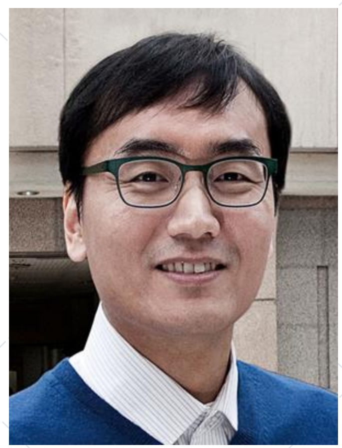
Engineering Perspectives in Blood Flow Mechanism due to Vascular Diseases

✓ **Speaker**

Dr. Joon Sang Lee

Associate Professor,
Dept. of Mechanical Eng.,
Yonsei University,
Seoul, Korea.
joonlee@yonsei.ac.kr



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8th IMAGING & PHYSIOLOGY SUMMIT2015

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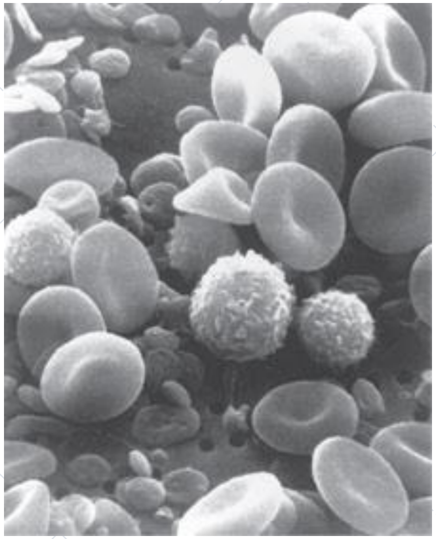
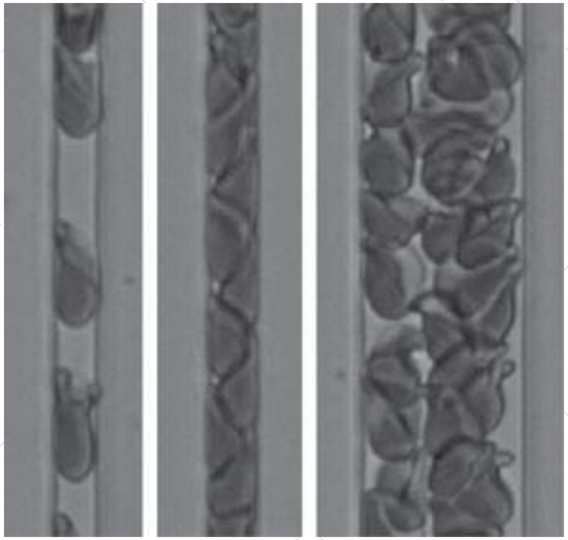
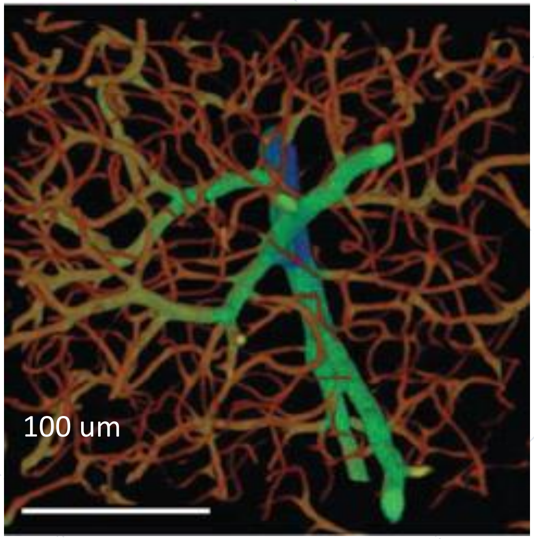
Research Objectives



Red and white blood cells and platelets at rest (Wetzel & Schaefer 1982)



Red blood cells flowing in a microfluidic device (Burns et al. 2012)



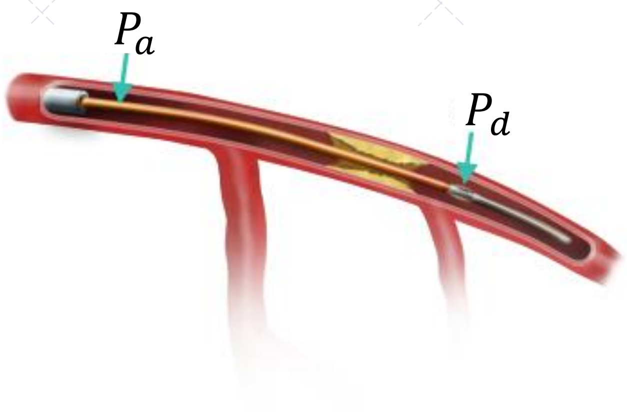
A mouse brain microvasculature scan showing its intricate geometry (Mayerich et al. 2011)

