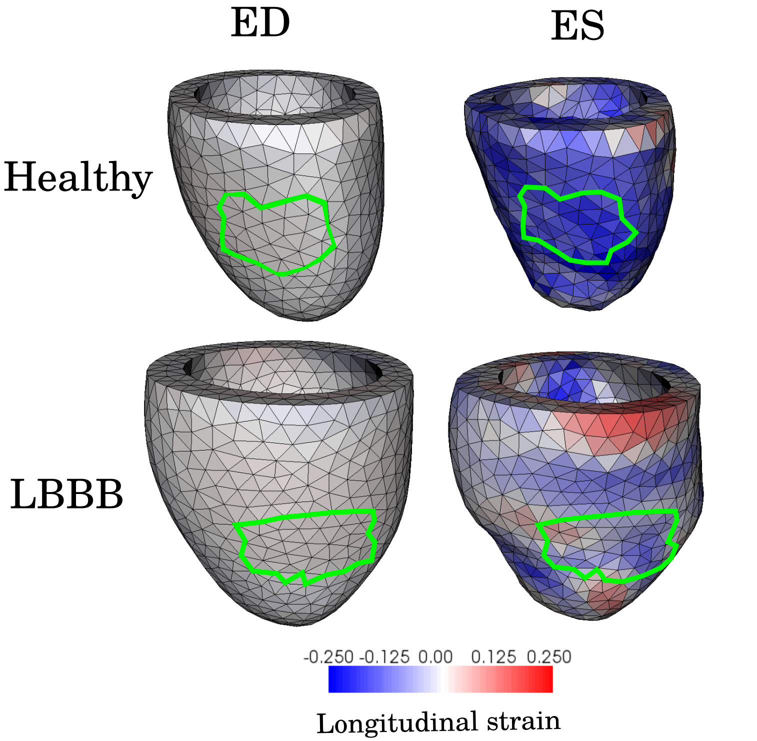


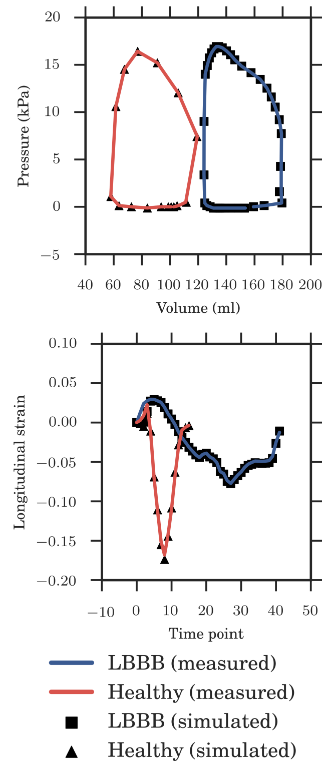
$$P(t) = E(t)(V(t) - V_0)$$

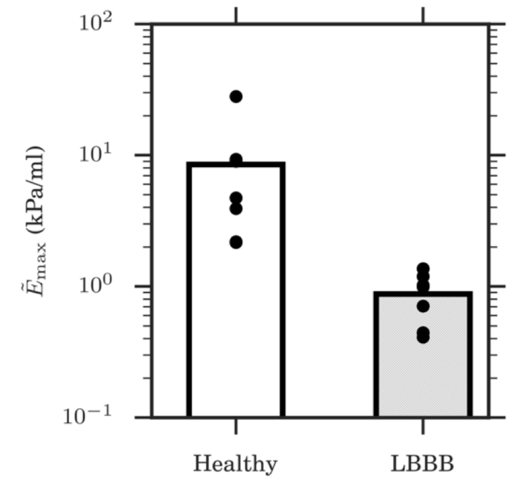
$$E_{\mathrm{ES}} \approx \frac{P(t_{\mathrm{ES}})^{\Delta} - P(t_{\mathrm{ES}})}{V(t_{\mathrm{ES}})^{\Delta} - V(t_{\mathrm{ES}})}$$

