

分子からPV-loopまでをつなぐ 心臓シミュレーション

UT-Heart

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日本循環制御医学会学術集会

利益相反（COI）開示

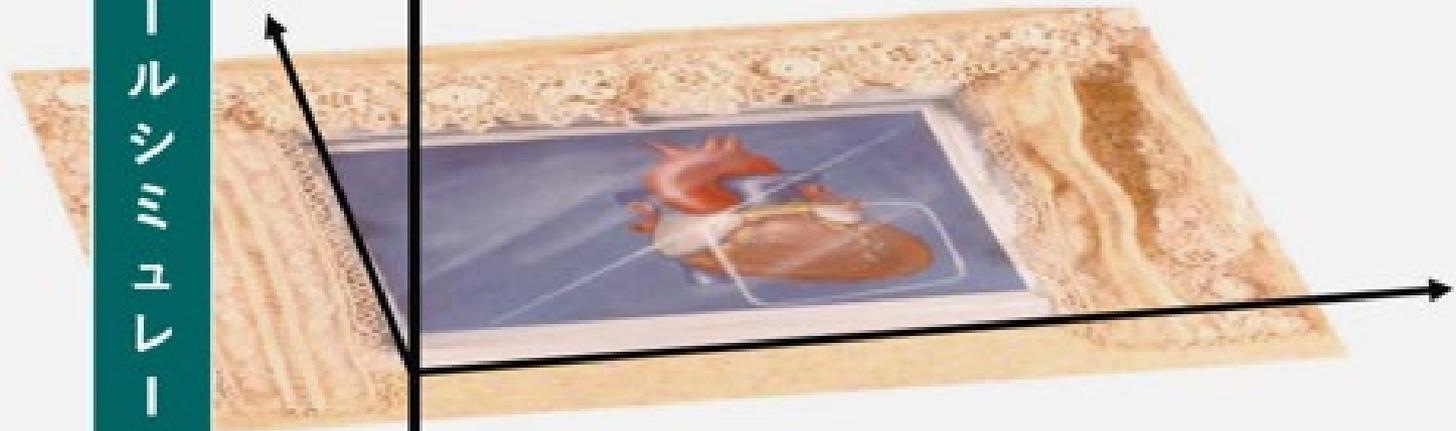
筆頭発表者名	杉浦 清了
施設名	(株)UT-Heart 研究所

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②株式の利益	有 <input checked="" type="radio"/> 無
③特許権使用料など	有 <input checked="" type="radio"/> 無
④講演料など	有 <input checked="" type="radio"/> 無
⑤原稿料など	有 <input checked="" type="radio"/> 無
⑥研究費・助成金など	<input checked="" type="radio"/> 有 無
⑦奨学(奨励)寄付金など	有 <input checked="" type="radio"/> 無
⑧寄付講座所属	有 <input checked="" type="radio"/> 無
⑨その他(旅費・贈答品など)	有 <input checked="" type="radio"/> 無

シミュレーションによる知識の統合

マルチスケールシミュレーション

新しい診断・治療
力学、電気生理の4次元情報
(CT, MRI, UCG, Mapping)
Ablation, Pacing, **VAD**...



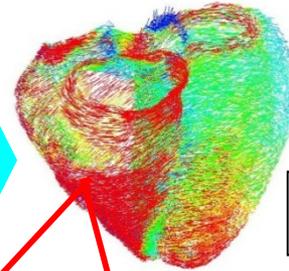
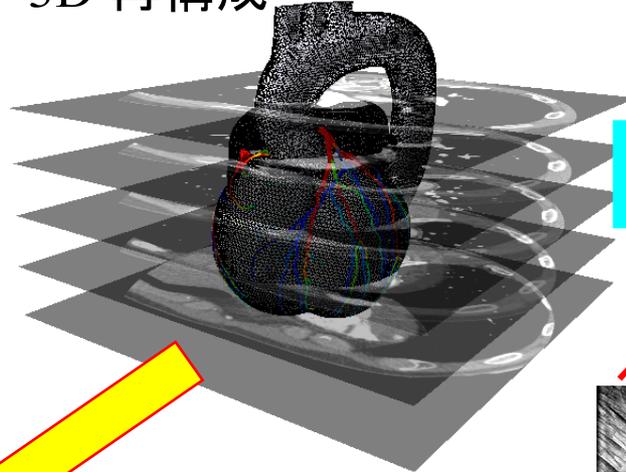
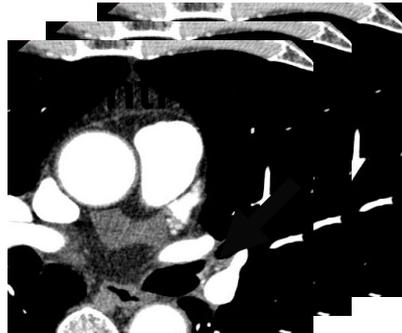
分子・細胞生物学



マルチスケール心臓シミュレータ UT-Heartとは

CT (MRI) images

3D 再構成



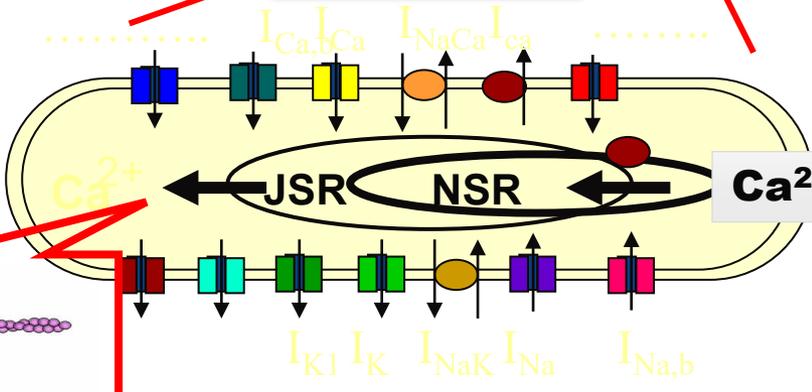
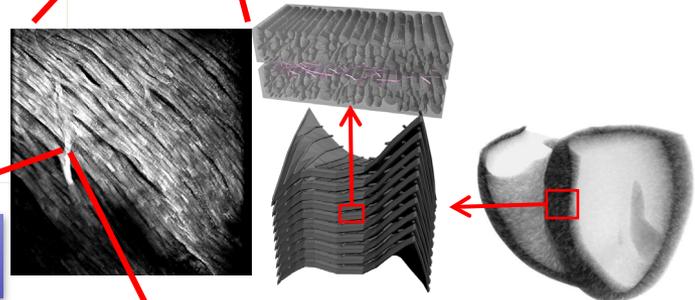
組織構造



Tissue specific conductivity

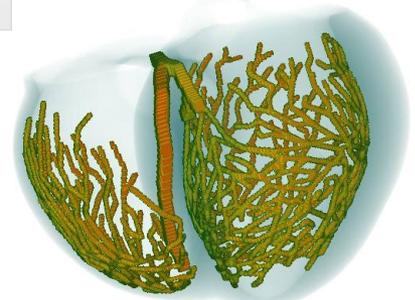
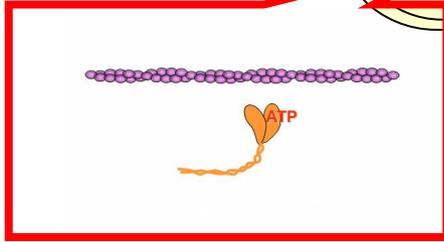
トルソ

細胞モデル



伝導系

>2400万要素から構成



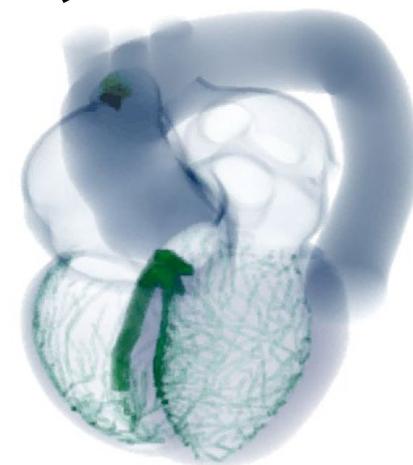
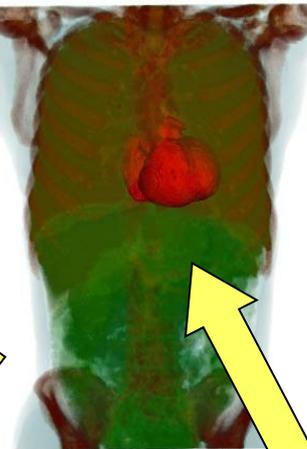
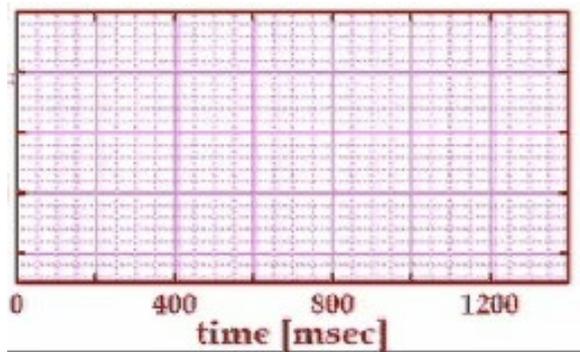
診断できます！

