

スパコンを知る集いin 宮崎 ～「京」からポスト「京」へ～  
12月10日 15:15-15:45

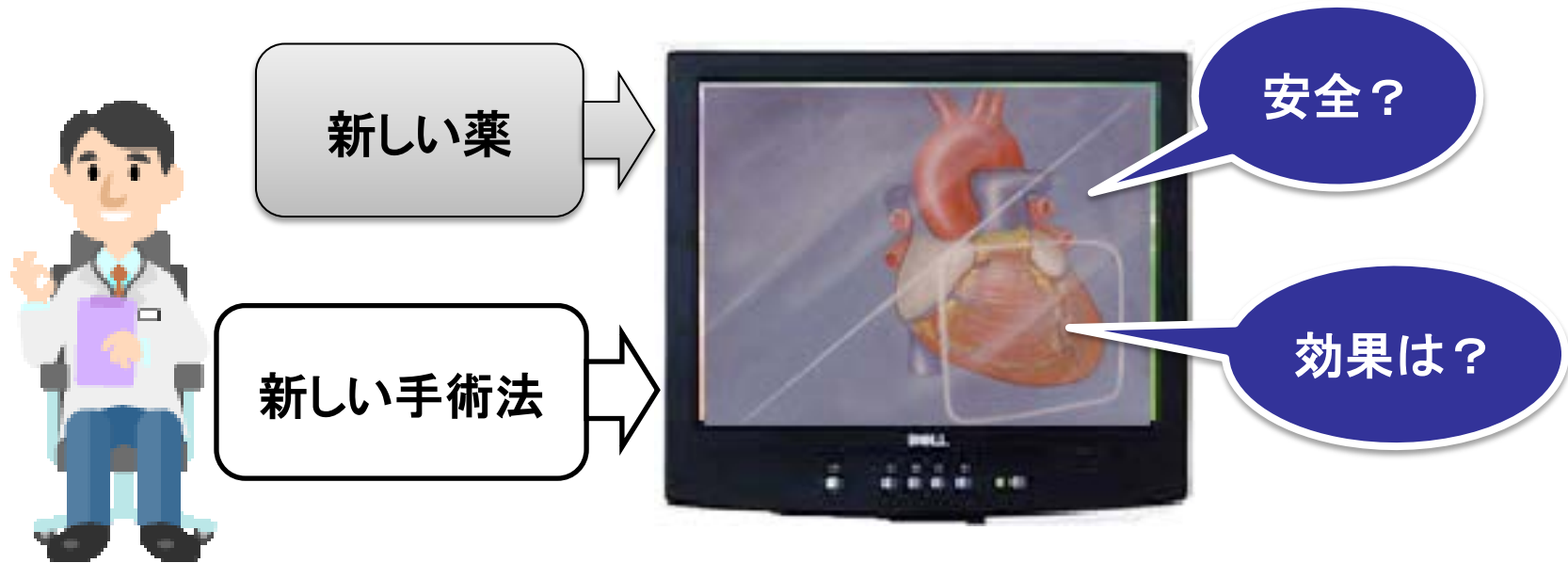
# スパコンの中に生きた心臓をつくり、 診断し治療する

## UT-Heart

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株式会社UT-Heart 研究所  
東京大学大学院新領域創成科学研究科

# もし本物の心臓が作れたら

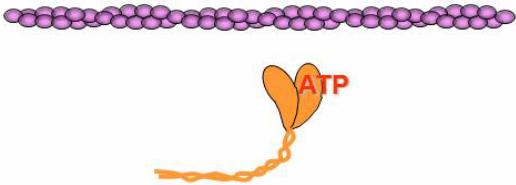


**動物実験、人間でのテストが不要**  
(リスク、費用,時間.....)

# UT-Heartは**現実**に**起きている** $10^7$ 倍スケール が異なる現象を科学的知見に基づいて同時に計算・再現 しています

## 分子レベル

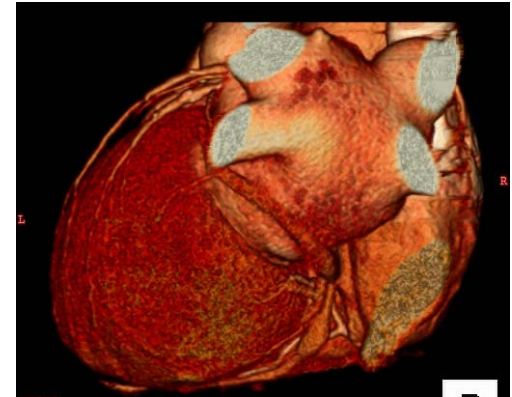
~pN  
~nm



サイズ  $10^7$ 倍  
力  $10^{12}$ 倍

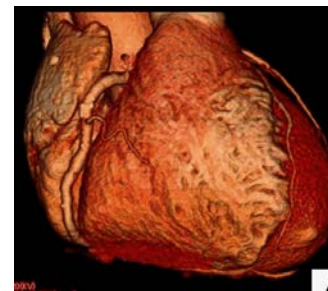
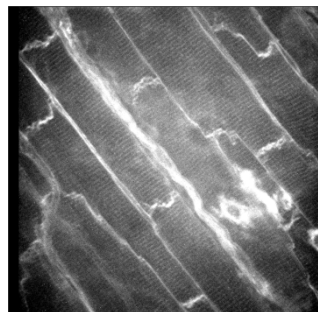
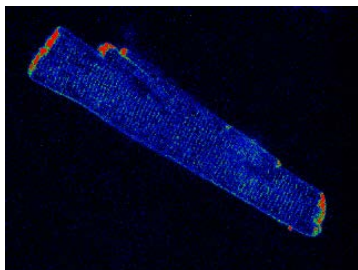
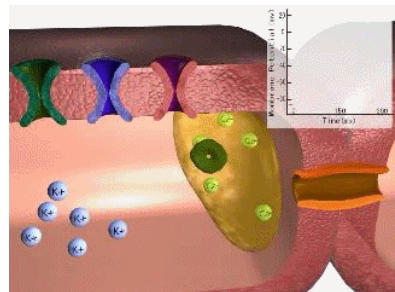
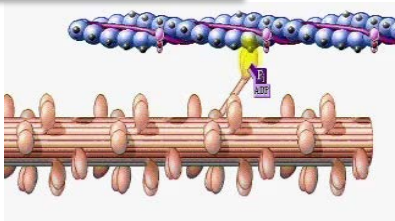
## 臓器レベル

~ N  
~ cm



# UT-Heart は本物の構造を再現

Real world



分子

細胞

組織

臓器

In silico

分子モデル

$$I_{Na} = 23m^3 \cdot h \cdot j \cdot (V - E_{Na})$$

$$I_{Si} = 0.09 \cdot d \cdot f \cdot (V - E_{Si})$$

• • • •

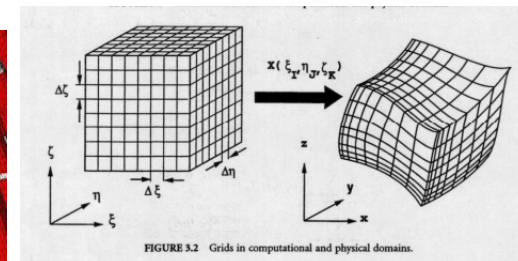
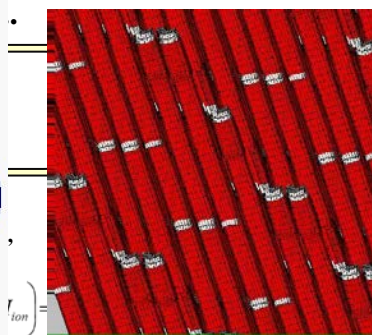
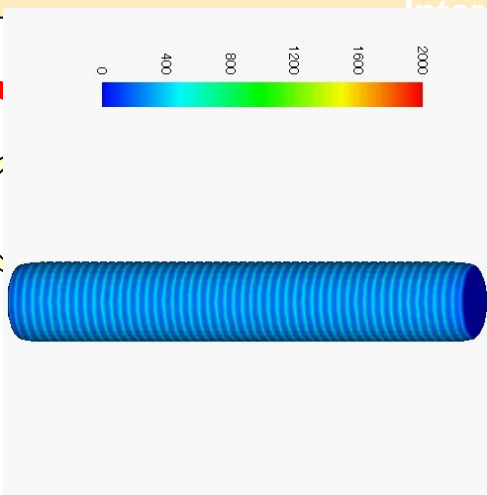
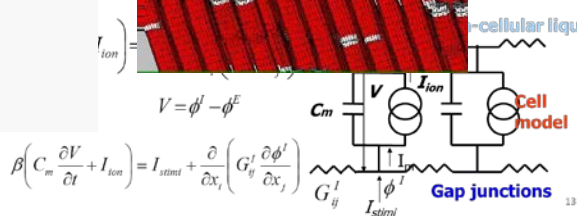


FIGURE 3.2 Grids in computational and physical domains.