Fractional Flow Reserve (FFR).

$$FFR = \frac{Maximum\ flow\ in\ presence\ of\ stenosis}{Normal\ maximum\ flow}$$

$$= \frac{Q^{S}_{\mathrm{max}}}{Q^{N}_{\mathrm{max}}} = \frac{(P_d - P_{\mathrm{v}}) / \mathrm{R}}{(P_a - P_{\mathrm{v}}) / \mathrm{R}}$$

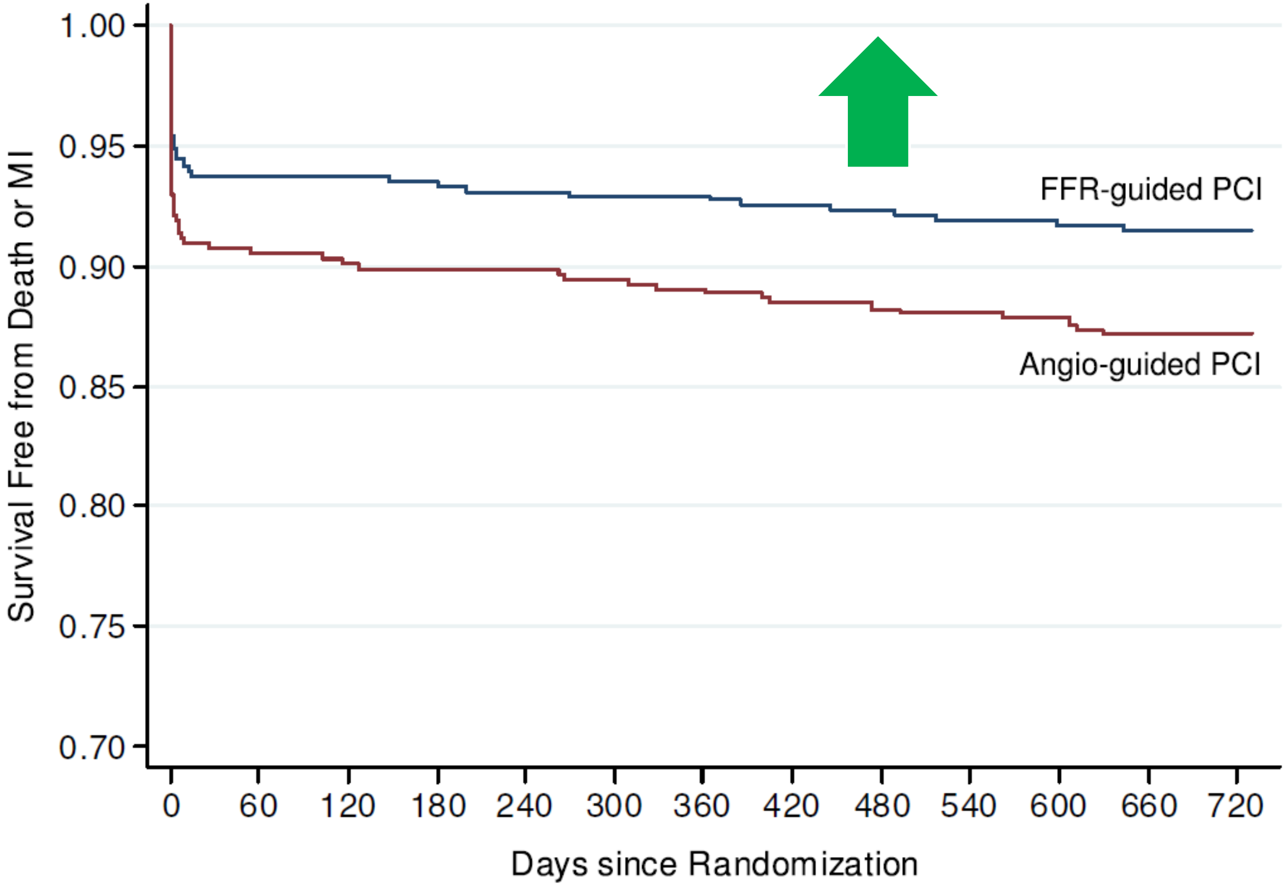
$$= \frac{Distal\ Coronary\ Pressure\,(P_d)}{Proximal\ Coronary\ Pressure\,(P_a)}$$



FFR 0.7 means that 30% of myocardial blood flow was reduced due to stenosis

Fractional Flow Reserve (FFR).

What can we do to increase survival?



Morton J. Kern, 2010

Engineering Perspectives on FFR.

