

Investigation of Left Atrial Flow Stasis and Thrombogenicity in Left Atrial Appendage Occlusion using 4D-Flow MRI

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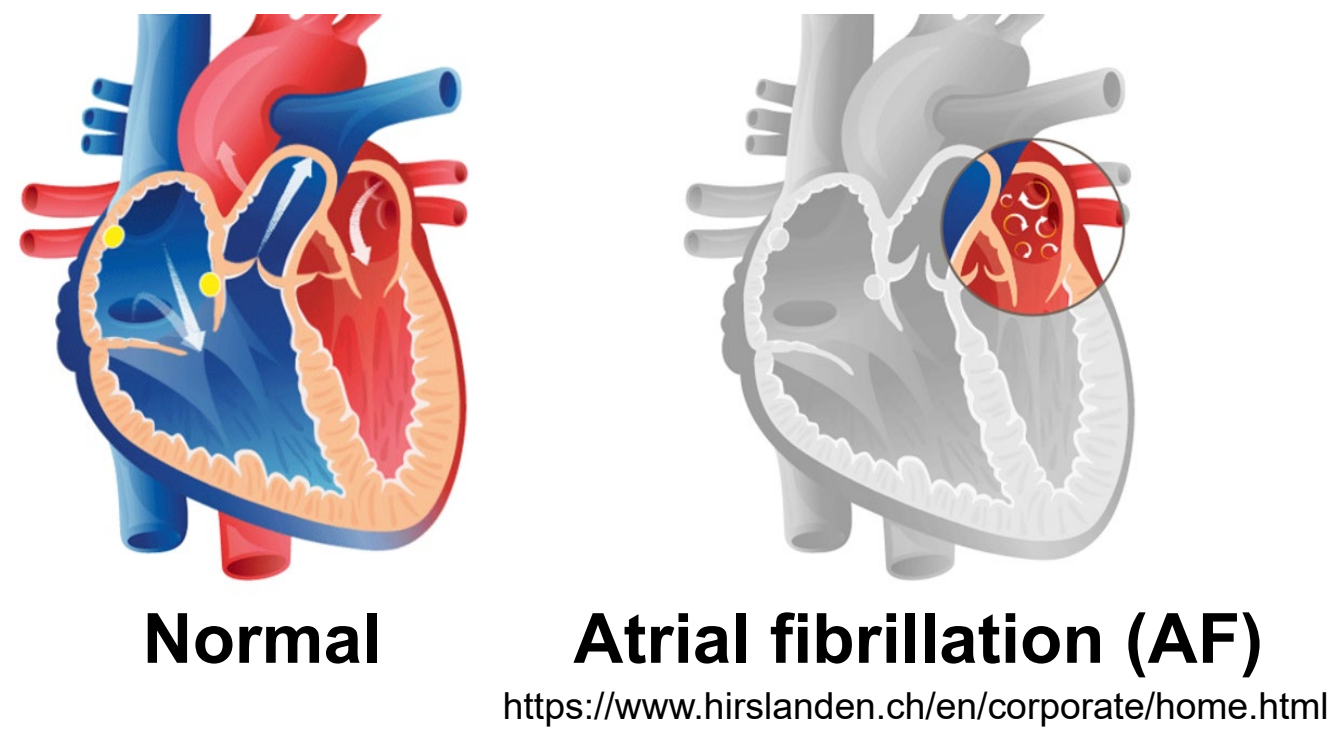
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Why hemodynamic study for LAAO?

