

Rheology in Congenital Heart Disease

**INJE University Medical College
Sanggye Paik Hospital, Cardiovascular Center**

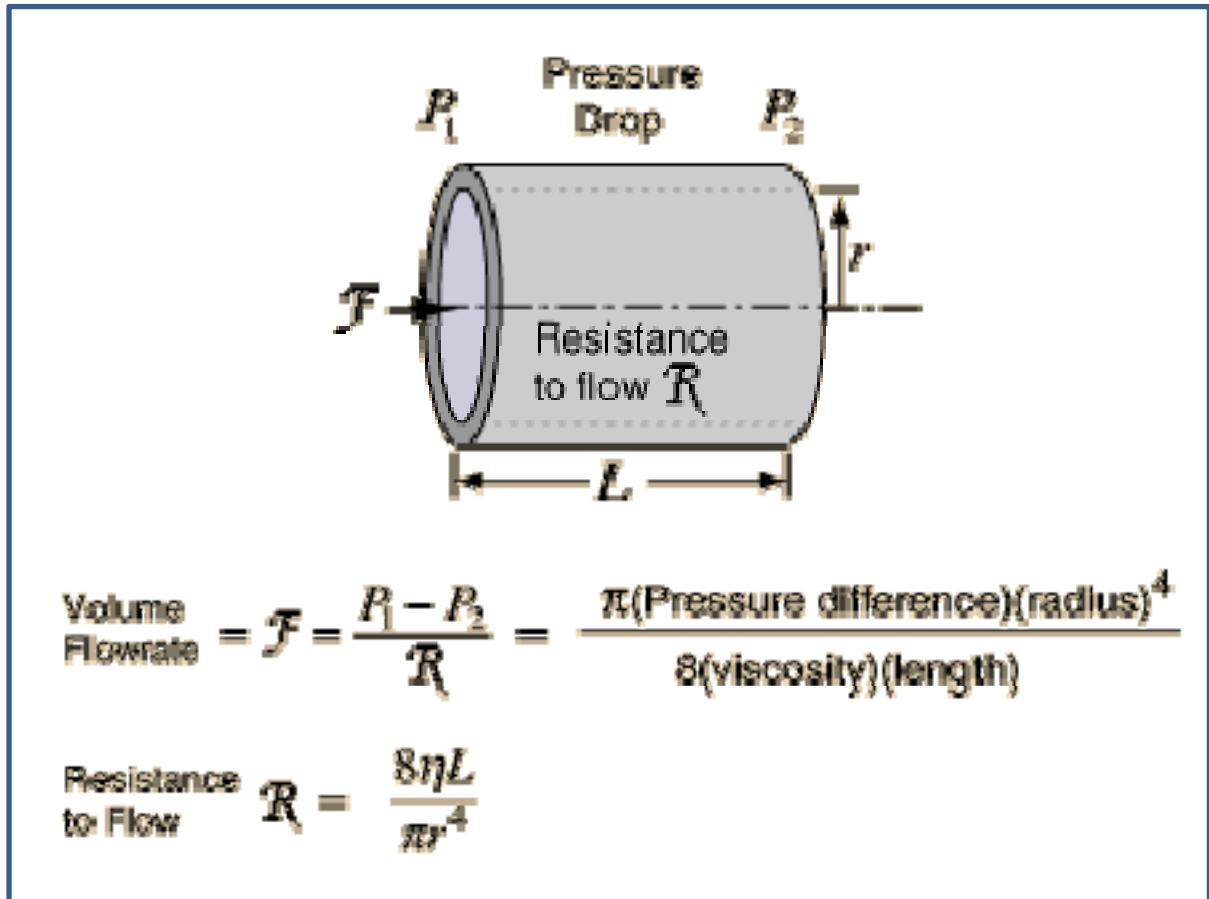
Byoung Kwon Lee MD, PhD

Basic concept in rheology

- Flow
 - Generated by pressure difference
- Basic Concept in Fluid Dynamics
 - Poiseuille's law
 - Shear stress
 - Shear rate

Relation; Pressure, Resistance, Flow

Poiseuille's Law

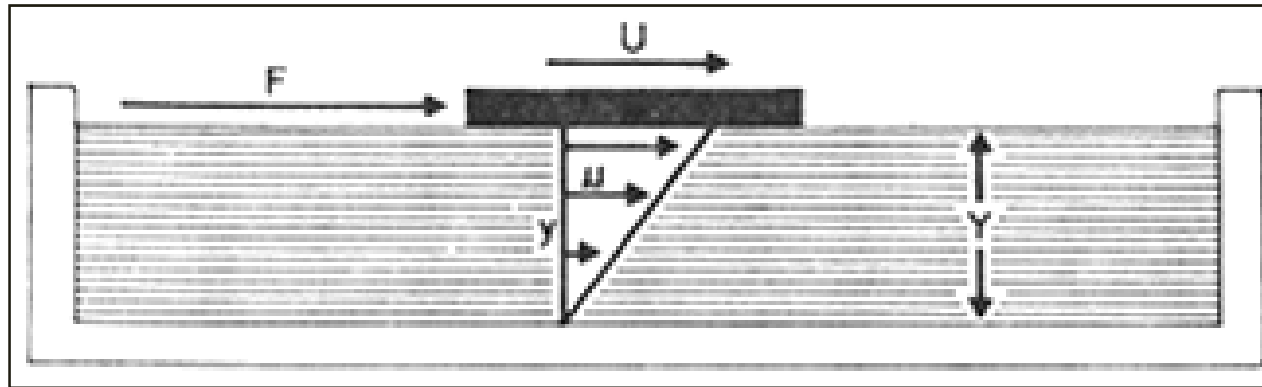


Geometric factors, and Viscosity

Shear Stress

Flow

(마찰저항력/혈관면적)



Shear stress = Viscosity x Shear rate

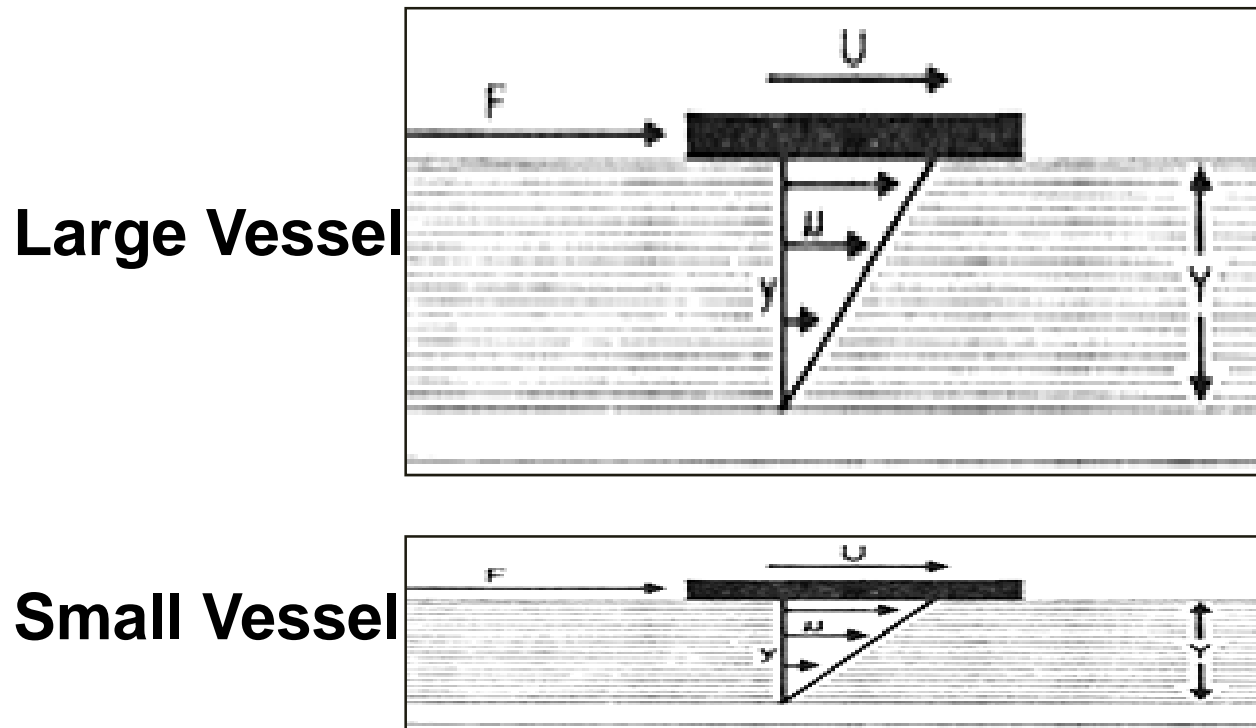
Shear stress (τ) = $\mu \cdot \dot{\gamma}$ (Viscosity x Shear rate)

$$= 4\eta Q / \pi r^3$$

(dyne/cm², Pascal, Poiseille)