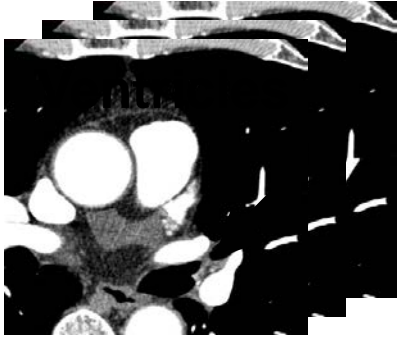
$$\beta \left( C_m \frac{\partial V}{\partial t} + I_{ion} \right) = I_{stim} + \frac{\partial}{\partial x_i} \left( G_{ij}^i \frac{\partial \phi^i}{\partial x_j} \right)$$

有限要素法

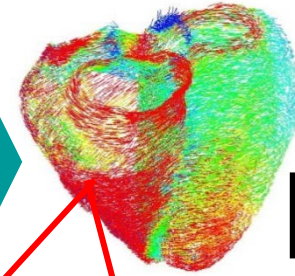
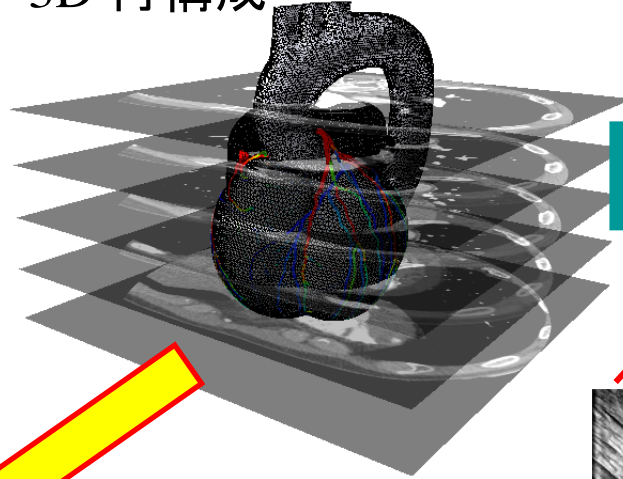


# マルチスケール心臓シミュレータ UT-Heart

CT(MRI) images



3D 再構成



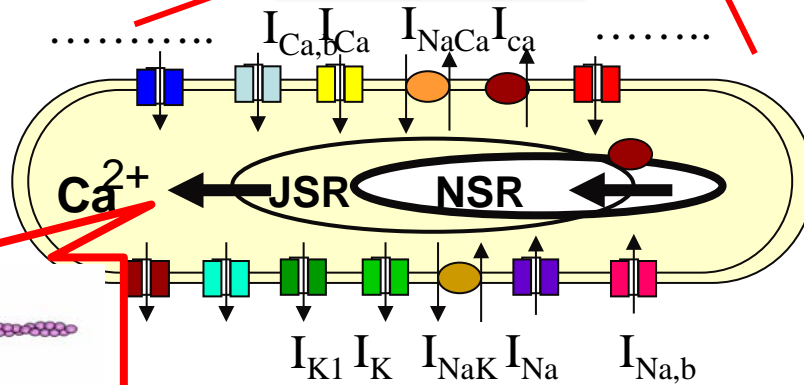
組織構造



Tissue specific conductivity

トルソ

細胞モデル

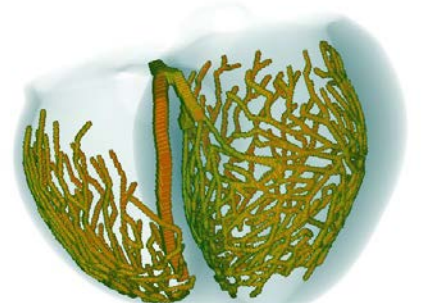


線維、シート構造

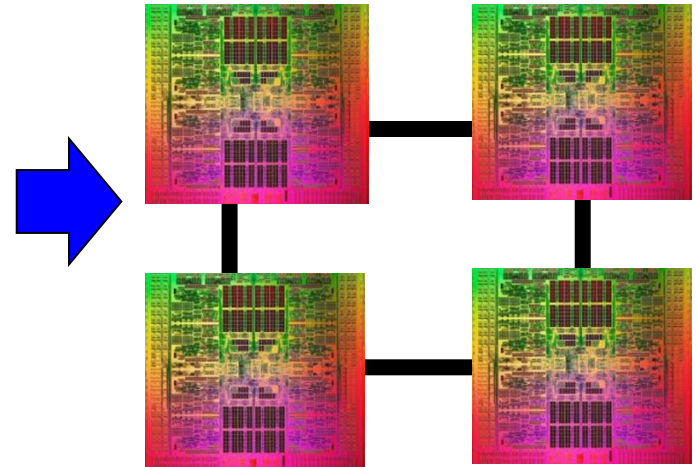
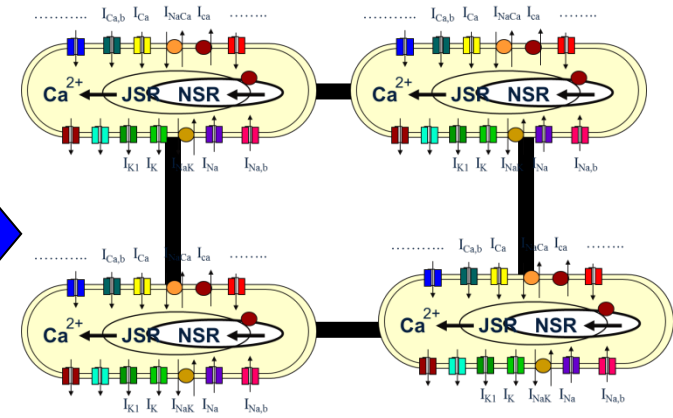
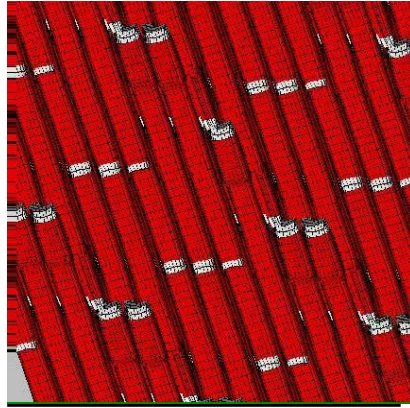
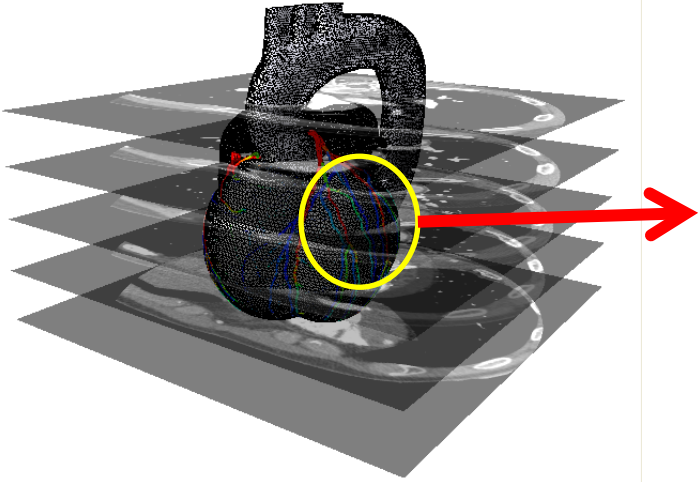
伝導系