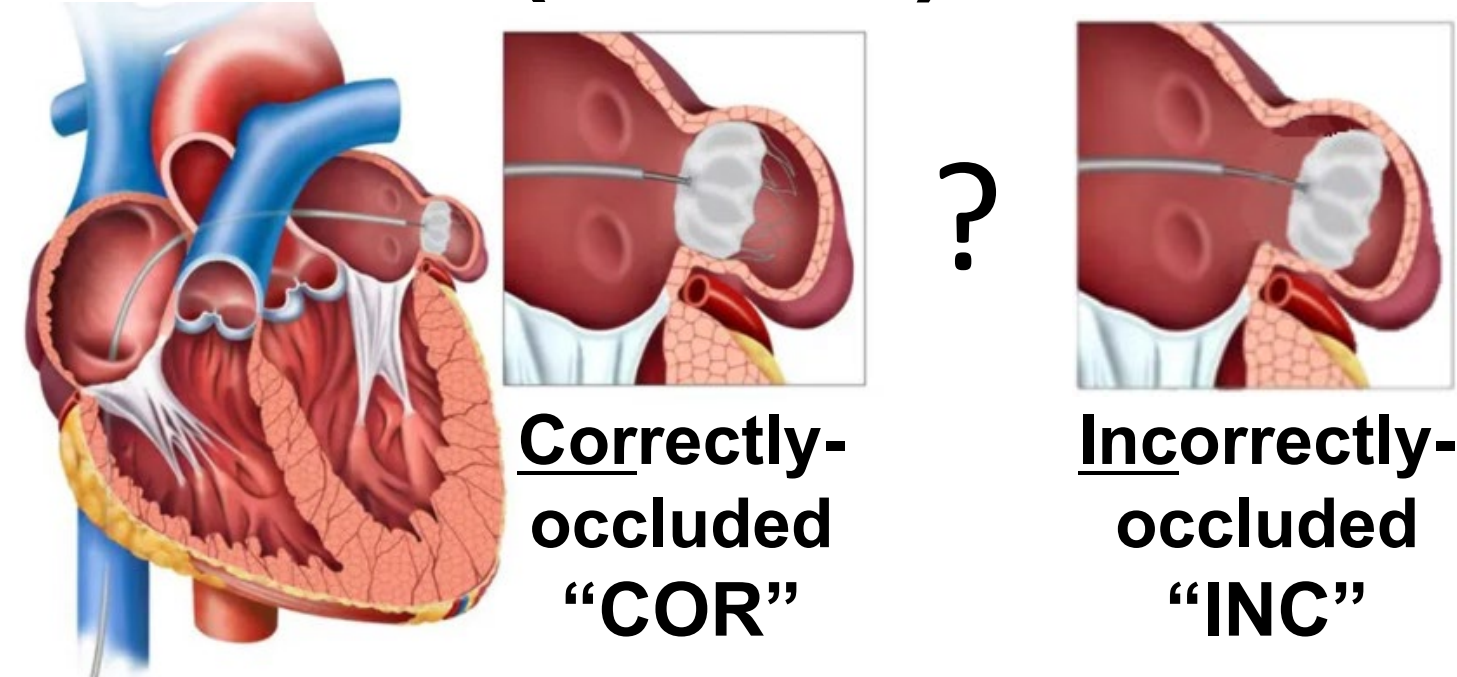
Risk of atrial fibrillation on left atrium



- Main cause of **thrombogenicity** on left atrial appendage
- Oral anticoagulants and **occlusion** are commonly used for the treatment.