FFR definition: $$FFR = \frac{Q^S_{\max}}{Q^N_{\max}}$$

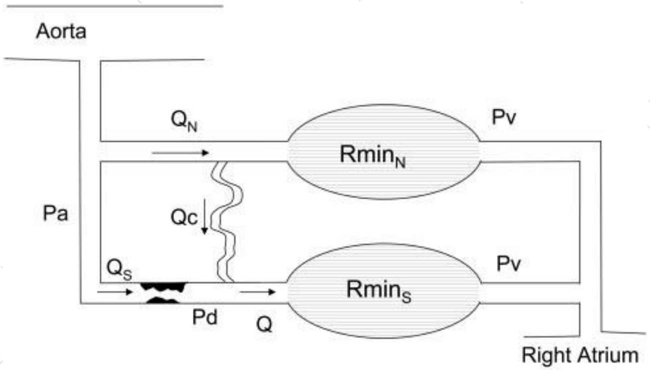
Flowrate-Pressure: $$Q^N_{\max} = \frac{(P_a - P_v)}{R^N_{\min}} \quad Q^S_{\max} = \frac{(P_d - P_v)}{R^S_{\min}}$$

Flowrate-Pressure: $$FFR = \frac{(P_d - P_v)}{(P_a - P_v)} \times \frac{R^N_{\min}}{R^S_{\min}}$$

Assumption: $$R^N_{\min} = R^S_{\min}$$

$$P_v = 0$$

Final equation: $$FFR \approx \frac{P_d}{P_a}$$



Electric circuit vs Vascular system

$$V = IR \qquad P = QR$$

Q^N = flowrate at normal vessel

Q^S = flowrate at stenosis vessel

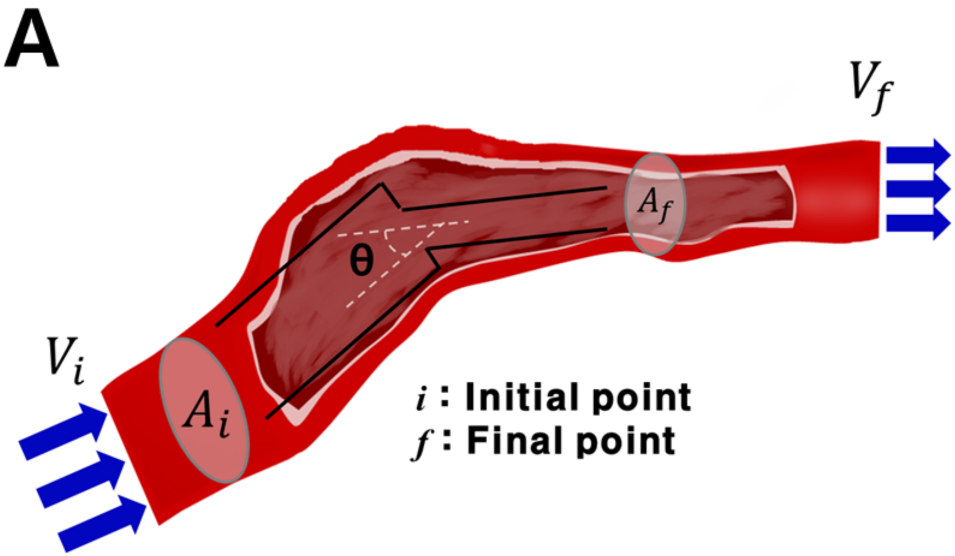
P_a = Aortic pressure

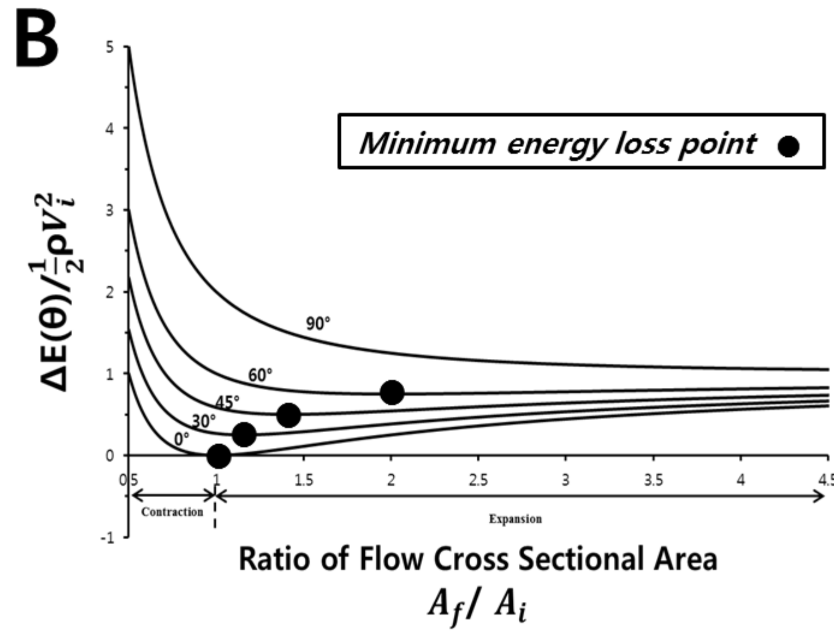
P_d = Distal coronary pressure

P_v = Coronary venous pressure

Geometric Factor.

