X선 영상기법을 활용한 생체유동현상 계측에 관한 연구

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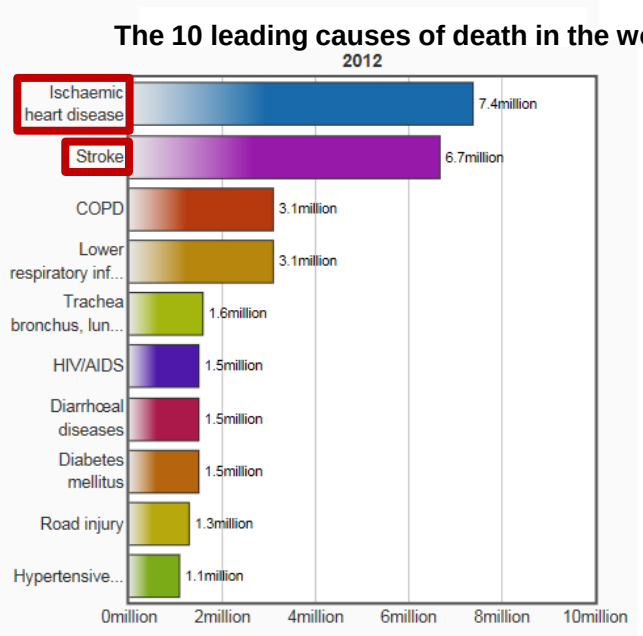
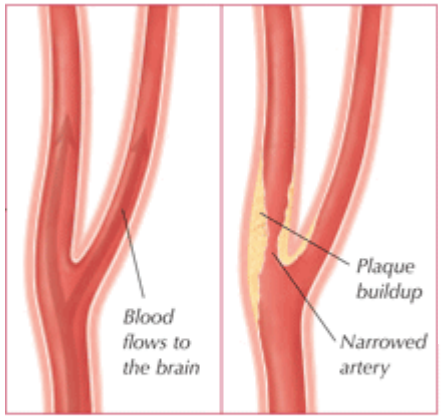
박한욱

Introduction

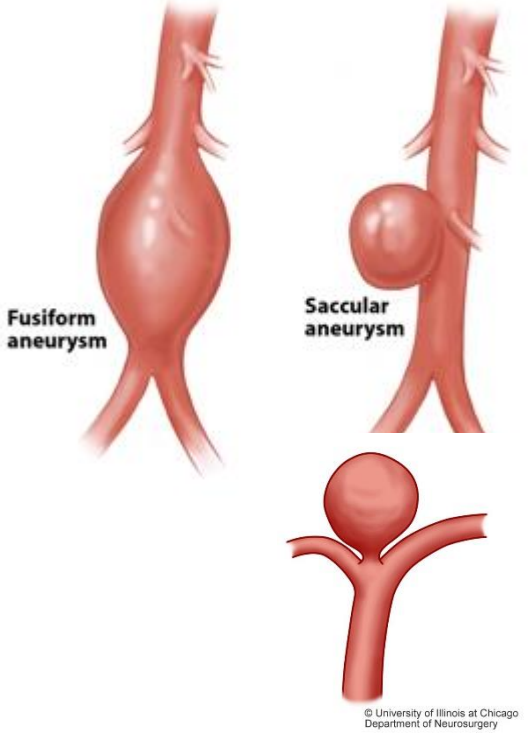
✓ Necessity of measurement of blood flows



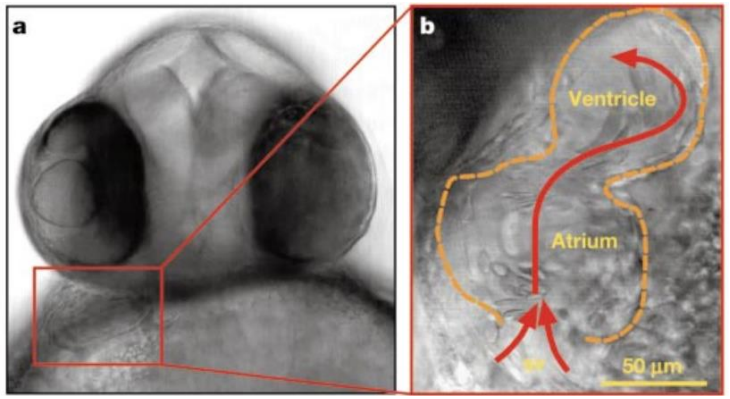


A healthy carotid artery lets blood flow easily to the brain.

Problems with blood flow can occur when an artery is narrowed by plaque.

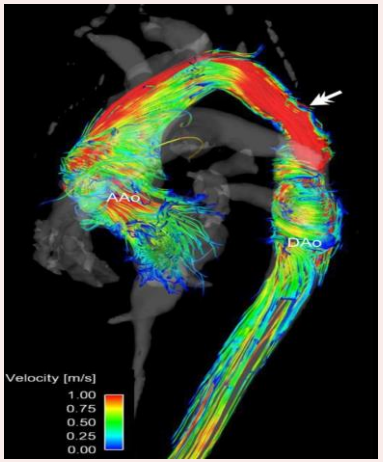
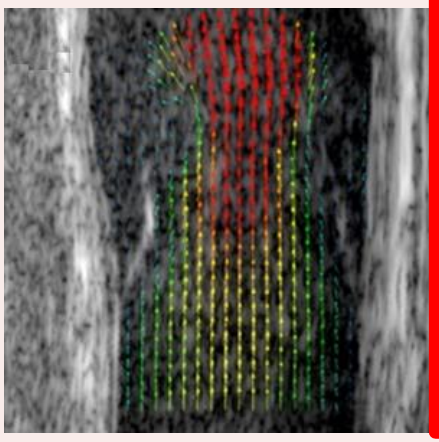


- Disorders in circulatory system are major mortality.



Introduction

✓ **Comparison of non-invasive technique.**

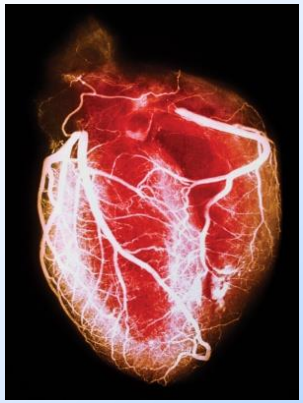
	MRI	Echo PIV	X-ray PIV
Merit	3D measurement	Portable, availability	Penetration depth, Spatial resolution
Limitation	Temporal resolution	Trade off : Penetration & temporal resolution	Availability
Application			

Introduction

X-ray PIV Technique

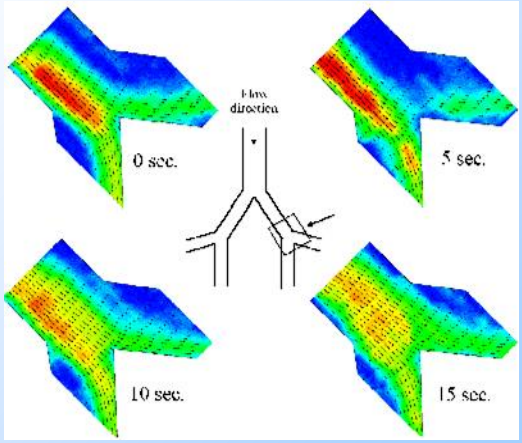
X-ray Imaging

- High resolution.
- Qualitative flow information.