Shear Rate

Flow

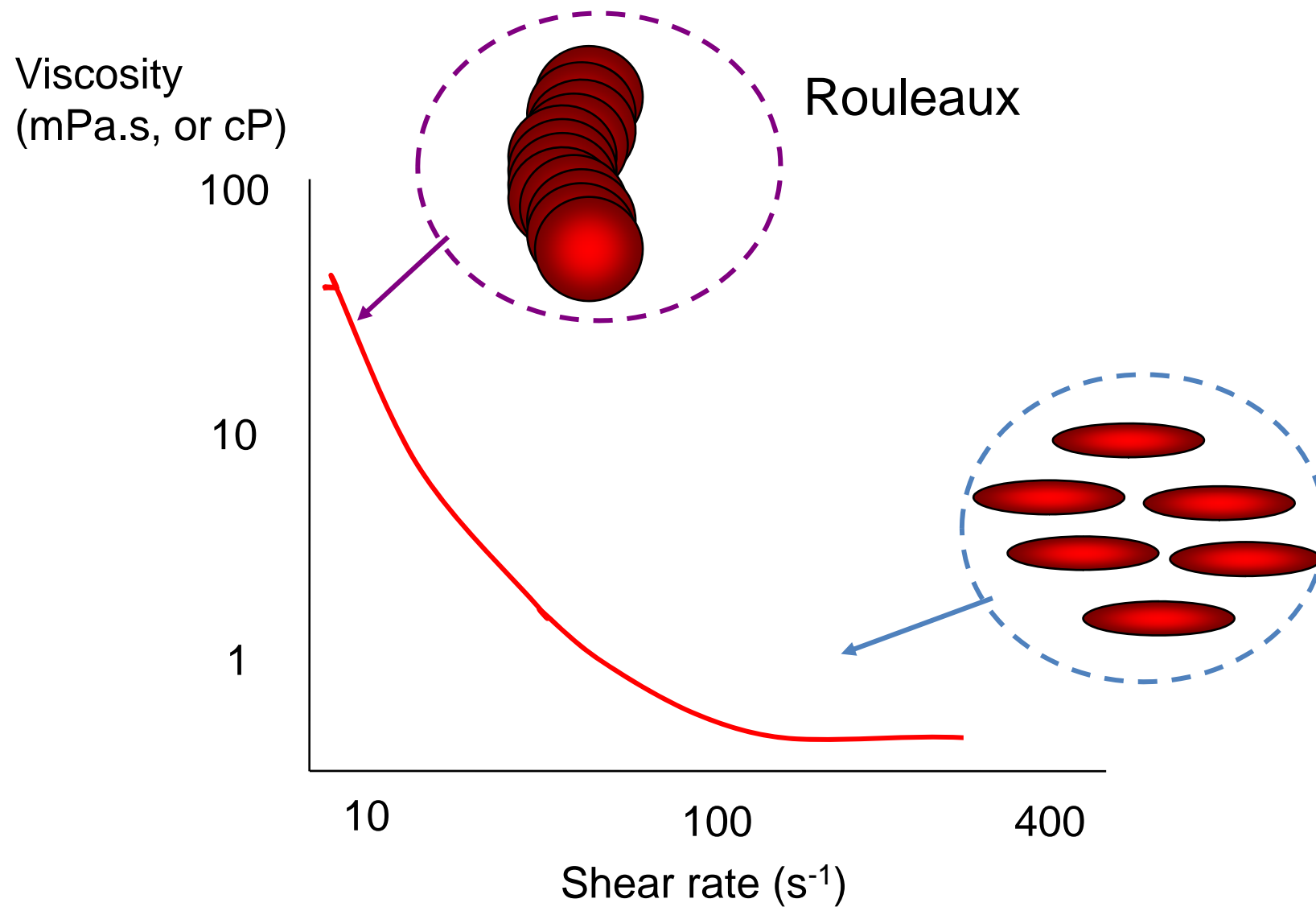


$$\begin{aligned} \text{Shear rate } (\dot{\gamma}) &= \text{velocity/distance} \\ &= dU/dy \text{ (sec}^{-1}\text{)} \end{aligned}$$

Basic hemorheologic parameters

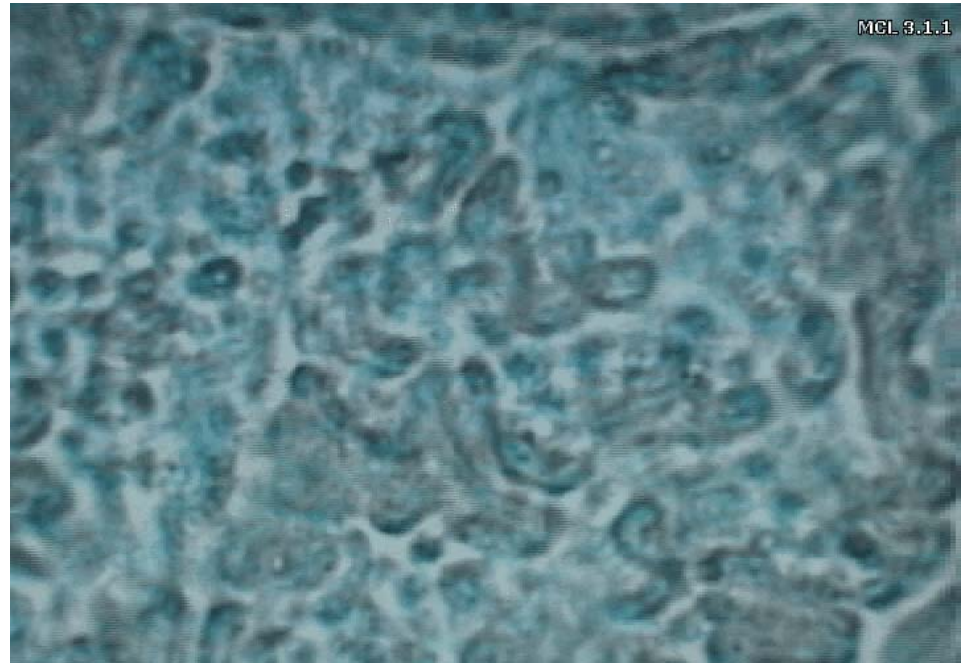
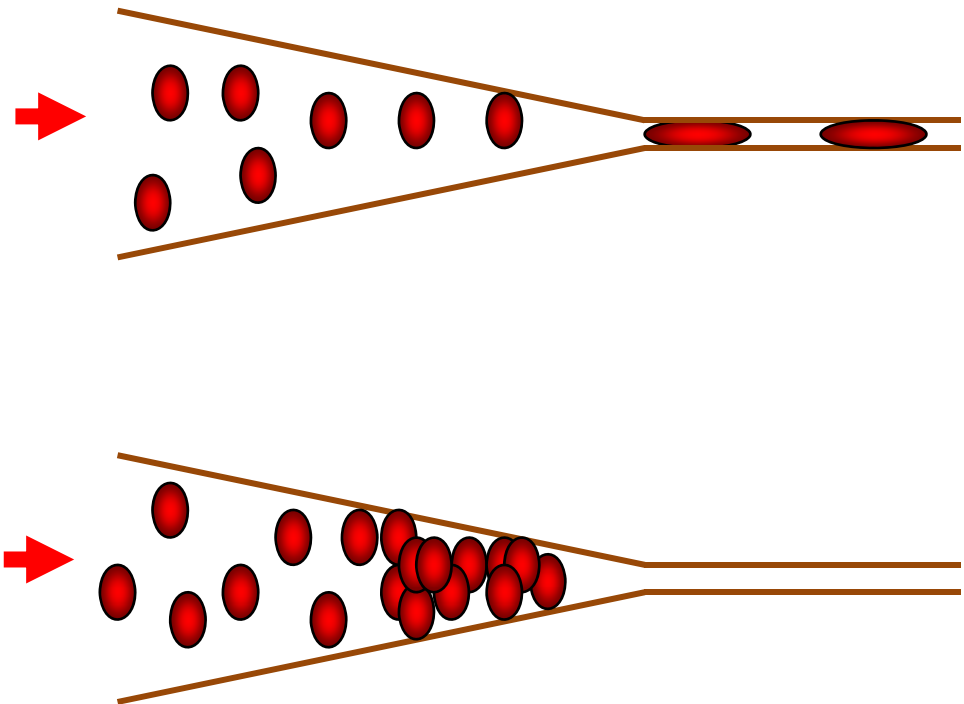
- **Blood as a Non-newtonian Fluid**
- **Viscosity**
- **RBC deformability**
- **RBC aggregability**

Viscosity correlates RBC aggregation



Decreased deformability

: microcirculation problems



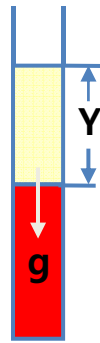
RBC aggregation



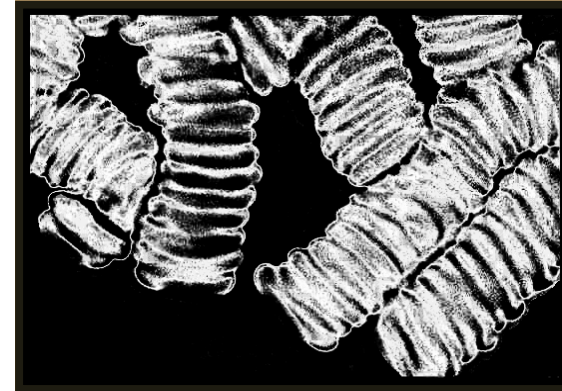
RBC aggregation

ESR (Erythrocyte Sedimentation Rate)

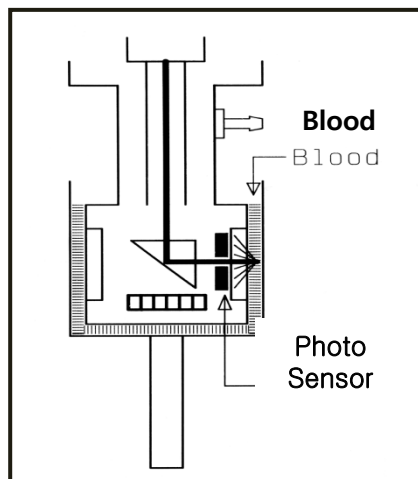
- Standard method –
Westergren technique