1.心電図

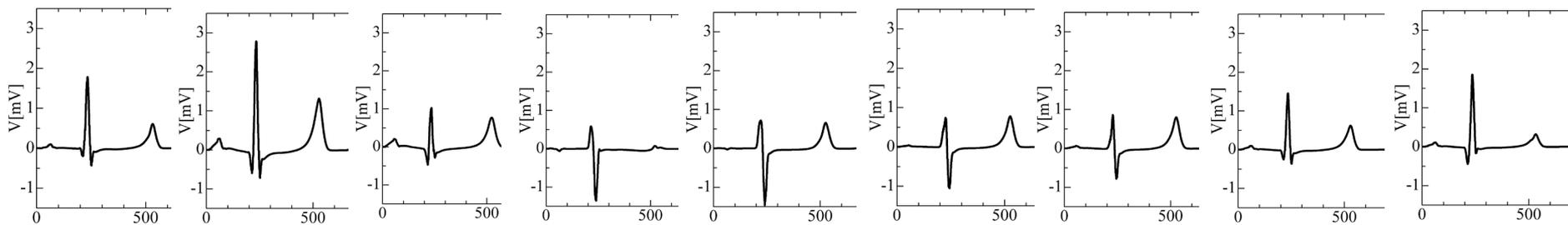
膜電位

体表面電位

第二誘導



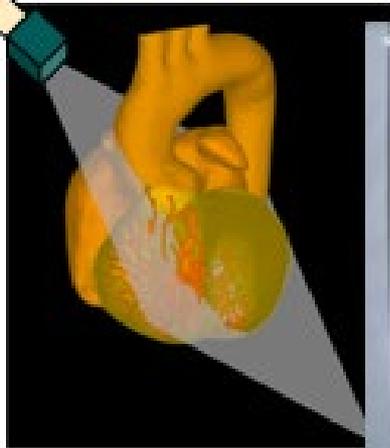
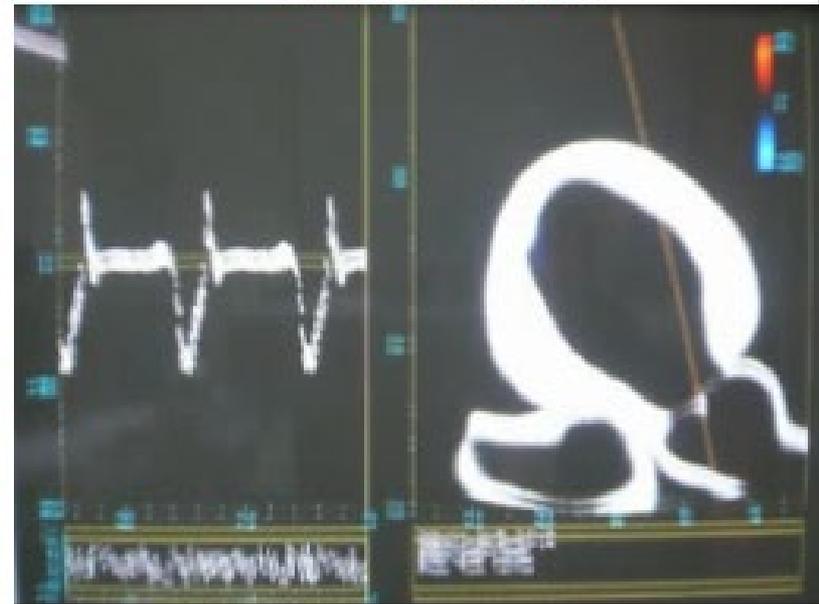
I II III V1 V2 V3 V4 V5 V6



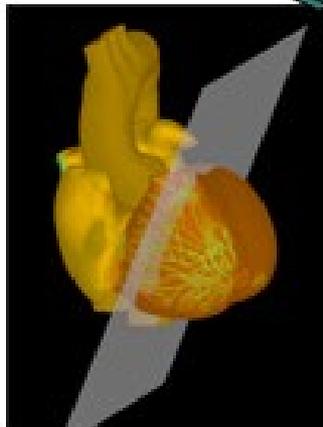
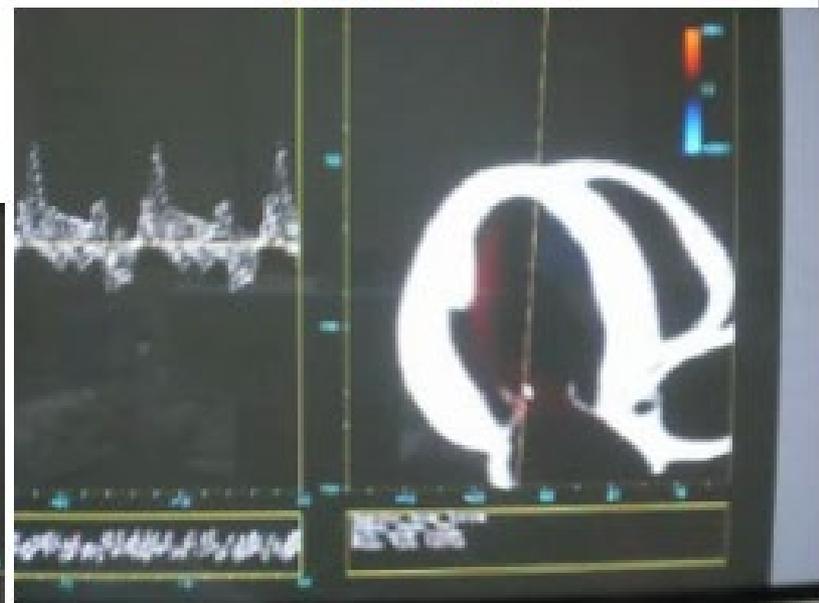
2. 心エコー



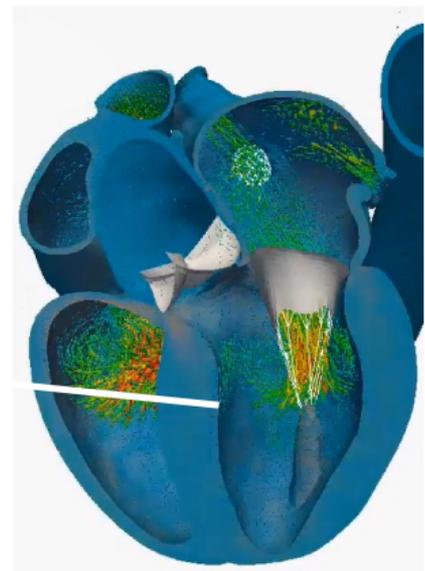
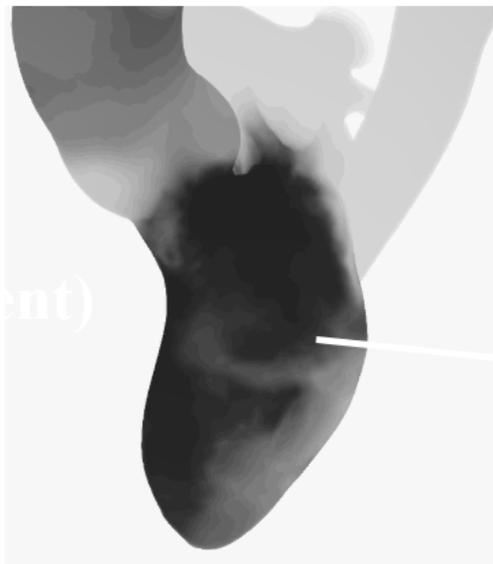
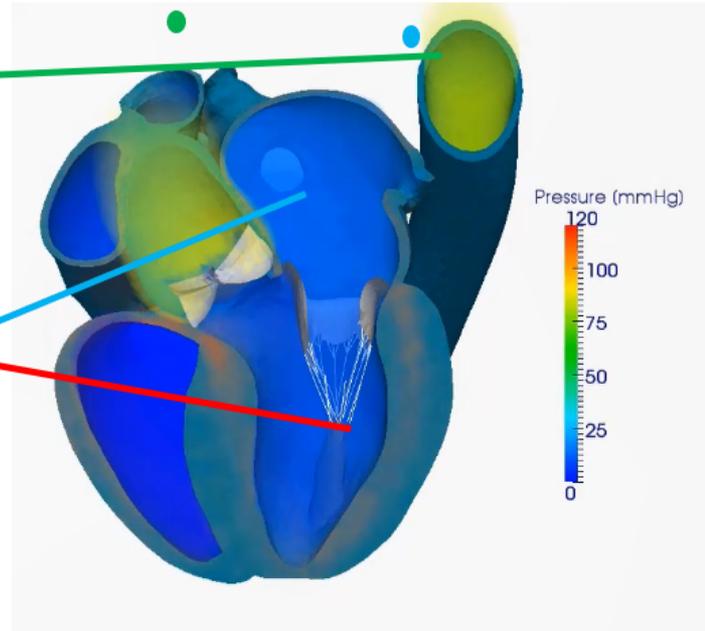
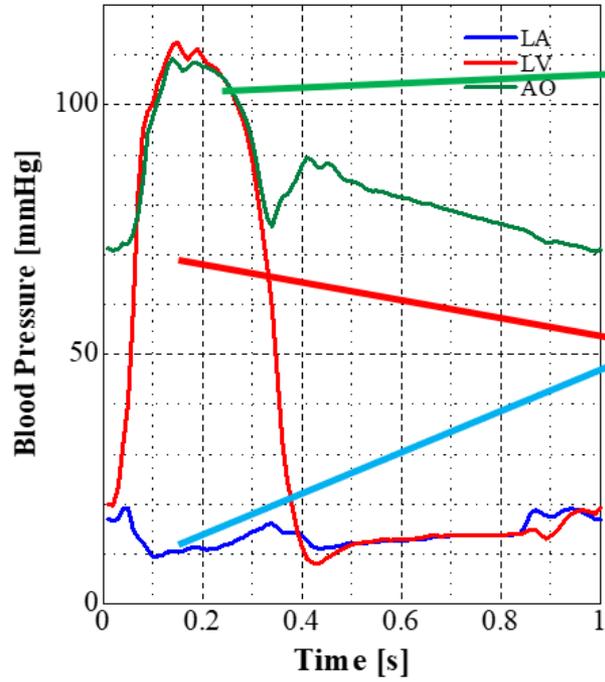
Aortic flow