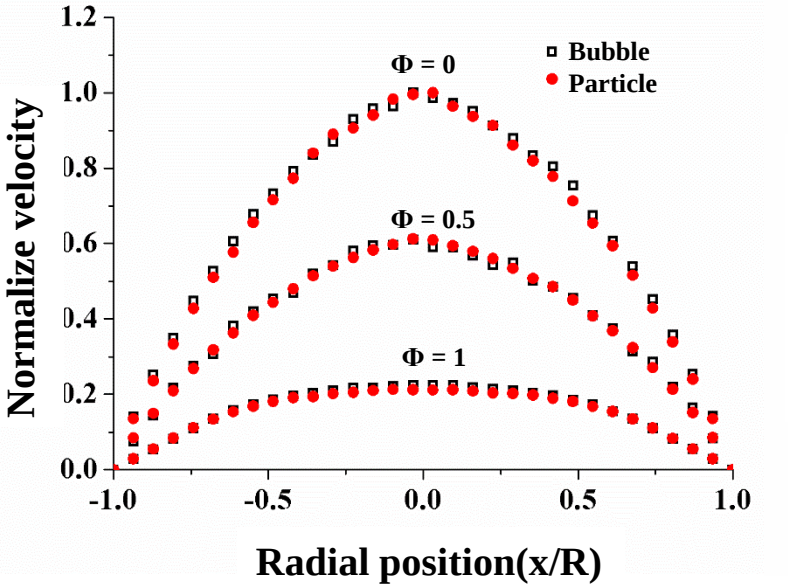
Particle Image Velocimetry

- A method of flow visualization.
- Quantitative flow information.

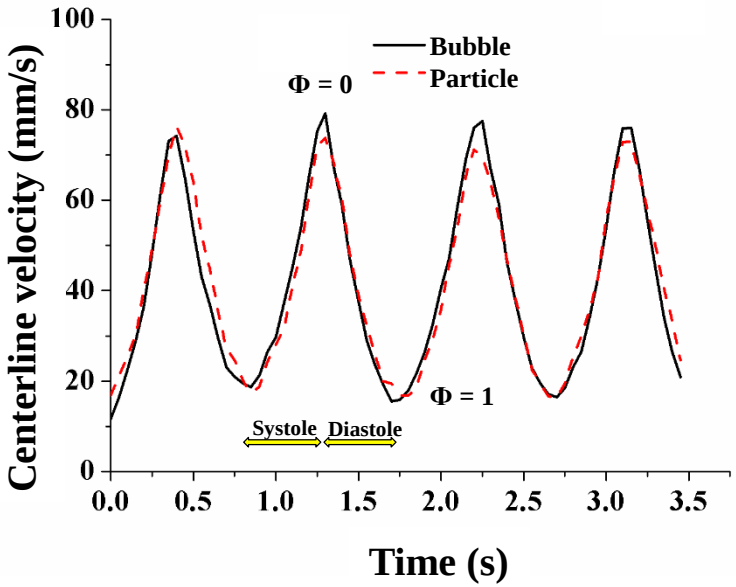


Validation of CO_2 microbubble in pulsatile flow

✓ **Velocity profile of Newtonian fluid flow**



Velocity profile of Newtonian fluid

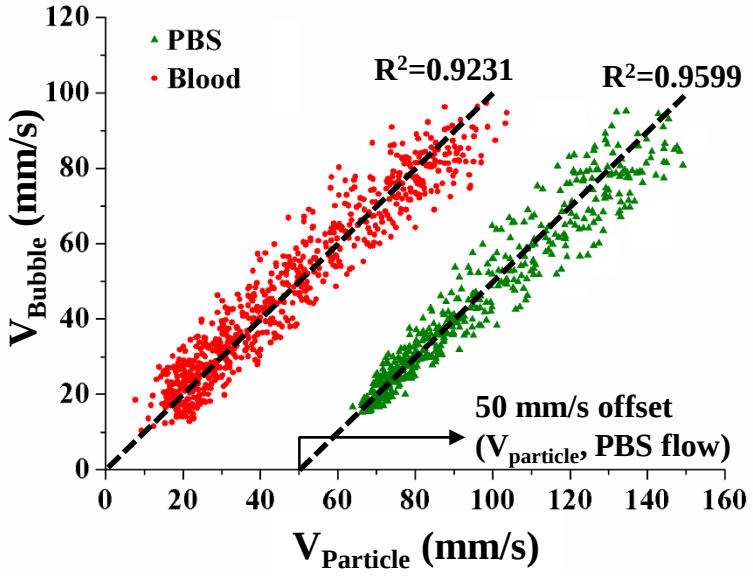


Variation of centerline velocities

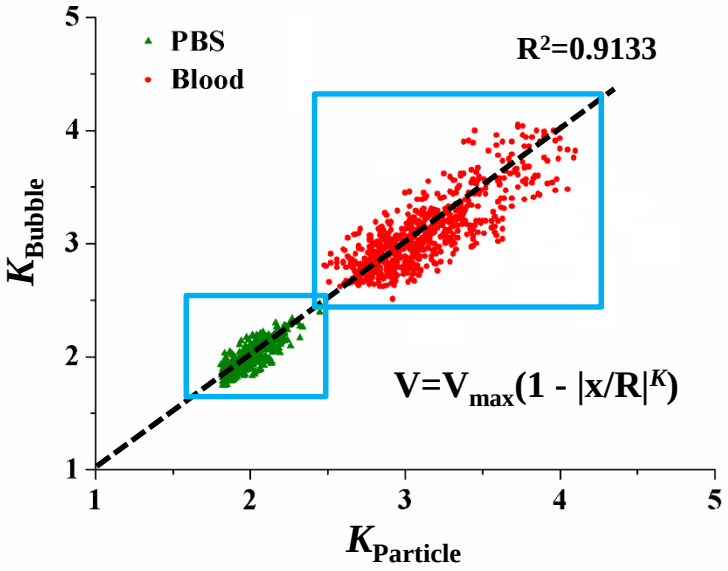
✓ **To validate the use of CO_2 microbubbles, the measured velocity data of the CO_2 microbubbles are compared with those of 14 μm silver-coated hollow glass beads widely used as tracer particles in X-ray PIV experiments.**

Accuracy of CO_2 microbubble in pulsatile flow

✓ Centerline velocity distribution.



✓ *K*-value distribution.



✓ Results at 10 phases (Φ = 0, 0.11, 0.22 .. 1) over 16 cycles were used.