The relationship between geometrical energy loss and cross-sectional area ratio.



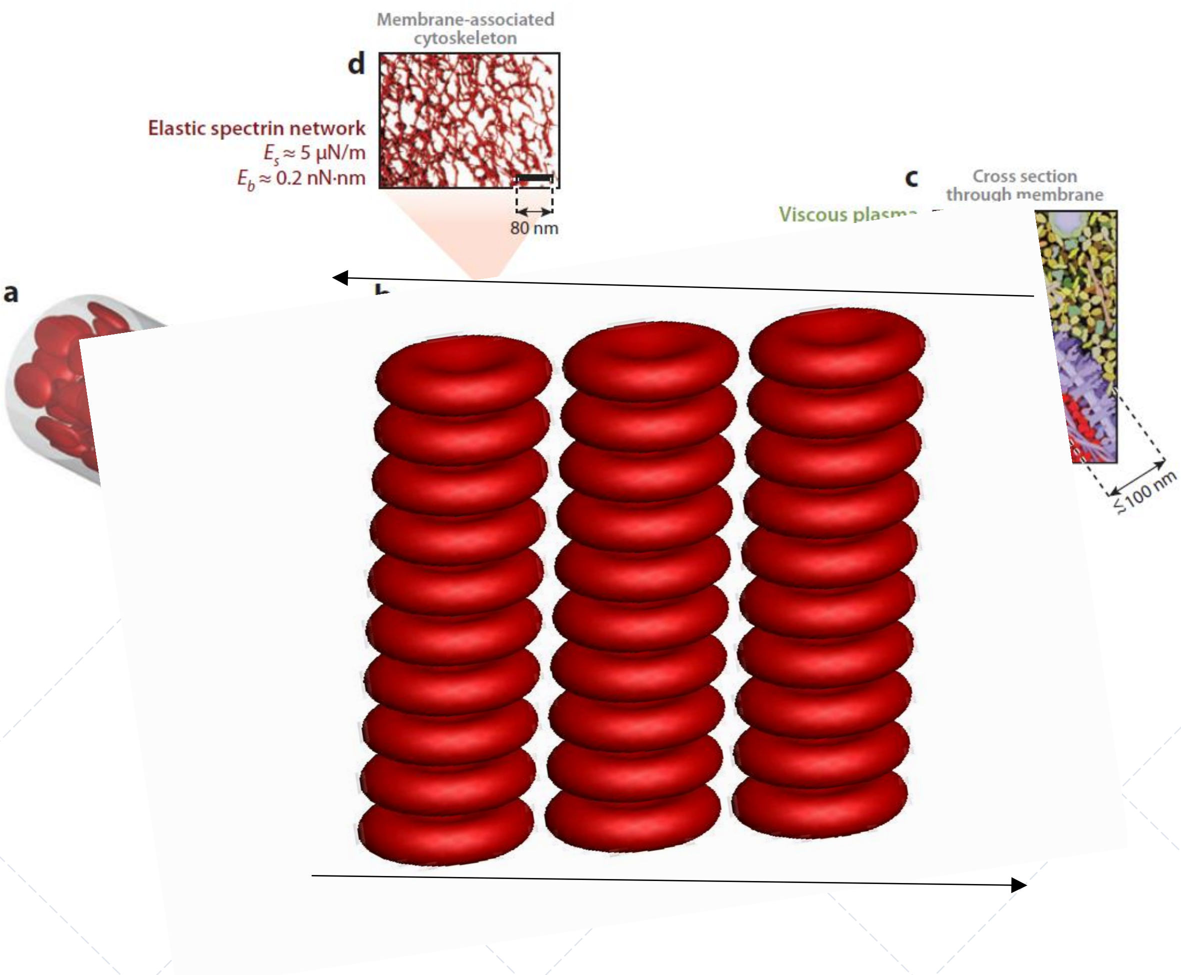


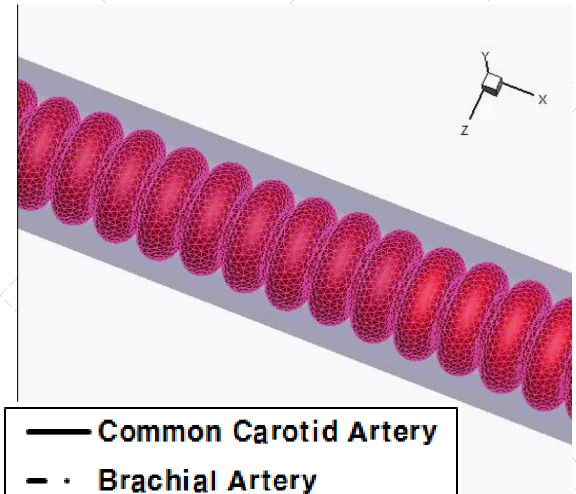
Schematic representation of a stream of fluid traversing a vessel from an initial position *i* to a final position *f*.