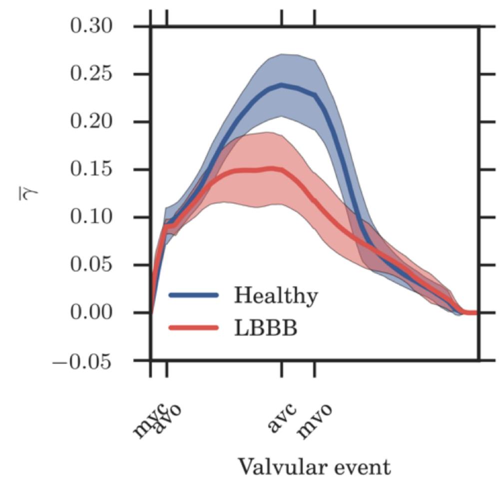
Suga, 1974

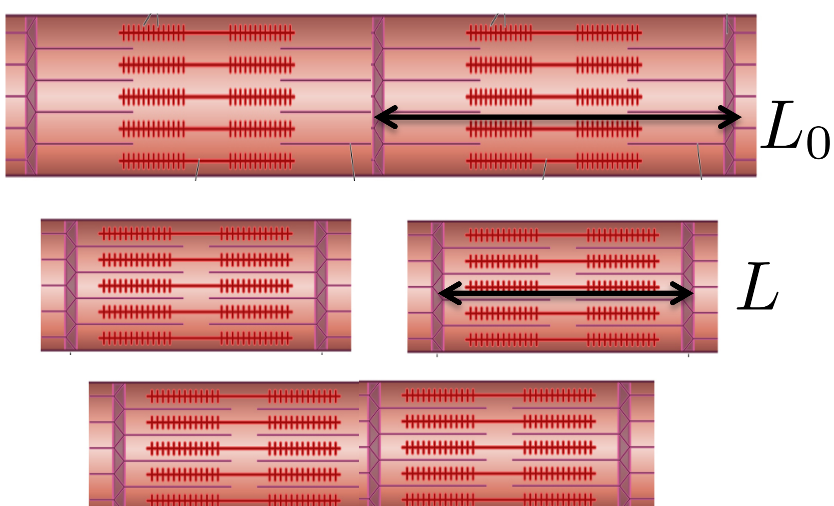
Estimation of contractility











Relaxed

Contracted

Total

$$\gamma \approx -\frac{L - L_0}{L_0}$$

Finsberg, 2017

Models can be used for extracting biomarkers, and (in the future) make predictions