Microscopic Image Analysis

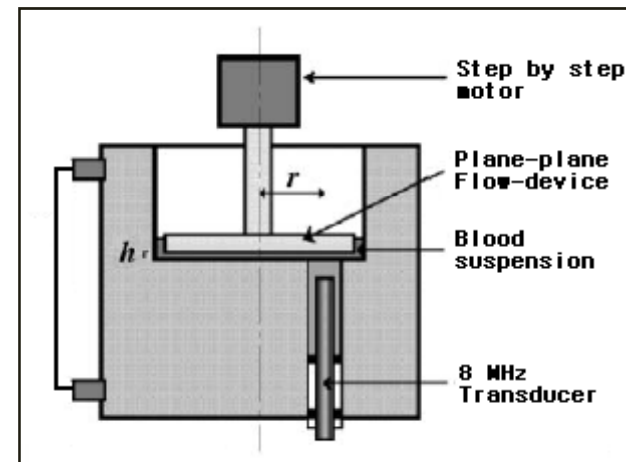


Light Transmission or Backscattering



Myrenne
aggregometer
or
LORCA
or
Rheoscan

Ultrasonic scattering



Available machine in Korea

- www.fras4korea.com
- Rheoscan



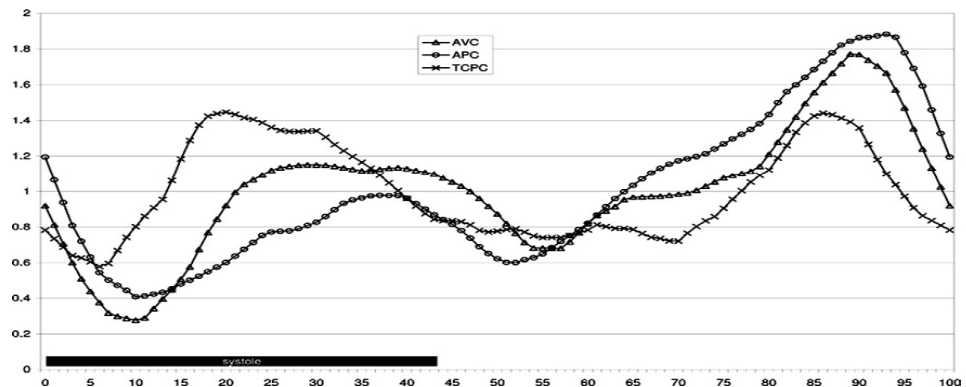
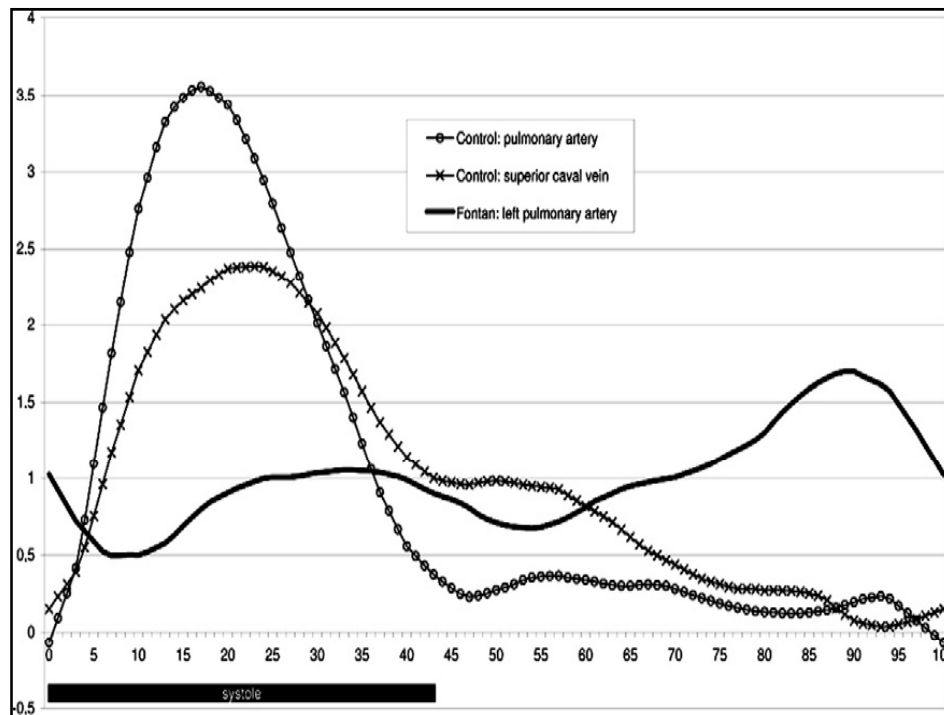
Fluid dynamics in Fontan circulation

- **Single ventricle physiology**

- 1. Separation the systemic and pulmonary venous return
 2. Establishment of the pathway of a passive, direct, and unobstructed connection between the systemic venous return and the pulmonary artery

Pulmonary Blood Flow Patterns in Patients With Fontan Circulation

- 17 patients vs. 21 healthy controls
- Phase-velocity cine MRI.
- Slight late diastolic flow acceleration.



Collision of Caval Flow

- **Cause early failure of the Fontan circulation?**

Murakami H et al. J Thorac Cardiovasc Surg 2006;132:1235

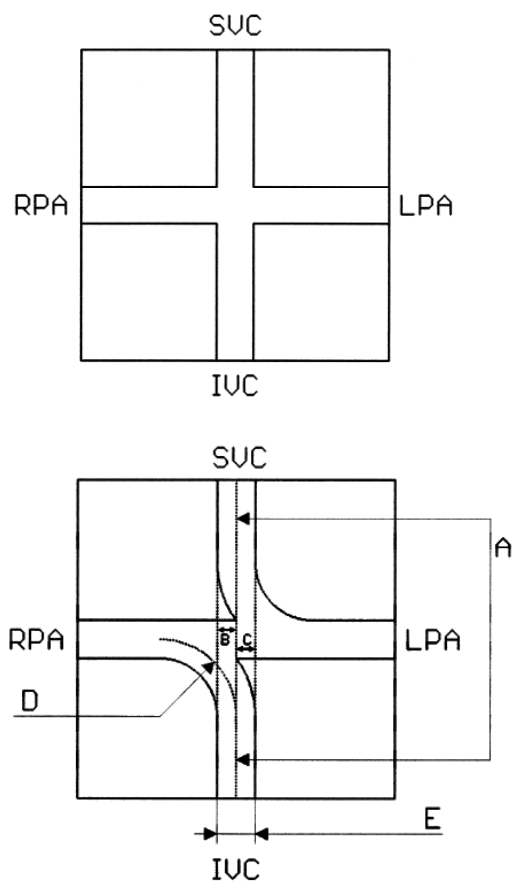
- **Collision, or Reduced Driving Force?**

- ❖ **Major Driving Force of pulmonary circulation.**

1. Heart Pump; RA, RV suction and forward power
2. Negative Pressure by Inspiration
3. Valve
4. Calf Muscle Power
5. Posture; Hydrostatic Energy

Addition of small curvature reduces Power loss across TCPC

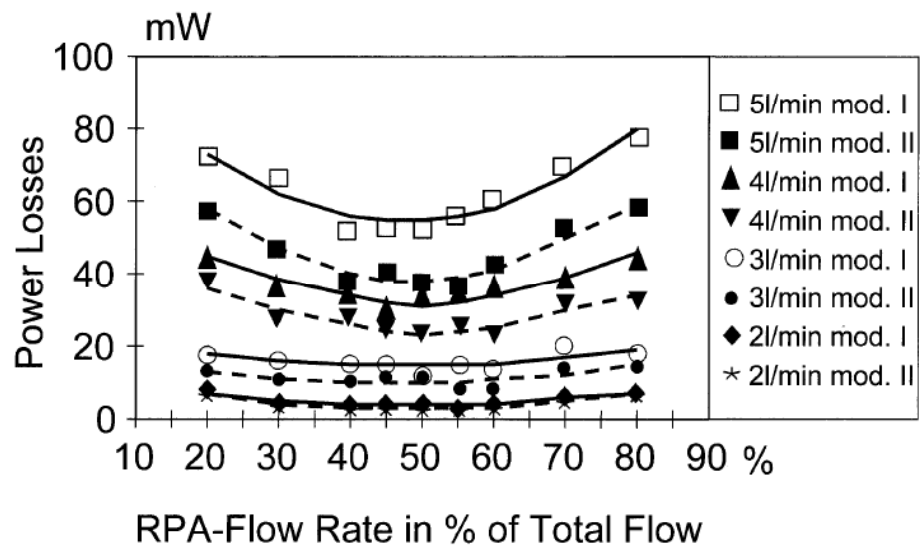
- In vitro study with 2 model
- Crosslike / curved