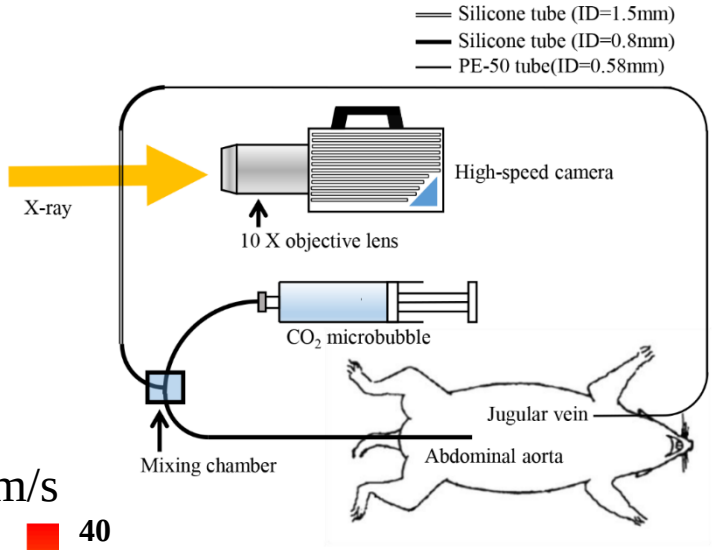
✓ Centerline velocity and *K*-value between CO_2 microbubbles and particles was revealed.

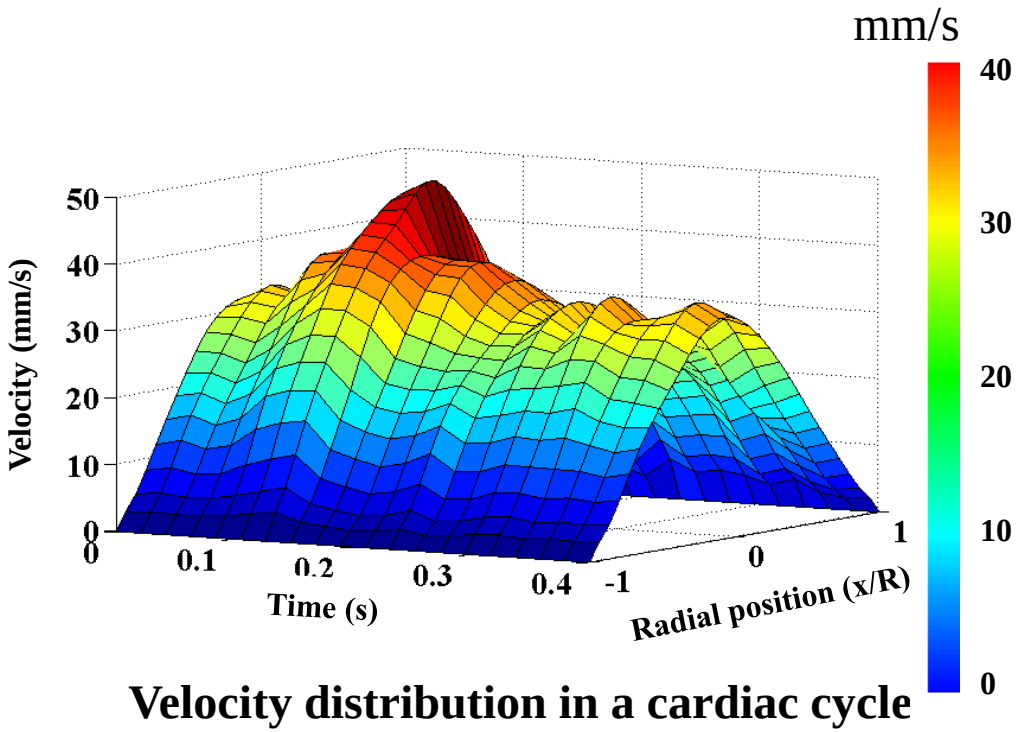
✓ The K-value and centerline velocity measured by CO_2 microbubble and particles was highly correlated with high R^2 value

Velocity information of rat extracorporeal loop

✓ **Rat extracorporeal loop system**

- **Real pulsatile blood flow.**
- **Control velocity, flow rate and pulsatility.**
- **CO_2 microbubbles were used as a tracer particle.**