Biomarkers

Tool to gain insight into cardiac physiology

Short term predictions

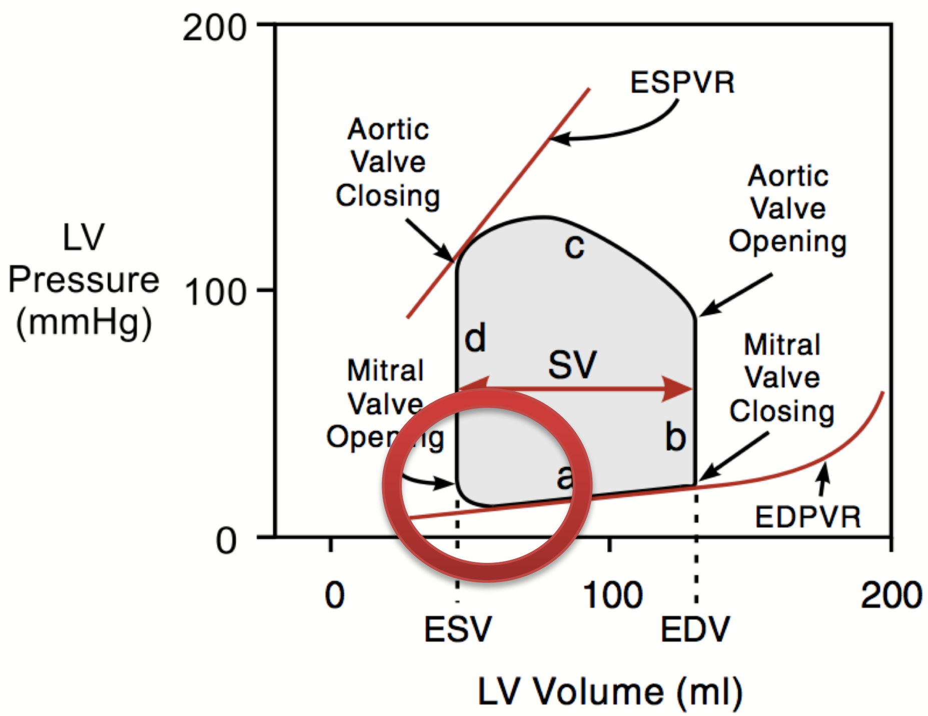
Long term predictions

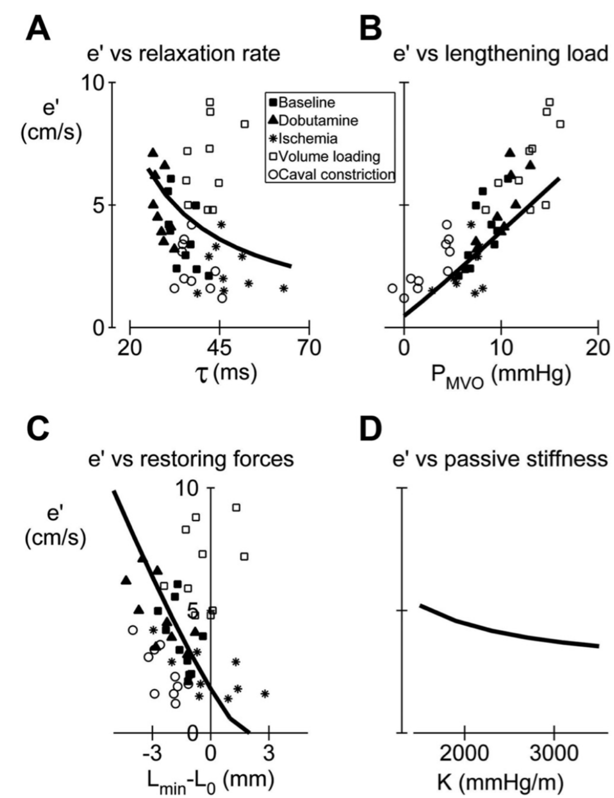
Am J Physiol Heart Circ Physiol 300: H1678–H1687, 2011.
First published February 11, 2011; doi:10.1152/ajpheart.00165.2010.

Mechanics of left ventricular relaxation, early diastolic lengthening, and suction investigated in a mathematical model

Espen W. Remme,[1,2] Anders Opdahl,[1,2] and Otto A. Smiseth[1,2]
[1]*Department of Cardiology and* [2]*Institute for Surgical Research, Oslo University Hospital, Rikshospitalet, and University of Oslo, Oslo, Norway*

Submitted 18 February 2010; accepted in final form 8 February 2011





Models can be used for extracting biomarkers, and (in the future) make predictions