Mitral flow

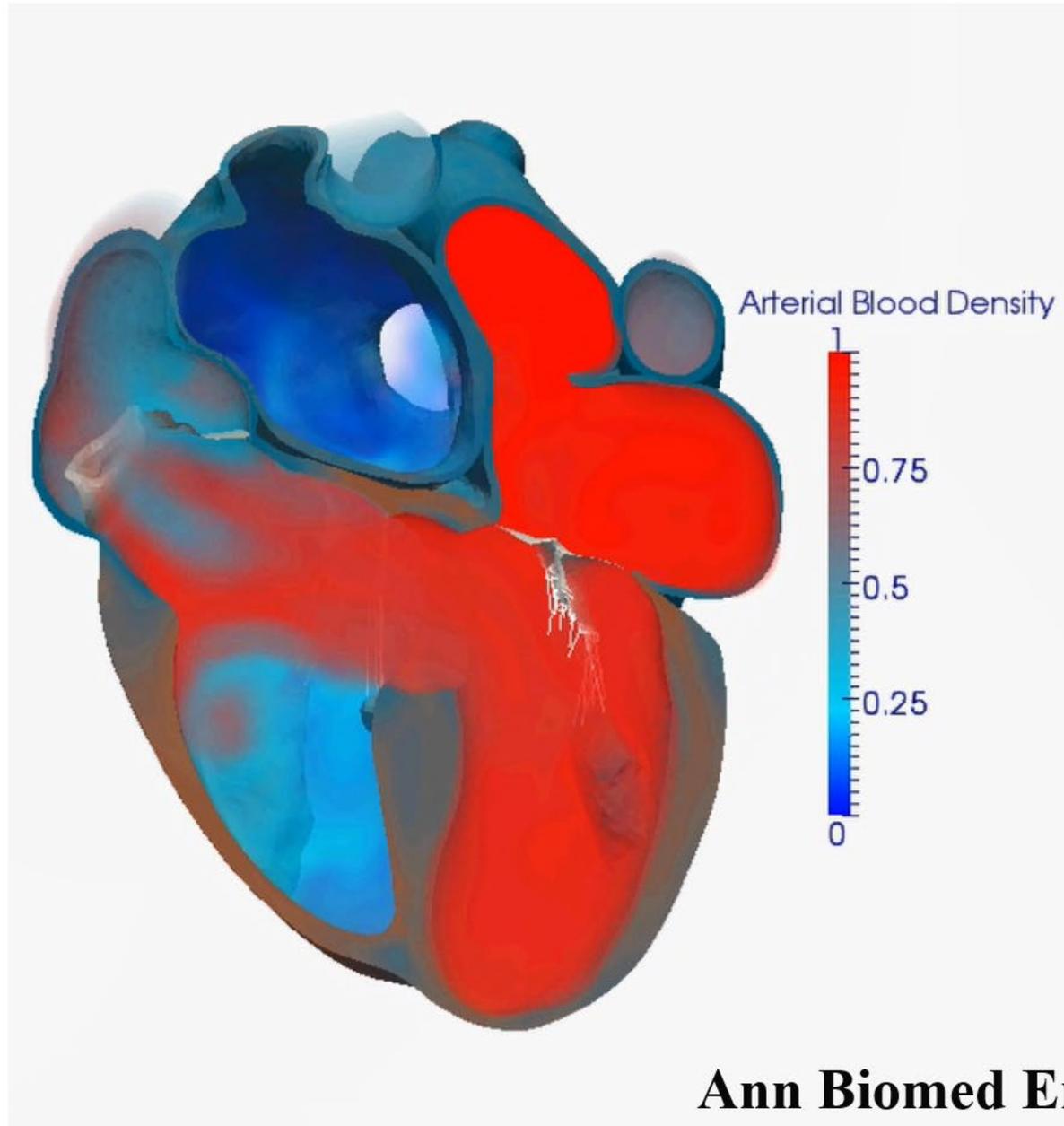


3. 血行動態



4. O₂ saturation imaging

DORV



応用範囲

基礎研究

創薬

分子レベルの変化 \leftrightarrow 臓器レベルの変化

臨床応用

LVAD

Impella

CRT効果予測

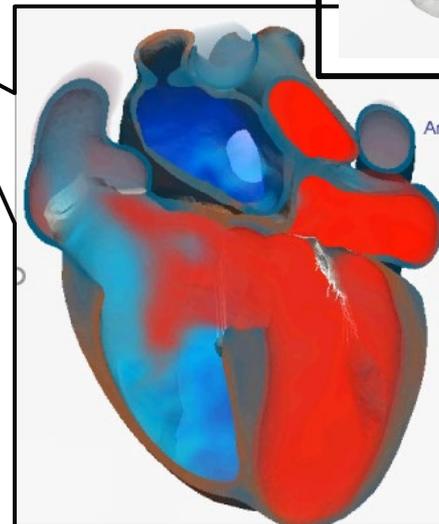
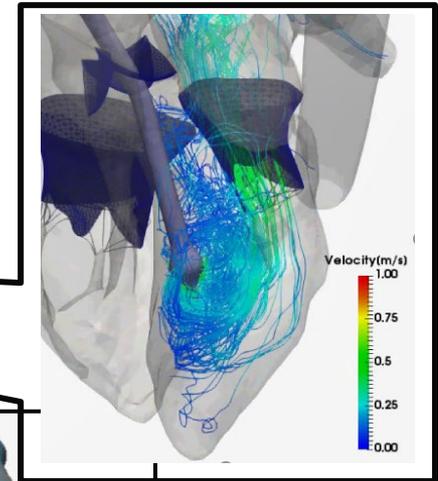
先天性心疾患の手術

弁膜症 (Mitral clip)

不整脈

His bundle pacing

etc.....

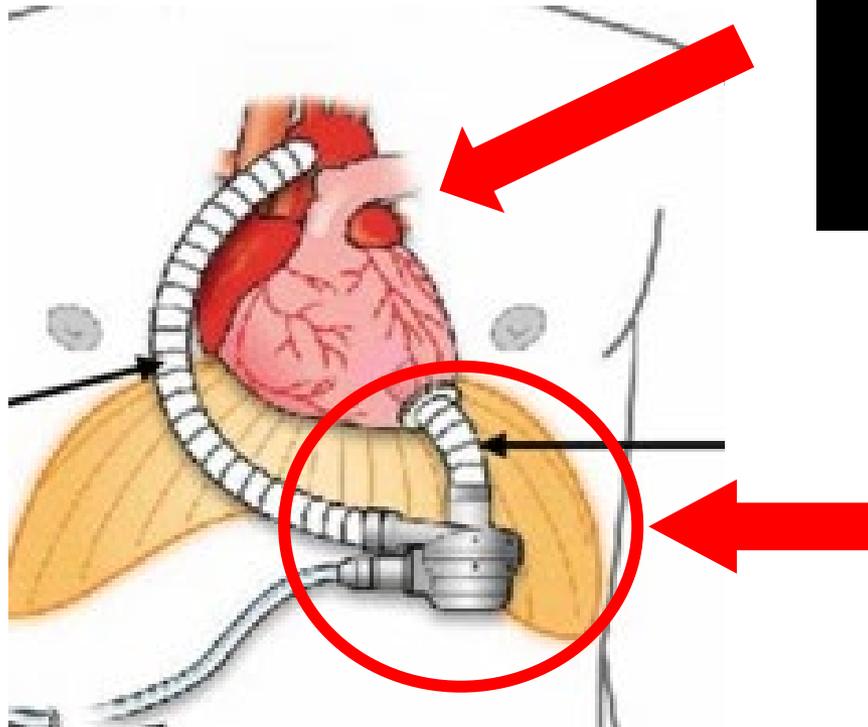
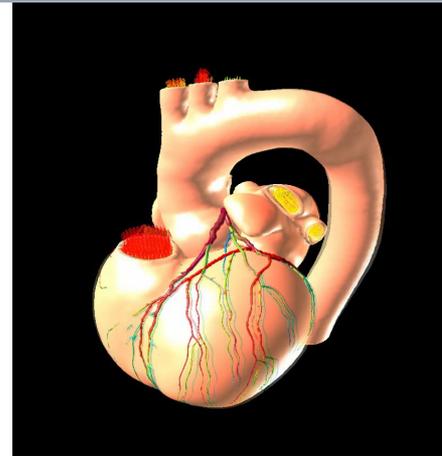