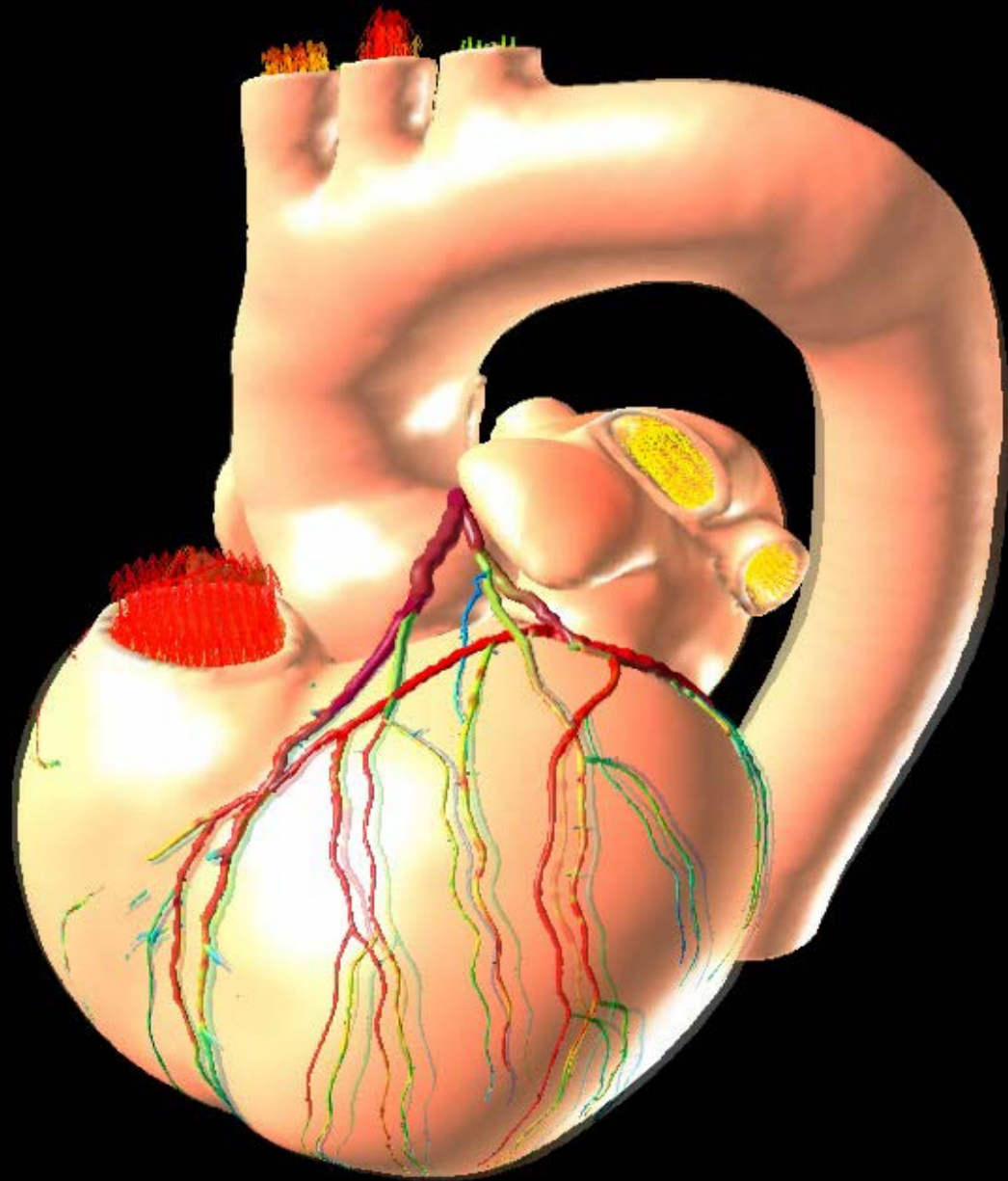
収縮タンパク

>2400万要素から構成



# コンピュータの中の心臓

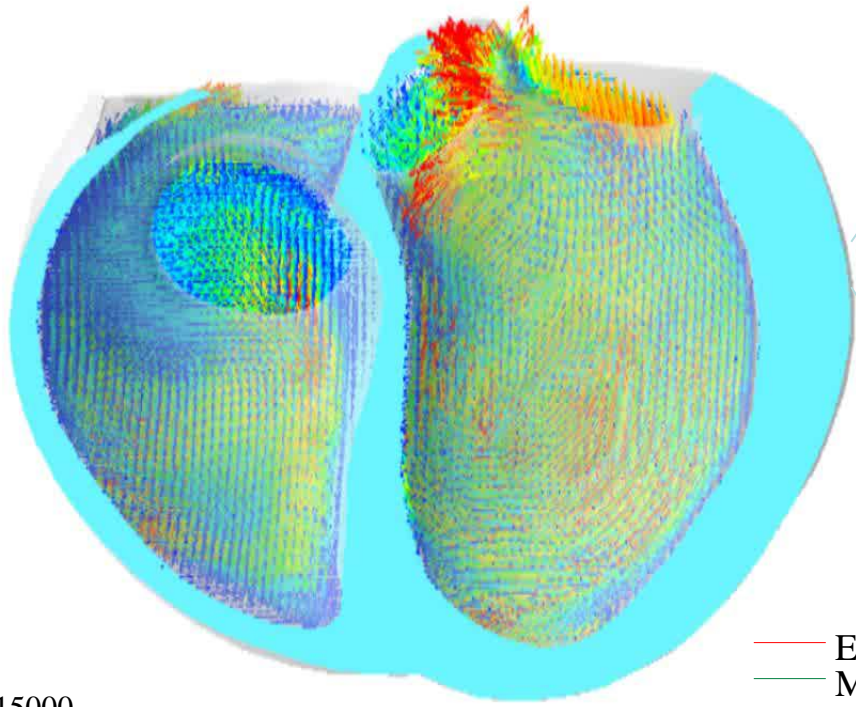




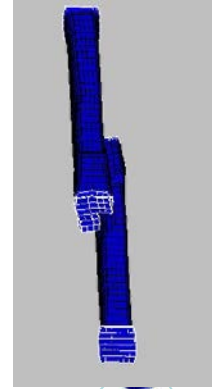


この中では

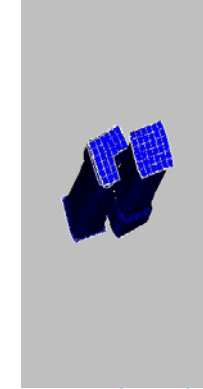
力を色で表示



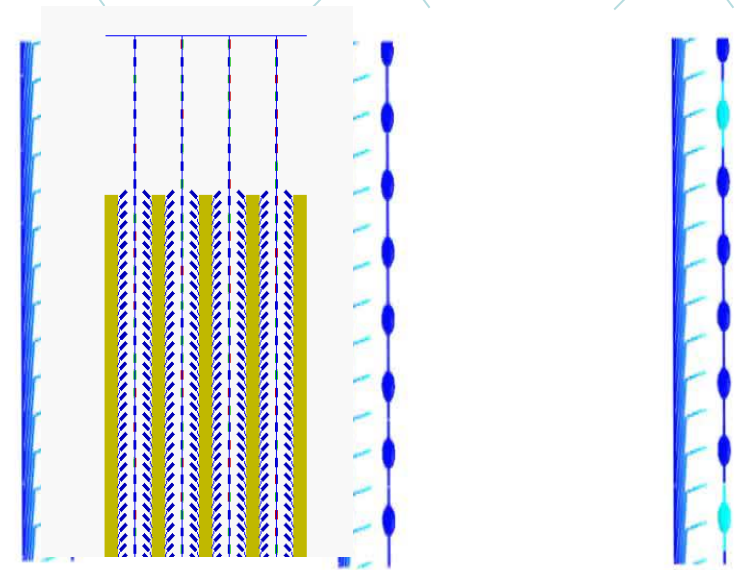
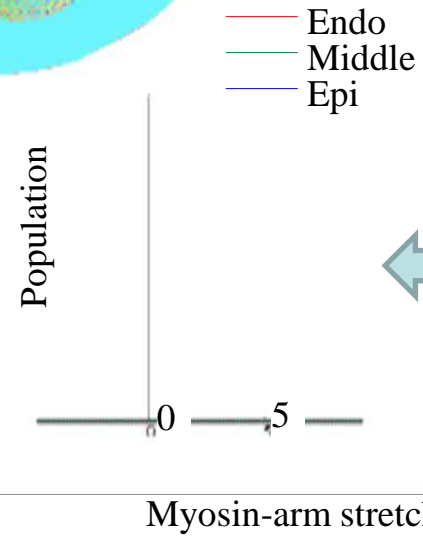
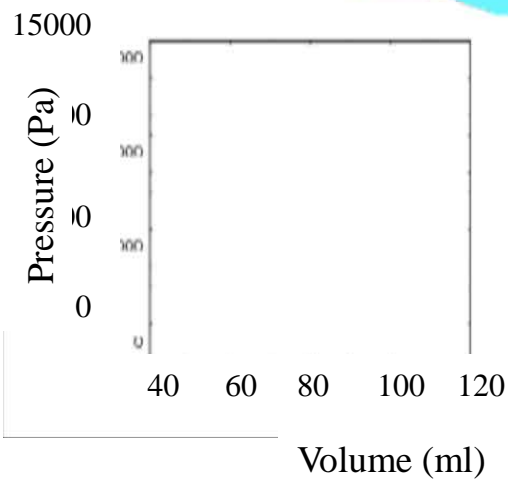
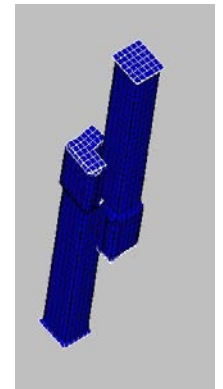
Endo