$$p_{kin} = 1/2 \rho v^2$$

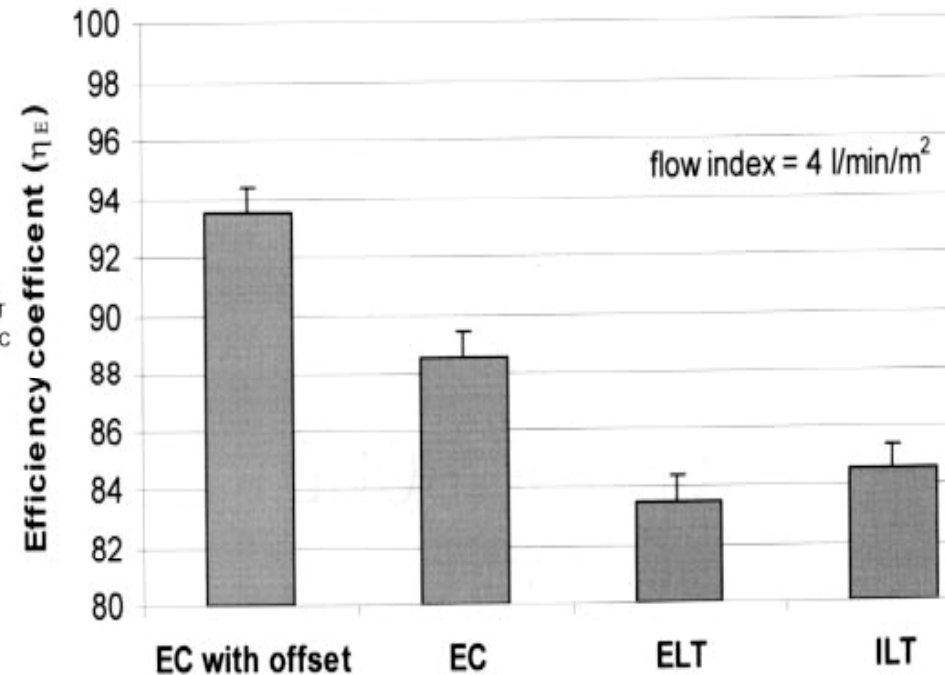
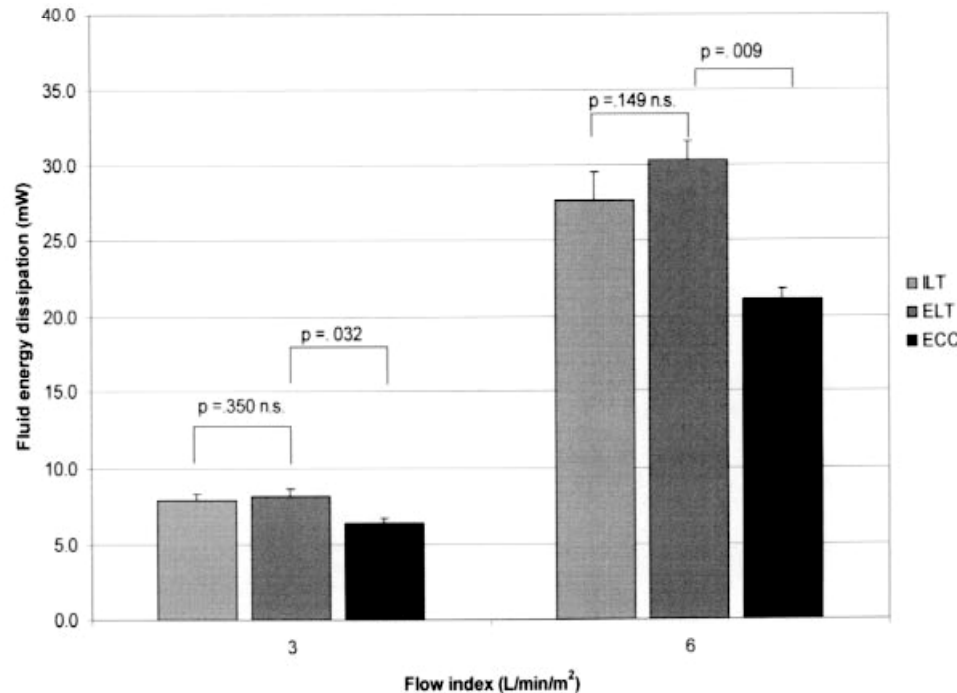
$$P_{loss,kin} = 1/2 \rho Q^3/A^2$$

$$P_{loss,static} = (Q_{IVC} \cdot P_{IVC} + Q_{SVC} \cdot P_{SVC}) - (Q_{RPA} \cdot P_{RPA} + Q_{LPA} \cdot P_{LPA}).$$

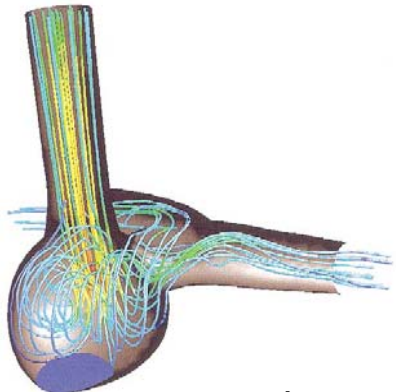


Fluid power loss & Efficacy coefficient according as TCPC type

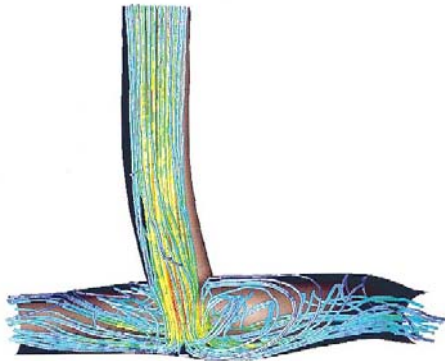
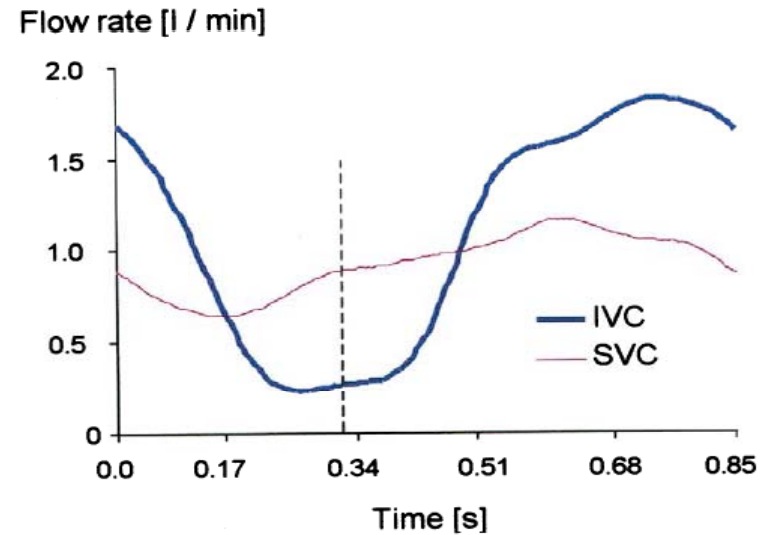
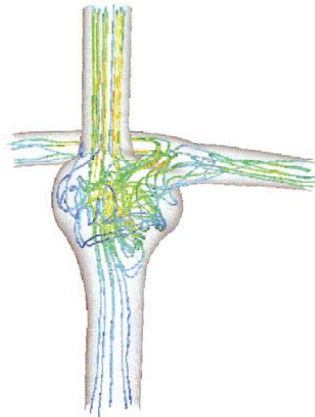
- Animal study(sheep)