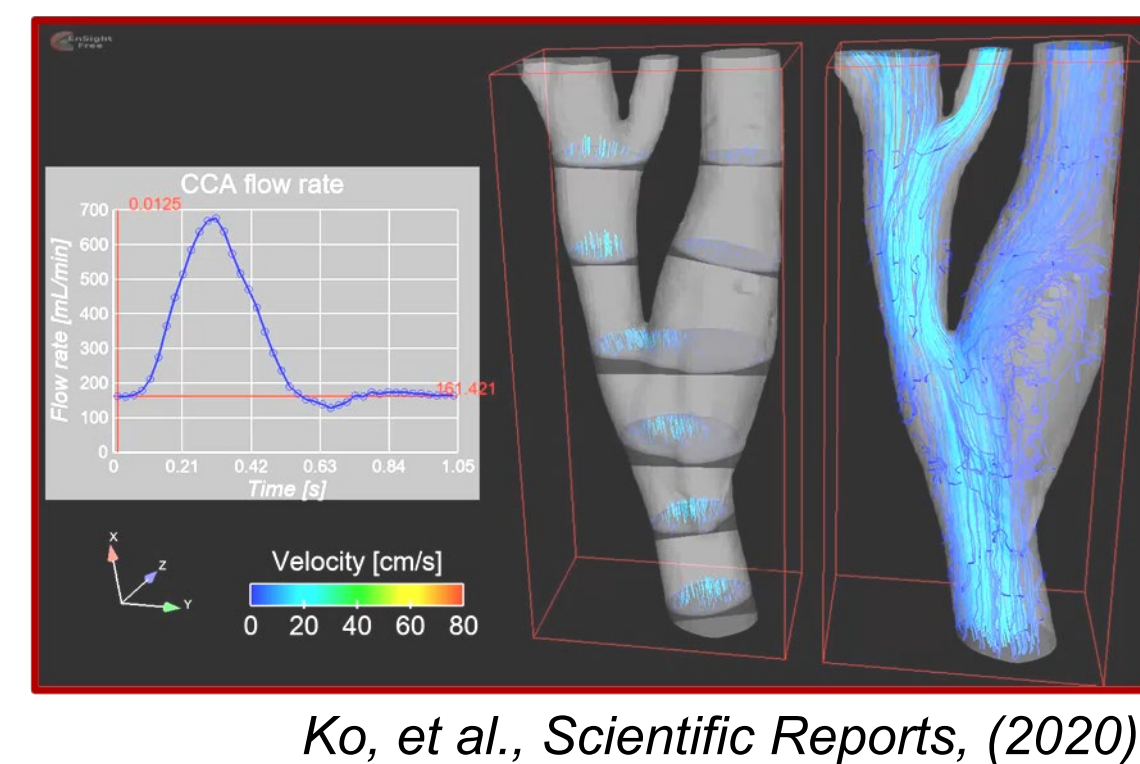
Left atrial appendage occlusion (LAAO)

- The effect of hemodynamic changes after LAAO on **thrombogenicity** is not known