Mid



Epi



Pressure-Volume loop

Arm stretch Distribution

One of 2K Sarcomere Samples

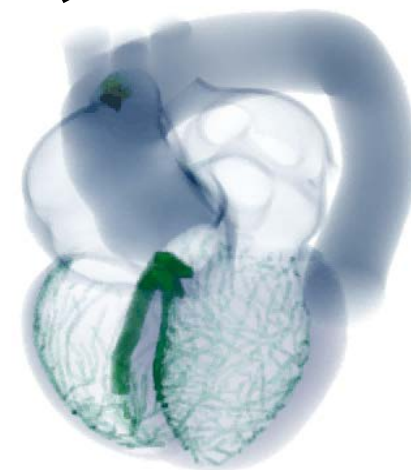
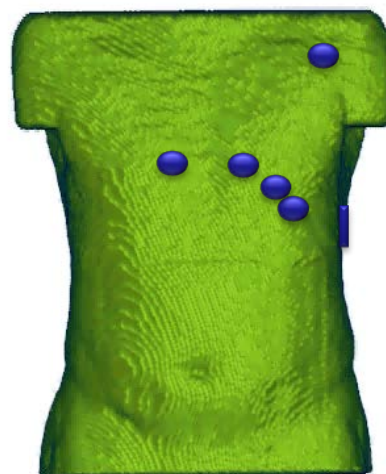
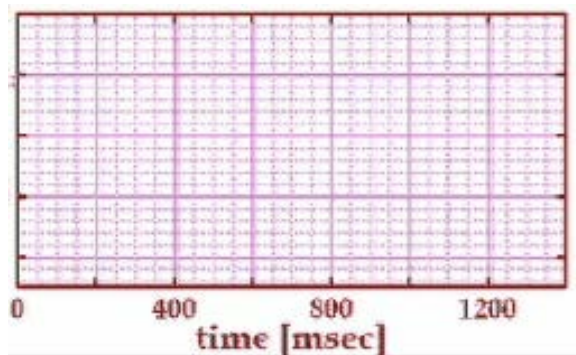


# 心電図

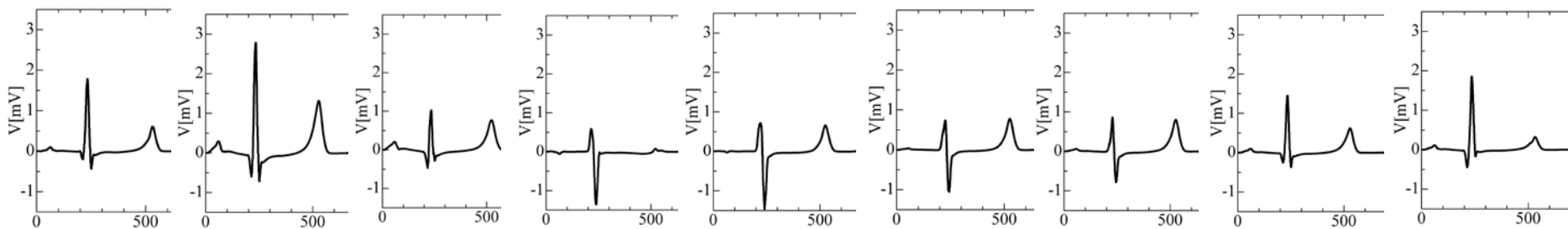
体表面電位

膜電位

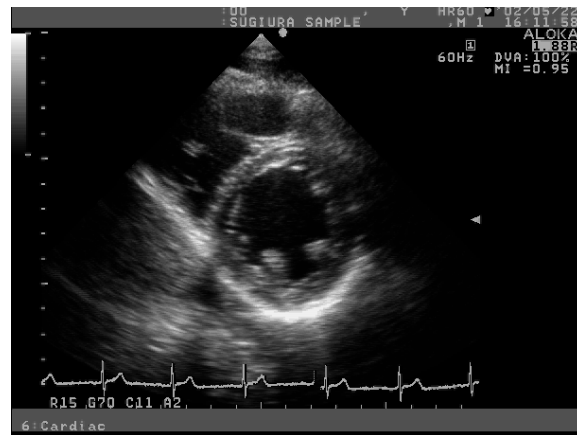
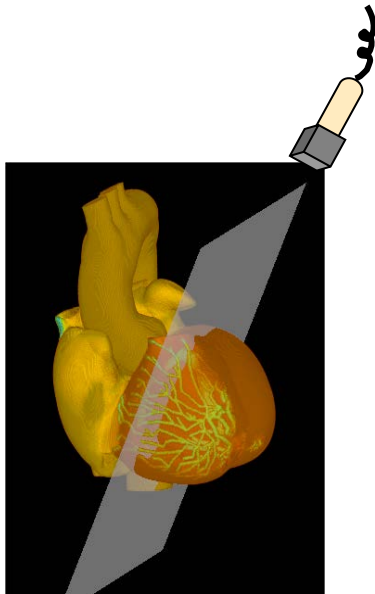
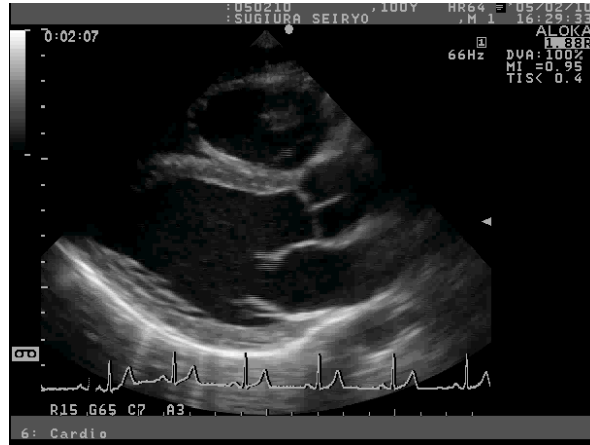
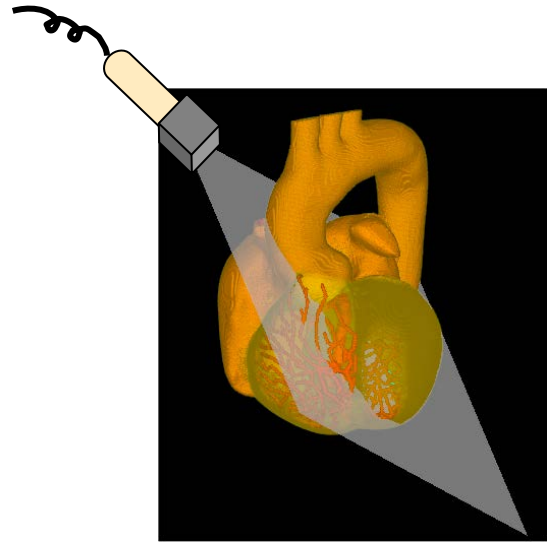
第二誘導



