Congenital heart disease: Can the principles of Physics turn things in our favor?

William M. DeCampli, M.D., Ph.D

Arnold Palmer Hospital for Children

The University of Central Florida College of Medicine and College of Engineering & Computer Science

ARNOLD PALMER HOSPITAL For Children

UCF

No disclosures

Period = $\sqrt{(L/g)}$

Laws of Physics

- Law of Conservation of Mass
- Newton’s Laws of Motion
- Laws of Thermodynamics

NOT NEGOTIABLE!!

$$F = ma$$

Blood flow ($\dot{Q}$) =

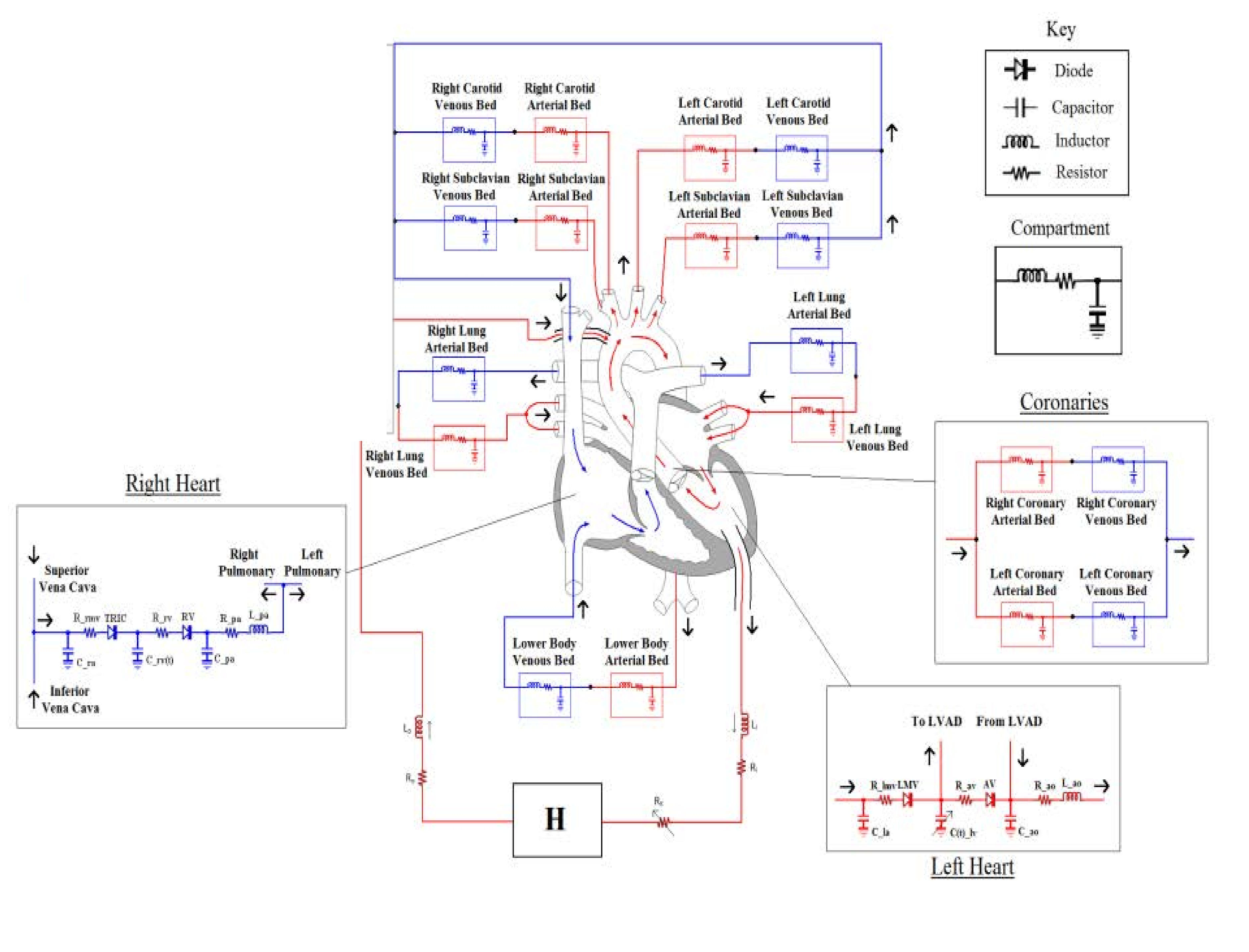
r^4

r	radius of vessel
ΔP	pressure gradient along vessel
L	length of vessel
η	viscosity of fluid

$$\nabla \cdot \vec{V} = 0$$

$$\rho \frac{\partial \vec{V}}{\partial t} + \rho \left(\vec{V} \cdot \nabla \right) \vec{V} = -\nabla p + \nabla \cdot \sigma$$

$$\sigma \quad = \mu(\dot{\gamma}) \left[\nabla \vec{V} + \left(\nabla \vec{V} \right)^{T} \right]$$



Key
Diode
Capacitor
Inductor
Resistor
Compartment
Right Carotid Venous Bed
Right Carotid Arterial Bed
Left Carotid Arterial Bed
Left Carotid Venous Bed
Right Subclavian Venous Bed
Right Subclavian Arterial Bed
Left Subclavian Arterial Bed
Left Subclavian Venous Bed
Right Lung Arterial Bed
Left Lung Arterial Bed
Left Lung Venous Bed
Right Lung Venous Bed
Coronaries
Right Coronary Arterial Bed
Right Coronary Venous Bed
Left Coronary Arterial Bed
Left Coronary Venous Bed
Right Heart
Superior Vena Cava
Inferior Vena Cava
Right Pulmonary
Left Pulmonary
R_mv TRIC
R_rv RV
R_pa L_pa
C_ra
C_rv(t)
C_pa
Lower Body Venous Bed
Lower Body Arterial Bed
H
Left Heart
To LVAD
From LVAD
R_lmv LMV
R_av AV
R_ao L_ao
C_la
C(t)_lv
C_ao

USE OF COMPUTATIONAL FLUID DYNAMICS IN THE DESIGN OF SURGICAL PROCEDURES: APPLICATION TO THE STUDY OF COMPETITIVE FLOWS IN CAVOPULMONARY CONNECTIONS

M. R. de Leval, MD, FRCS[a]
G. Dubini, PhD[c§]
F. Migliavacca[c§]
H. Jalali, MD[a§]
G. Camporini[a§]
A. Redington[b§]
R. Pietrabissa, PhD[c§]