LVADシミュレーション

遠心ポンプと軸流ポンプの比較

方法

UT-Heart不全心モデル



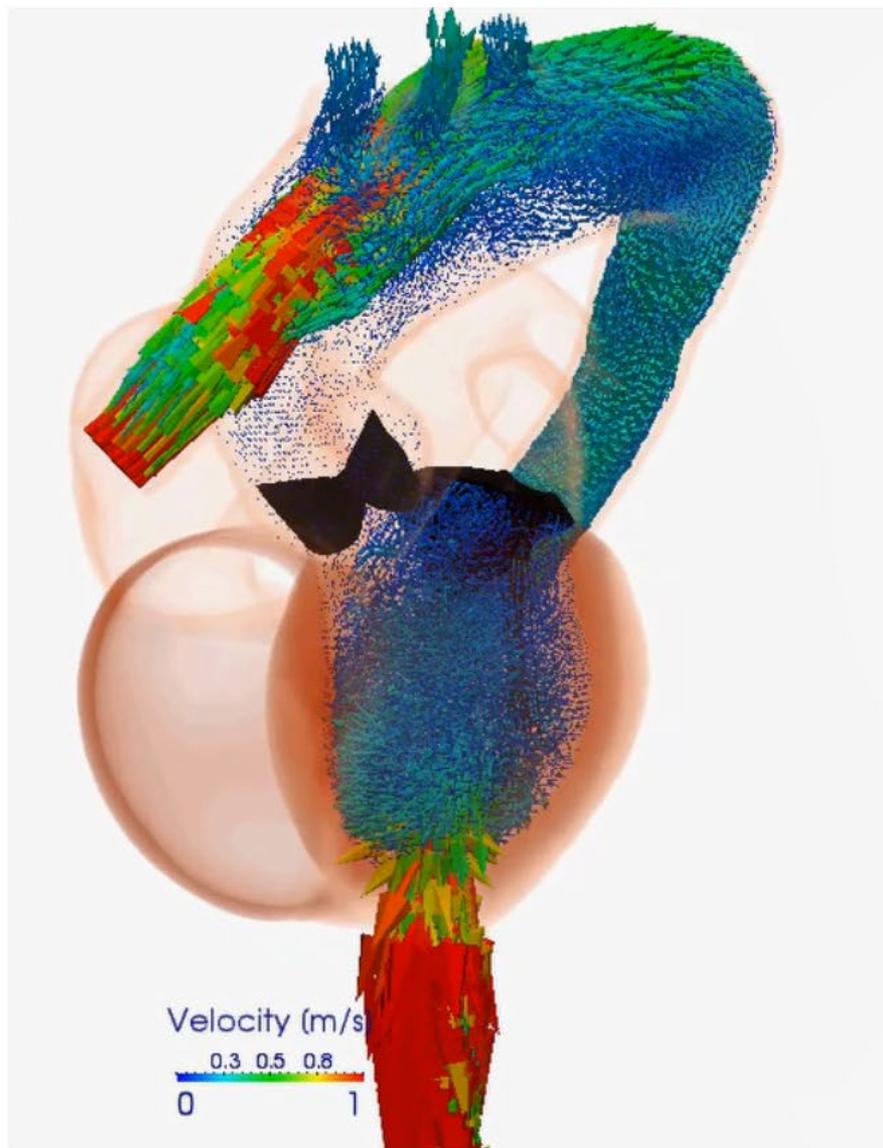
ポンプのH-Q特性を表す数理モデル

$$\frac{dH_M}{dt} + \frac{1}{T_H}(H_M - H) = 0$$

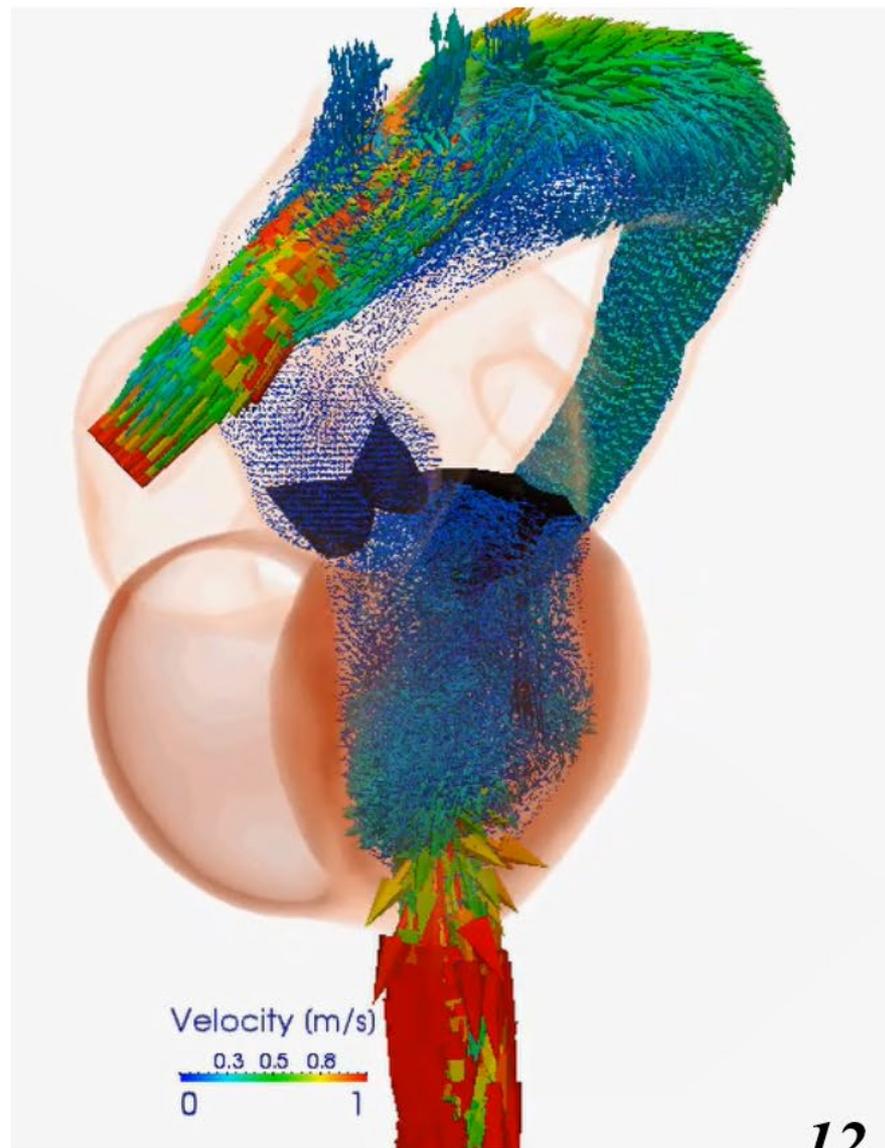
$$\frac{dQ}{dt} + \frac{1}{T_Q}(Q - F_M(H_M)) = 0$$

流量

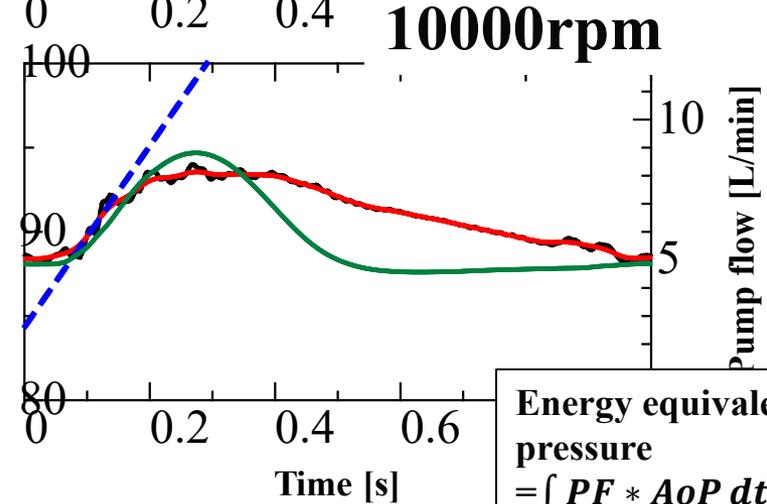
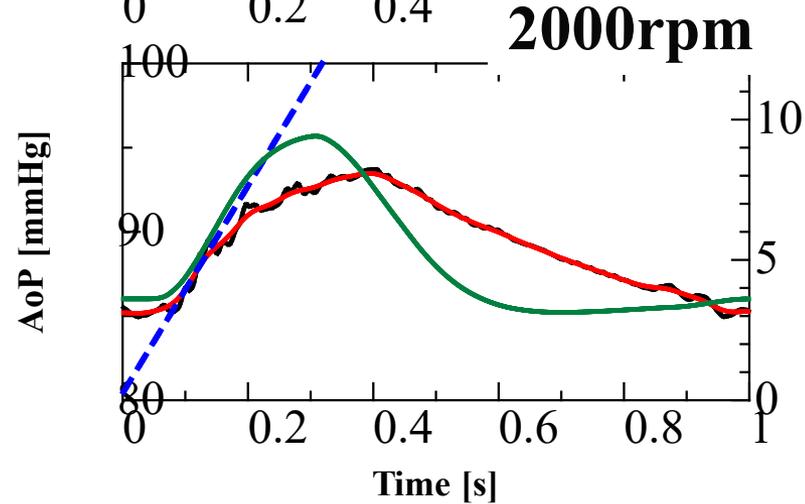
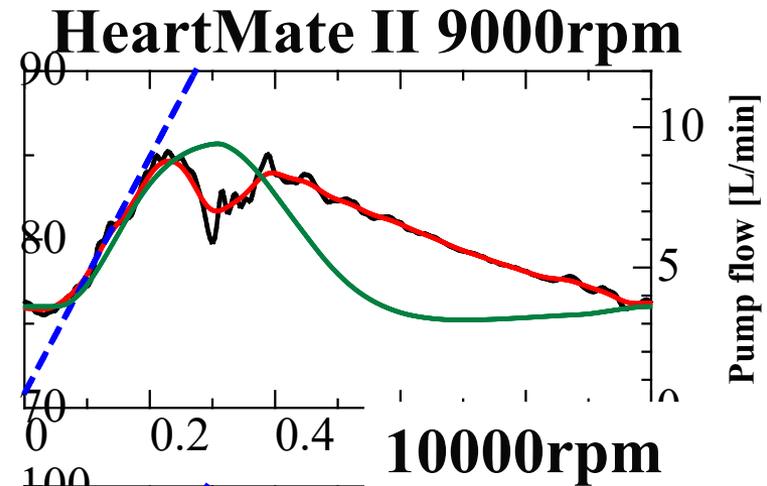
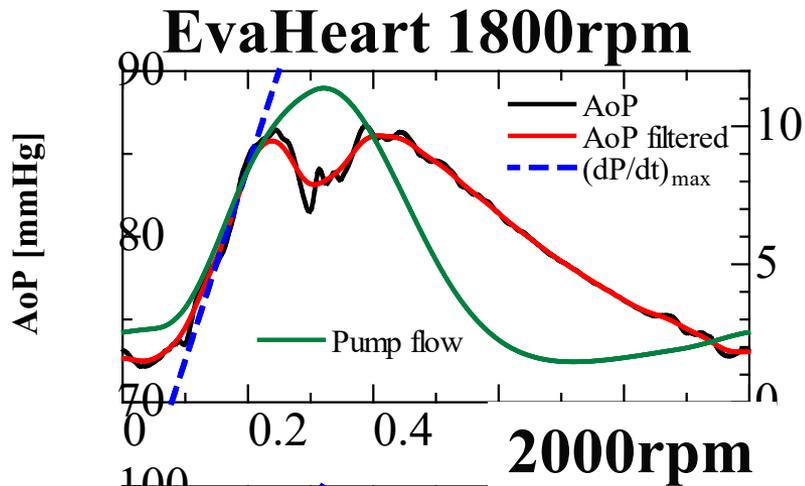
EvaHeart 2000rpm



HeartMate II 10000rpm



Pulsatility (EvaHeart > HMII) →どんな効果を生むか?