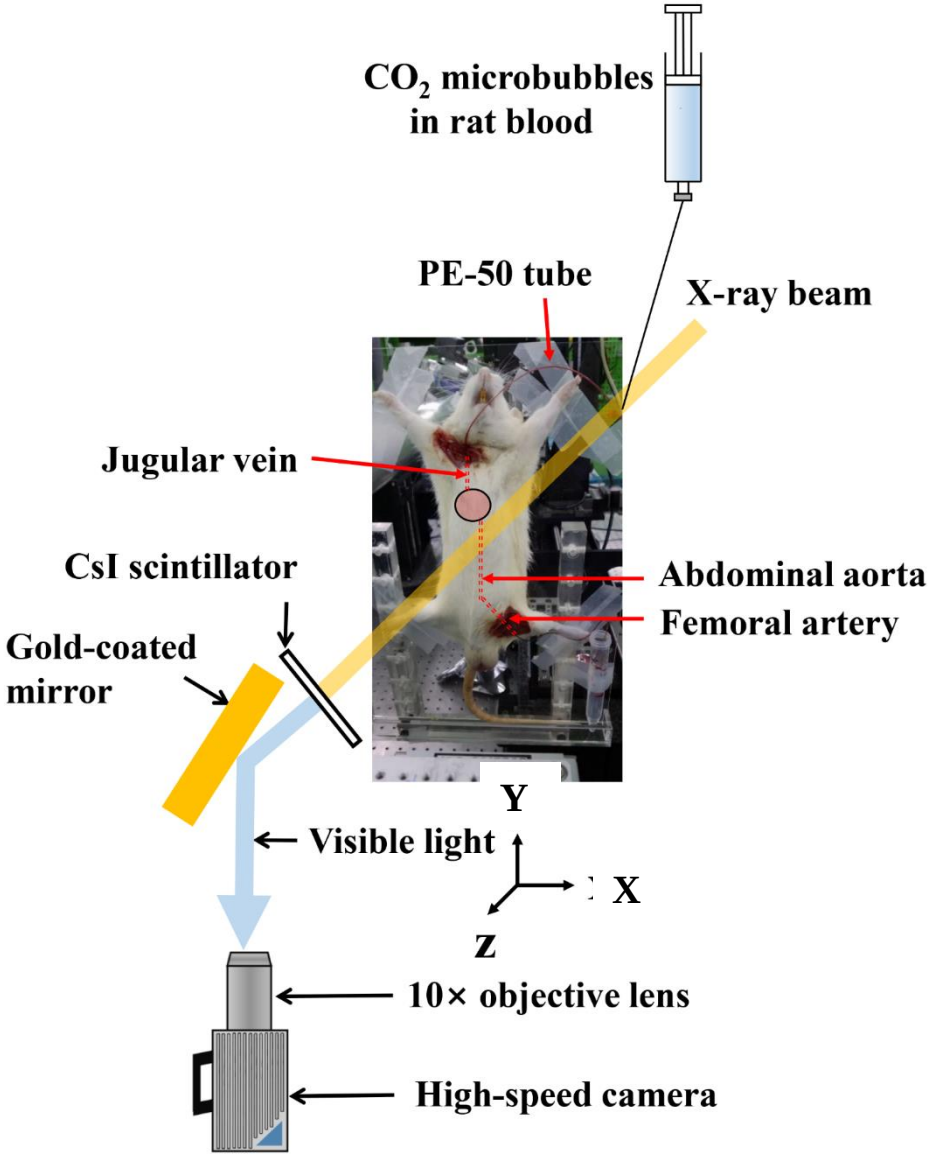


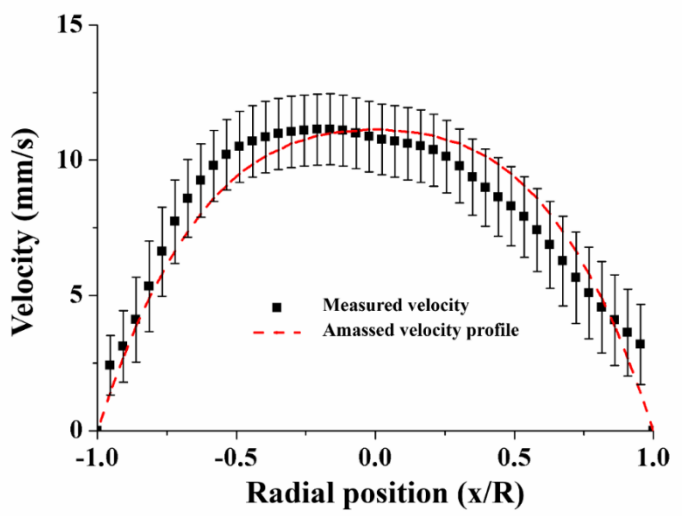
Velocity distribution in a cardiac cycle

Results

Centerline velocity (systolic) : 47.97 mm/s
Centerline velocity (diastolic) : 23.19 mm/s
Pulsatile index : 0.7728
Heart rate : 2.53 Hz
K-value : 2.83
Flow rate : 2.3620 mL/min

Velocity profile of abdominal aorta





Velocity profile of abdominal aorta

Cadaver experiment condition

Working fluid : Blood

Particle : CO_2 bubble

1000fps

10x lens

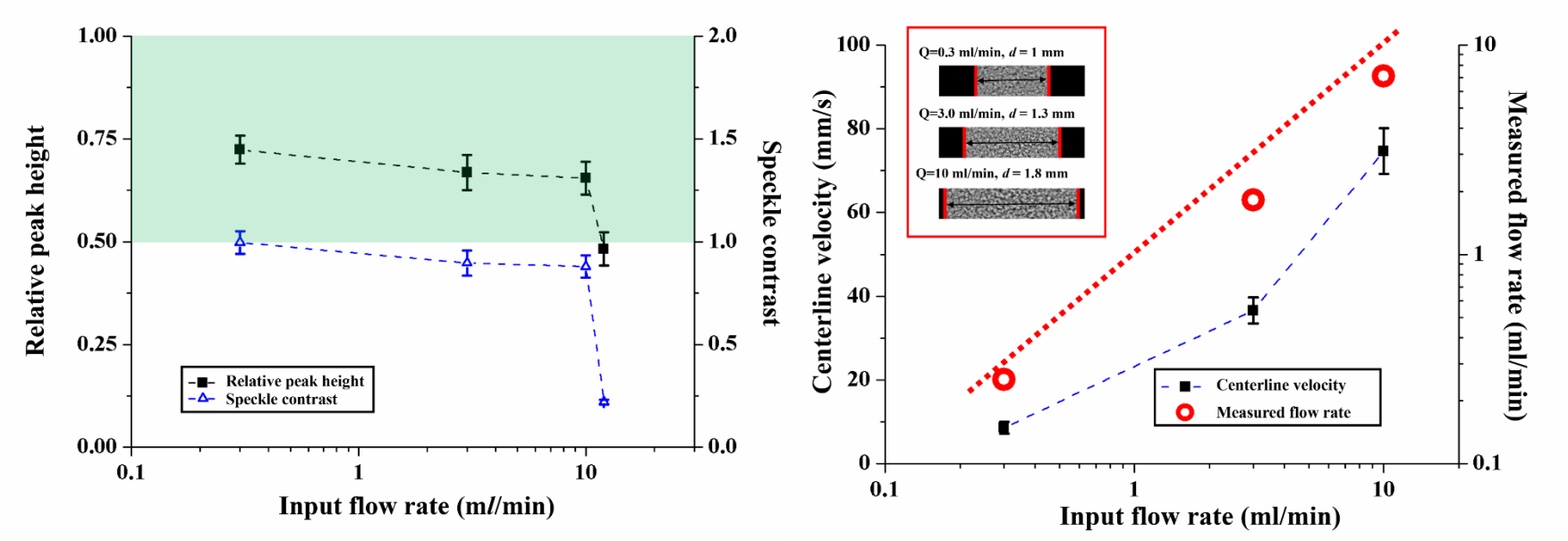
PIV condition

1024 × 1024 pixel(2.0 mm × 2.0 mm).

32 × 64 interrogation window.

50% overlapping.

Maximum measurable velocity

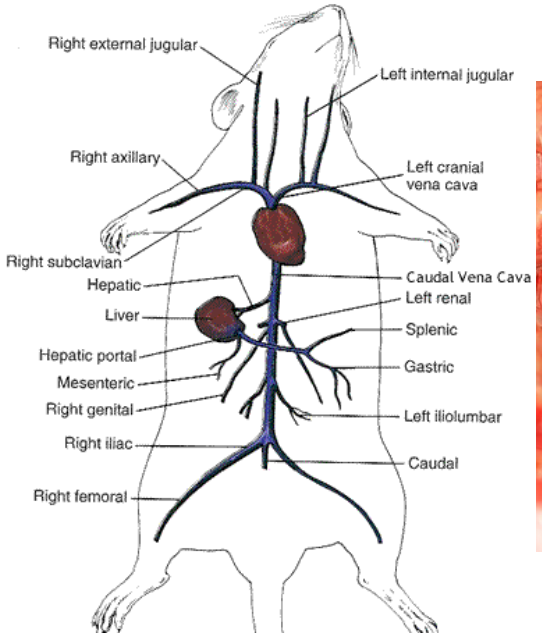


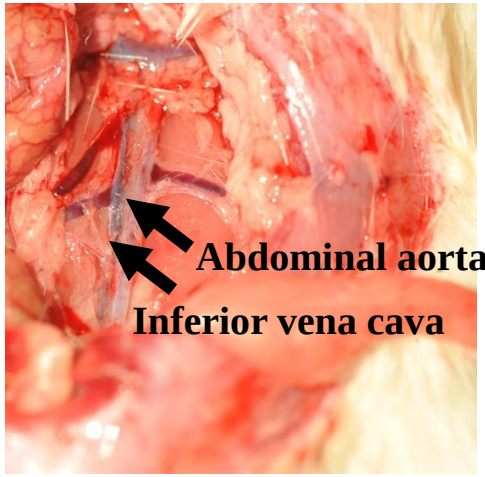
1. **The maximum measurable velocity that corresponds to the input flow rate of 10 mL/min should be determined.**