Computational fluid dynamic methods based on a finite-element technique were applied to the study of (1) competition of flows in the inferior and superior venae cavae in total cavopulmonary connection, and (2) competition between flow in the superior vena cava and forward flow from a stenosed pulmonary artery in bidirectional cavopulmonary anastomosis. Models corresponding to various degrees of offsetting and shape of the inferior vena caval anastomosis were simulated to evaluate energy dissipation and flow distribution between the two lungs. A minimal energy loss with optimal flow distribution between the two lungs was obtained by enlarging the inferior vena caval anastomosis toward the right pulmonary artery. This modified technique of total cavopulmonary connection is described. A computational model of the operation was developed in an attempt to understand the mechanisms of postoperative failure. In tight pulmonary artery stenosis (75%), the pulsatile forward flow is primarily directed to the left pulmonary artery, with little influence on superior vena caval pressure and the right pulmonary artery. Pulsatile forward flows corresponding to 15%, 30%, 45%, and 60% of the systemic artery output increased the mean pulmonary artery and superior vena caval pressures by 1, 1.7, 2.4, and 3.6 mm Hg, respectively. Although the modeling studies were not able to determine the cause of postoperative failure, they emphasize the impact of local geometry on flow dynamics. More simulations are required for further investigation of the problem. (J Thorac Cardiovasc Surg 1996;111:502-13)

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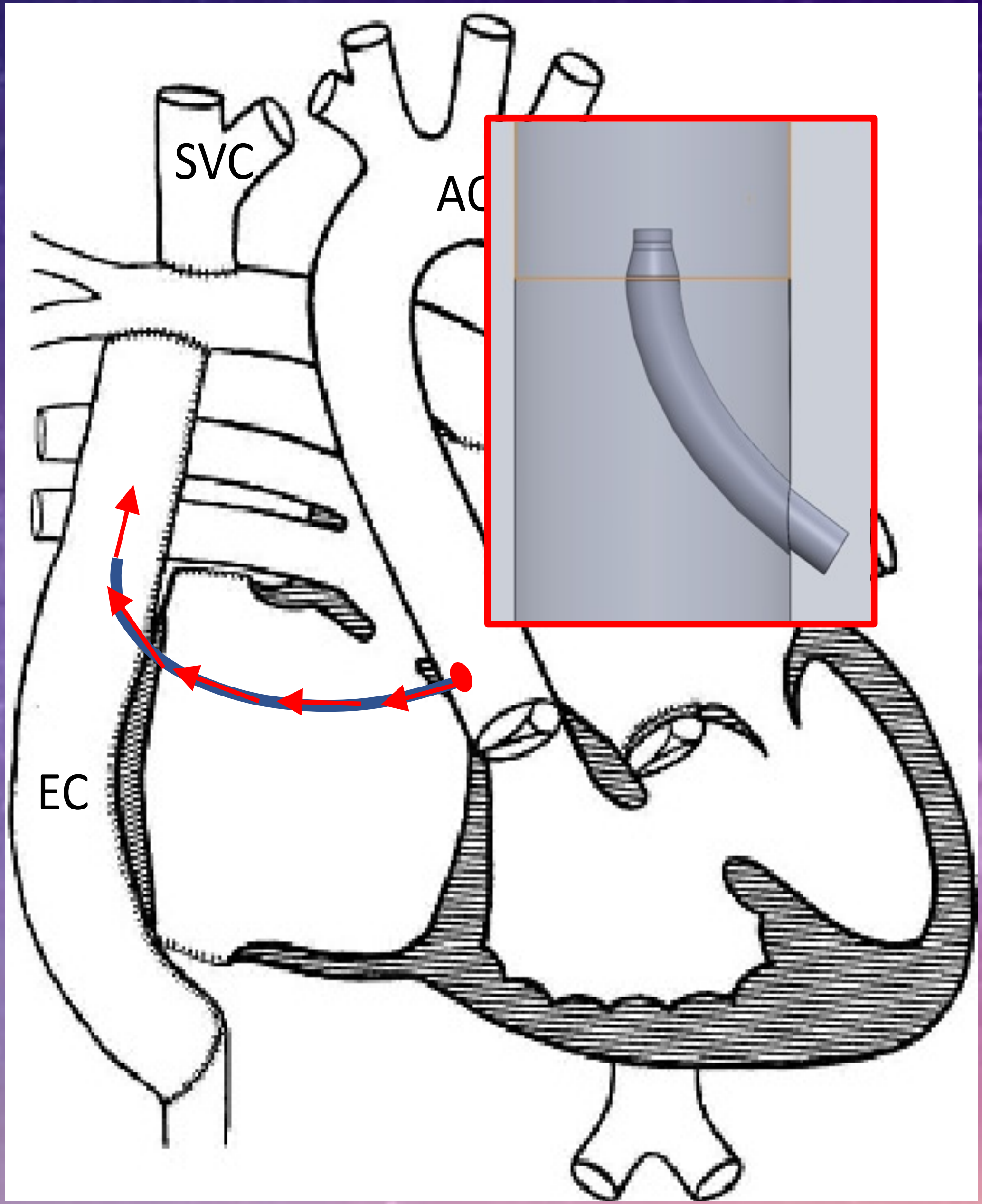
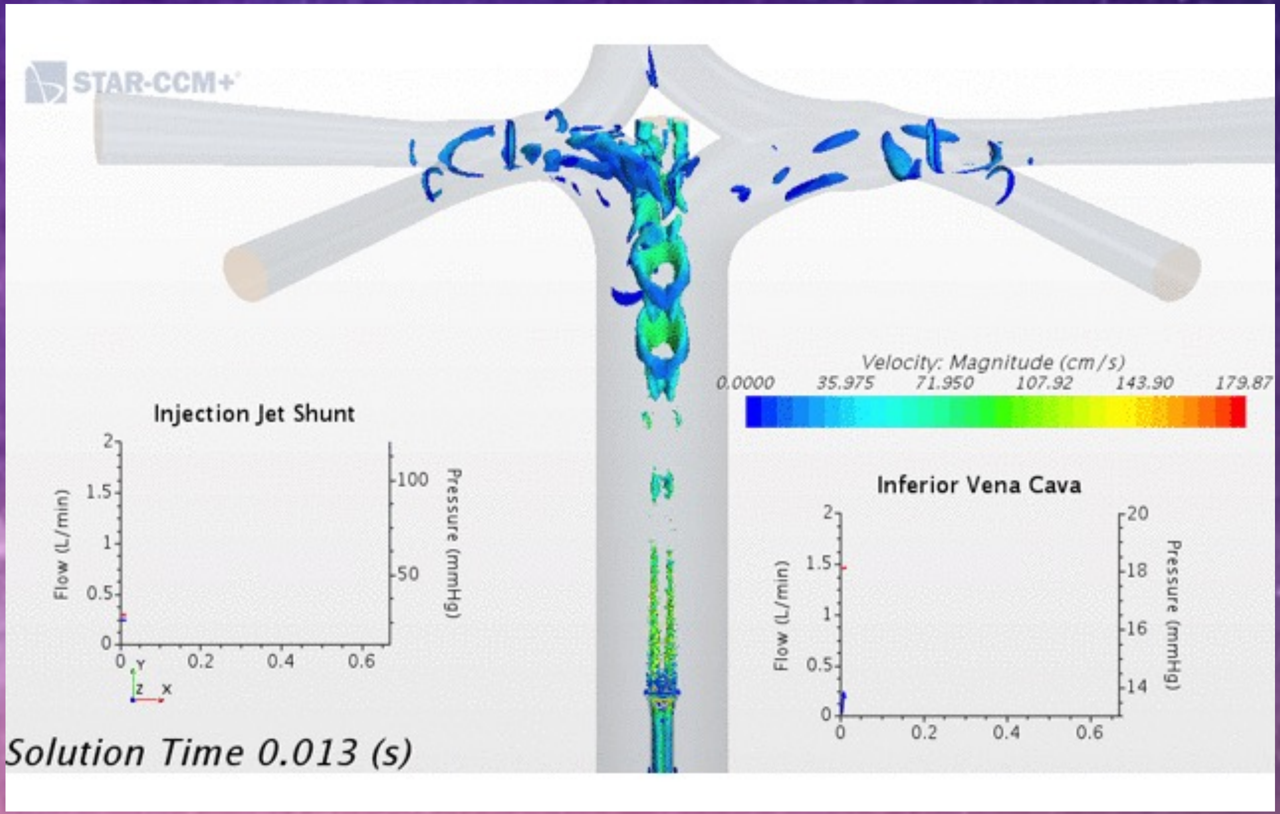
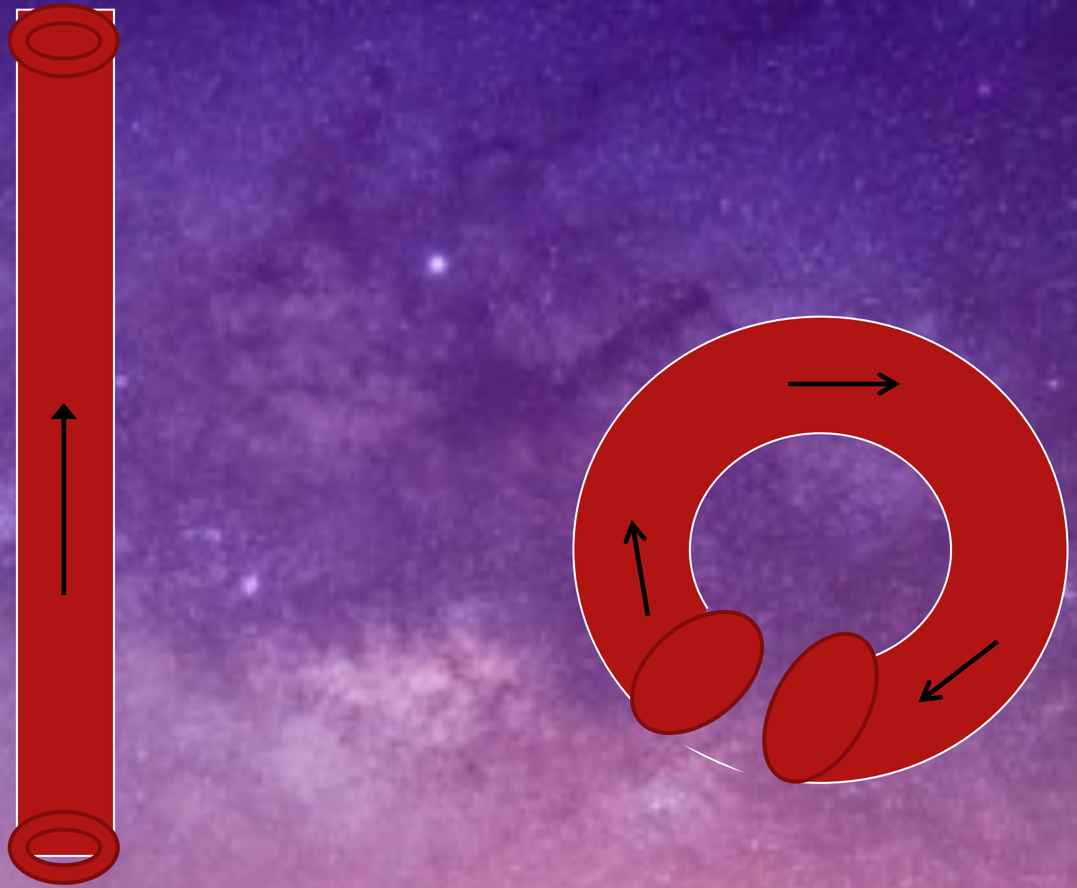
Parametric investigation of an injection-jet self-powered Fontan circulation