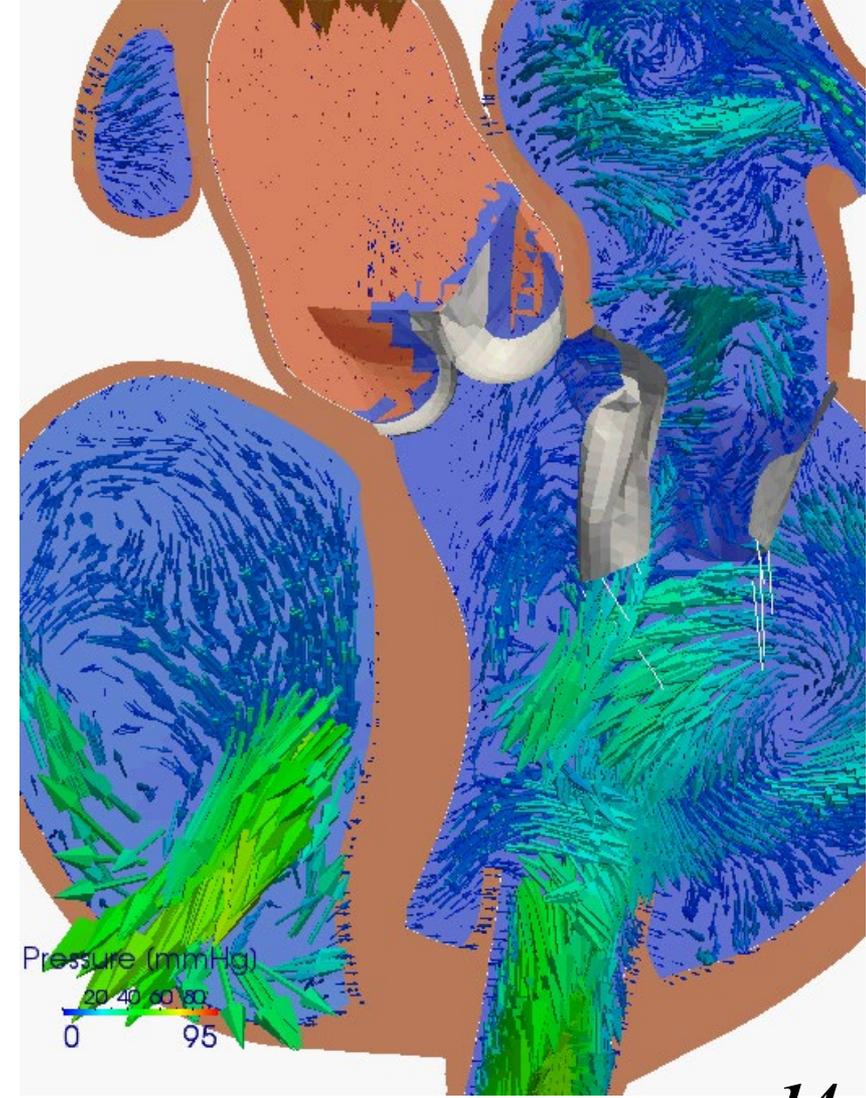
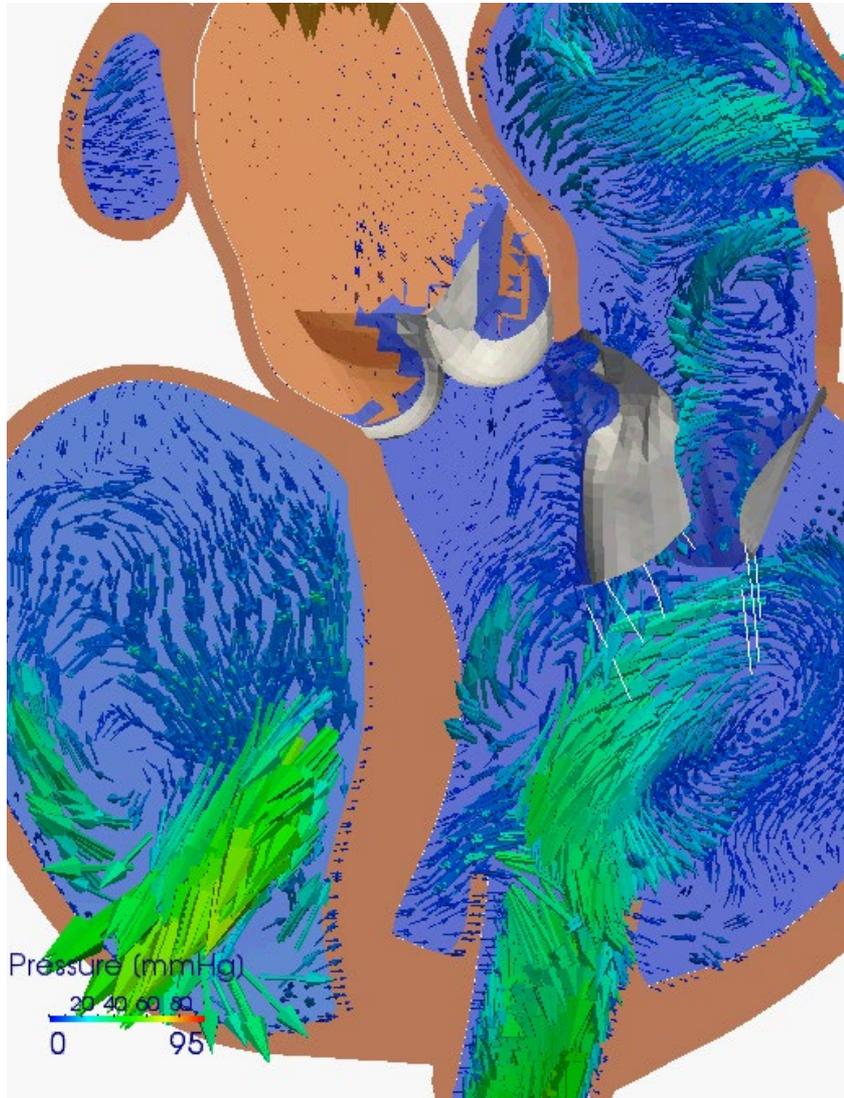
Energy equivalent pulse pressure
 $= \int PF * AoP dt / \int PF dt$

	Pulse Pressure [mmHg]	dp/dt max [mmHg/s]	EEP [mmHg]
EvaHeart 1800rpm	13.6	117	82
HeartMate II 9000rpm	8.8	70	81
EvaHeart 2000rpm	8.3	62	90
HeartMate II 10000rpm	5.1	54	91

大動脈弁の開閉 (流量) Full-support: 差なし

EvaHeart 2000rpm

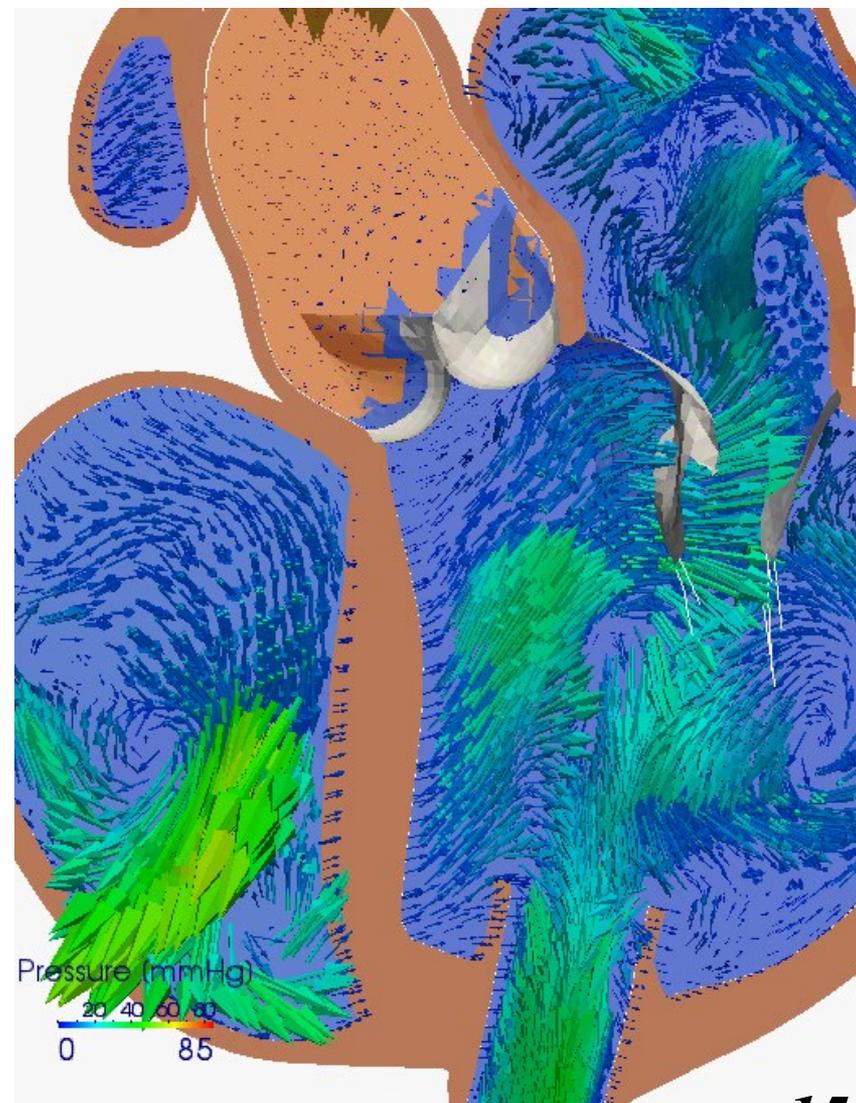
HeartMate II 10000rpm



大動脈弁の開閉 (流量) **Partial-support**

EvaHeart 1800rpm

HeartMate II 9000rpm



拍動流ポンプの利点



Circulation Journal
Official Journal of the Japanese Circulation Society
<http://www.j-circ.or.jp>

Aortic Insufficiency in Patients With Sustained Left Ventricular Systolic Dysfunction After Axial Flow Assist Device Implantation

Teruhiko Imamura, MD, PhD; Koichiro Kinugawa, MD, PhD; Takeo Fujino, MD, PhD;
Toshiro Inaba, MD, PhD; Hisataka Maki, MD, PhD; Masaru Hatano, MD; Osamu Kinoshita, MD, PhD;
Kan Nawata, MD, PhD; Shunei Kyo, MD, PhD; Minoru Ono, MD, PhD

	Centrifugal pump (n=38)		Axial pump (n=14)	
	EVAHEART (n=24)	DuraHeart (n=14)	HeartMate II (n=11)	Jarvik 2000 (n=3)
Aortic valve				
AV opening	11 (46)	6 (43)	1 (9)	0 (0)
AI	3 (13)	3 (21)	5 (45)	2 (67)
Clinical course				
PVO ₂ (ml·min ⁻¹ ·kg ⁻¹)	14.3±3.6	13.1±3.0	13.0±4.6	9.9±2.0
6MWD (m)	404±78	388±46	361±104	314±44
Re-admission rate (%)	4 (17)	1 (7)	4 (36)	2 (67)

Data given as mean ± SD or n (%). PVO₂, peak oxygen consumption; 6MWD, 6-min walk distance. Other abbreviations as in Table 1.