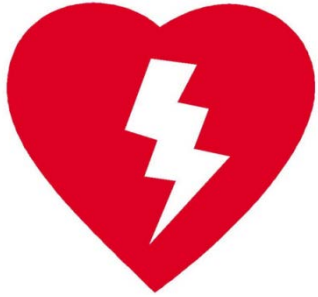
I II III V1 V2 V3 V4 V5 V6



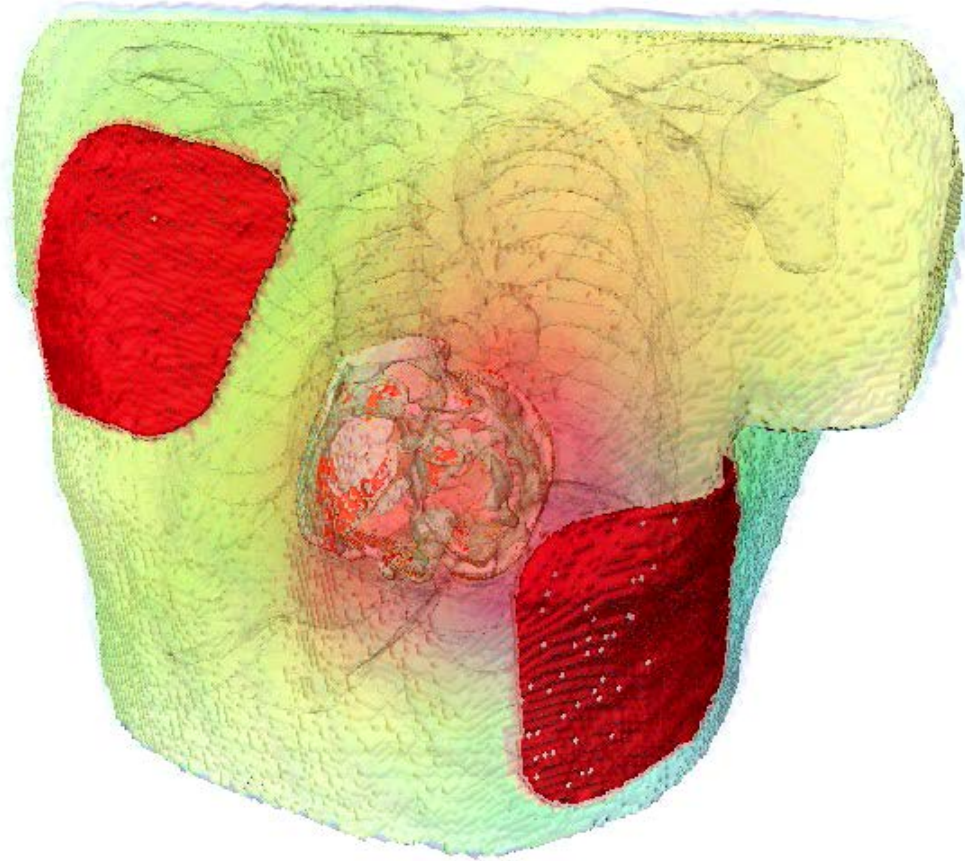
# 心臓超音波(エコー)