Biomarkers

Tool to gain insight into cardiac physiology

Short term predictions

Long term predictions

Contents lists available at ScienceDirect

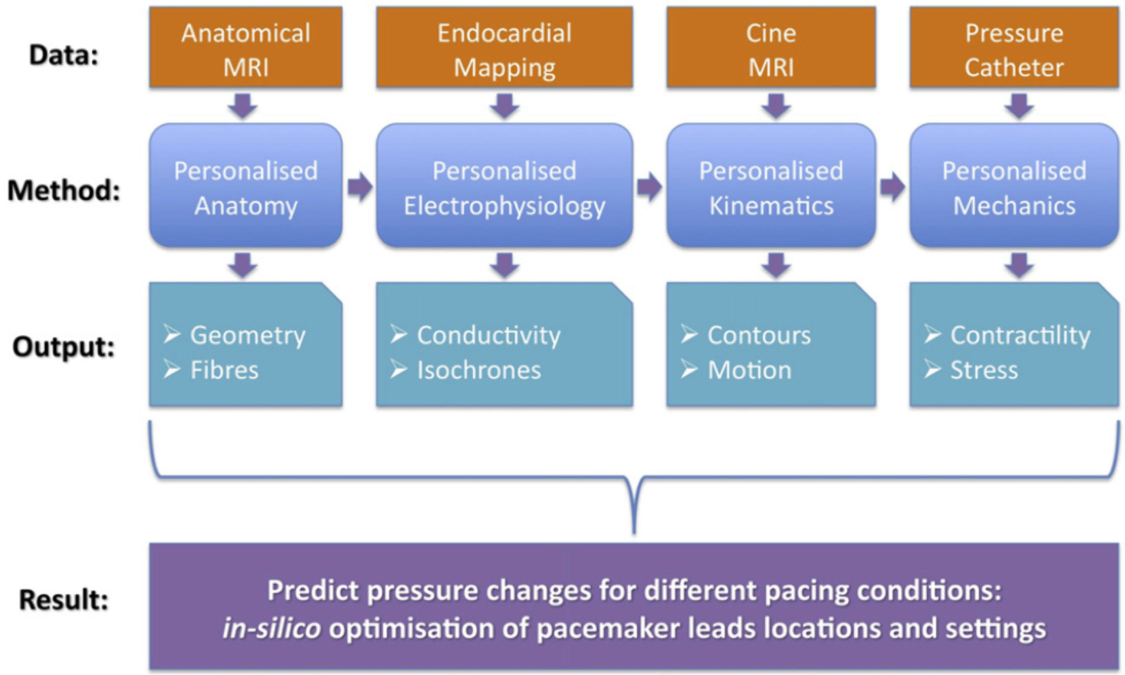
Medical Image Analysis

journal homepage: www.elsevier.com/locate/media

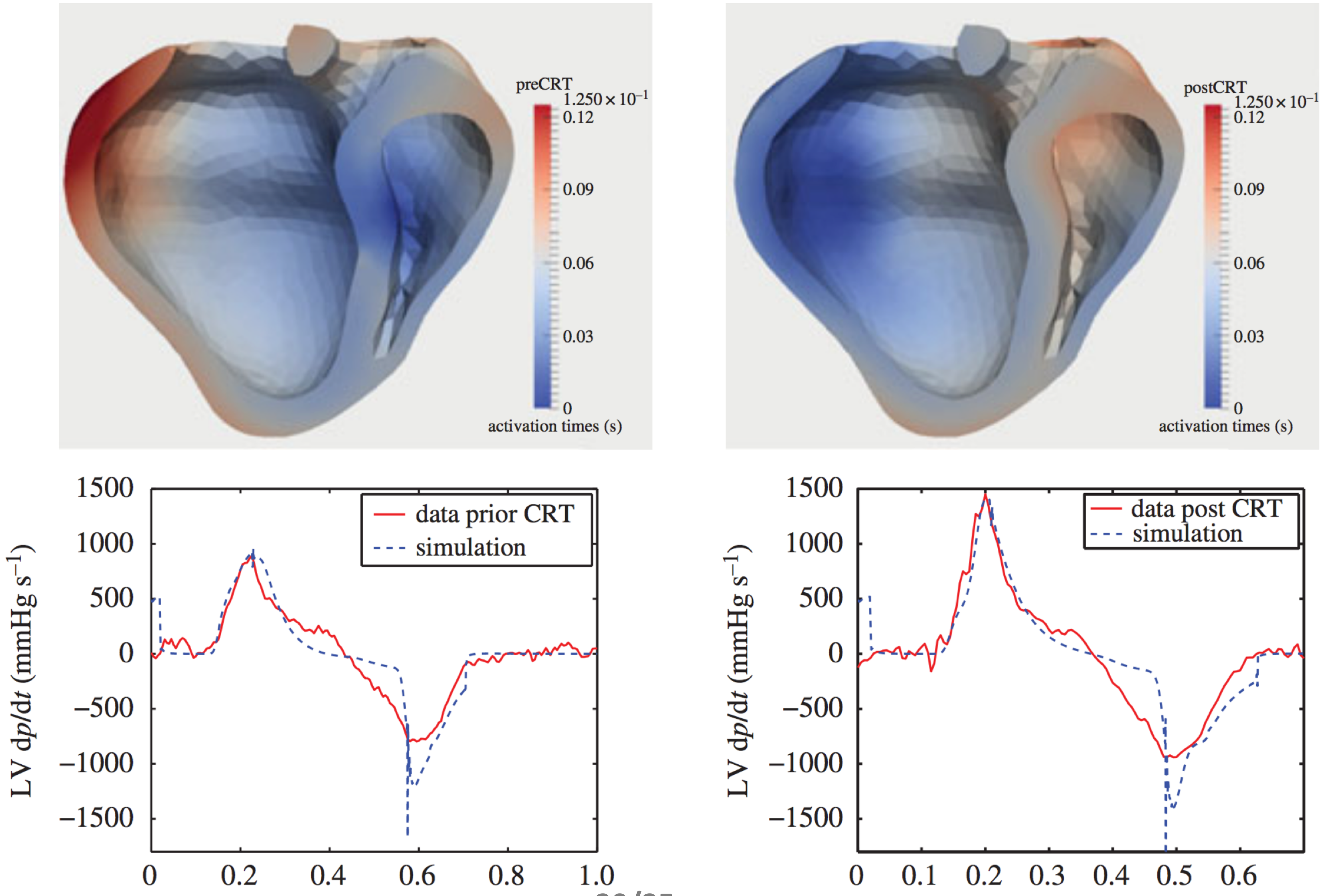
Patient-specific electromechanical models of the heart for the prediction of pacing acute effects in CRT: A preliminary clinical validation

M. Sermesant [a,b,*], R. Chabiniok [c], P. Chinchapatnam [b], T. Mansi [a], F. Billet [a], P. Moireau [c], J.M. Peyrat [a], K. Wong [a], J. Relan [a], K. Rhode [b], M. Ginks [b], P. Lambiase [e], H. Delingette [a], M. Sorine [f], C.A. Rinaldi [d], D. Chapelle [c], R. Razavi [b], N. Ayache [a]

[a] INRIA, Asclepios Project, 2004 route des Lucioles, 06 902 Sophia Antipolis, France
[b] King's College London, Division of Imaging Sciences, St. Thomas' Hospital, London, UK
[c] INRIA, Macs Project, Rocquencourt, Le Chesnay, France
[d] Department of Cardiology, St. Thomas' Hospital, London, UK
[e] Heart Hospital, University College London NHS Foundation Trust, London, UK
[f] INRIA, Sisyphe Project, Rocquencourt, Le Chesnay, France



Agreement between simulated and measured dp/dt (both pre- and post CRT) were obtained using baseline as calibration



Models can be used for extracting biomarkers, and (in the future) make predictions