Ray Prather[1,2,3]✉, Arka Das[2], Michael Farias[3], Eduardo Divo[2], Alain Kassab[1] & William DeCampli[3,4]

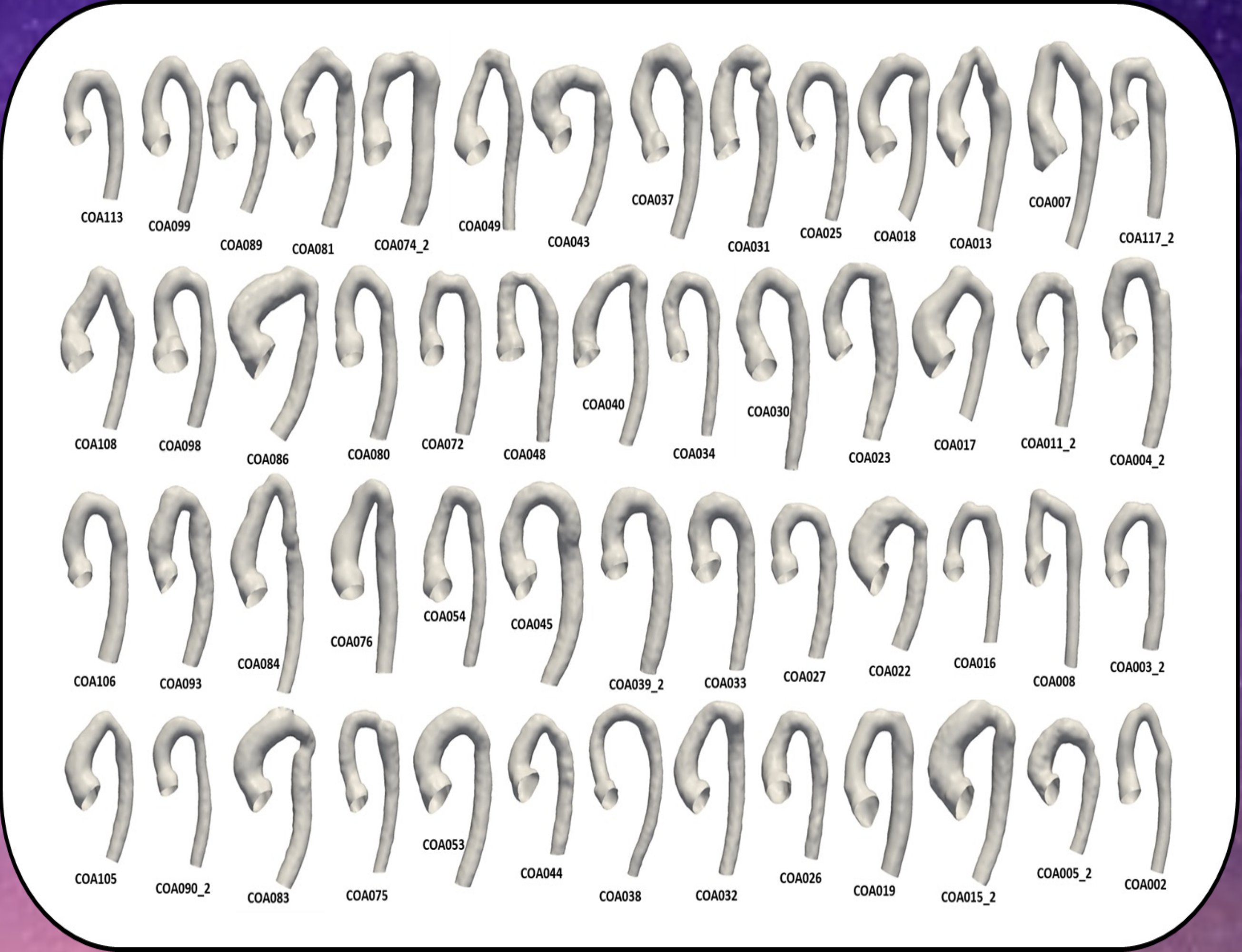

SVC
AO
EC


STAR-CCM+
Velocity: Magnitude (cm/s)
0.0000 35.975 71.950 107.92 143.90 179.87
Injection Jet Shunt
Flow (L/min)
Pressure (mmHg)
Inferior Vena Cava
Flow (L/min)
Pressure (mmHg)
Solution Time 0.013 (s)

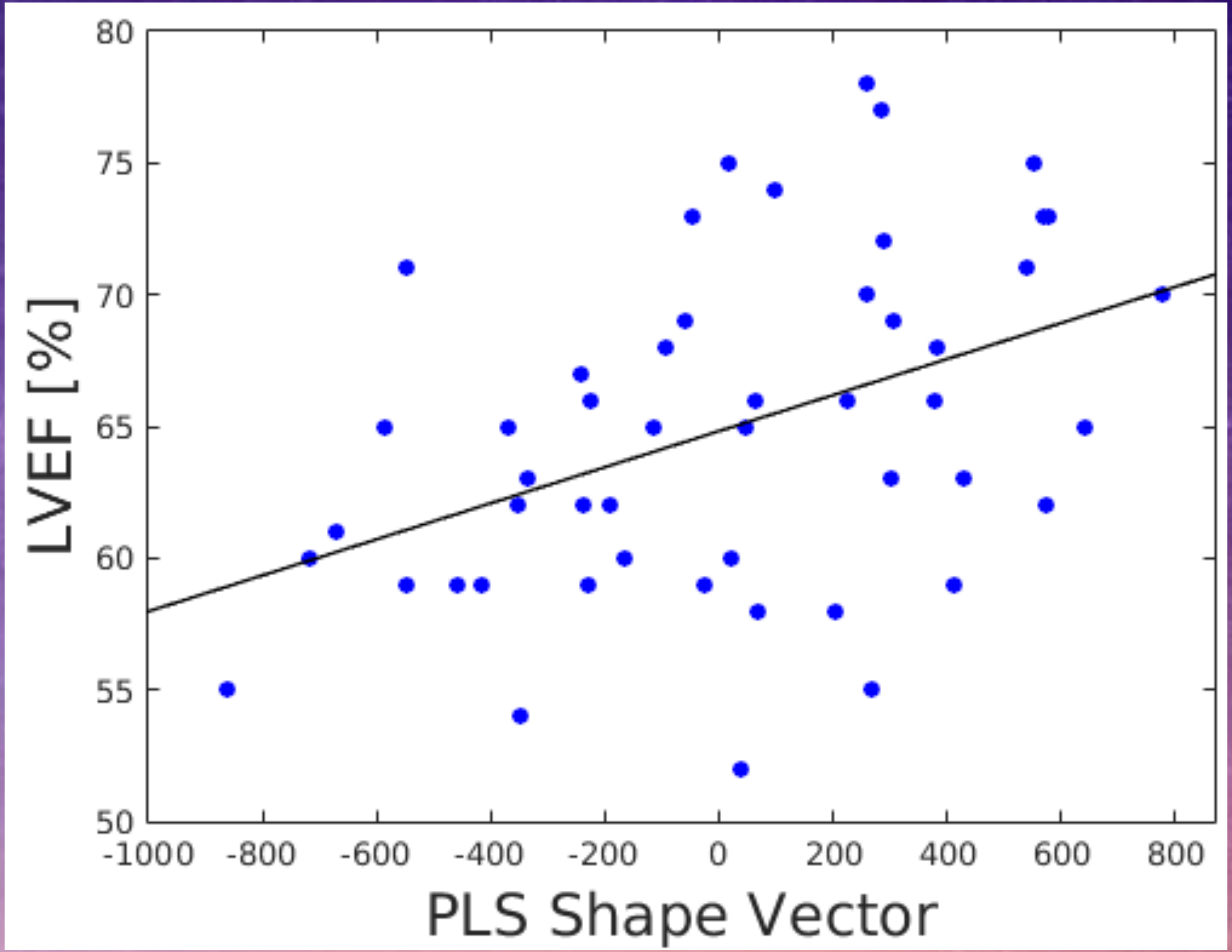
Model [#]	Geometry [shape]	$\Delta_{IJS-TCPC}$ [cm]	D_{ijs} [mm]	IJS shape [aspect ratio]	D_{fen} [mm]	Δ_{SVC} [%]	Qp [L/min]	Qs [L/min]	CO [L/min]	Qp/Qs	CO/Qs	Pivc [mmHg]	Psvc [mmHg]	Plpa [mmHg]	Prpa [mmHg]	ΔPivc [mmHg]	IJS VF	sysO2 [%]	
1a	Stnd	-	-	-	4.0	0.0	2.18	2.33	2.33	0.94	1.00	18.2	18.1	17.2	17.2	-	-	97-99	
1b	Stnd	-	-	-	6.5	0.0	1.59	2.30	2.30	0.69	1.00	14.6	14.6	14.0	14.0	3.6	-	89-91	Baseline
1c	Stnd	-	-	-	7.5	0.0	1.32	2.31	2.31	0.57	1.00	13.1	13.1	12.6	12.6	5.0	-	82-84	
2	Stnd	5.0	2.0	3e NES	7.5	0.0	1.54	2.23	2.66	0.69	1.19	14.8	14.9	14.3	14.2	3.4	0.19	85-87	
3	2Y	7.0	2.0	3e	7.5	0.0	1.46	2.26	2.72	0.64	1.20	13.9	14.2	13.8	13.9	4.2	0.26	84-86	
4	Skew	7.0	2.0	3e	7.5	0.0	1.55	2.24	2.71	0.69	1.21	14.7	14.9	14.3	14.3	3.5	0.21	85-87	
5	Torus	7.0	2.0	3e	7.5	0.0	1.41	2.26	2.72	0.62	1.20	14.1	14.0	13.6	13.5	4.1	0.26	83-85	Group 1
6	Torus	7.0	2.5	3e	7.5	0.0	1.52	2.24	2.87	0.68	1.28	14.7	14.6	14.2	14.2	3.5	0.32	85-87	
7	Torus	3.0	2.0	3e	7.5	0.0	1.46	2.25	2.71	0.65	1.20	14.4	14.3	13.8	13.8	3.8	0.23	84-86	
8	Stnd	7.0	2.0	3e	7.5	100.0	1.43	2.26	2.72	0.63	1.20	14.0	14.1	13.7	13.6	4.2	0.26	83-86	
9	Skew	7.0	2.0	3e	7.5	100.0	1.57	2.24	2.71	0.70	1.21	14.5	14.9	14.4	14.5	3.7	0.24	86-88	Group 2
10	torus	5.0	2.0	3e	7.5	100.0	1.45	2.26	2.72	0.64	1.20	14.2	14.2	13.8	13.7	3.9	0.26	84-86	



