Usefulness of velocity profiles based on 3D cine PC MR used as boundary conditions for computational fluid dynamics of an intracranial aneurysm : investigation with the aid of simulated data set

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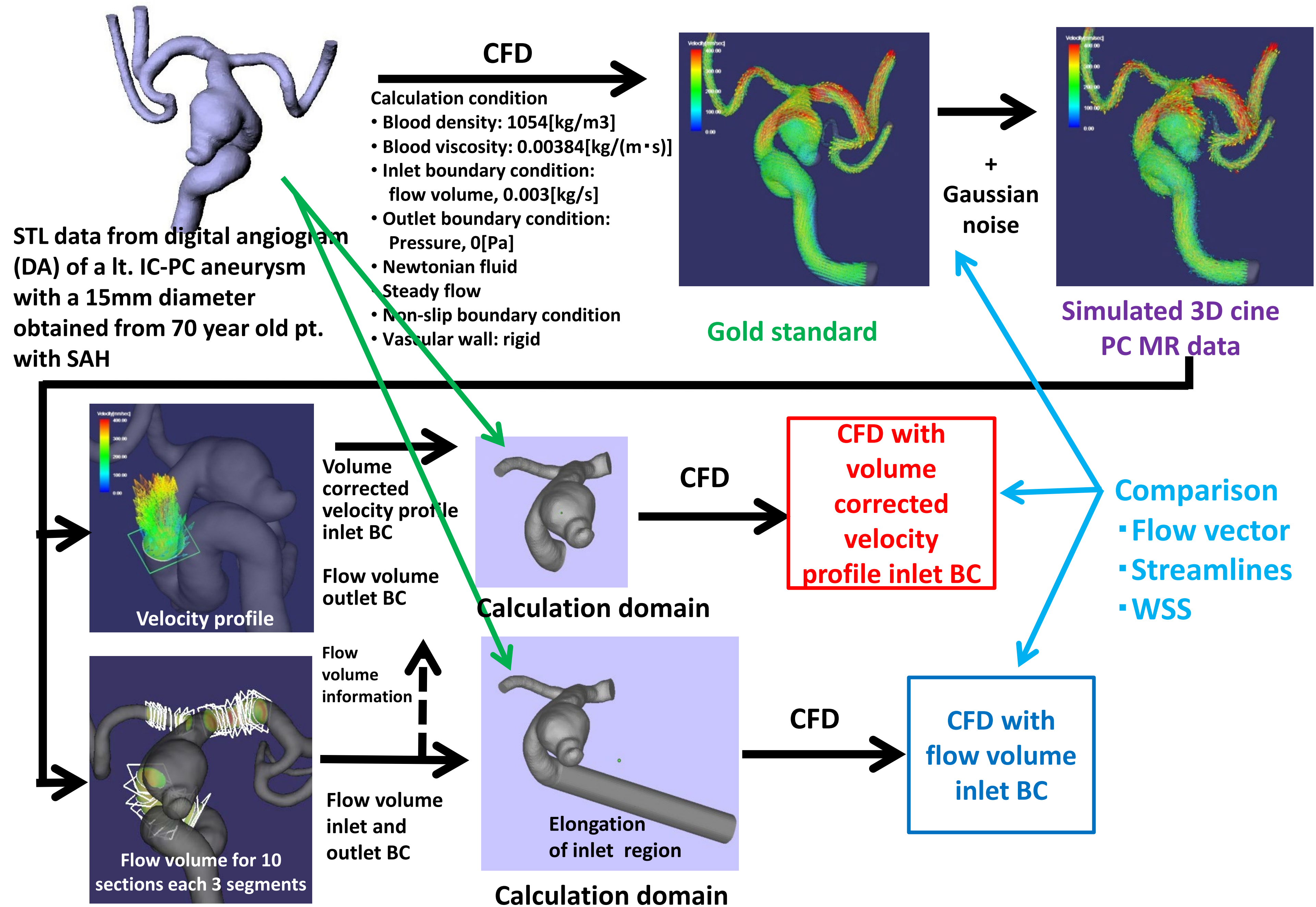
BACKGROUND

- Hemodynamics, especially wall shear stress (WSS), plays a very important role in the initiation, progression and rupture of intracranial aneurysms.
- Human hemodynamic analysis mainly includes MR fluid dynamics (MRFD) based on 3D cine phase-contrast MR imaging and Computational fluid dynamics (CFD). They have several merits and deficits.
- MR-based CFD, which uses flow information of 3D cine PC MR as boundary conditions, provides us with intracranial aneurysmal hemodynamics with high spatial resolution and high temporal resolution. However, adequate inlet region length can not be obtained, because imaging slab of 3D cine PC MR is limited due to relatively longer imaging time.
- Inlet velocity profile boundary conditions (BC) or flow volume BC are thought to affect the results of MR-based CFD.