Conclusions: Native AV opening during LVAD support is profoundly associated with reversal of LV systolic function, especially in patients with preoperative shorter heart failure duration. Among those in whom the native AV remains closed, low pulsatility of axial flow pump may facilitate aortic root remodeling and post-LVAD AI development that results in worse clinical outcome.

個別化心臓モデルによる CRTの効果予測

Non-responderを同定できるか？

Retrospective study



CRT simulation protocol

Personalized heart model

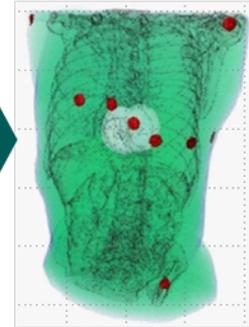
Clinical
Data

ECG
UCG
.....

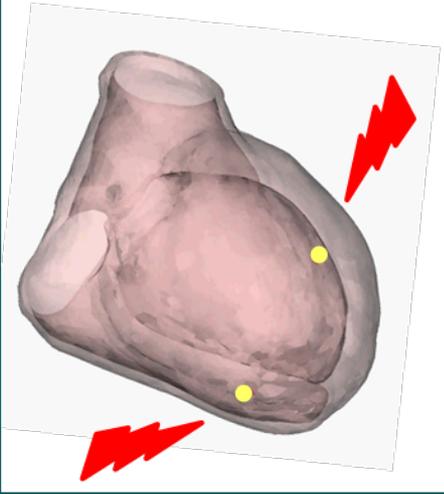
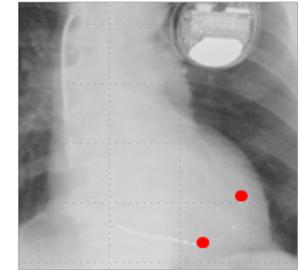
CT, MRI



Torso



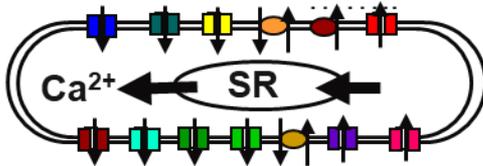
CRT simulation



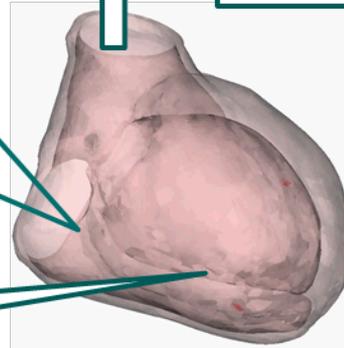
Cell model



..... Na⁺ Ca²⁺ K⁺

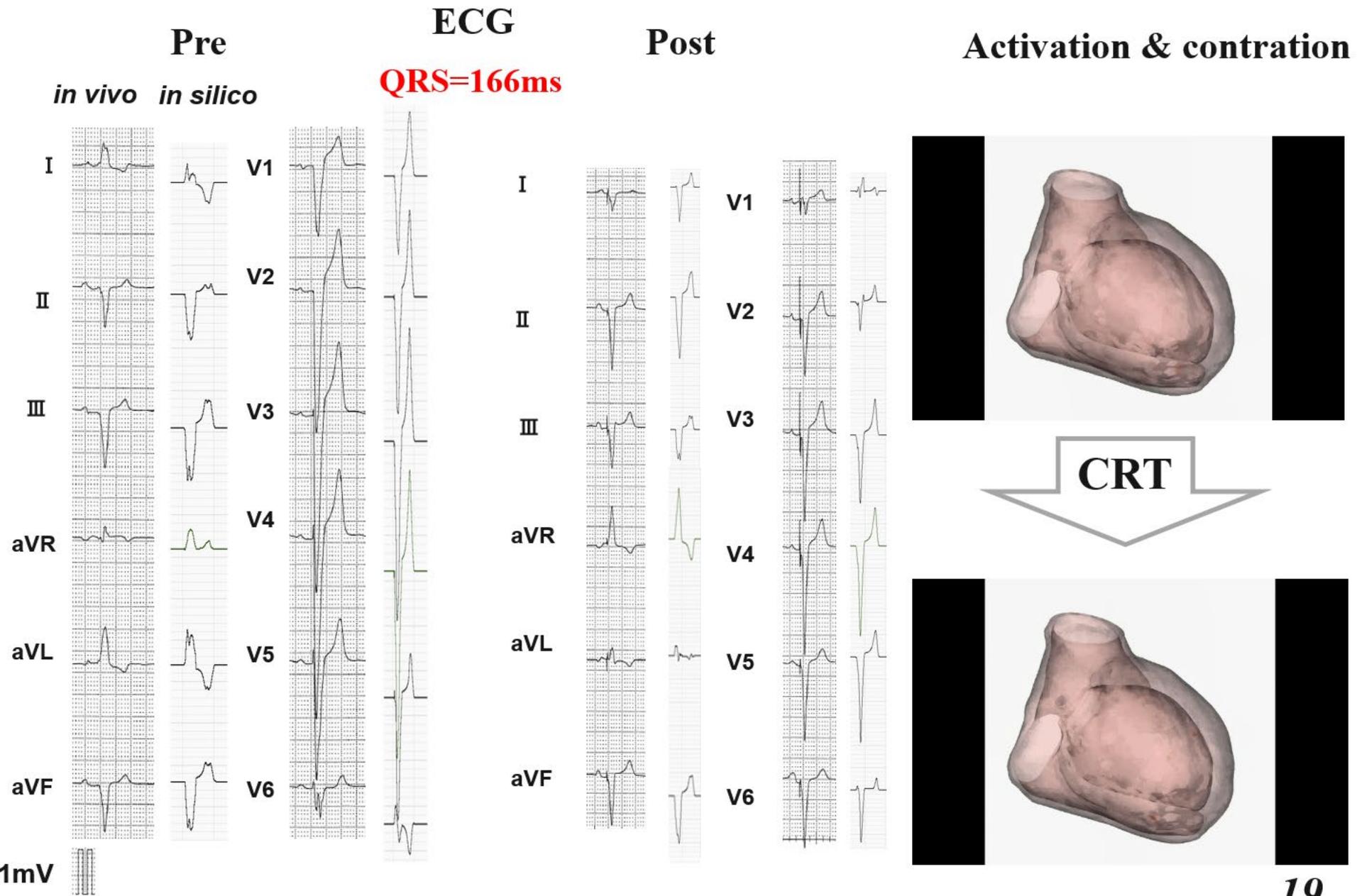


Circulation model



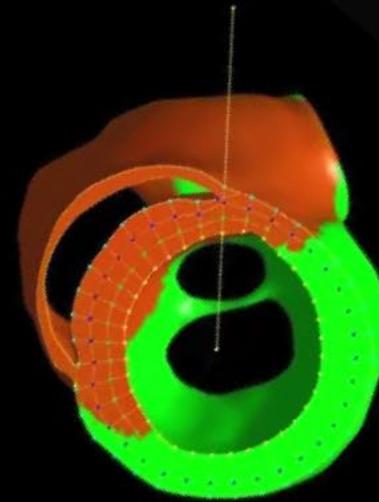
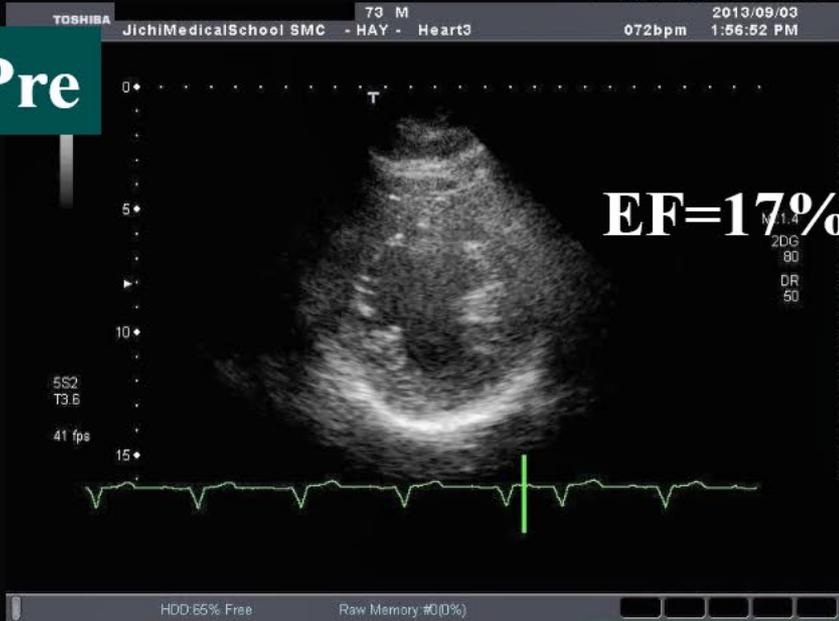
Fiber orientation