- 53 patients
- 12-37 yrs post arch-CoA repair
- No residual obstructions
- CMR, LV Function



r = 0.42, p =0 .024

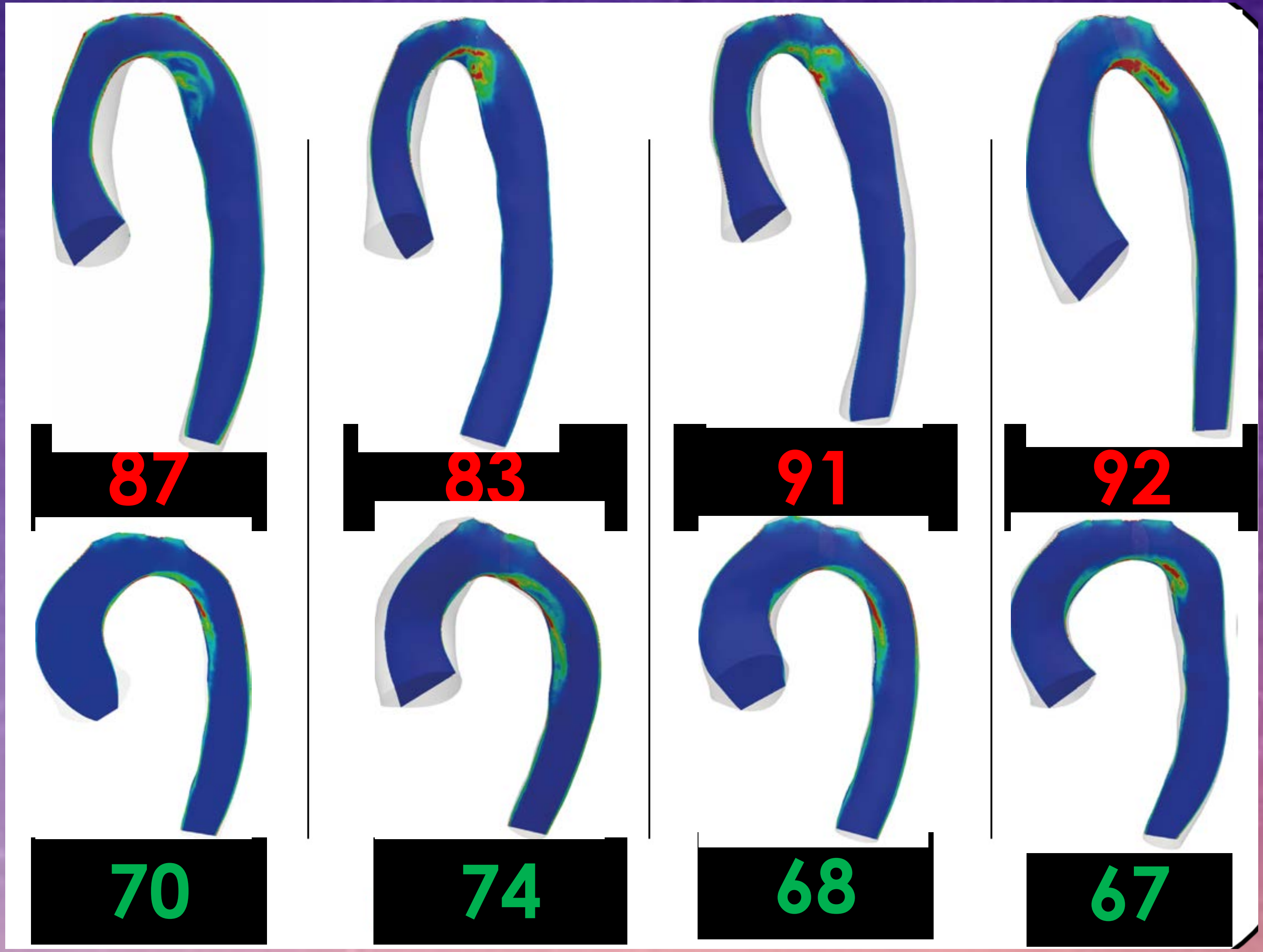


LVEF [%]
80
75
70
65
60
55
50
-1000
-800
-600
-400
-200
0
200
400
600
800
PLS Shape Vector