Biomarkers

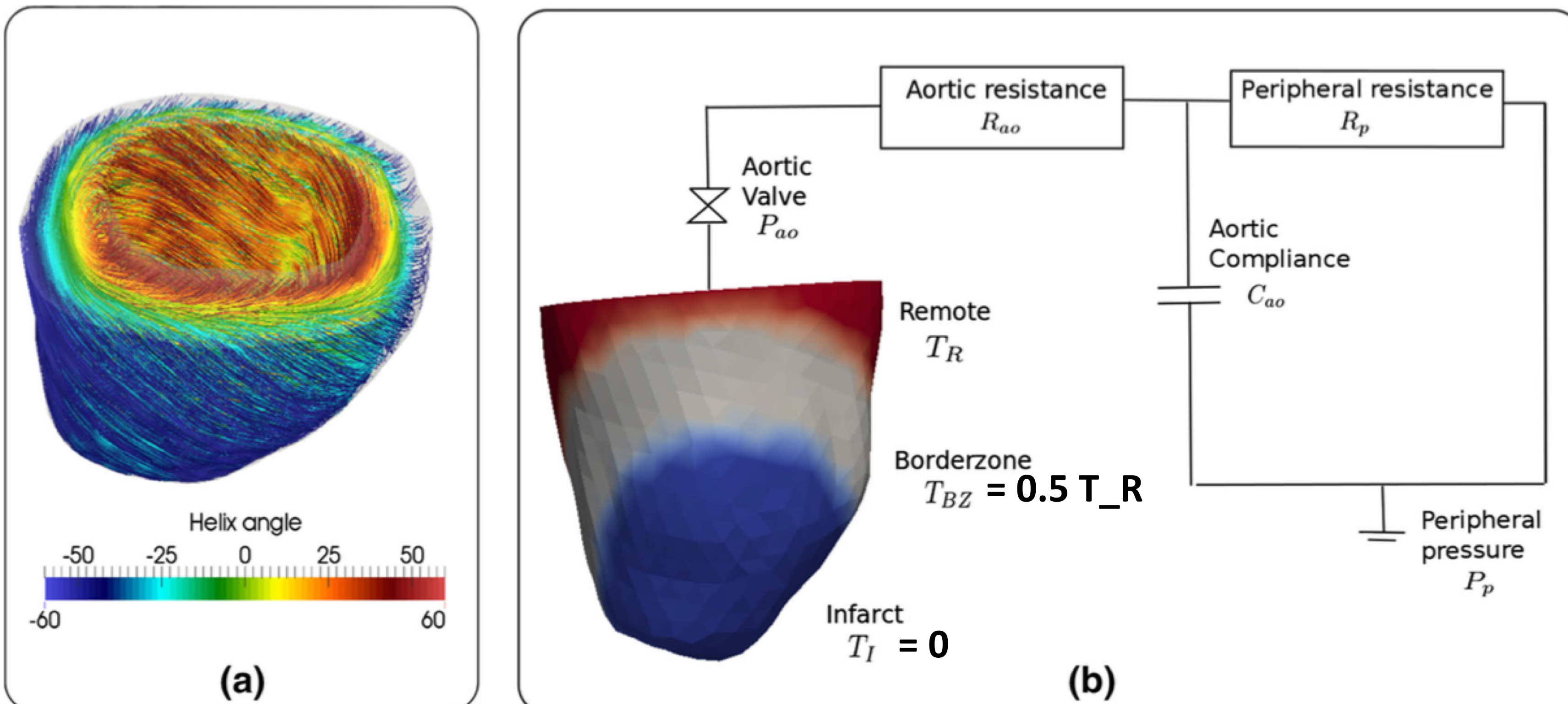
Tool to gain insight into cardiac physiology