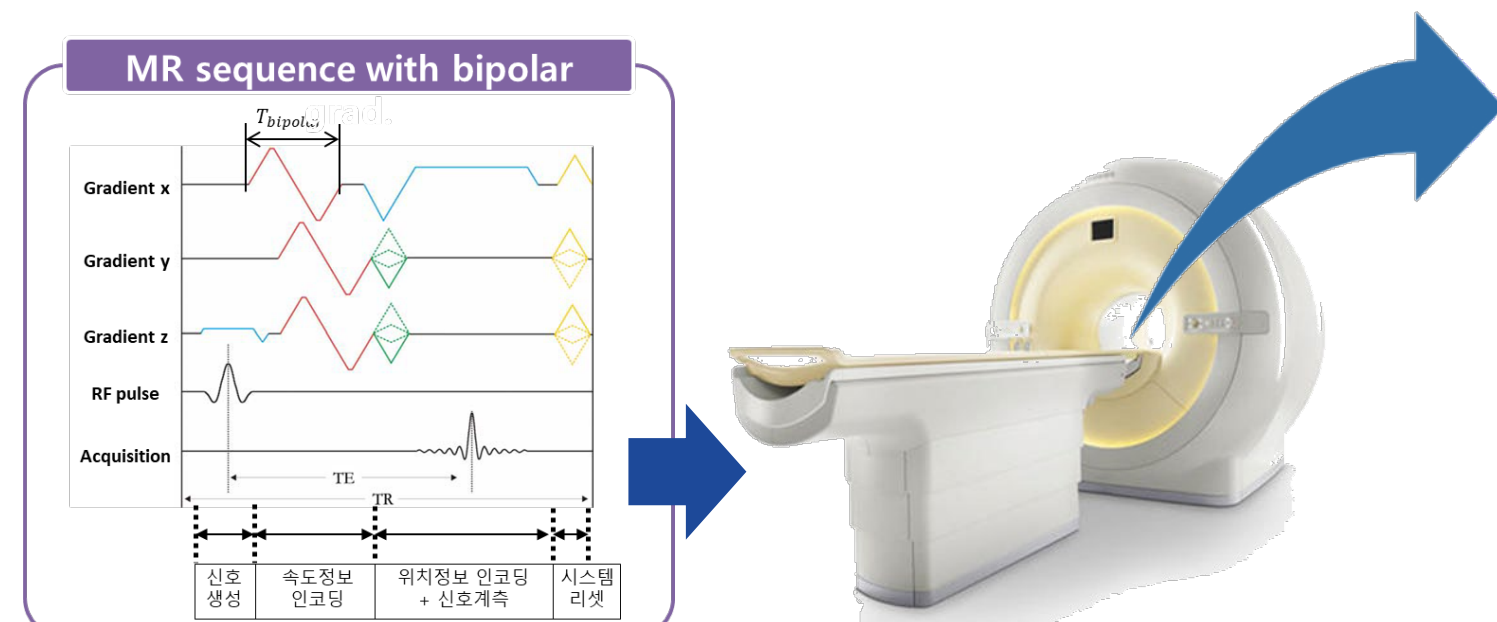


4D-Flow MRI

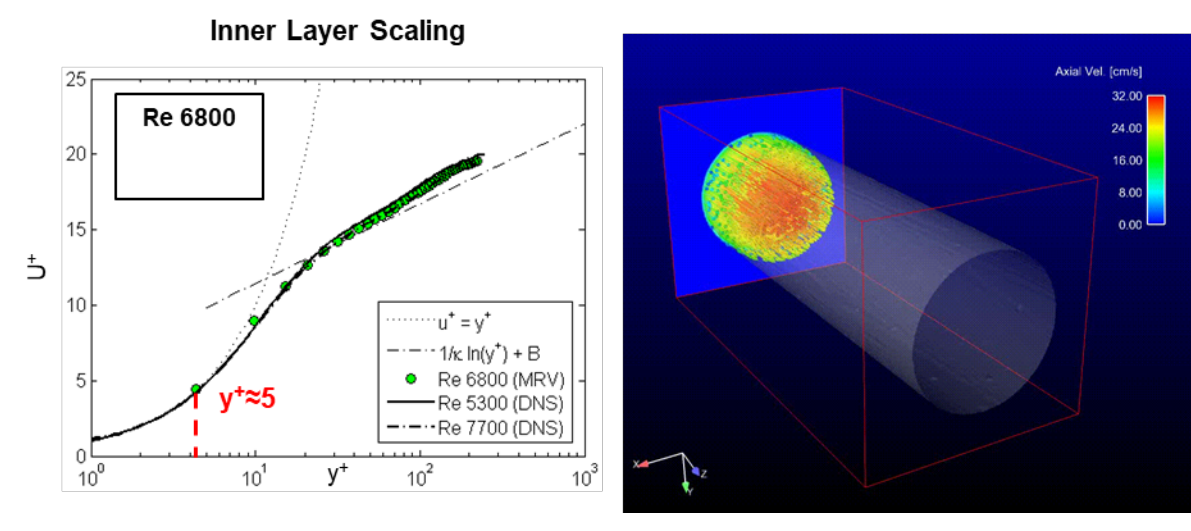
- Non-invasive flow visualization technique that uses commercial MRI to time-resolve the three-dimensional, three-component velocity field of blood flow in a patient.



Ko, et al., Scientific Reports, (2020)