Results: Viscous Energy Loss, E_L

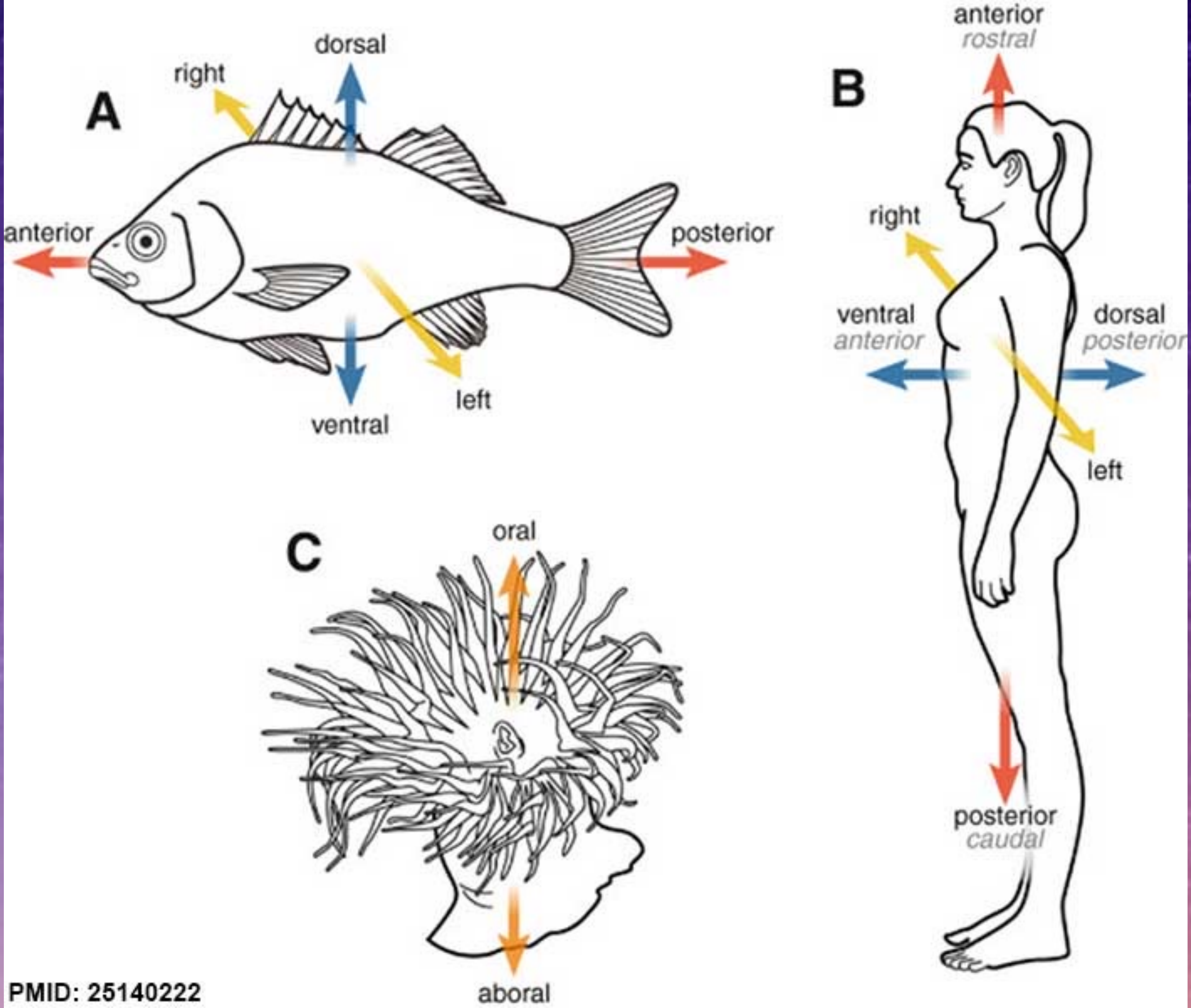
Low EF

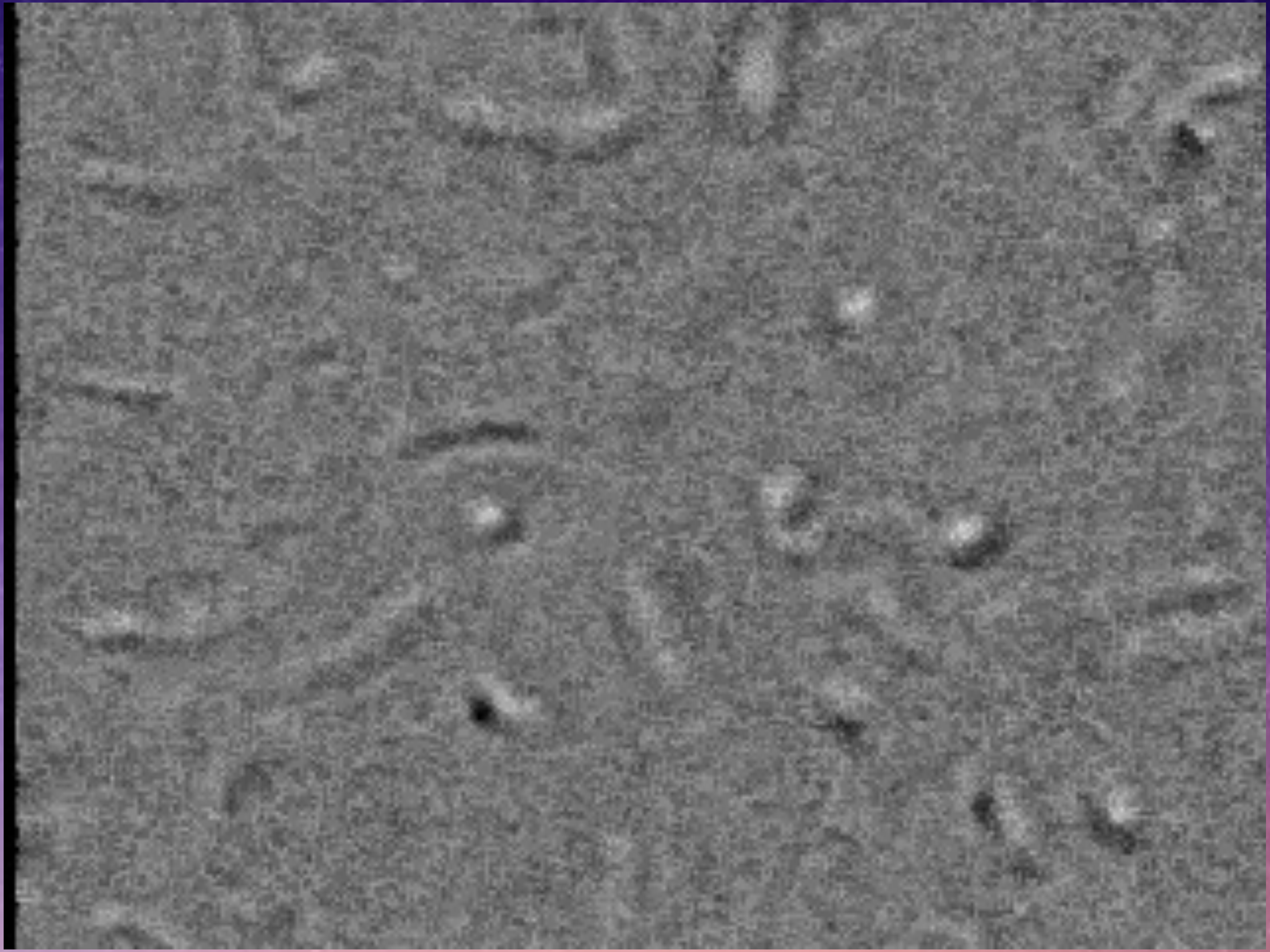
High EF



Average difference in E_L:

15-32%


A
right
dorsal
anterior
posterior
left
ventral
B
anterior
rostral
right
ventral
anterior
dorsal
posterior
left
posterior
caudal
C
oral
aboral
PMID: 25140222