Case1: DCM Responder

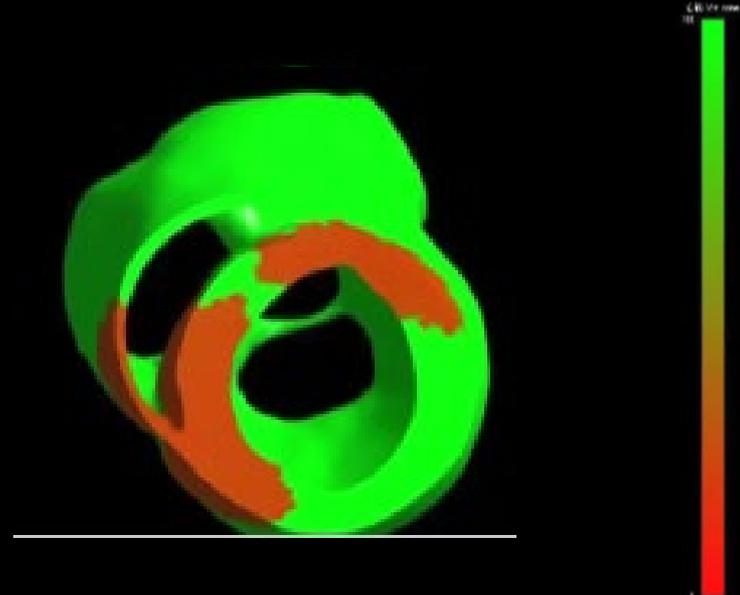


Activation & wall motion

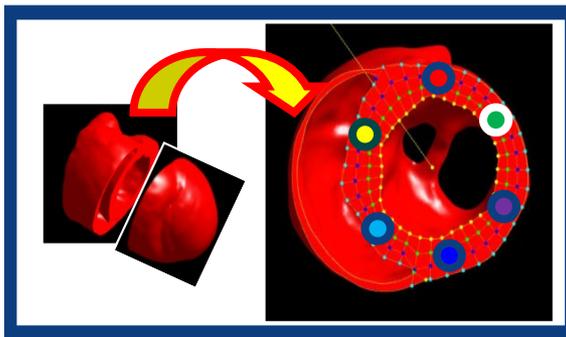
Pre



Post



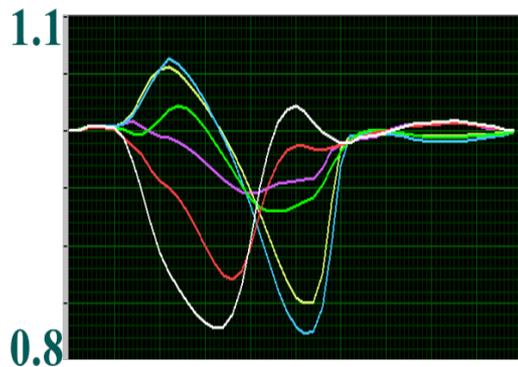
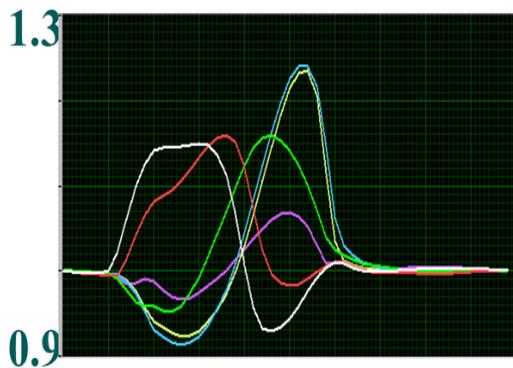
Wall motion & hemodynamics



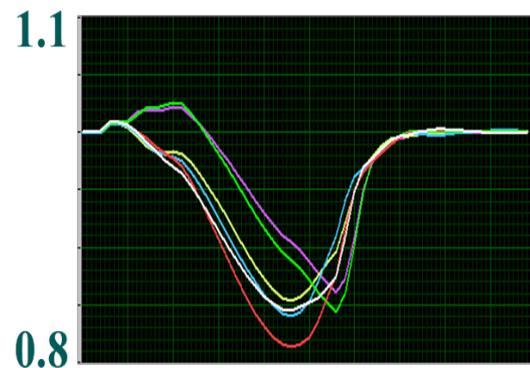
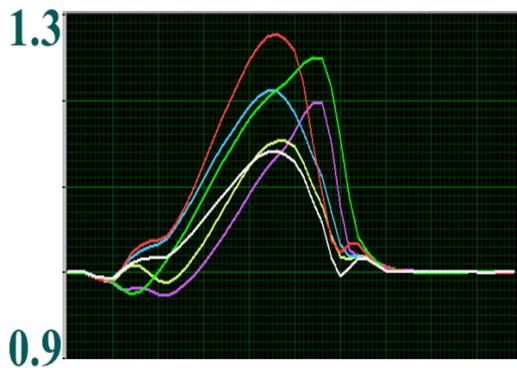
Radial strain [-]

Circumferential strain [-]

Pre

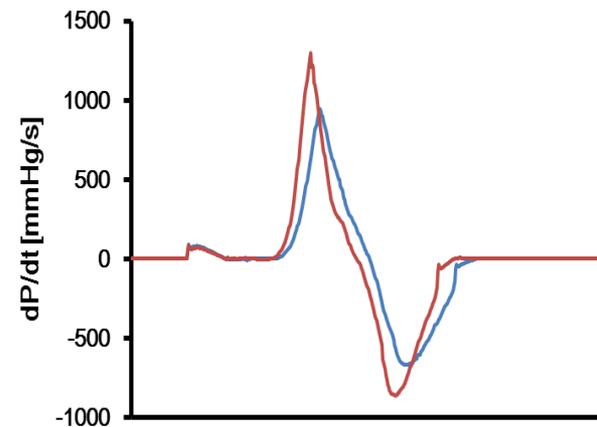
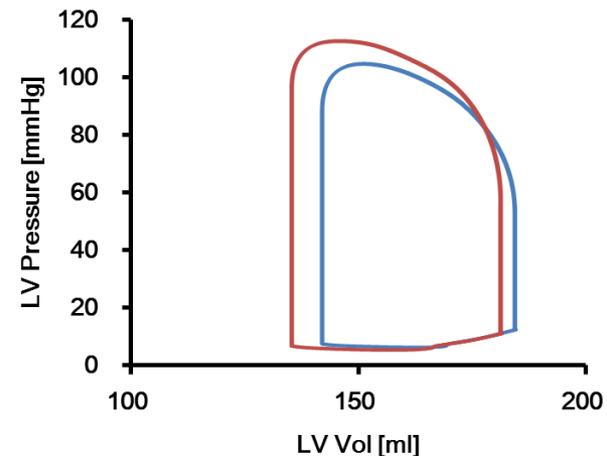


Post

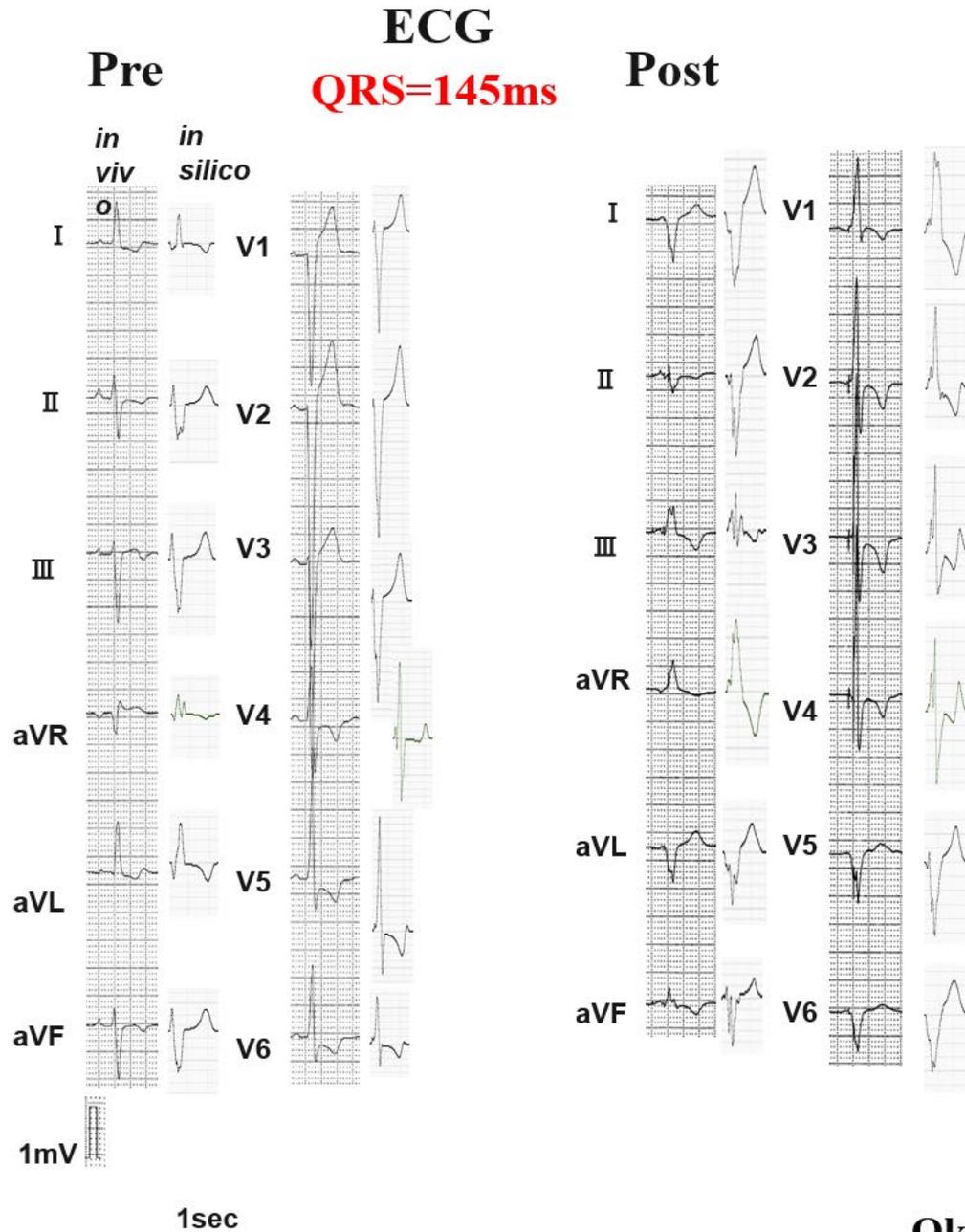


time

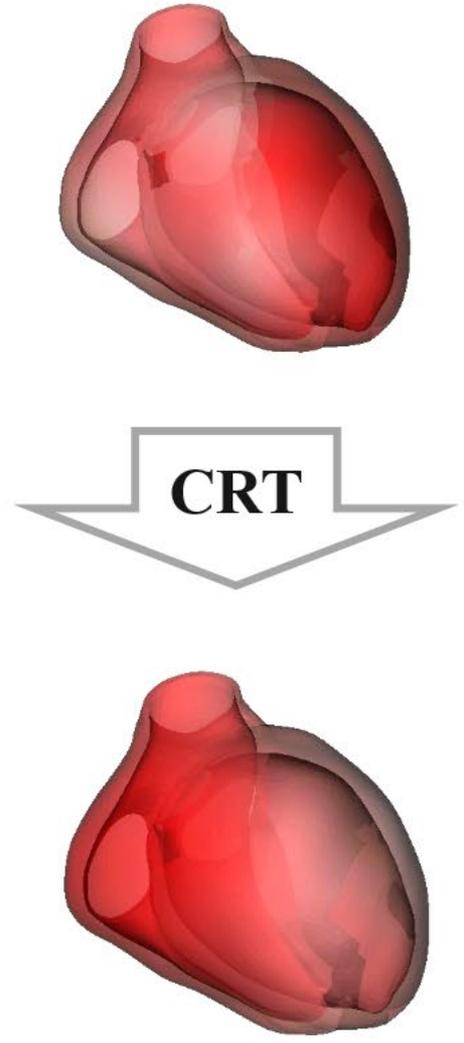
— CRT(-)
— CRT(+)



