Finite Element Modeling of Cardiac MRI

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The Basics

\[ x(X) = X + u(X) \]

\[ u(X) = \sum_{n=1}^{N} \Psi_n(X)P_n \]

\[ u(X) = \sum_{a=1}^{4} \sum_{b=1}^{4} \Psi_{a}^{e}(\xi_X)\Psi_{b}^{e}(\xi_Y)P_{a,b}^{e} \]

SCMR Cardiac MRI Atlas

Auckland Cardiac MRI Atlas

Kieran O’Brien

http://atlas.scmr.org/CardiacAtlas/
Google “Cardiac MRI”
Cardiology - a numbers game

- End diastolic volume
- End systolic volume
- Stroke volume
- Ejection fraction
- Left ventricular mass

![Time Volume Graph](image)

EF = 69%  LVM = 140g  EDV = 122ml  ESV = 37ml
Guide Point Modeling of the heart

Guide-Point Modeling

- 4D model-based interactive analysis
- EDV, ESV, EF, SV, mass.

Young et al Radiology 2000;216(2):597-602
RV Function

Right Ventricular Modeling

✓ Most frequent user request
✓ Critical to pediatric evaluation
✓ Technologically challenging
Advantages of Model-Based Analysis

- Long axis slices define base plane.
- Long axis slices define apex.
- LV mass averaged through cycle.
- Dynamic function parameters (dV/dt).
- Fewer slices if necessary.
Disadvantages of 4D Guide-Point Modeling

- Breath-hold misregistration.
- Thinking in 4D.
- Papillary muscles and trabeculae included in blood pool.
- Not automated enough.
Motion Tracking

Non-rigid registration

✔ MRIR implementation
✔ GPU implementation
Motion Tracking
Regional Wall Function from Tagging
3D strain maps

Images courtesy Brent French, University of Virginia

Tissue Function = 3D Strain

What Strain is Good for the Heart?

\[ F = RU = VQ \]
\[ E = \frac{1}{2} \left( U^2 - I \right); E_i \in \left( -\frac{1}{2}, \infty \right) \]
\[ e = \frac{1}{2} \left( I - V^{-2} \right); e_i \in \left( -\infty, \frac{1}{2} \right) \]
\[ \eta = \ln(V); \eta_i \in \left( -\infty, \infty \right) \]
Myocardial viability - late Gd enhancement

True-FISP cine

Late enhancement

Courtesy of Dr Gerhard Laub, UCLA, SIEMENS.
Data Fusion -

- Regions of delayed enhancement were outlined manually and registered to the model in 3D

Young et al. JCMR 8(5):685-92; 2006
Data Fusion

i) Cine Tagged Images
ii) Guide Point Modeling
iii) Tag Tracking
iv) 3D Reconstruction
v) Late Enhancement Images
vi) 2D Infarct Contours
vii) Bullseye Infarct Plot
viii) Data Fusion: Structure/Function Mapping

Young et al. JCMR 8(5):685-92; 2006
Mathematical Model of the Heart

Geometry
Microstructure
Stress
Perfusion
Activation

CARDIOME Project –
Bioengineering Institute, University of Auckland, New Zealand

Material Parameter Estimation

\[ F_{kN} = \frac{\partial x_k}{\partial X_N} \]

\[ E = \frac{1}{2} \left( F^T F - I \right) \]

\[ \text{det} F = 1 \]

\[ \frac{\partial}{\partial X_N} \left( T^{MN} \frac{\partial x_j}{\partial X_N} \right) = 0 \]

\[ T^{MN} = T^{NM} \]

\[ T^{MN} = \frac{1}{2} \left( \frac{\partial W}{\partial E_{MN}} + \frac{\partial W}{\partial E_{NM}} \right) \]

\[ e = \sum_{i=1}^{N} \left\| x_i - x(\xi_i; C) \right\|_2^2 \]
Material Parameters from MRI

Biophysical Modeling- in vivo high resolution data

Dan Ennis
Biophysical Modeling – Stress

LV pressure against Time

IVC  Ejection  IVR  Diastole

Pressure (kPa)  RF pulse

Time
Biophysical Modeling – Data Fusion

Hoi Ieng Lam
Biophysical Modeling – Stress

Wang et al MICCAI 2008 Best Young Investigator Simulation Paper
Functional Modes

- Longitudinal shortening
- Wall thickening
- Hinge
- Long.-radial shearing
- Base tilting
- Septal bulging

Rotation of endo base
Rotation of endo apex
Rotation of epi apex
Functional Modes: Normal and Type II Diabetes.

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