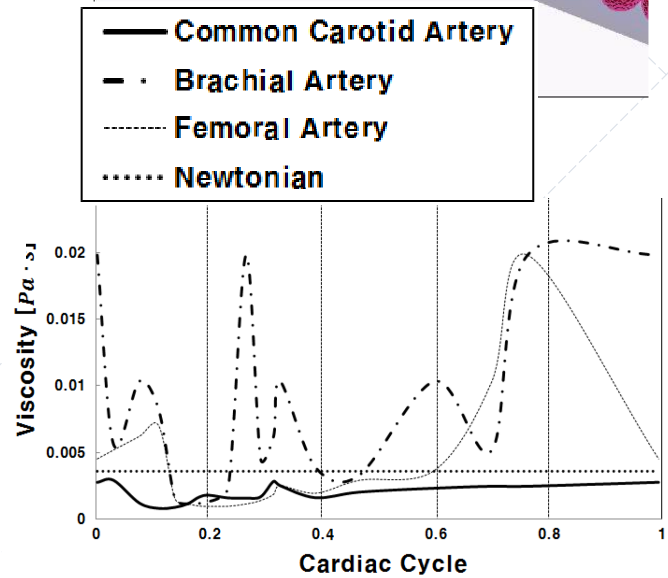
Each line represents the degree of change in flow angle. Each dot represents the point where the loss becomes minimum at the listed angles.

Viscosity Factor.

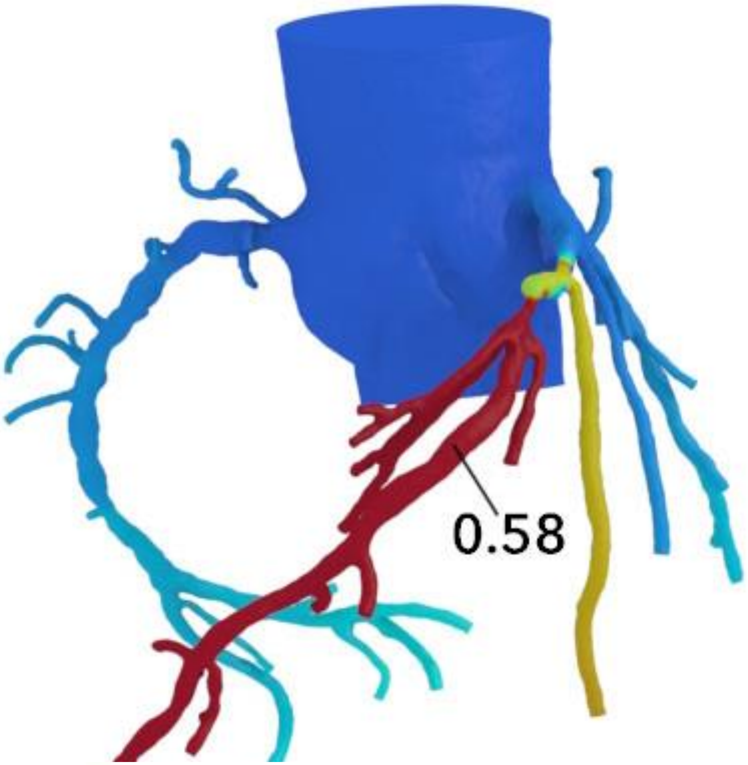
Blood viscosity : non-Newtonian fluid







Current Modeling Challenges



HeartFlow™

Accuracy of CT based FFR by the reference of wire based FFR

	$FFR_{CT} \leq 0.80$
Accuracy	80 (75–85)
Sensitivity	85 (74–91)
Specificity	79 (72–84)
PPV	63 (53–72)
NPV	92 (87–96)

Bjarne L.N. et al., 2014

Assumptions in CT FFR model.

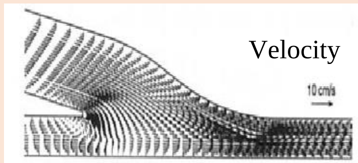
Assumption	Explanation	Real Situation
Steady flow	Blood flow is regarded to have constant flowrate, neglecting the heart functions	Pulsatile flow from the heart
Newtonian fluid	Assumes that the blood is similar to water which the viscosity of blood is constant	RBCs and other compounds in the blood causes the viscosity of blood to change
Resistance Boundary Condition	Assumes that the blood vessel is stiff without any elasticity.	Blood vessel is an elastic tube which causes the reflection of blood pressure wave.