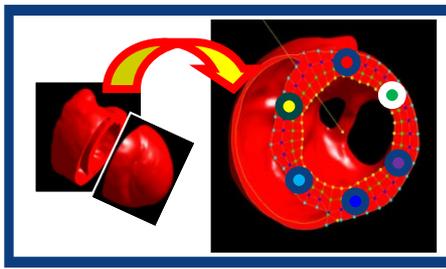
Case2: DCM Non-responder



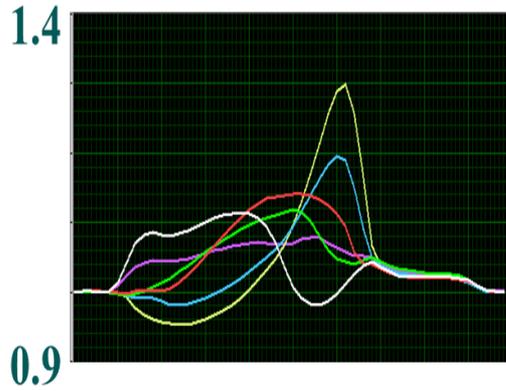
Activation & contraction



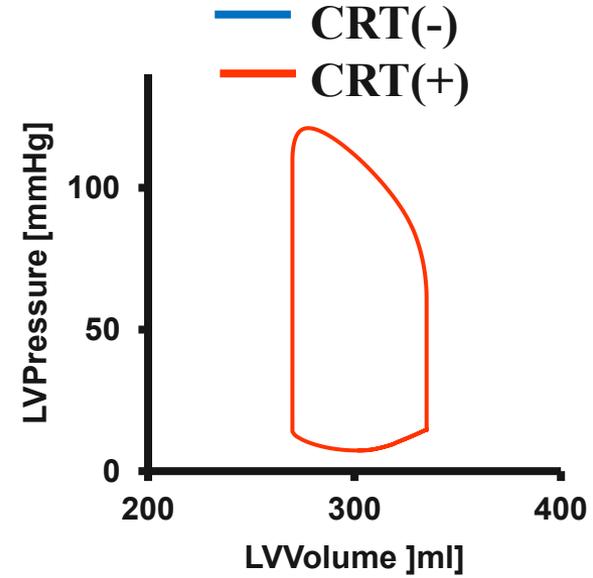
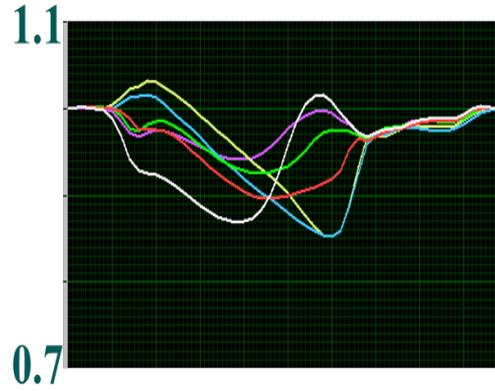
Wall motion & hemodynamics



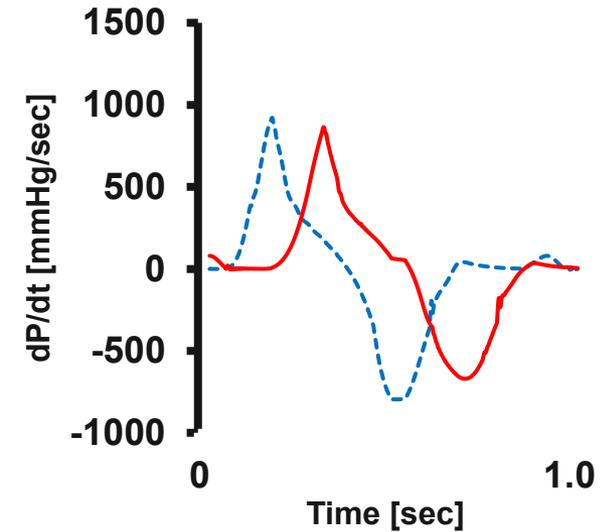
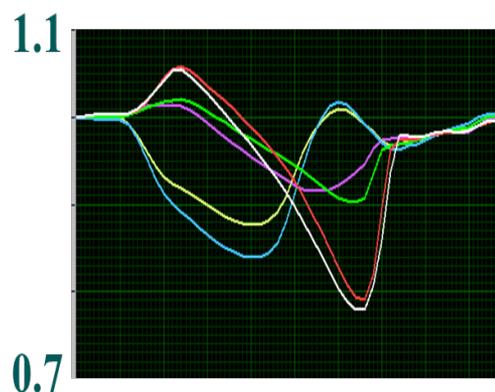
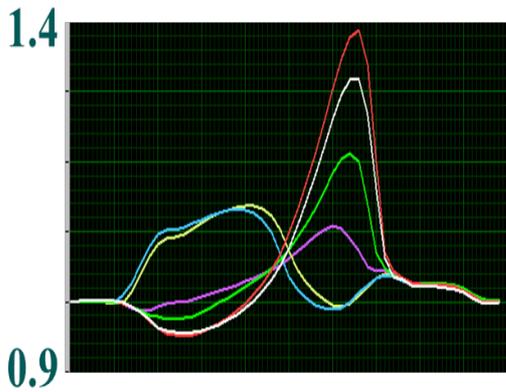
Radial strain [-]

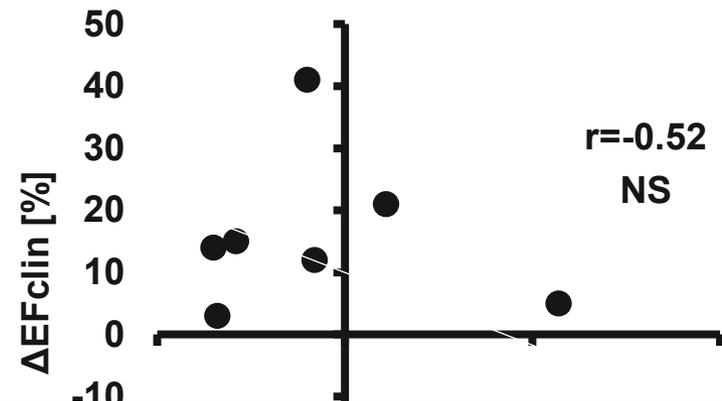
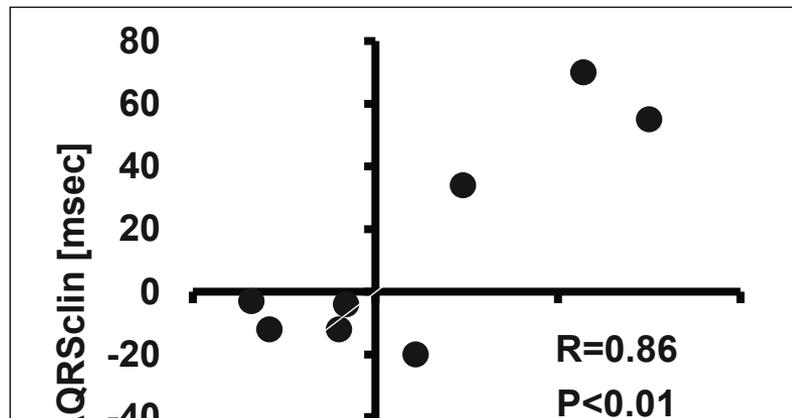


Circumferential strain [-]



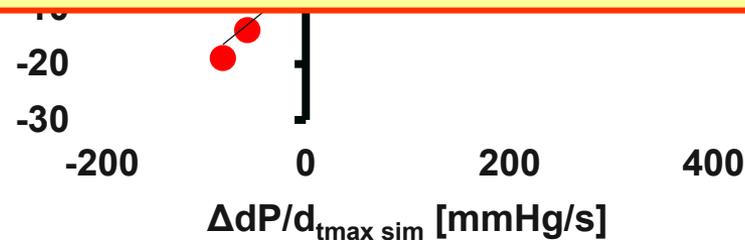
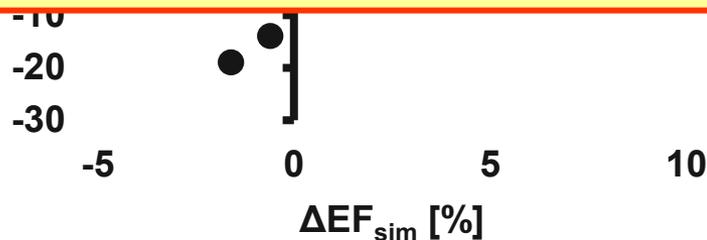
Post





CRTシミュレーションによる dP/dt_{\max} の増加は臨床効果と良く相関

→ non-responder予測性能を検証中



Indices by simulation

共同研究者

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Masahiro Watanabe

Machiko Nakagawa

Sun Medical Technology
Research Corp

Daisuke Ogawa

Hideki Kanebako

ご静聴ありがとうございました.....

UT-Heart