MRI sequence for velocity measurement



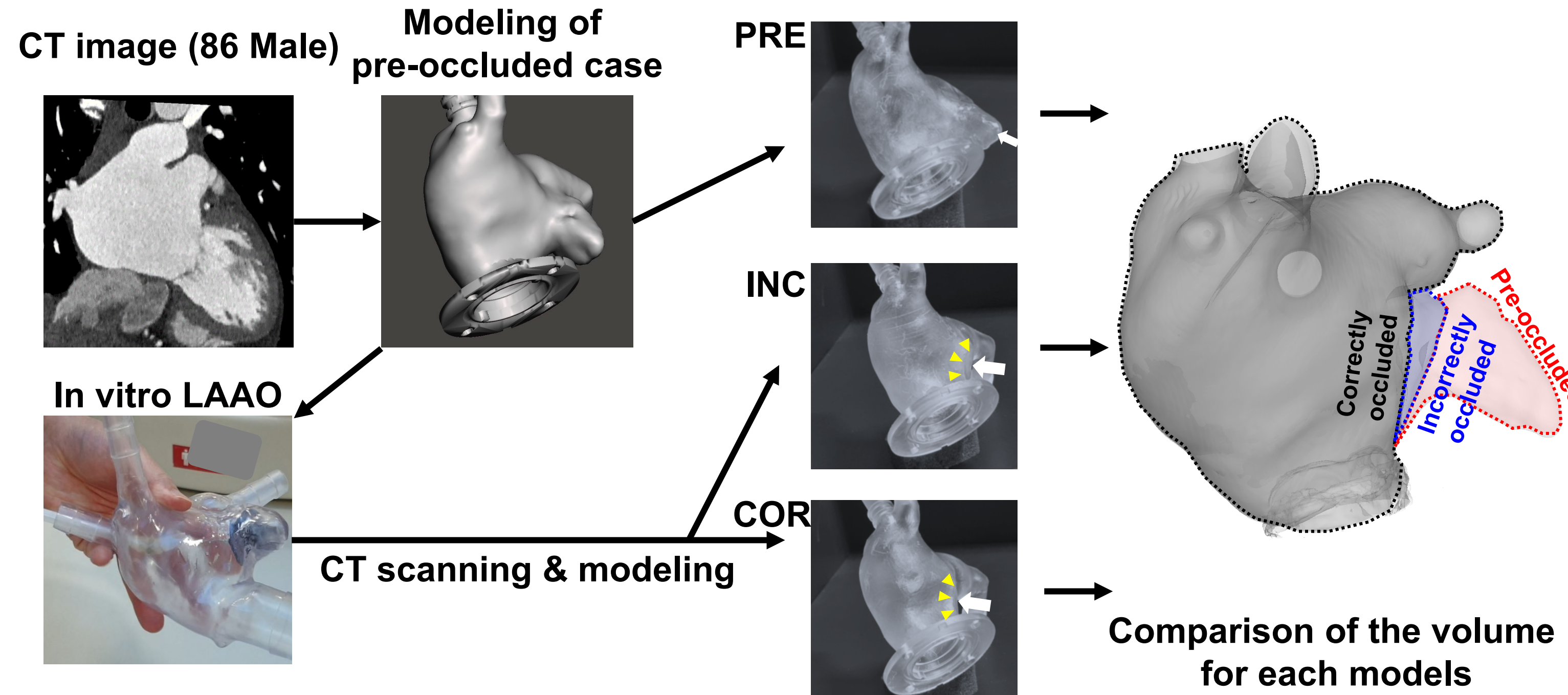
J. Lee et al., JMST, (2017)

Objectives