These assumptions were made for the purpose of reducing calculation time. However, these assumptions cost the accuracy of CT FFR.

⇒ **With the advance of computational fluid dynamics, it is able to both increase accuracy and decrease its time.**

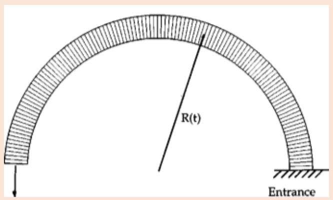
History of Hemodynamic Simulation.

1998



Blood flow model using CAD(computer-aided design)
M. Lei et al

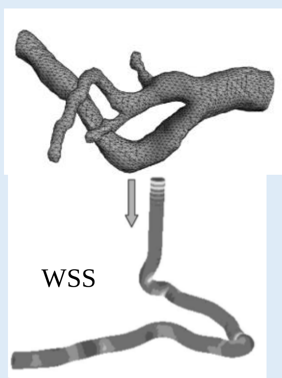
1997



Blood flow analysis in curved vessel
A. Santamairna et al

ideal geometry simulation

1999



Construction of vessel mesh by CT image
J. R. Cebral et al

real geometry simulation

2002

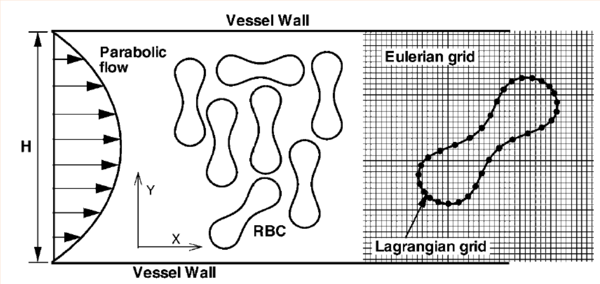
Coronary vessel analysis using realistic vessel image
B. Berthier et al

2004

Multiple branch model of coronary artery
E. Boutsianis et al

History of Hemodynamic Simulation.