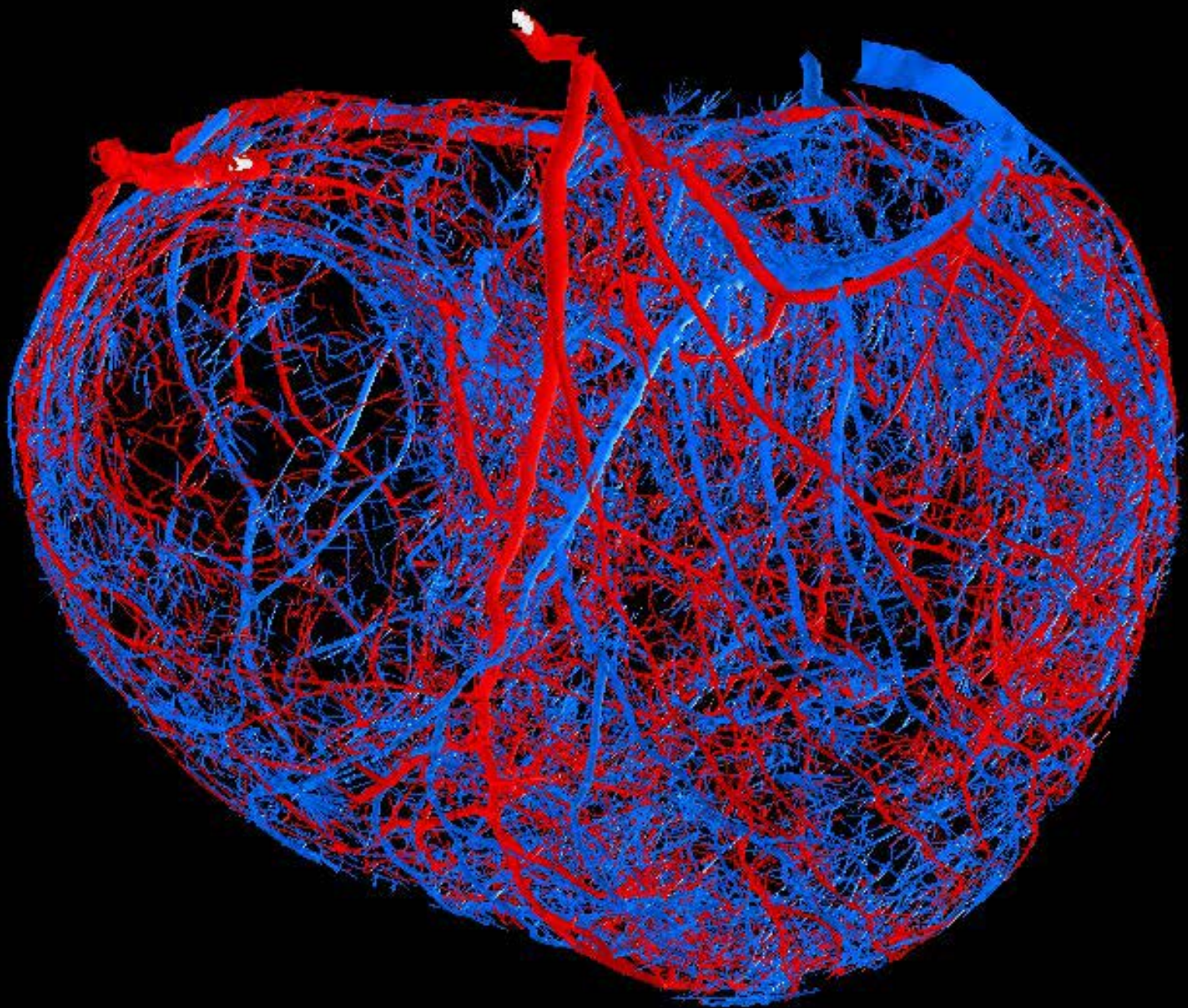
# AED



## 心室細動が起こったら







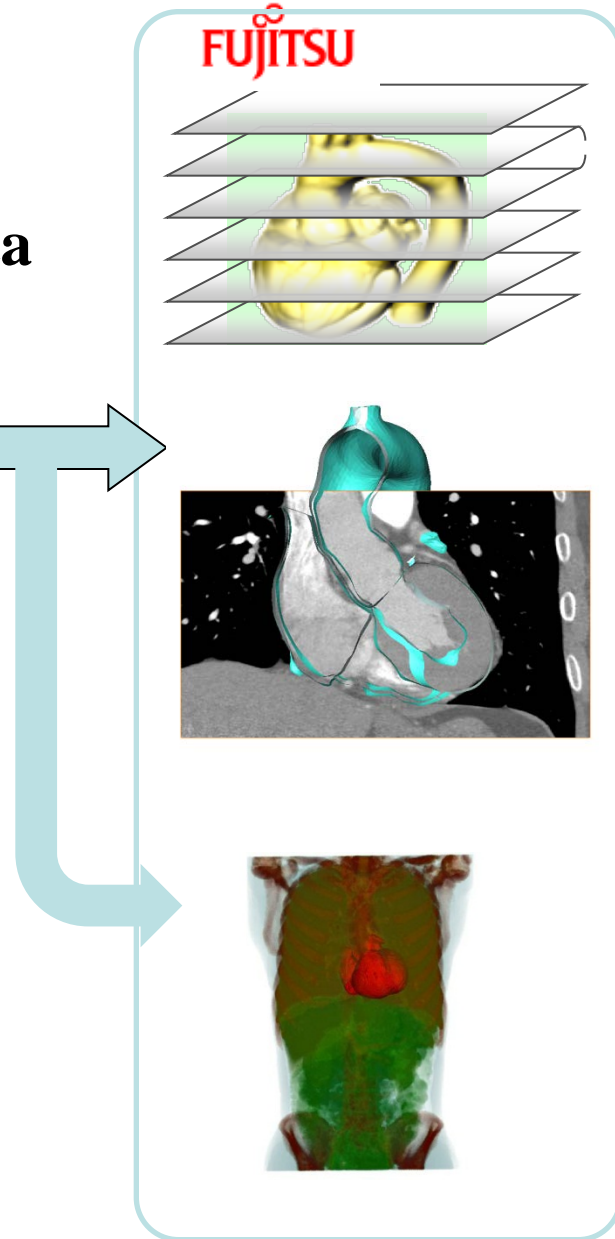
do

d

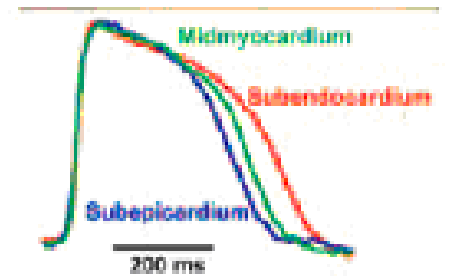


# 個別モデルの作り方

CT data



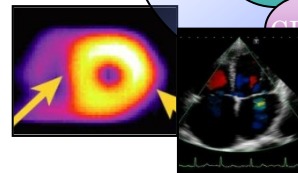
APD 分布  
Transmural or apico-basal



Labo. data

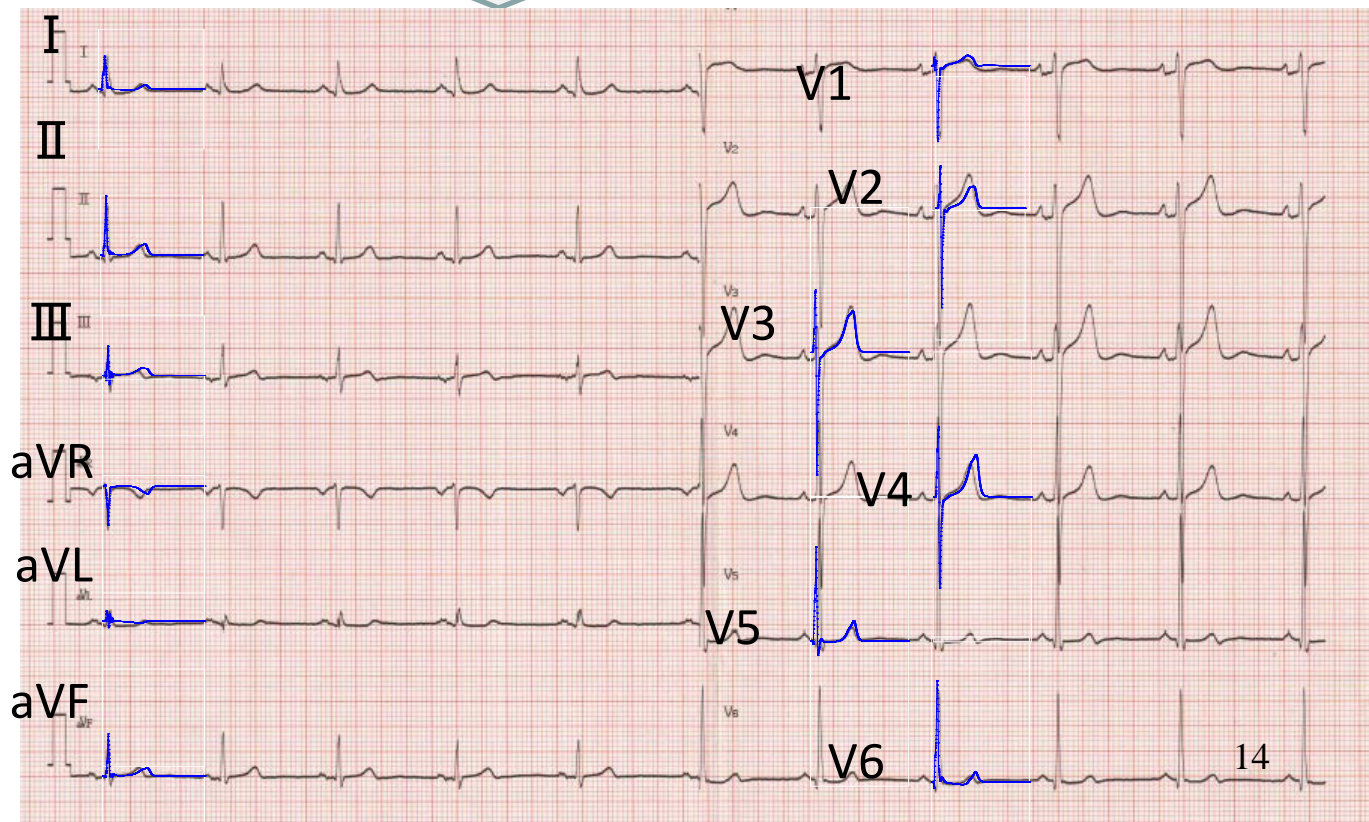
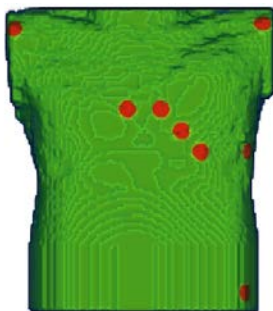
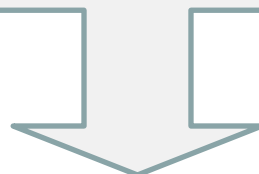
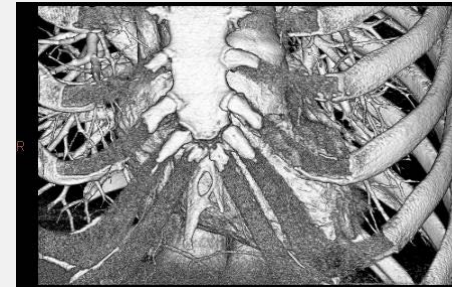
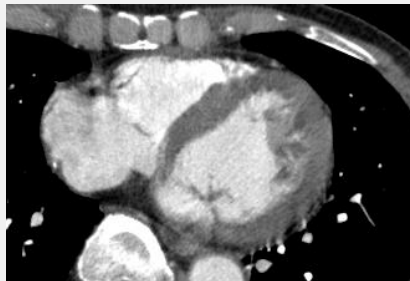
臨床検査