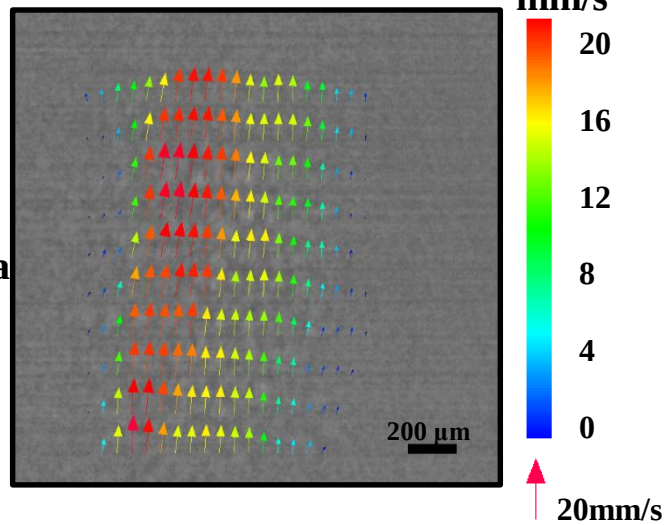
2. **The maximum measurable blood flow rate is approximately 7.1 mL/min, at which the centerline velocity is 74.64 mm/s, as determined using X-ray PIV in the rat model.**

In vivo measurement of blood flow

✓ **Velocity fields in interior vena cava under *in vivo* conditions**



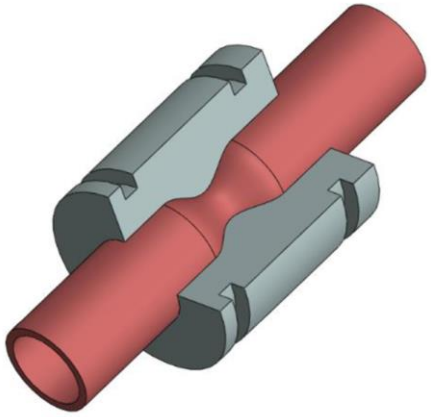




1. **The velocity fields of blood flow were measured in the inferior vena cava (IVC) of the rat under *in vivo* conditions.**

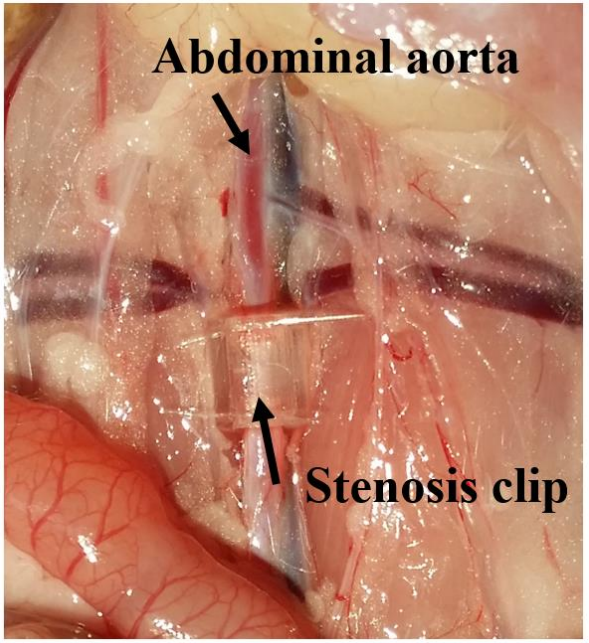
2. **The present X-ray PIV technique with CO_2 microbubbles has a strong potential in the *in vivo* measurements of real blood flows in animal models.**

Stenosis model



3D stenosis clip installed in a blood vessel

Abdominal aorta



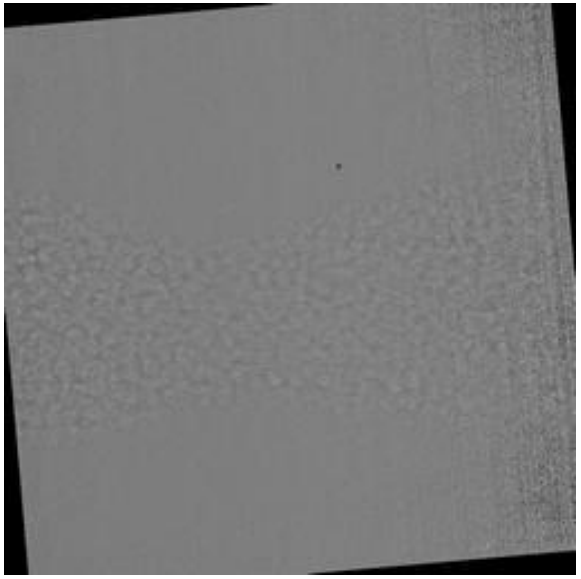
Stenosis model at abdominal aorta

Severity S	26%	36%	54%
Inner diameter of vessel D (mm)	1.04	0.96	1.05
Radius of stenosis throat r_0 (mm)	0.77	0.614	0.484
Length of stenosis L (mm)	1.92 (1.85 D)	1.66 (1.73 D)	1.54 (1.47 D)

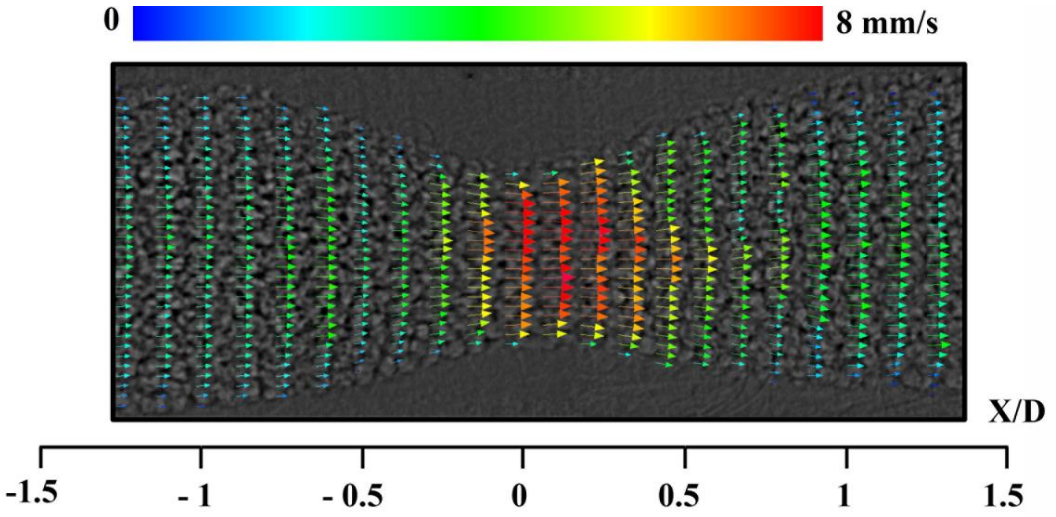
Geometric parameters of three stenosis clips tested in this study