Short term predictions

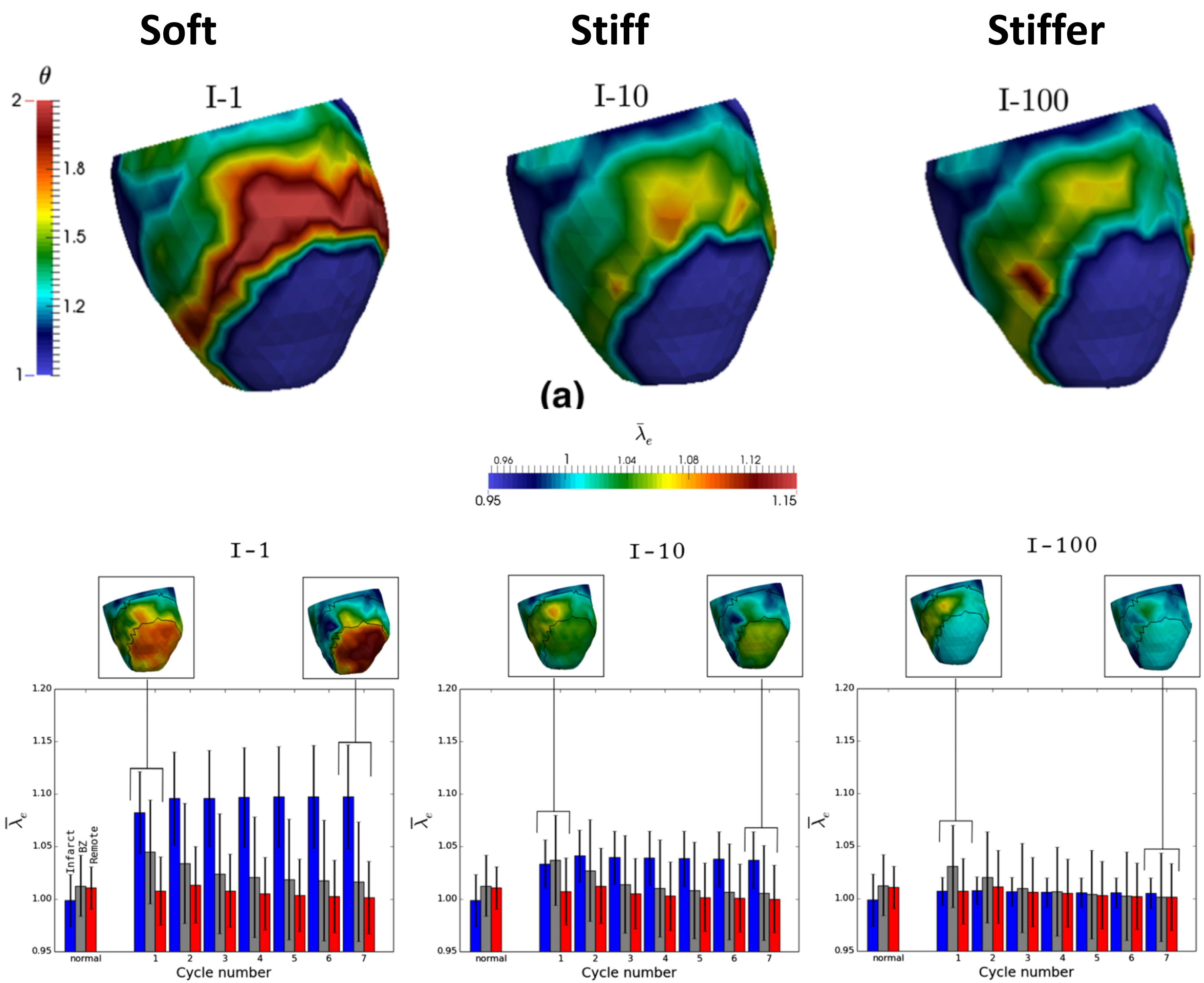
Long term predictions

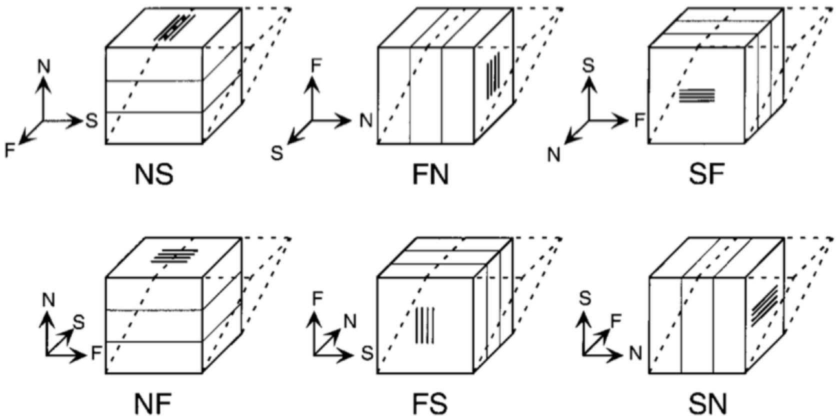
An integrated electromechanical-growth heart model for simulating cardiac therapies