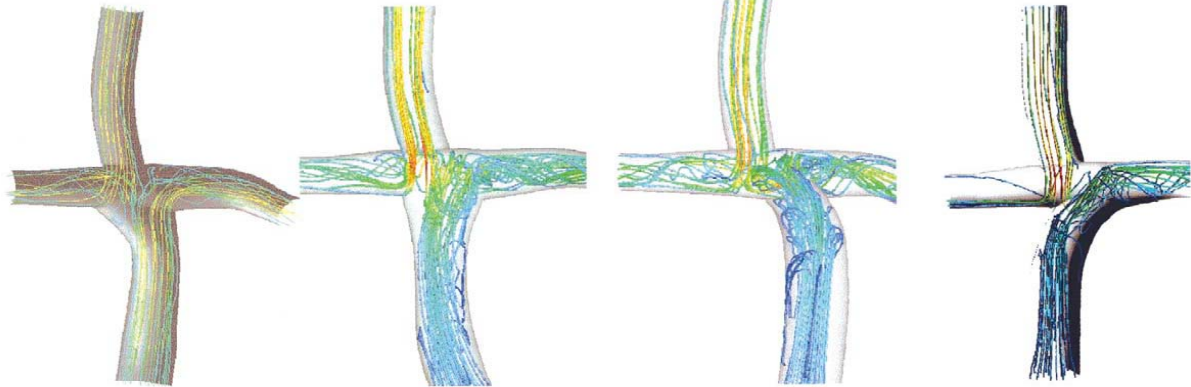
Computational Fluid Dynamics



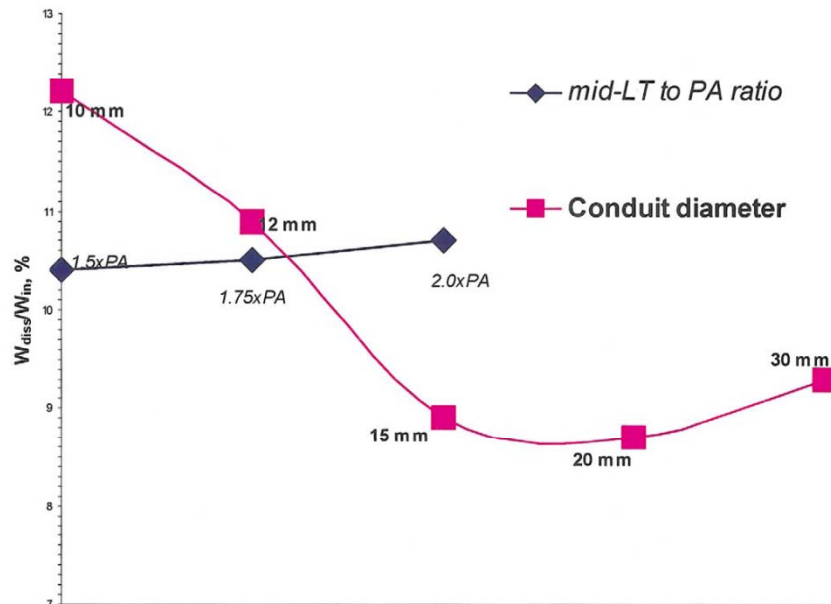
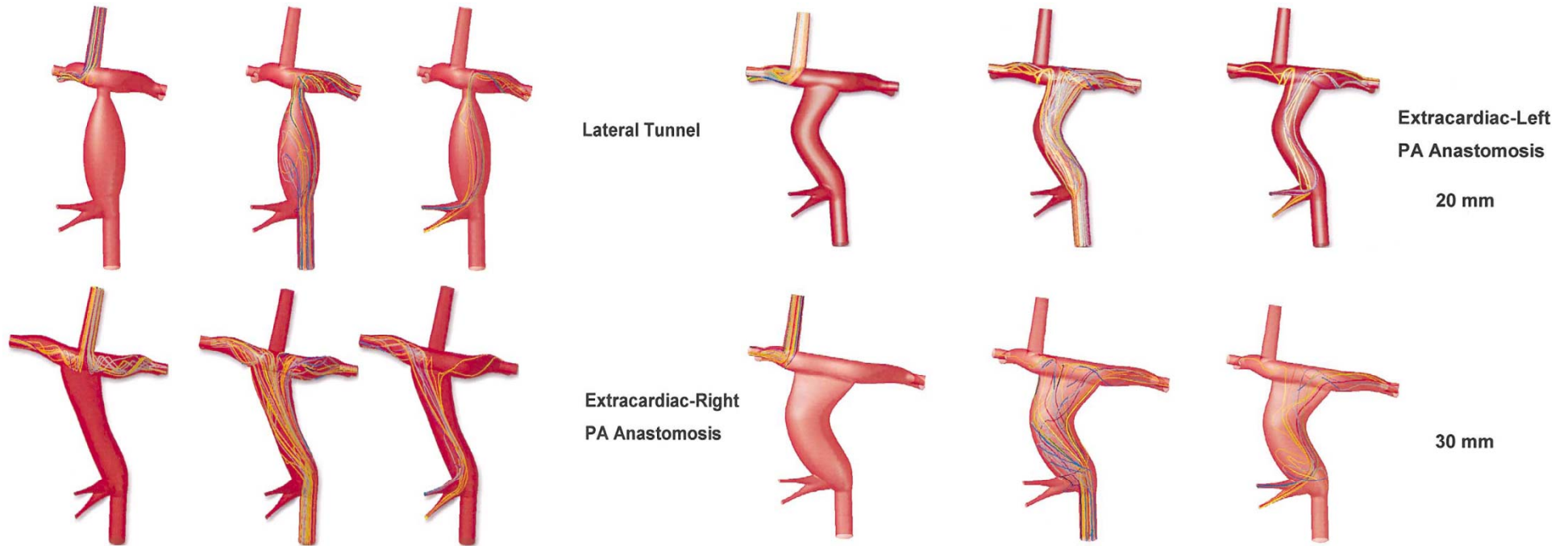
Hemi-Fontan Procedure



Bi-directional Glenn Procedure



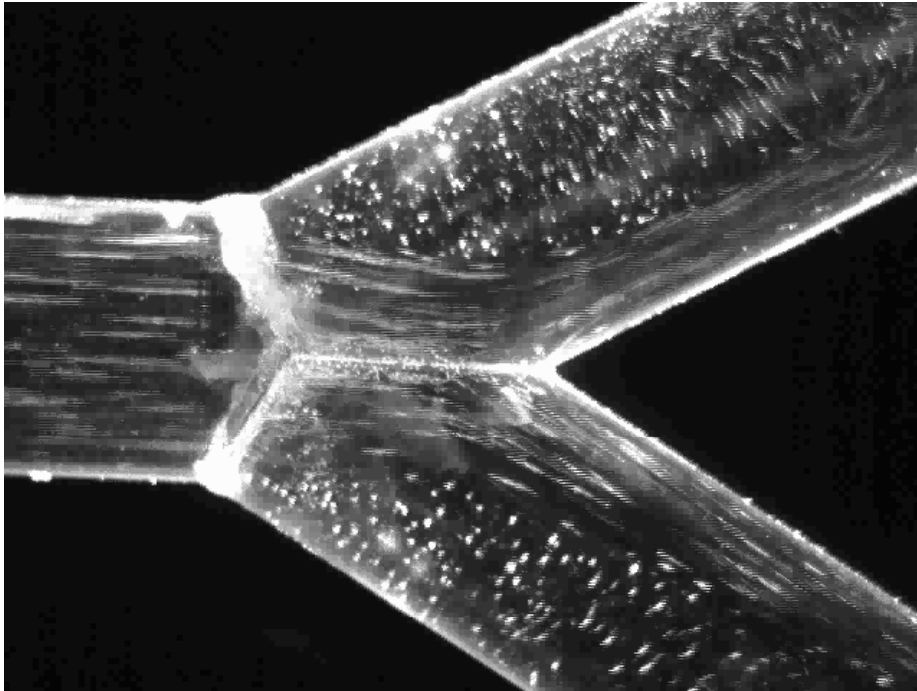
CFD in various type of TCPC



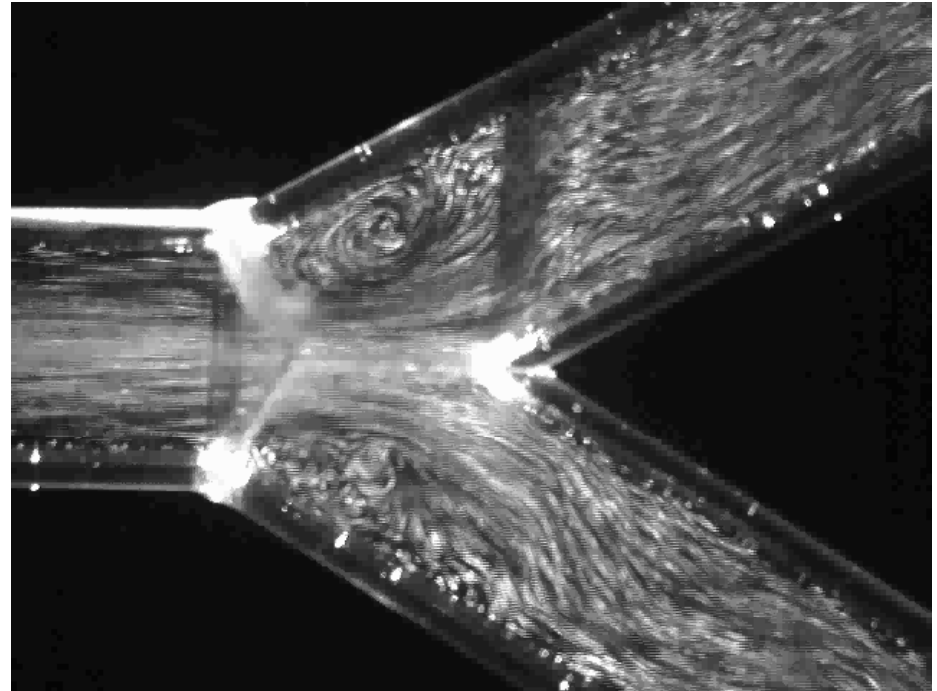
- Extracardiac conduit with left PA anastomosis having the lowest energy loss.
- Varying the extracardiac conduit from 10 to 30 mm resulted in the least energy dissipation at 20 mm.
- Serial dilation of the lateral tunnel pathway showed a small incremental worsening of energy loss.