Images

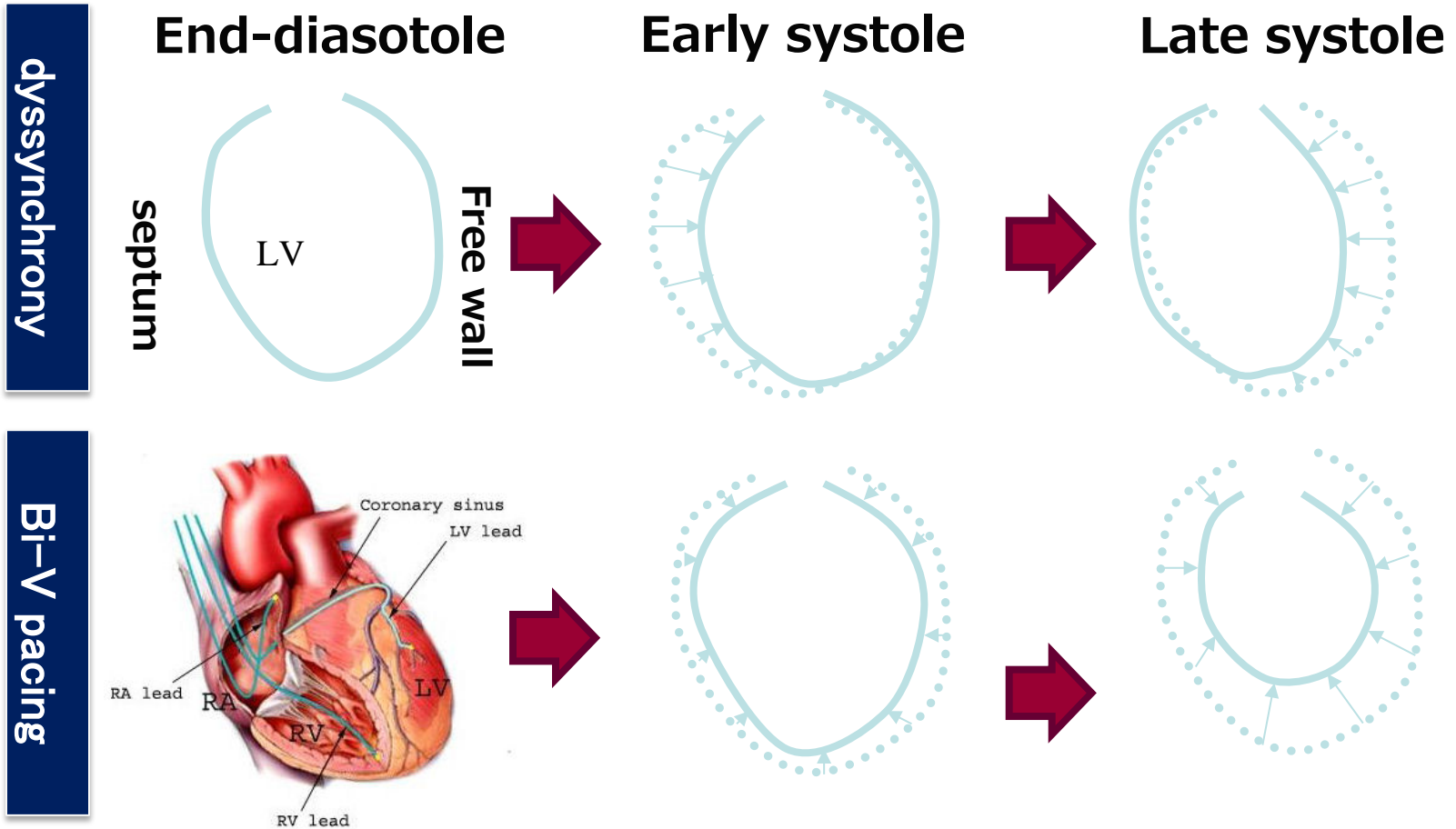


troponin<sup>+</sup>  
HbA1c  
NT-MB  
BNP

健常例



# 心臟再同期兩方(CRT)



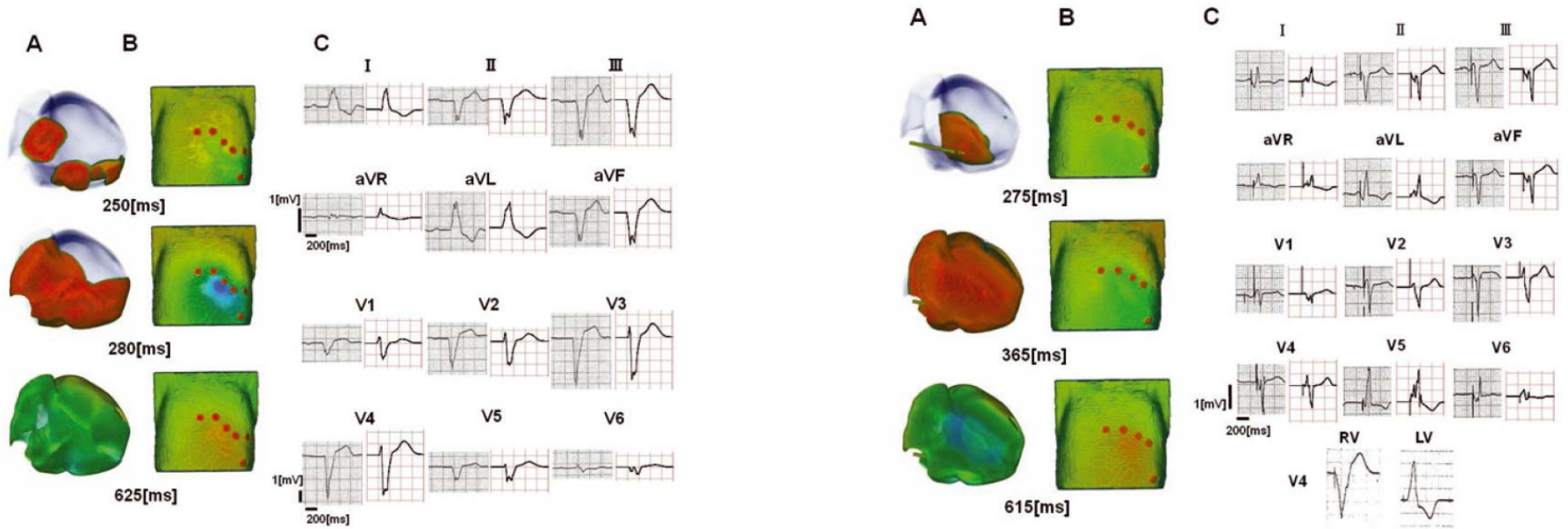
[www.thewellingtoncardiacservices.com](http://www.thewellingtoncardiacservices.com)

While its effects on survival and QOL have been proved, high rate (>30%) of non-responder poses a question on cost effectiveness.

**Detection of responder and optimization of regimen are eagerly needed.**



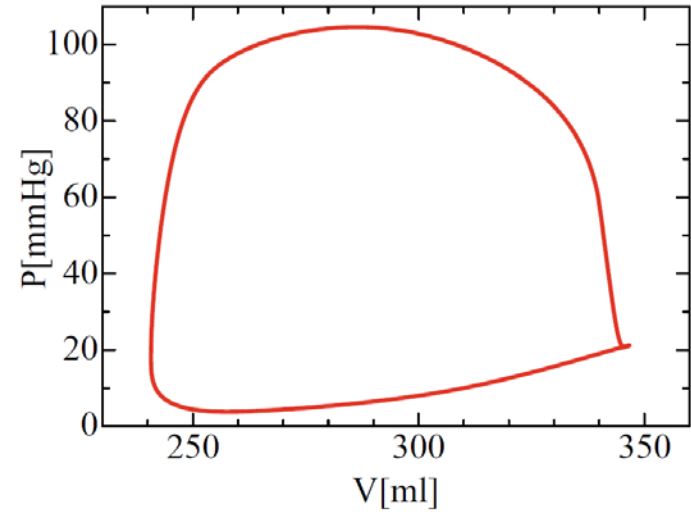
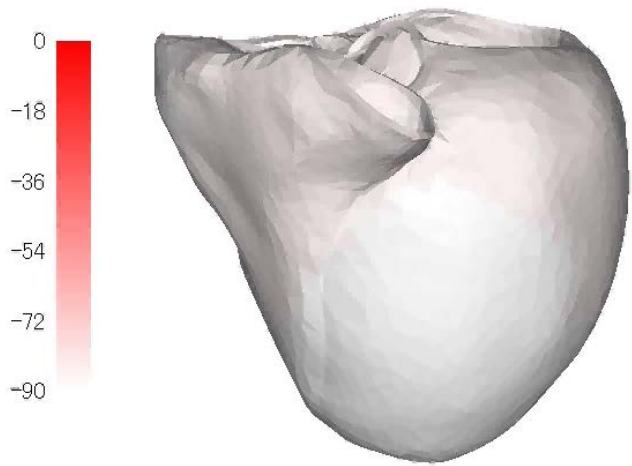
# シミュレーションによる病歴の再現



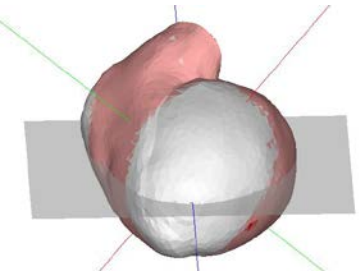
Okada et al. PACE 36:309 (2013)



# CRTの効果



Virtual UCG



# 3レベルの解析: サルコメア—細胞—心臓

## 確率的サルコメアモデル

## 連続体モデル

MC (Monte Carlo Method)

FEM (Finite Element Method)