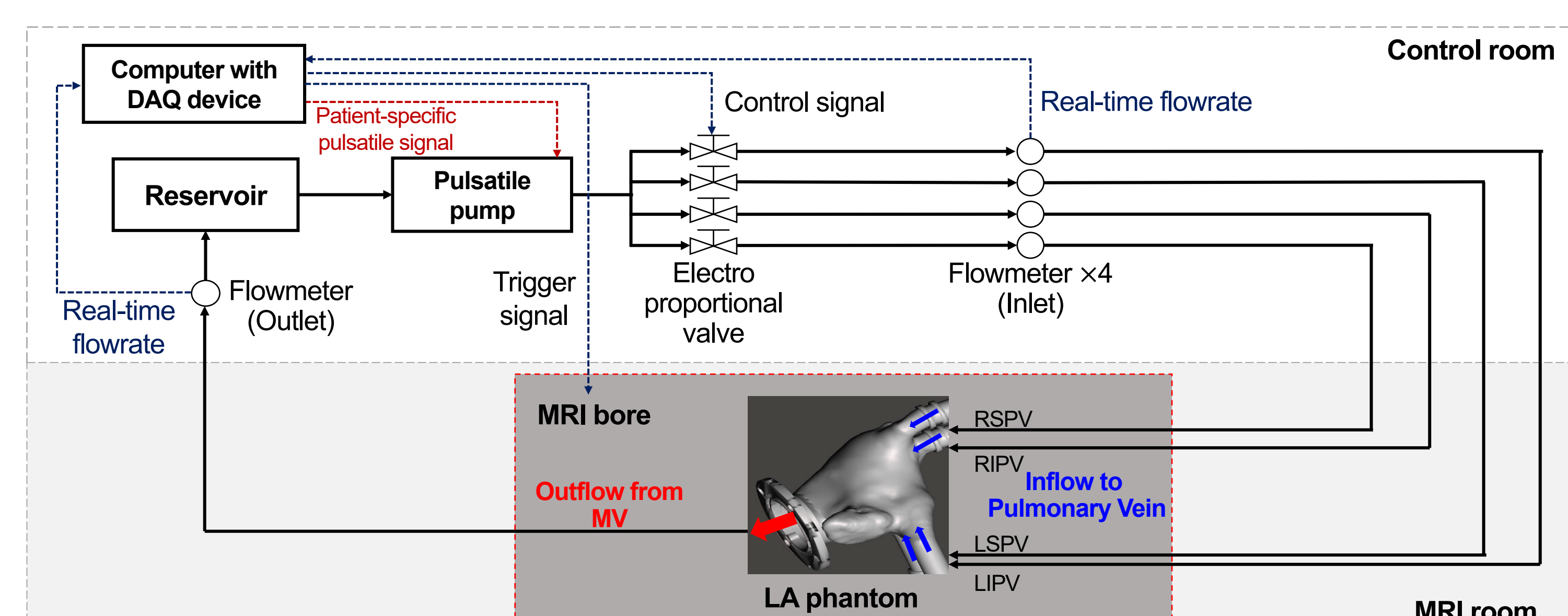
- To confirm the hemodynamic improvements in thrombogenicity after correct LAAO using 4D-Flow MRI