Velocity field

✓ **Velocity field information in 36% concentric stenosis.**



X-ray images in 36% concentric stenosis



Instantaneous velocity field

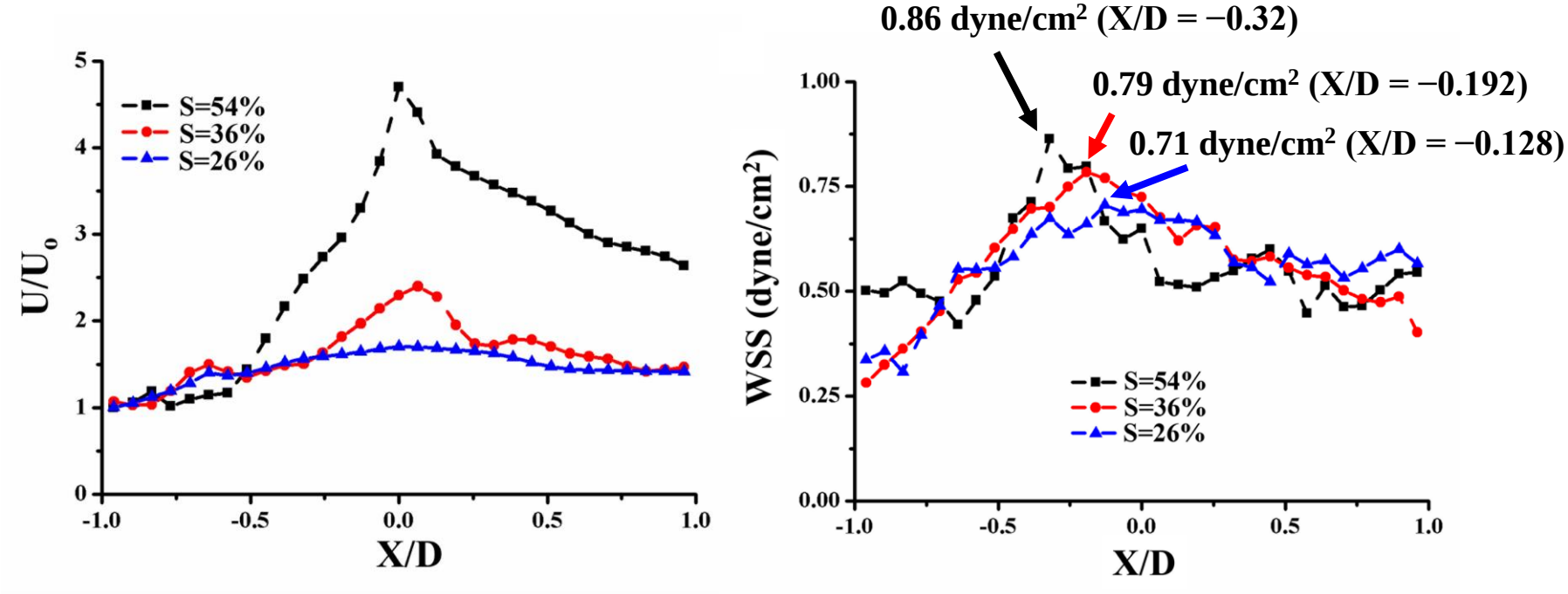
Experiment condition

Working fluid : Blood
Particle : CO_2 microbubbles
Q = 0.5mL/min
500 fps
10x objective lens

PIV condition

1024 x 1024 pixel(2 mm x 2 mm).
64 x 32 interrogation window.
50% overlapping.
Average 400 pairs of velocity field.

Velocity and WSS distribution



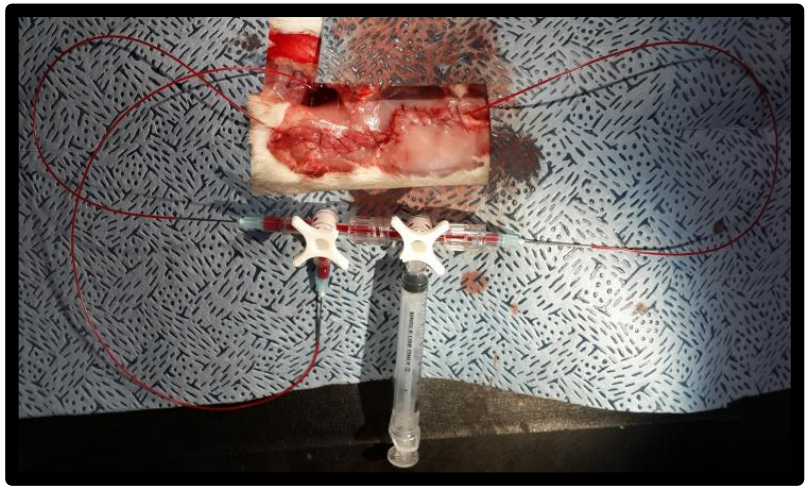
Variations in normalized velocity

Variations in WSS

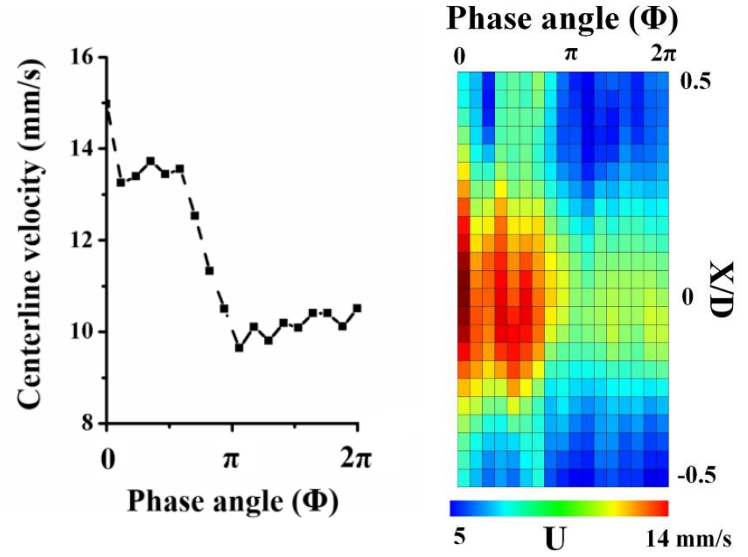
1. The peak values of WSS occurred at locations prior to the throat of the stenosis (X/D < 0) in all cases.

2. The peak location shifted forward to the throat, and the corresponding WSS peak value increased with the increase in stenosis severity.