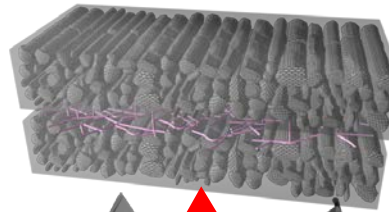
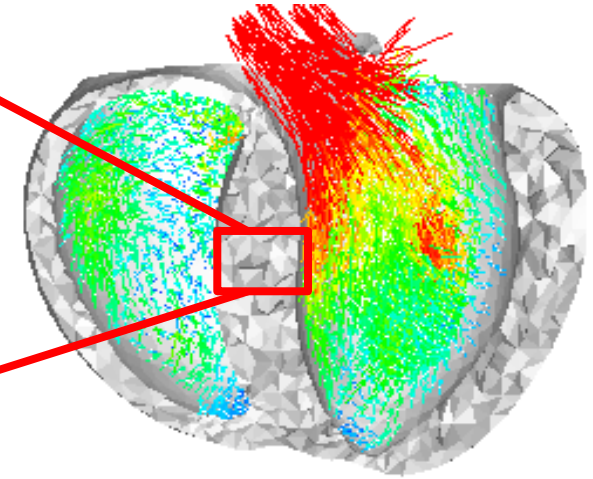
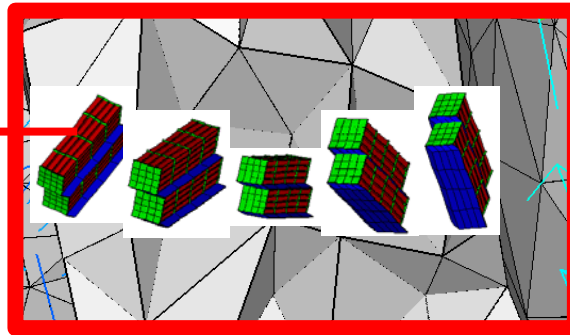
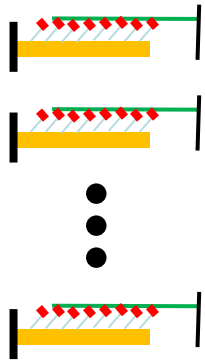
Time step size :  $5\mu\text{s}$

Time step size :  $2.5\text{ms}$

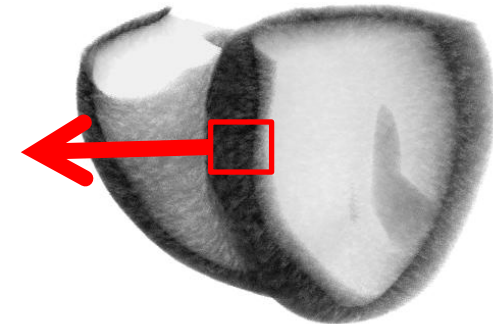
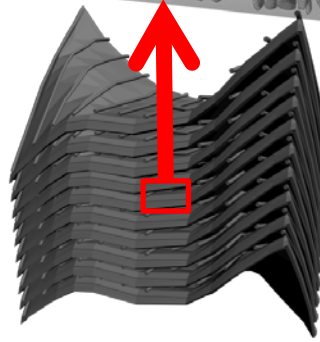
それぞれの筋原線維につき 32  
サルコメアサンプル

細胞のFEM モデルを  
各要素に含む

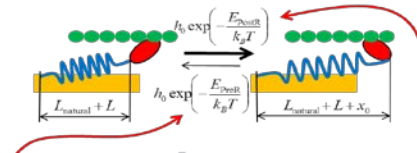
流体構造連成  
FEM 解析



興奮伝播シミュレーション



パワーストロークにおける遷移(one step)



Energy  
(chemical energy in head + strain energy in arm)

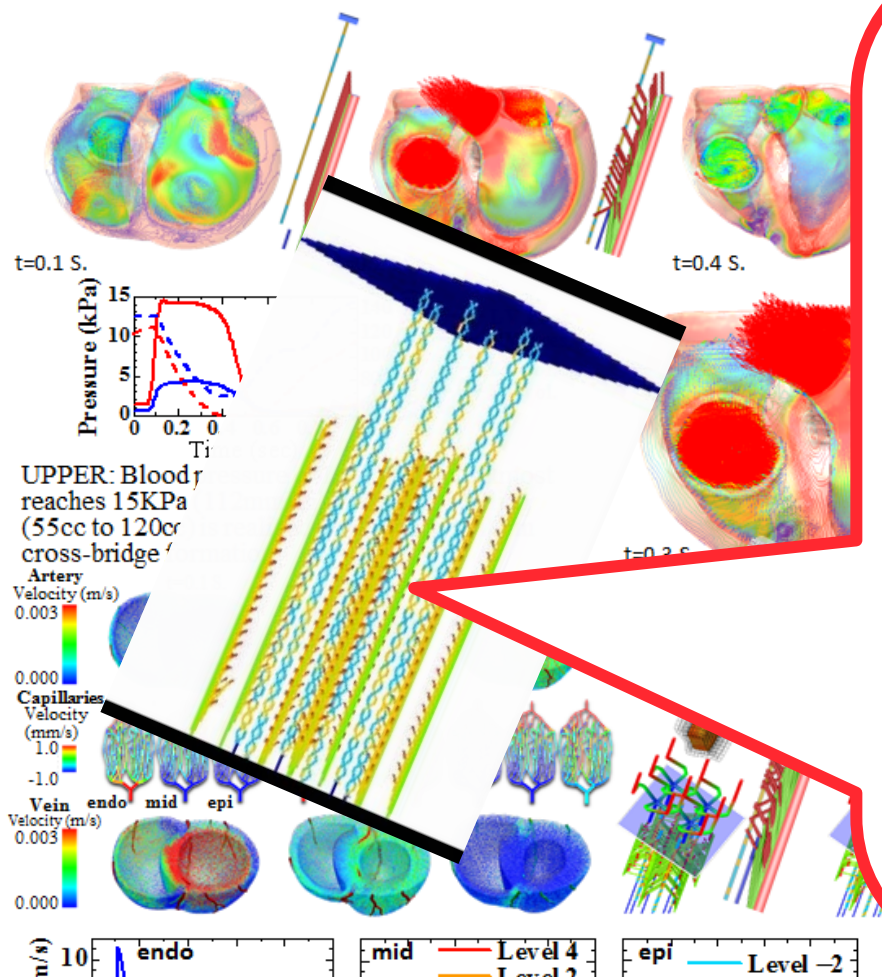
$$E_{\text{preft}} = U_{\text{preft}} + W_{\text{arm}}(L) \quad E_{\text{postft}} = U_{\text{postft}} + W_{\text{arm}}(L+x_0)$$

Boltzmann factor

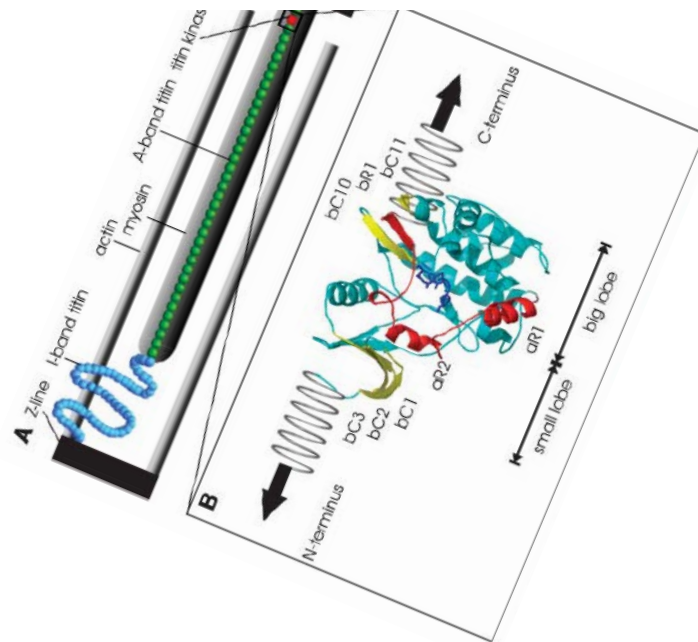
$$\exp\left(-\frac{E_{\text{preft}}}{k_B T}\right) \quad \exp\left(-\frac{E_{\text{postft}}}{k_B T}\right)$$

Single step<sup>22</sup>

精密なモデル→フルロードに近い構成で京を約17時間連続稼働  
 1.5拍動させ生理学的に妥当な結果を得た(実行効率30%弱)



## 粗視化MDとの融合



Grater et al. Biophys J 2015

マクロの機械的負荷→分子シグナルへ

0 0.2 0.4 0.6 0.8 1 0 0.2 0.4 0.6 0.8 1 0 0.2 0.4 0.6 0.8 1 time and position.