Steady vs. Pulsatile flow

PIV experiment

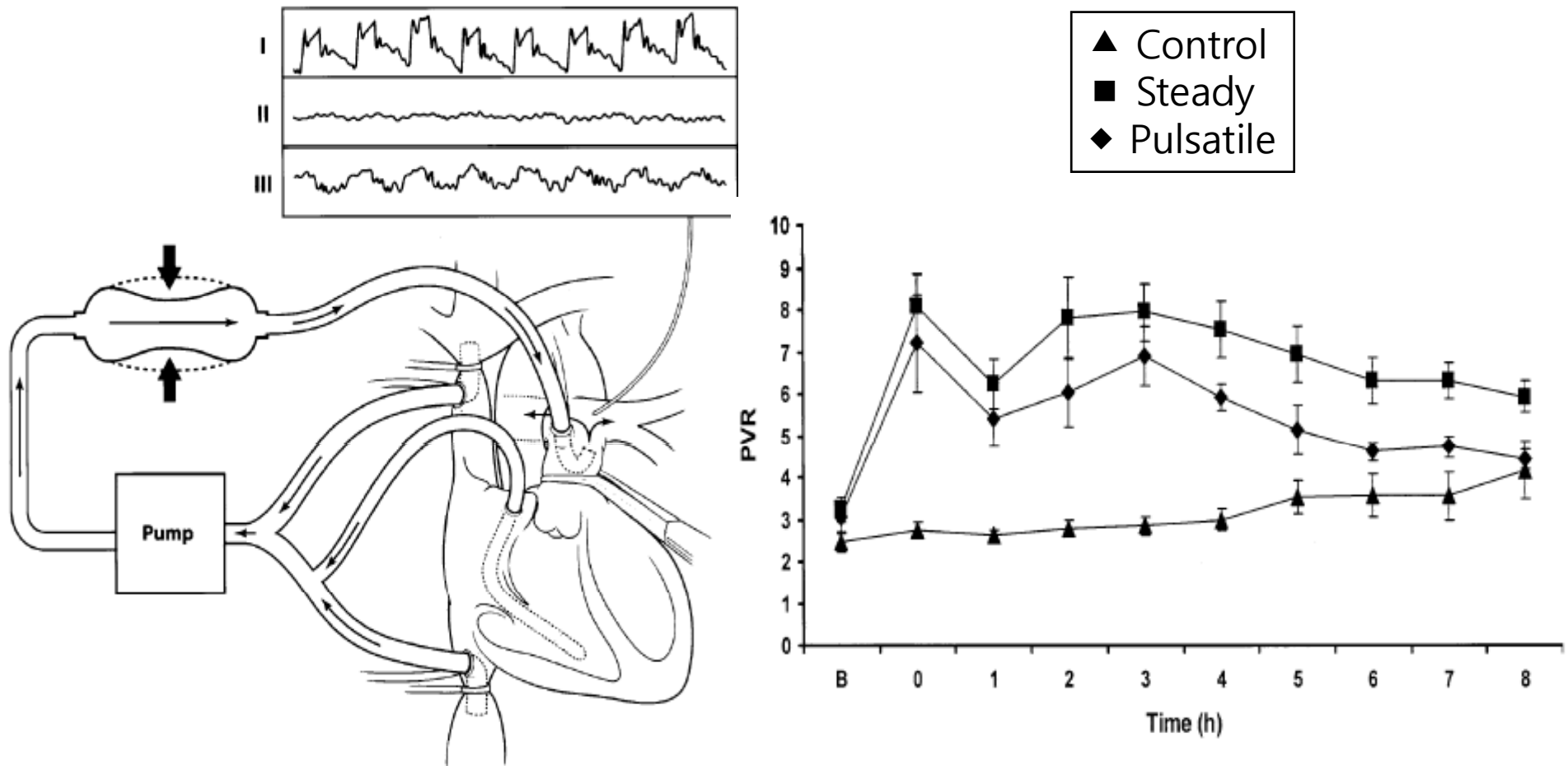


Steady flow



Pulsatile flow

Steady vs. Pulsatile flow

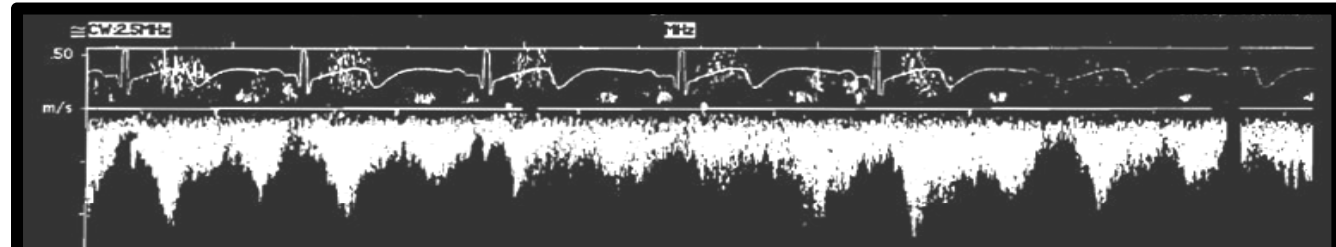


Positional change

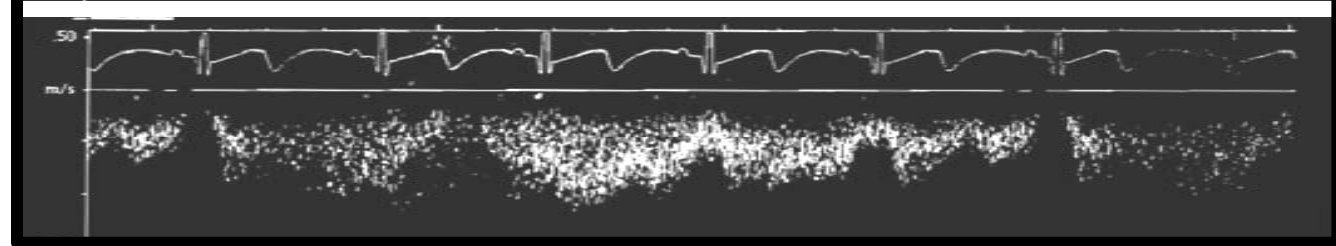
Influence of Hydrostatic Energy

Supine

SVC

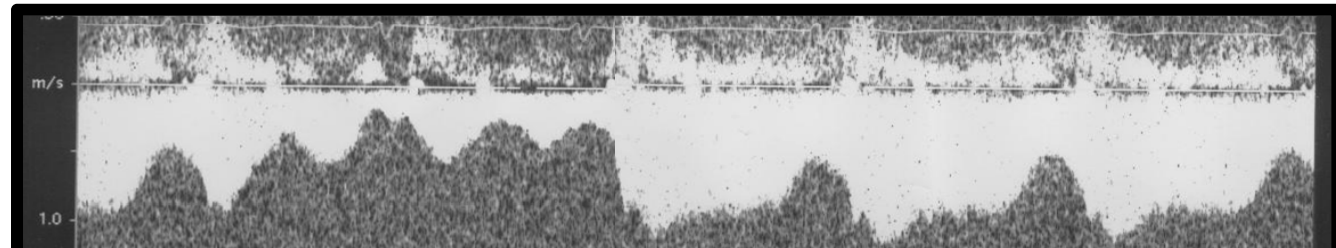


IVC

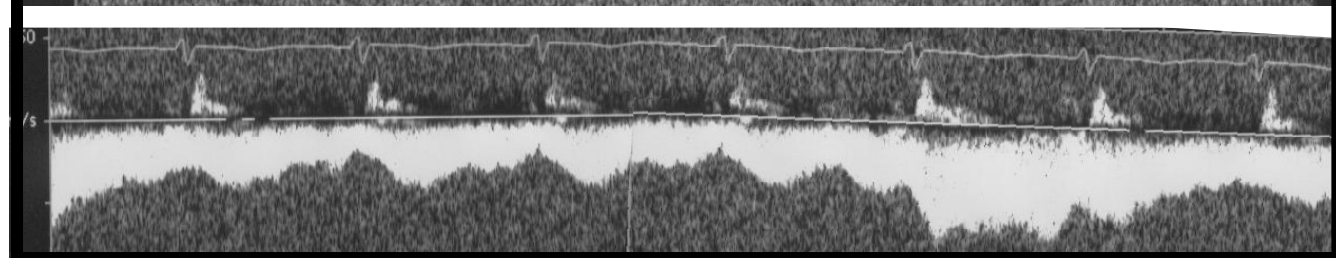


Upright

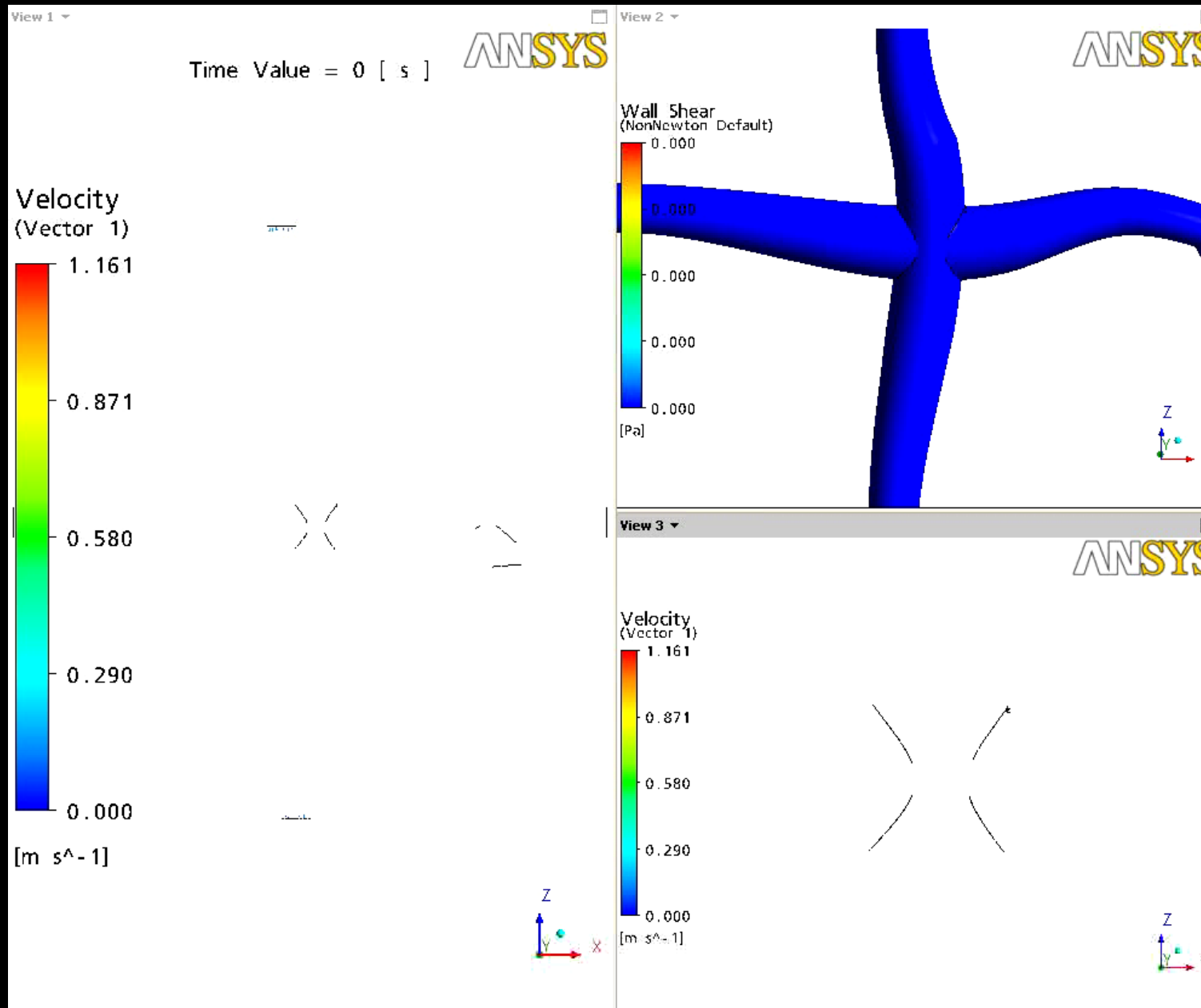
SVC



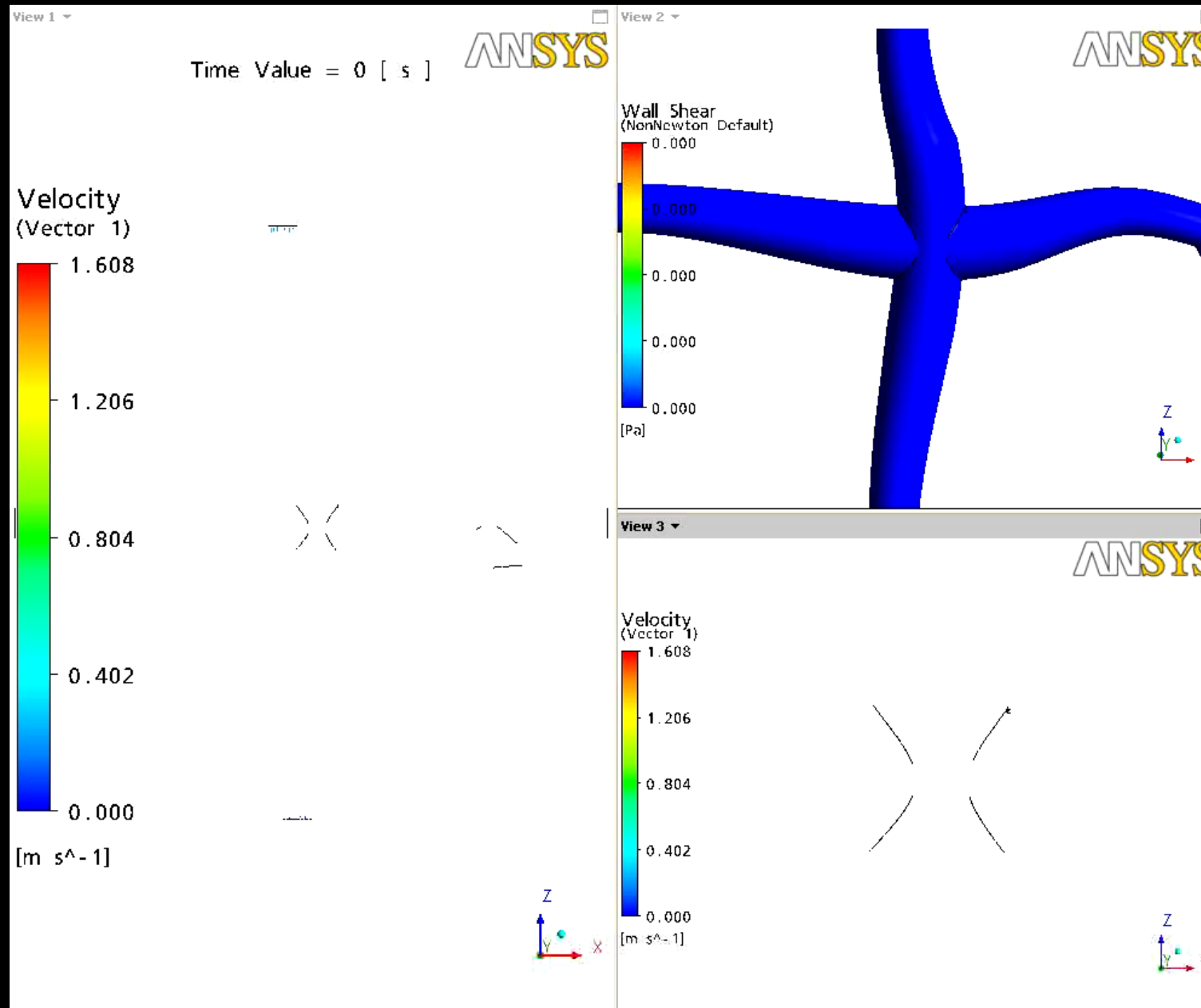
IVC



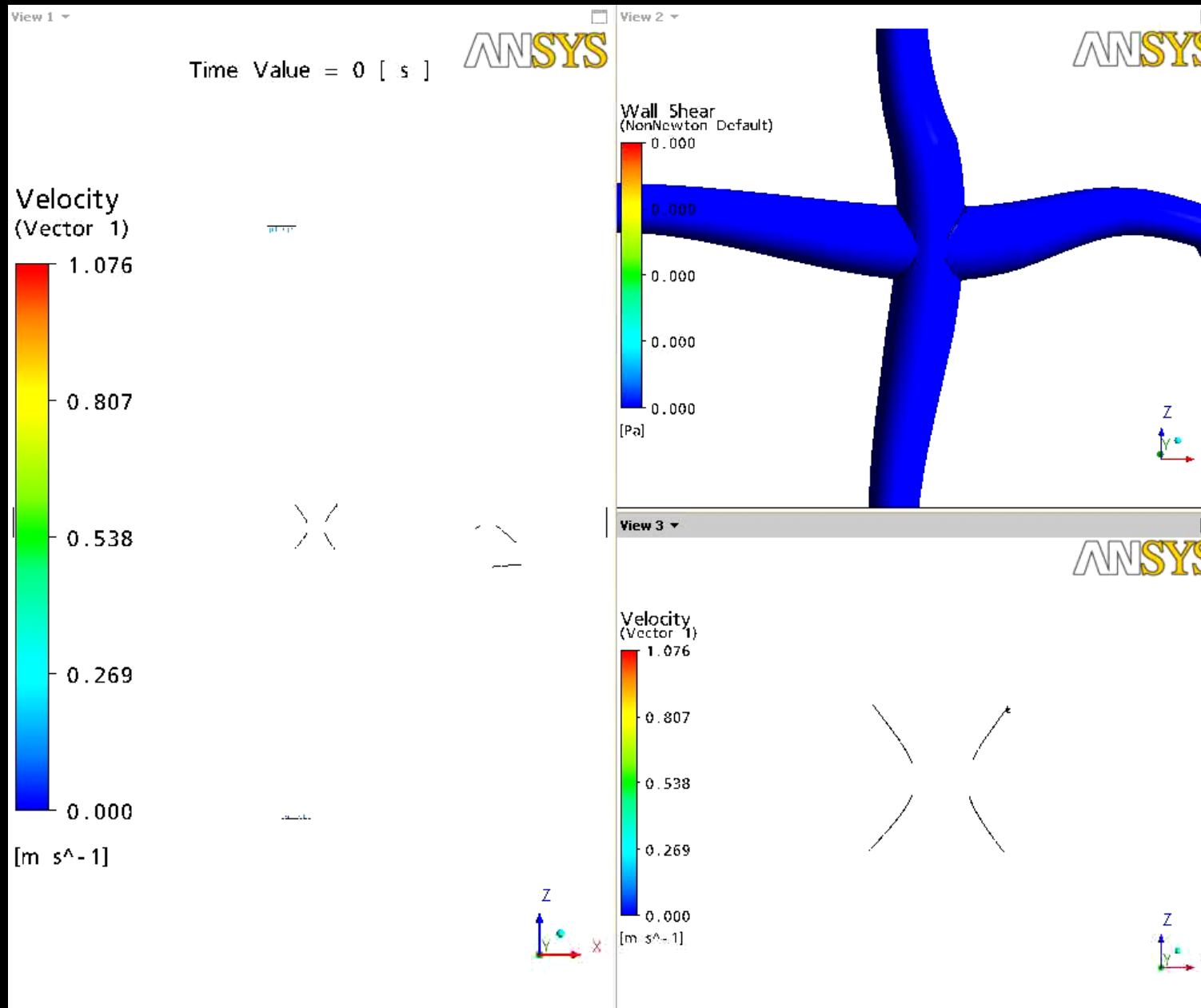
Supine - Expiration