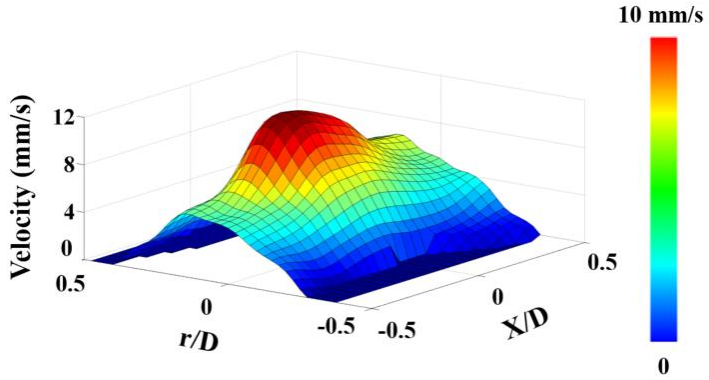
Hemodynamic information on *in vivo* model



Rat stenosis model for *in vivo* measurement



Phasic variation and vibration in centerline velocity

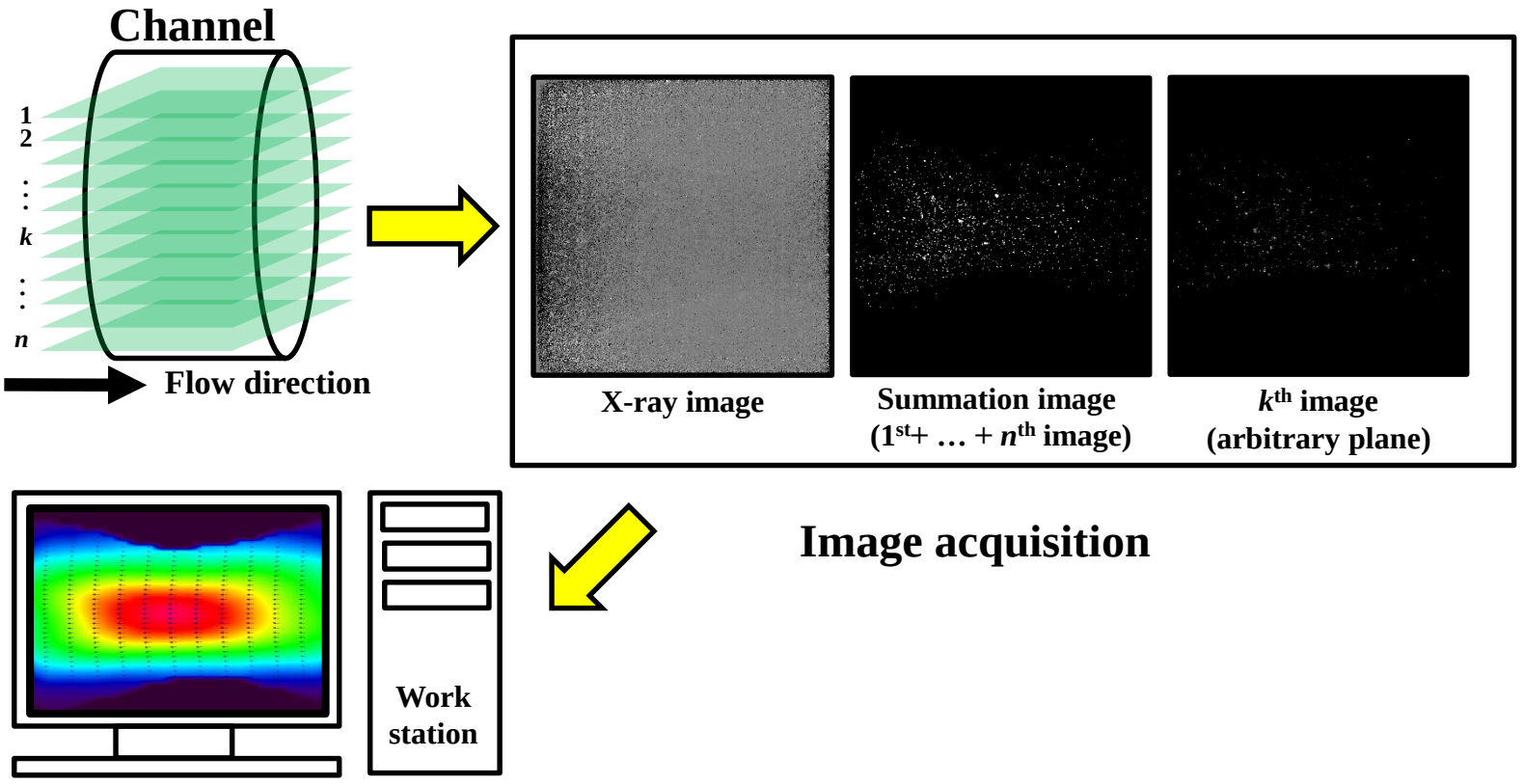


Variation in radial velocity profile in stenosis

Results

Centerline velocity (systolic) : 14.97 mm/s
Centerline velocity (diastolic) : 10.51 mm/s
Pulsatile index : 0.43
Heart rate : 1.35 bpm