Methodology

3D printed left atrium phantom

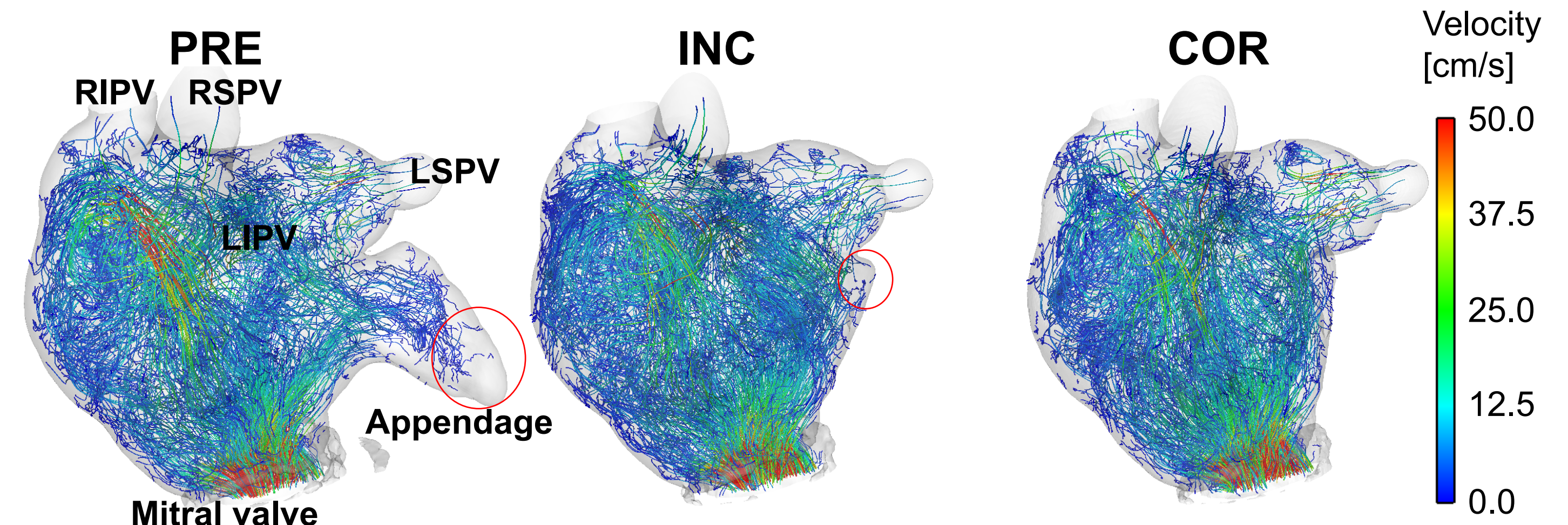


Patient-specific flow circuit



Results and discussion

Pathline using velocity fields



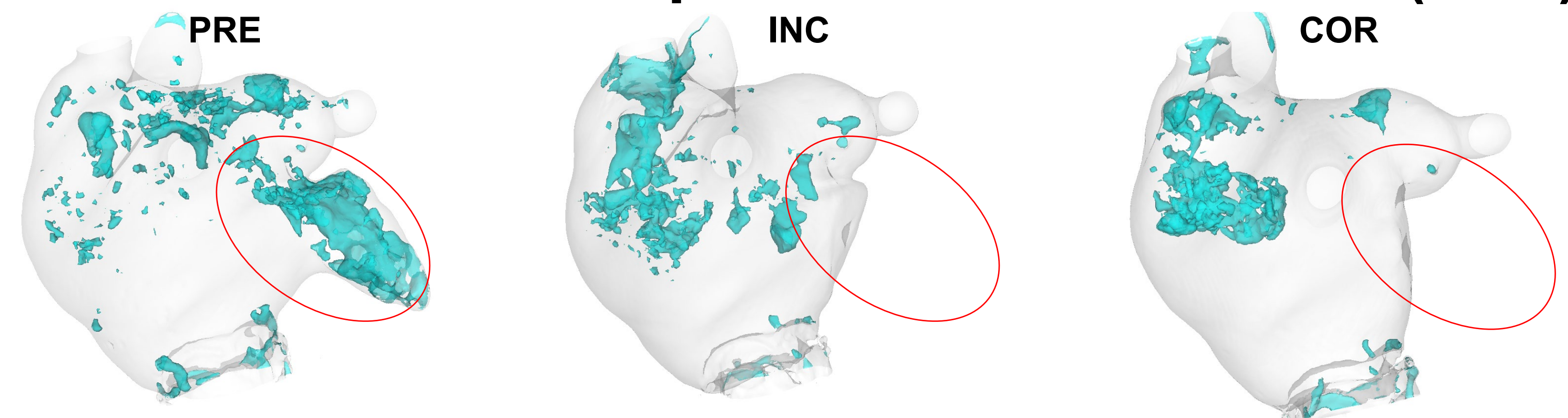
Stasis volume

	within the entire LA phantoms			within the common LA chamber, excluding appendage*			within the appendage (pouch)	
	PRE	INC	COR	PRE	INC	COR	PRE	INC
Entire volume	199.21 ml	187.54 ml	181.72 ml	181.72 ml	181.72 ml	181.72 ml	17.49 ml	5.82 ml
Time-averaged volume of LA stasis	79.11 ml (39.71%)	73.17 ml (39.02%)	70.82 ml (38.97%)	68.94 ml (37.94%)	69.03 ml (37.99%)	69.97 ml (38.50%)	10.17 ml (58.15%)	4.14 ml (71.20%)
Volume of $r_{stasis} > 50\%$	46.84 ml (23.51%)	42.54 ml (22.58%)	38.25 ml (21.05%)	38.54 ml (21.21%)	38.02 ml (20.92%)	37.49 ml (20.63%)	8.30 ml (47.46%)	4.52 ml (77.73%)

$$r_{stasis}(\%) = \frac{\text{\# of time frames with velocities below the threshold}}{\text{total \# of cardiac time frames}} \times 100$$

(Markl M, et al., Invest Radiol, 2016; 51:147-154.)