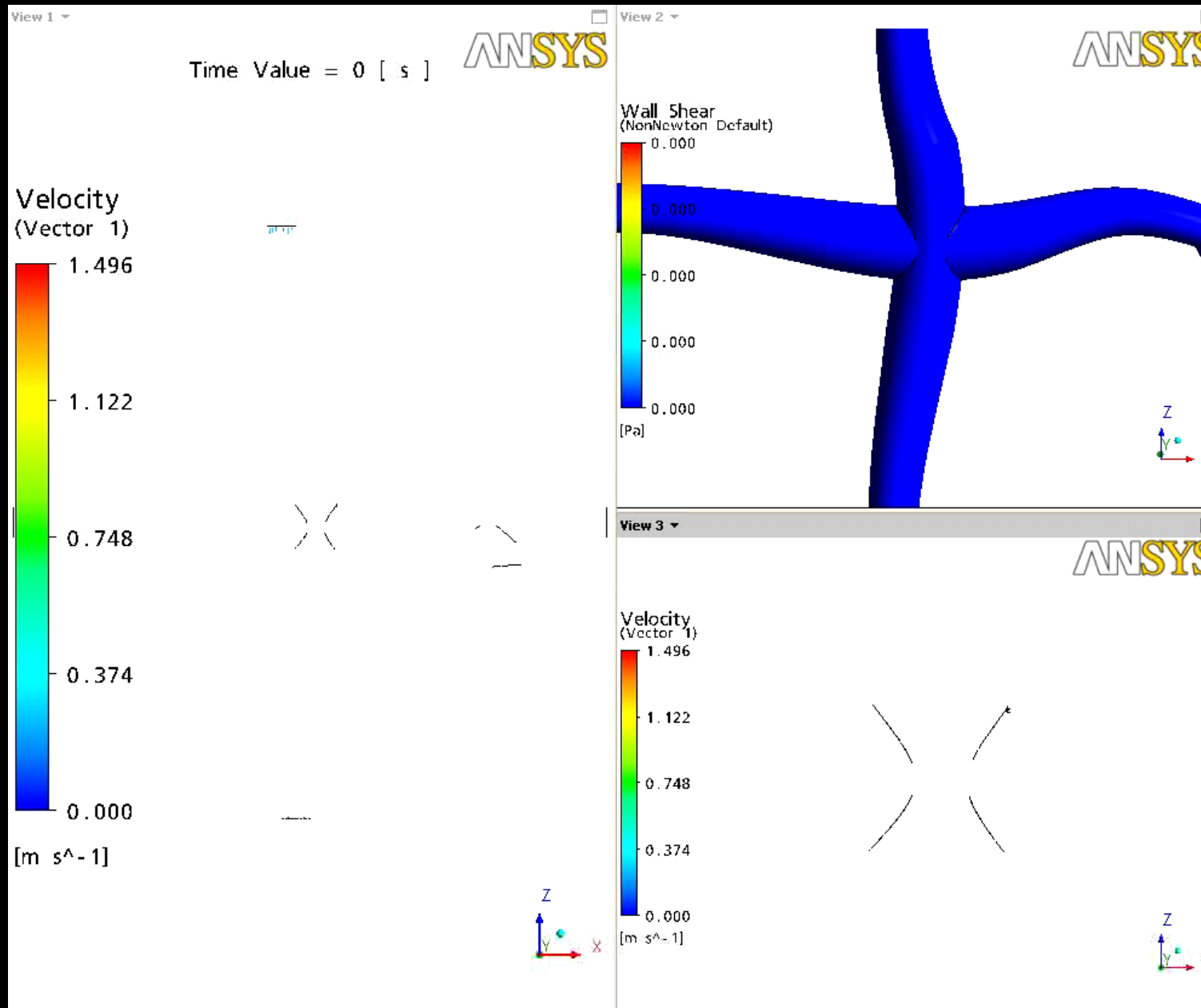
Supine - Inspiration



Upright - Expiration



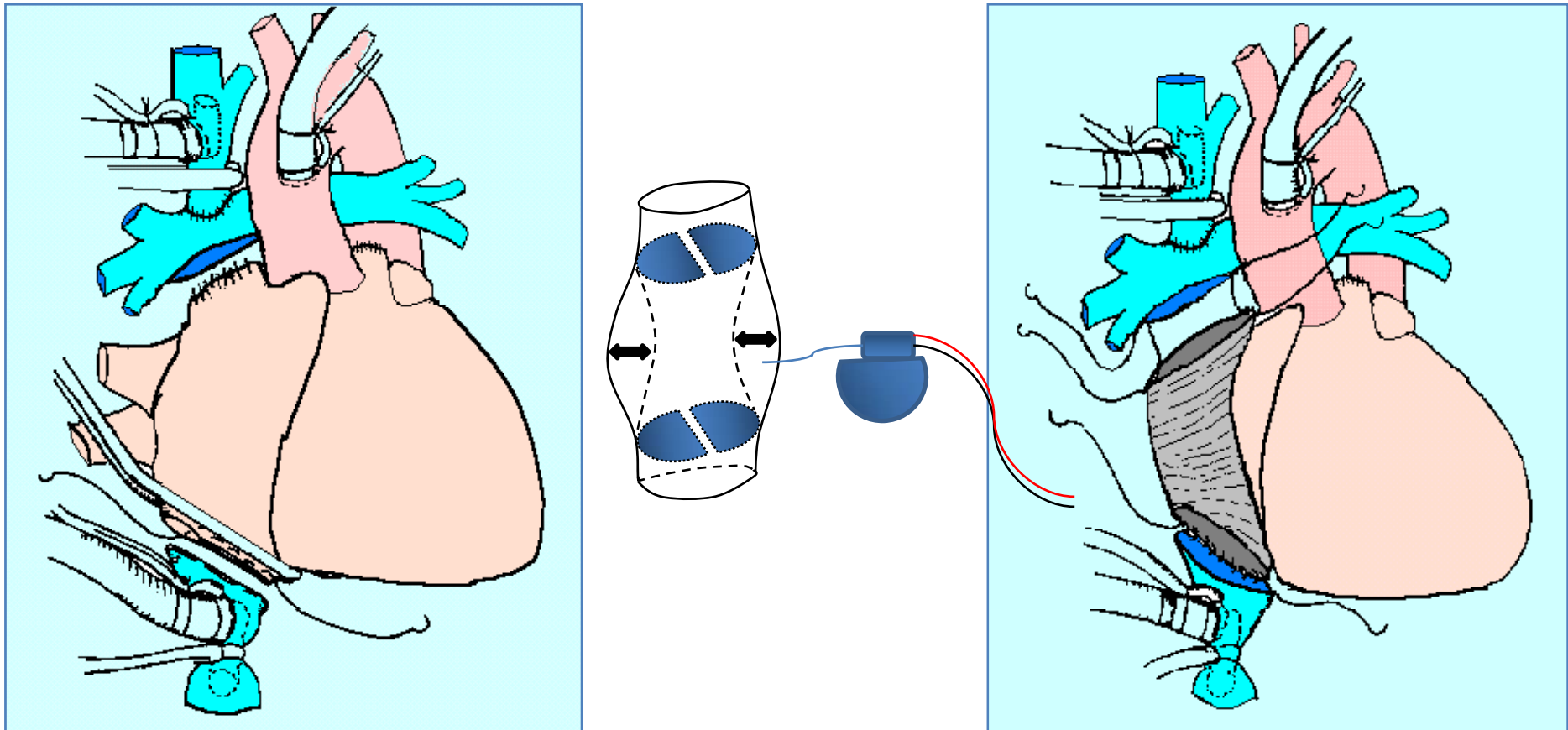
Upright - Inspiration



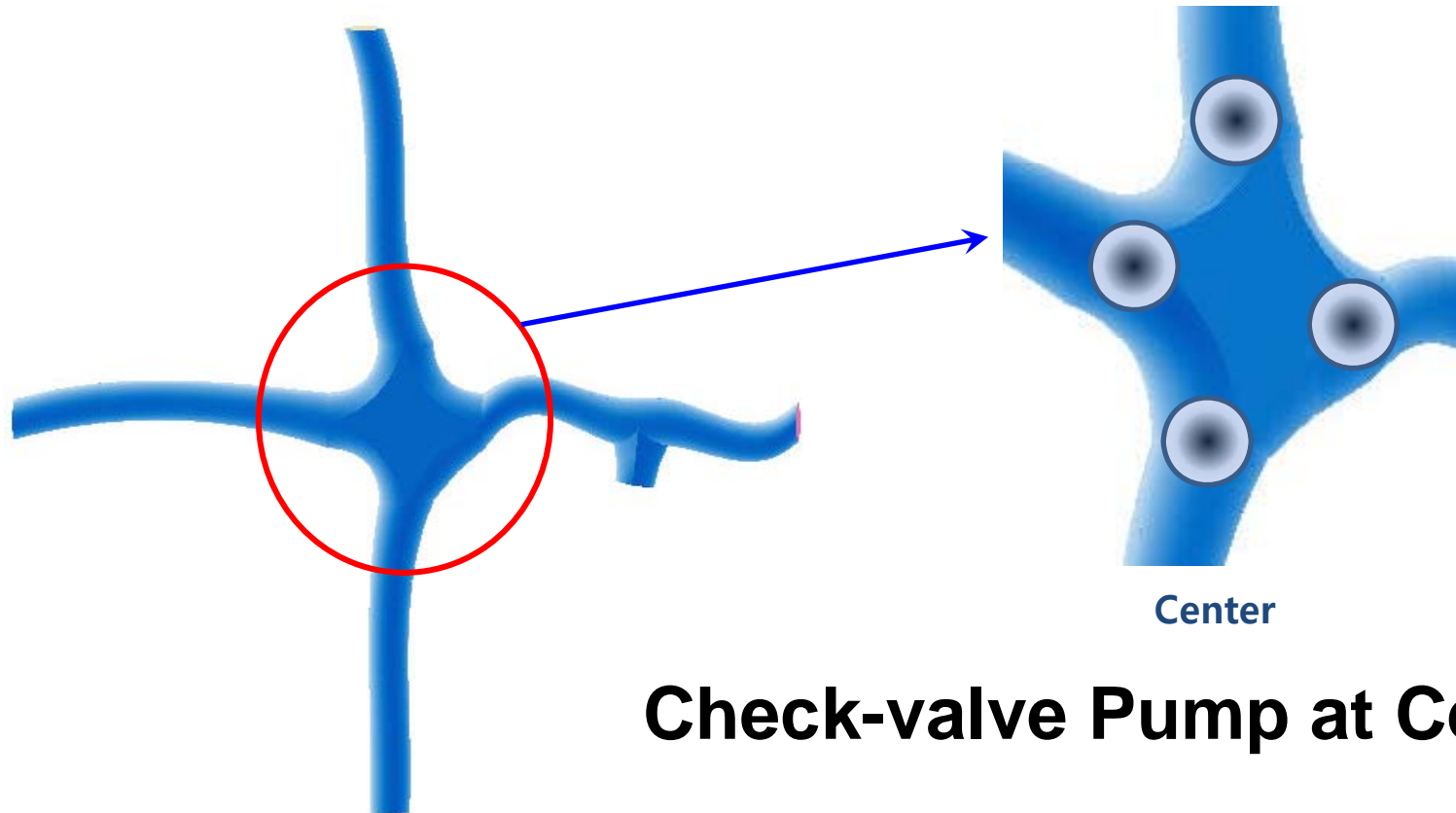
Suggestion I

Suggestive concept of conduit

Valve & Pump; self-rhythm synchronized



Suggestion II



Check-valve Pump at Center

Suggestion III

- **Hemorheologic parameters**
 - in various condition of CHD
 - Hypoxia, Hypercapnia, Shunt, etc
- **Microcirculation**
& Tissue perfusion

Acknowledgement

Computational simulation & Mathematical analysis

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The banner features the Penn State logo in the top left corner, which includes the text "PENNSTATE" above a shield containing a lion and the year "1855". The background is a photograph of a building with a prominent dome, likely the Conference Center Hotel in State College, Pennsylvania. The text is overlaid on this background.

PENNSTATE

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6TH INTERNATIONAL
Conference on Clinical Hemorheology

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