Lik Chuan Lee[1] · Joakim Sundnes[2] · Martin Genet[3] · Jonathan F. Wenk[4] · Samuel T. Wall[2]

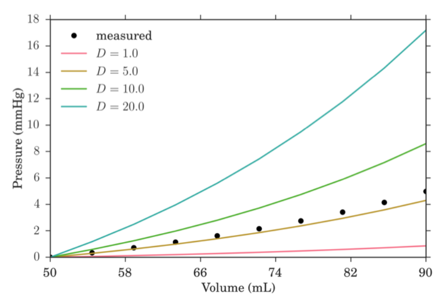


A stiffened infarct reduces the elastic myofiber stretch in BZ and hence reduces growth



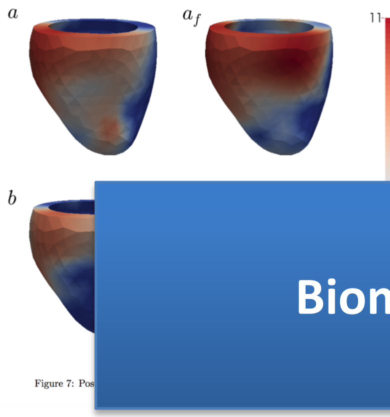


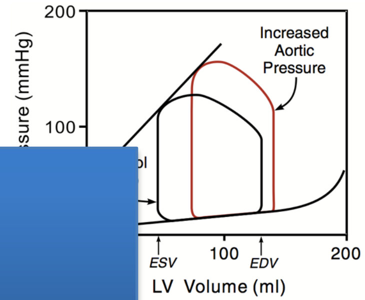
A model starts with physical reasoning, simplifications and experiment



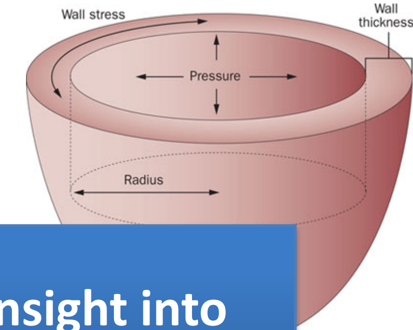
Making a model patient specific requires good images and data assimilation techniques

Do we really need mechanical models? Yes!

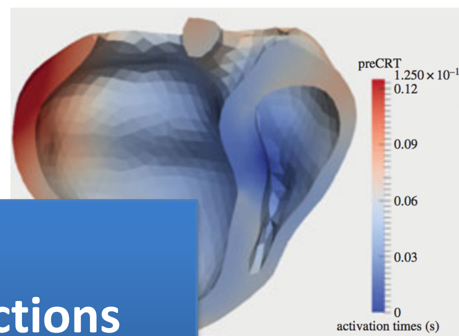




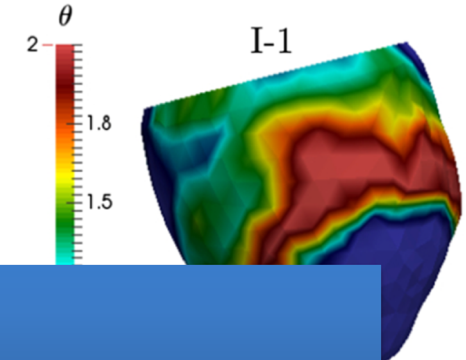
Biomarkers



Tool to gain insight into cardiac physiology



Short term predictions



Long term predictions

CENTER FOR CARDIOLOGICAL INNOVATION

sfi Centre for Research-based Innovation

Questions?