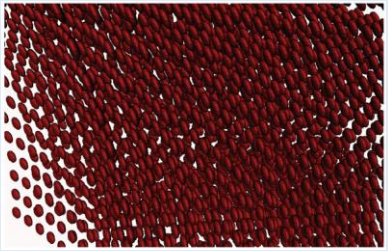
2007



Blood flow simulation with RBC
P. Bagchi et al

2D RBC

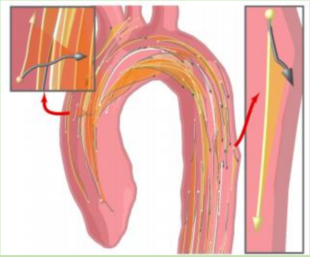
2010



Numerical Simulation of Blood Flow on 200,000 Cores
A. Rahimian et al

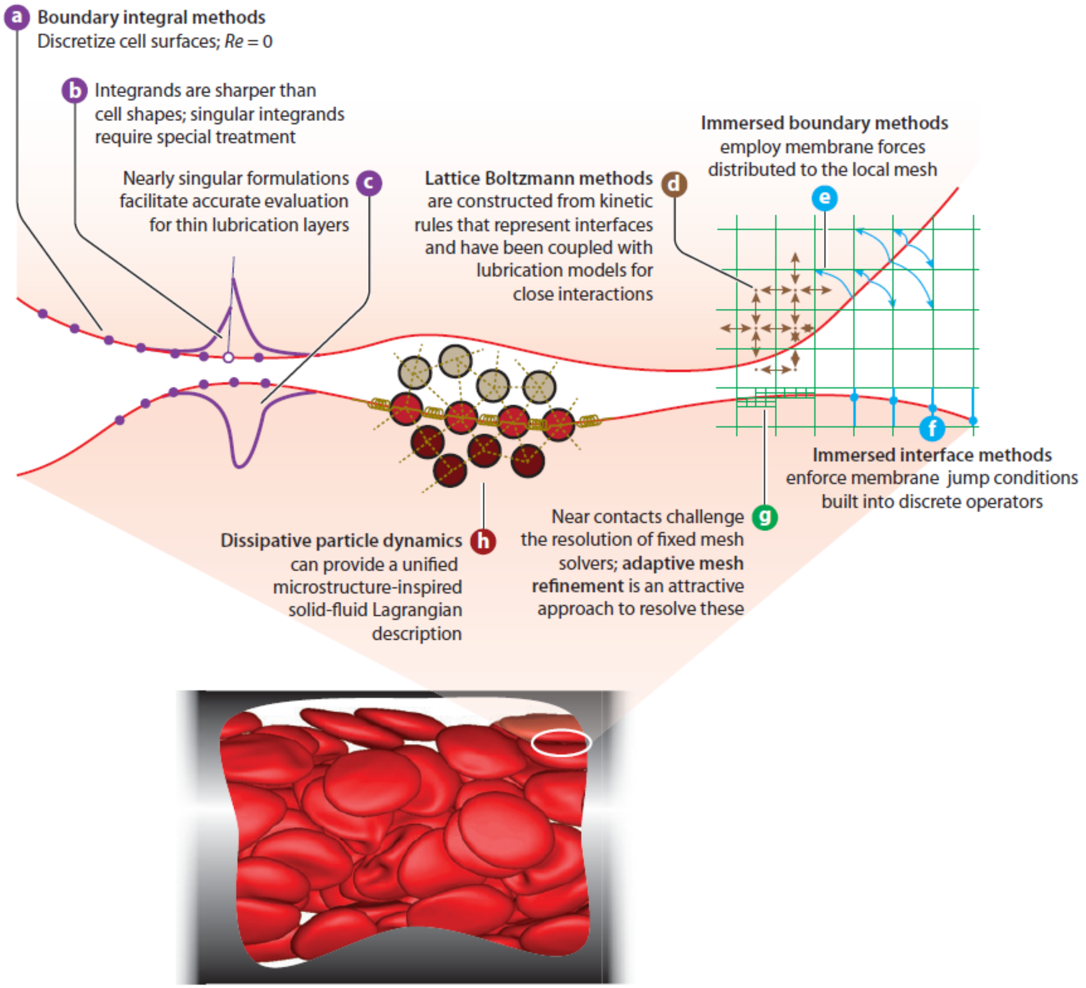
40,000 3D RBC

2014



MRI Flow Coupled to Physics-Based Fluid Simulation
N. De Hoon et al

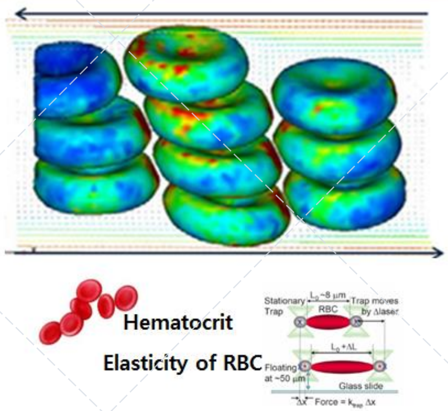
VEIREC Research Plans.



VEIREC Research Plans.

Scale bar

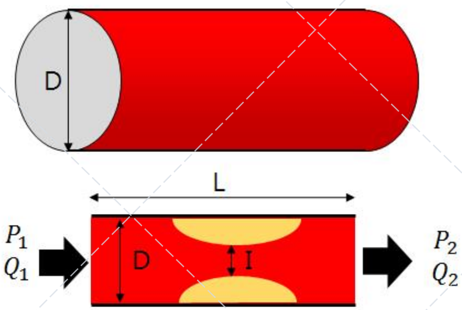
Micrometer	Centimeter	Meter



Computational viscometer

Development of viscometer by considering patient specific factors (age, sex, medical history, etc.).

- Cell to cell interaction
- Cell to fluid interaction
- Fluid to wall interaction

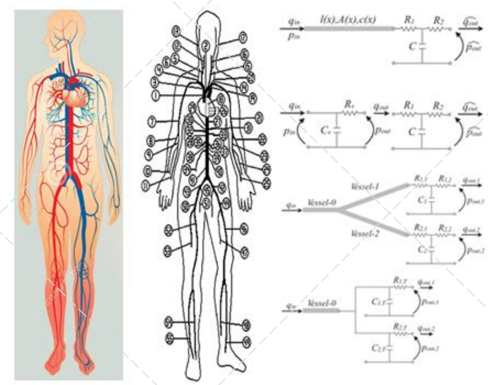


$$R = f(P_1, P_2, Q_1, Q_2)$$
$$I' = g(I, P_1, P_2, Q_1, Q_2)$$

Ideal vessel 3D modeling

Construction of variable chart required for 1D circulatory system modeling by 3D ideal vessel modeling.

- Reflection index calculation
- Stenosis effect calcluation
- Chartering of modeling data



1D modeling

Calculation of boundary conditions by using 1D circulatory system model from variable chart

- Entire circulatory system model
- Provides boundary condition for 3D stenosis vessel modeling

Objective : Development of patient specific viscometer & 3D ideal vessel modeling for simulation-based Cardiovascular disease diagnosis/treatment system.