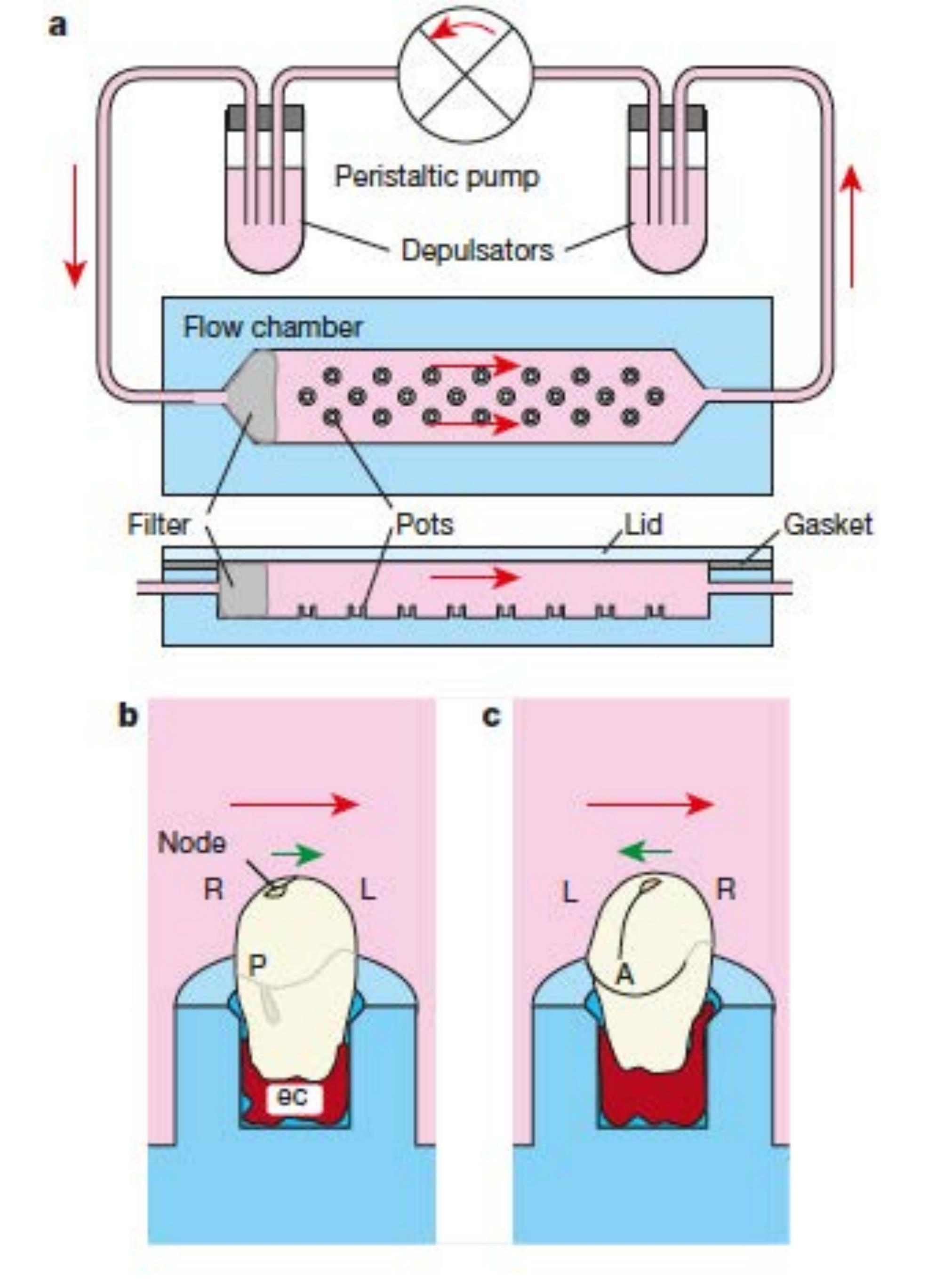


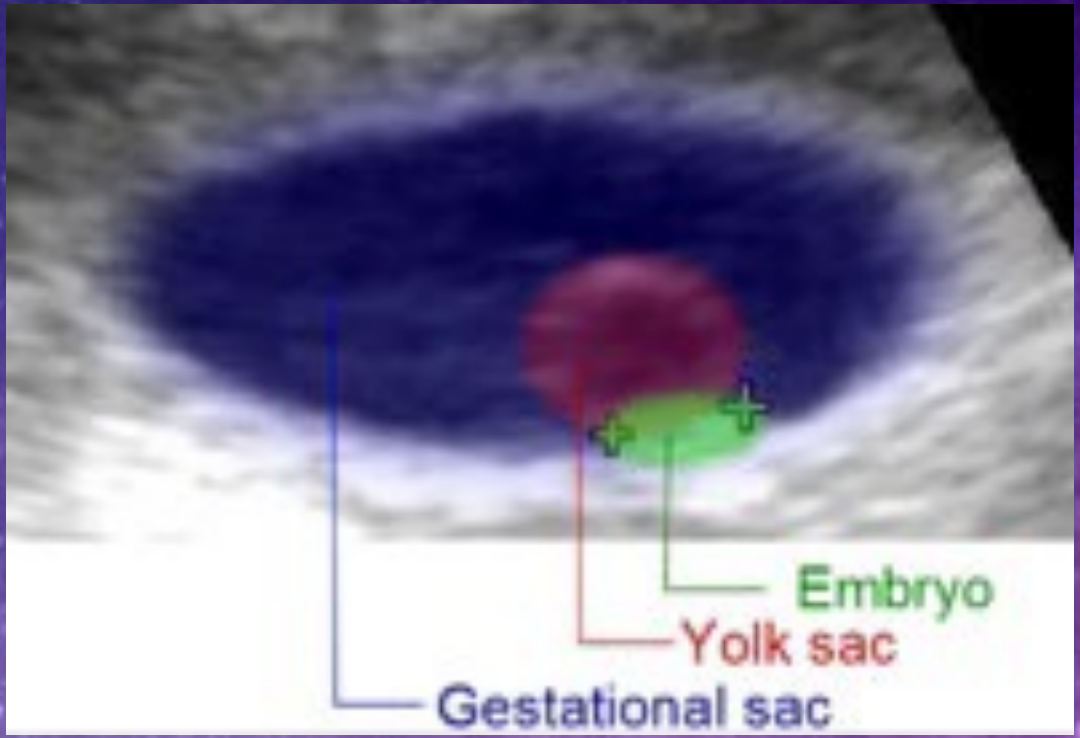
Determination of left–right patterning of the mouse embryo by artificial nodal flow

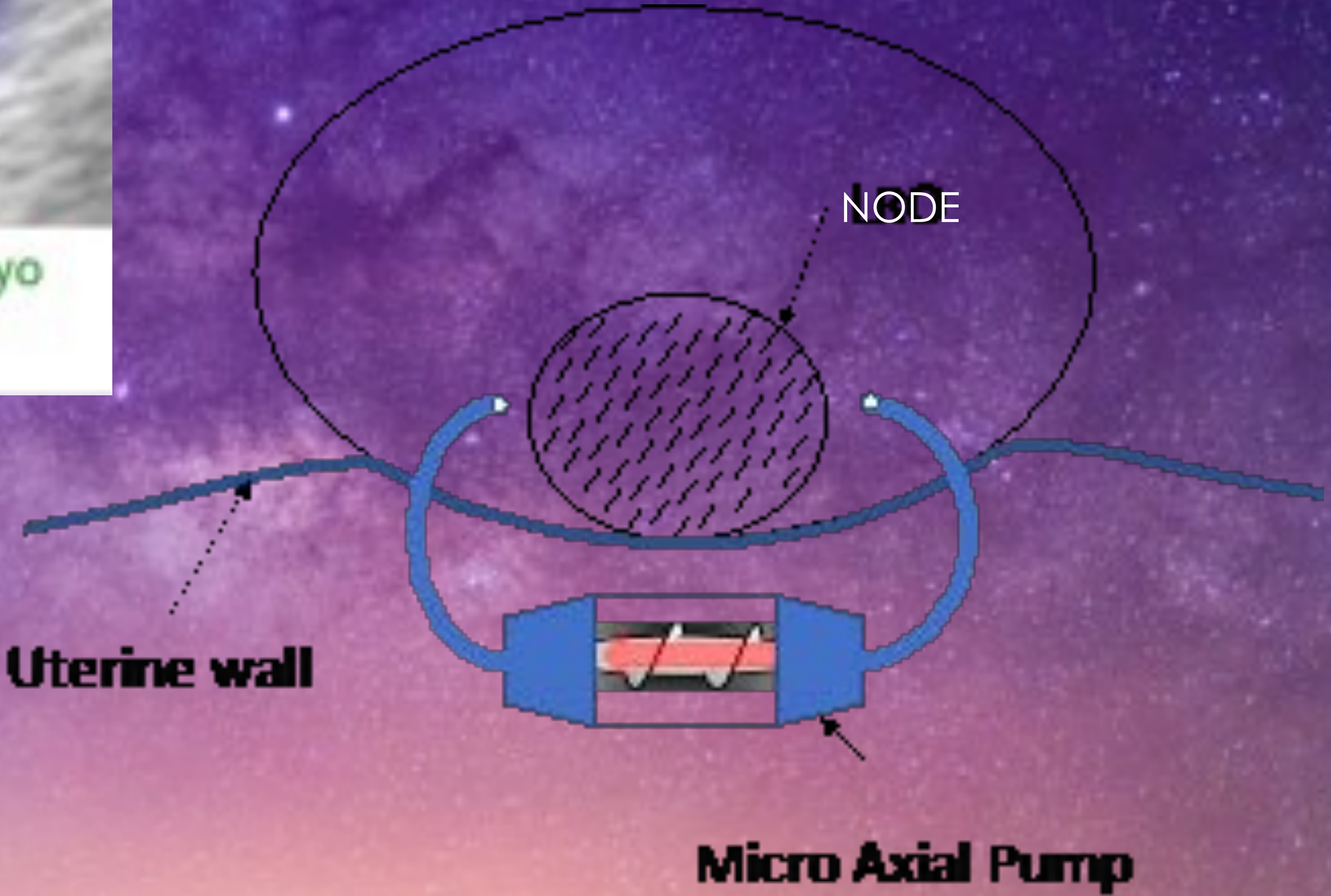
Shigenori Nonaka, Hidetaka Shiratori, Yukio Saijoh & Hiroshi Hamada

Graduate School of Frontier Biosciences, Osaka University, 1–3 Yamada-oka, Suita, Osaka 565-0871, Japan; and CREST, Japan Science and Technology Corporation (JST), Japan

Nonaka S. et al. *Nature* 418, 4 July 2002




Embryo
Yolk sac
Gestational sac


NODE
Uterine wall
Micro Axial Pump


Quiz after Reception