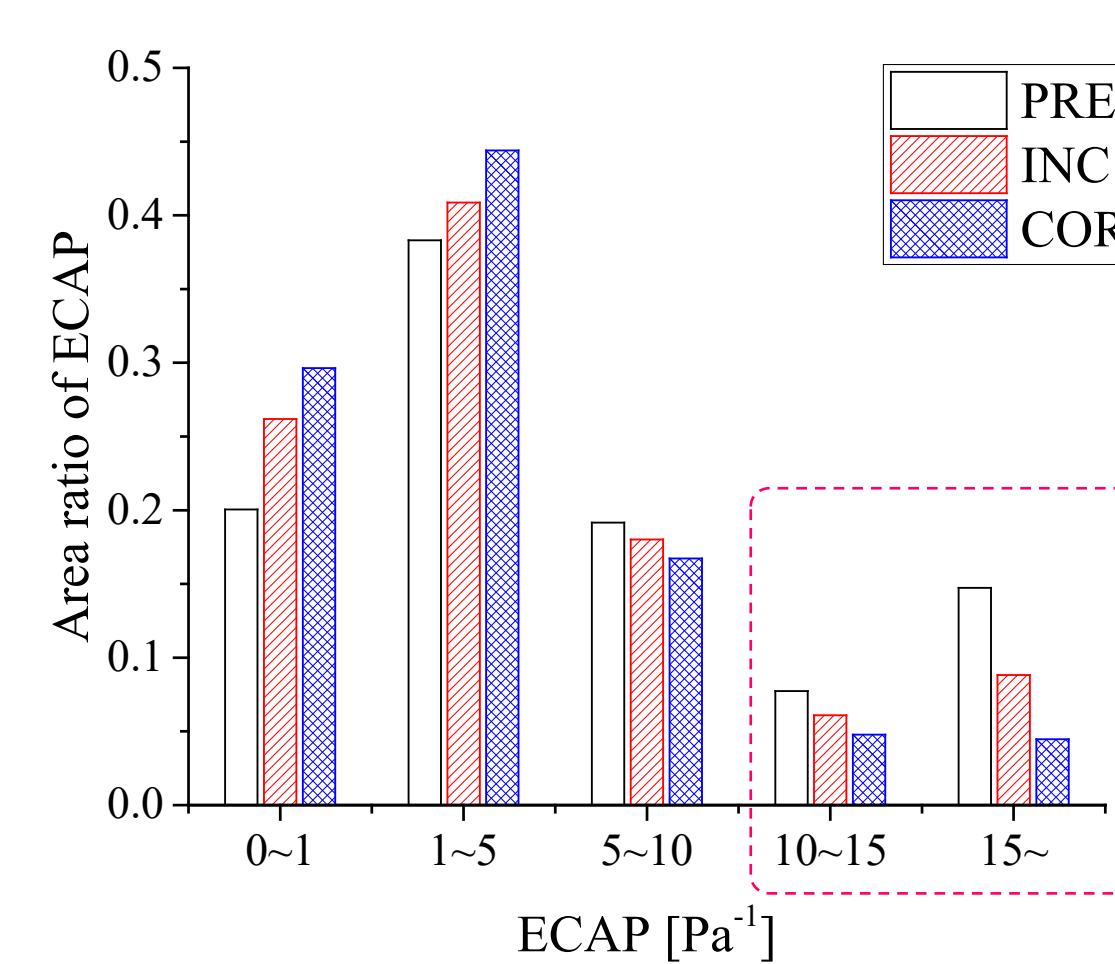
The iso-surface of particle residence time (PRT)



*The surface of initial positions of fluid particles of which particle residence time is set to the 5 cardiac cycles.

	PRE	INC	COR
Entire volume of LA	199.21 ml	187.54 ml	181.72 ml
Volume covered by iso-PRT-surface	10.57 ml (5.31%)	5.56 ml (2.96%)	3.88 ml (2.14%)

Endothelial cell activation potential (ECAP)



$$ECAP = \frac{OSI}{\frac{1}{T} \int_0^T |WSS| dt}$$

Mean ECAP

PRE : 5.861 Pa⁻¹

INC : 4.792 Pa⁻¹

COR : 4.004 Pa⁻¹

- PRE has the highest ECAP and COR has the lowest ECAP

Conclusions and future work

- In vitro 4D-Flow MRI experiments enabled detailed analysis on hemodynamic changes due to occluder after LAAO
- According to the results, LAAO had significant effects on the reduction of thrombogenesis, but incorrect occlusion could be a potential risk factor of thrombosis in a remnant pouch.
- In vivo 4D-Flow MRI experiments would lead to a firm conclusion with a large study population.