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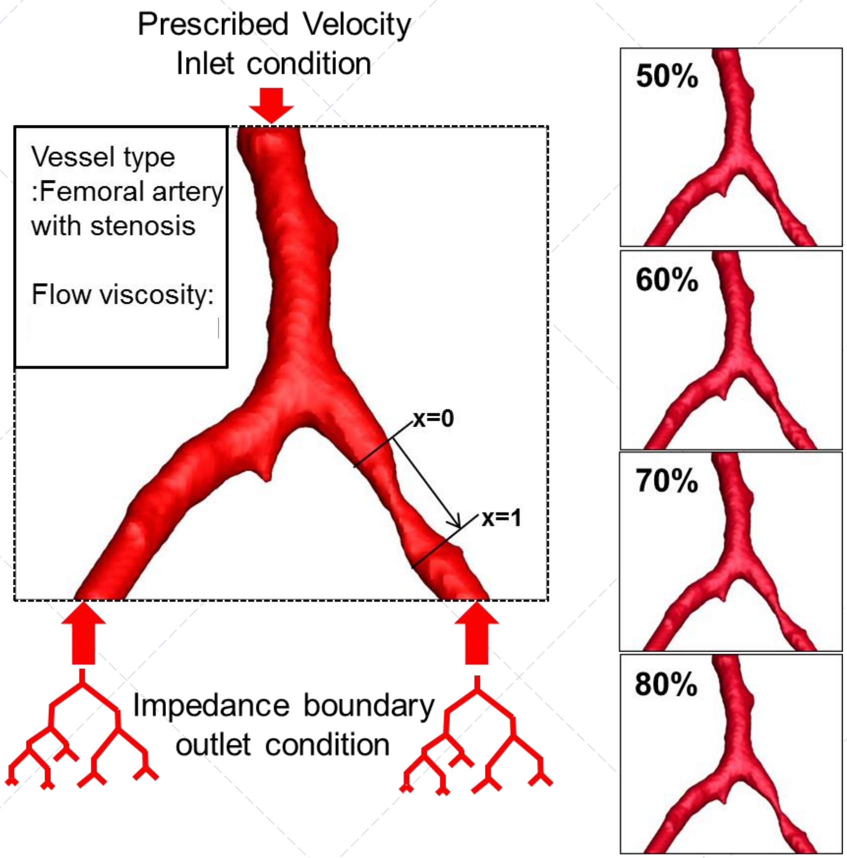
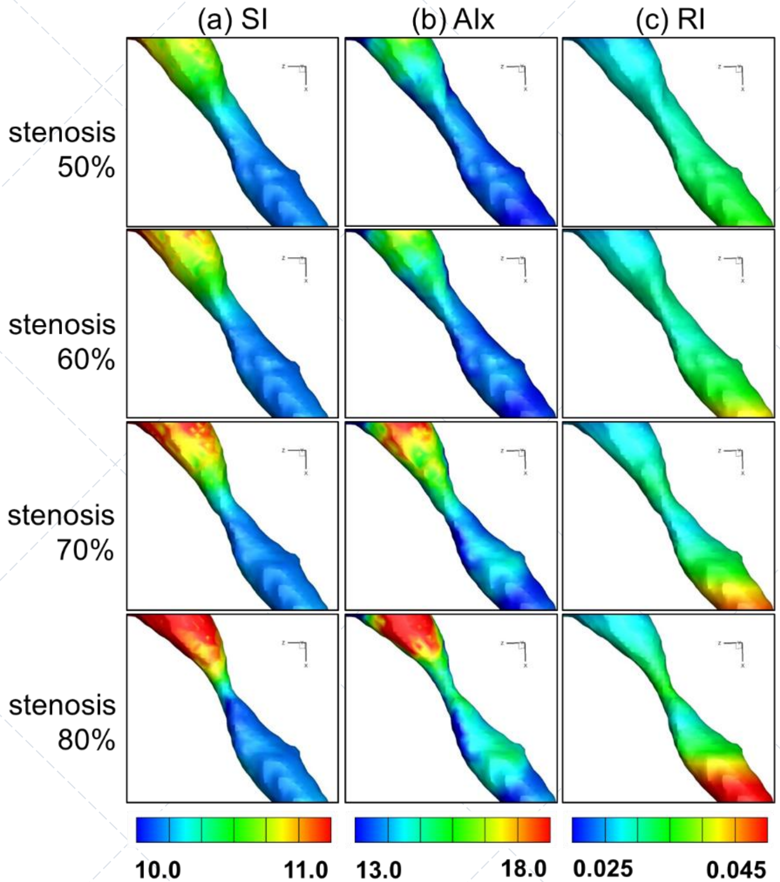


(a) (b)



VEIREC Research Plans

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E-MAIL
joonlee@yonsei.ac.kr