Objective & theoretical background



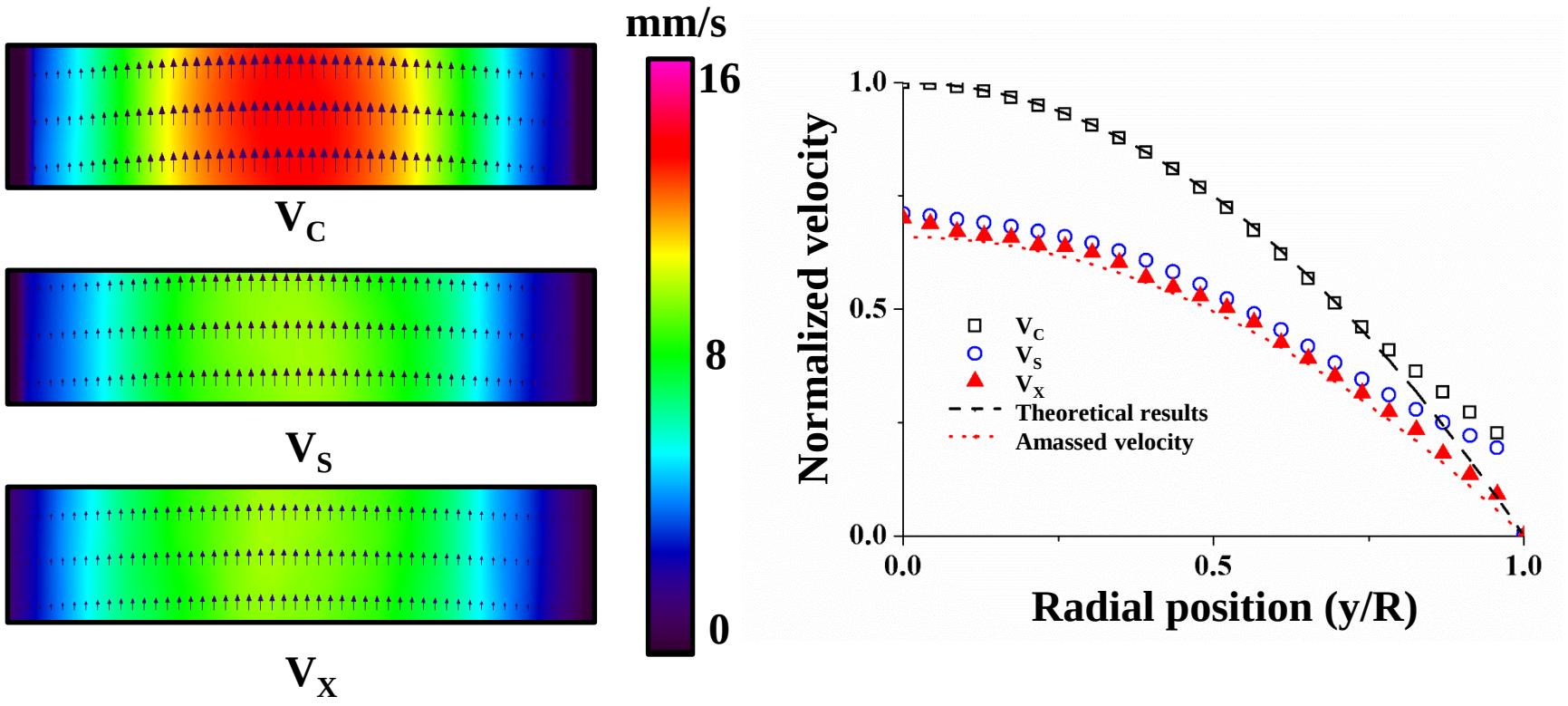
PIV (two-frame cross correlation)

1. Identify the similarity of V_X and V_S and confirm the relationship between I_s , I_k .

2. Find correction coefficients for every I_k and apply them to X-ray PIV results.

Results

✓ Velocity information in Poiseuille flow

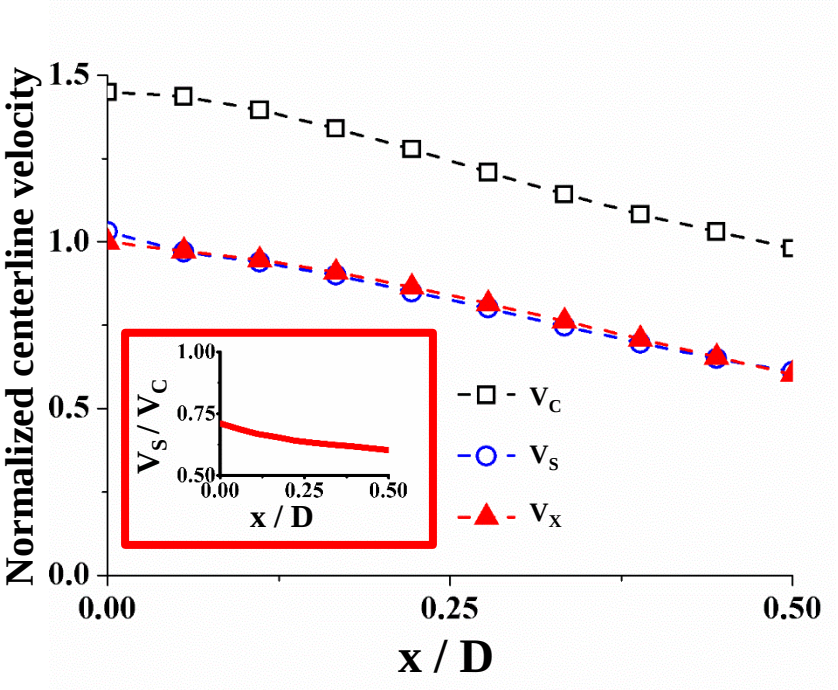


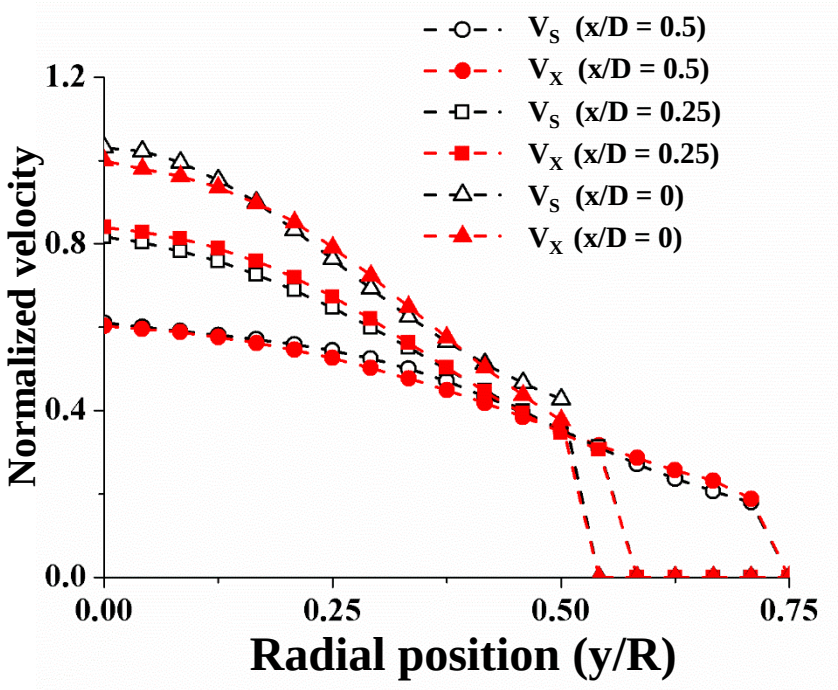
1. Velocity information (V_C, V_S, V_X) were directly compared in this study.

2. The measurement accuracy of X-ray PIV was constant throughout the radial direction.

Results

✓ **Velocity information of flow in the 50% concentric stenosis**





1. **Different from the constant value (2/3) for the Poiseuille flow, the correction coefficient gradually decreased as the x/D increases.**

2. **Except in the near-wall region, the velocity information of V_X and V_S are well matched in both Poiseuille flow and flow in the stenosis with 50% severity.**

Conclusion

1. **X-ray PIV technique with hollow CO_2 microbubbles were employed to investigate hemodynamic characteristic of blood flows.**

2. **The traceabilities of CO_2 microbubbles in steady and pulsatile blood flows were demonstrated.**

3. **The feasibility of CO_2 microbubbles streaming in a live rat model with real surrounding tissues after applying digital image processing was also demonstrated.**

4. **The direct comparison of the experimental data measured by the proposed X-ray PIV technique with those of micro-PIV technique demonstrated improvement in measurement performance.**

5. **The hemodynamic information of blood flows in the stenosed vessel of a rodent model was obtained using X-ray PIV.**

Thank you