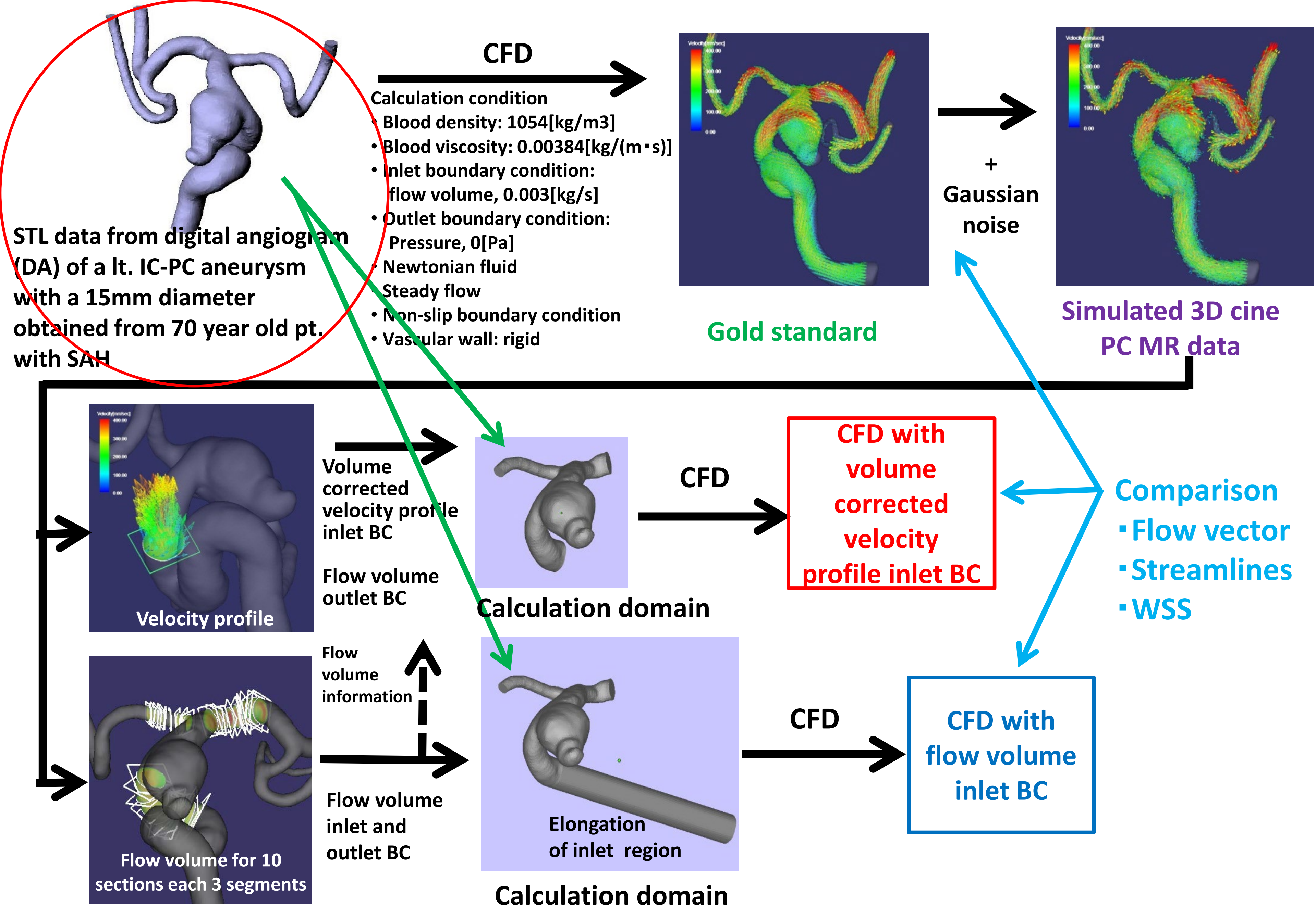
PURPOSE

- The purpose of our study was to perform CFD with velocity profile inlet BC and flow volume inlet BC with the aid of simulated 3D cine PC MR data set of an intracranial aneurysm, and to compare velocities, streamlines and WSS obtained from the two types of CFD, using the true 3D data set as a gold standard.

Materials and Methods



Overview of this study



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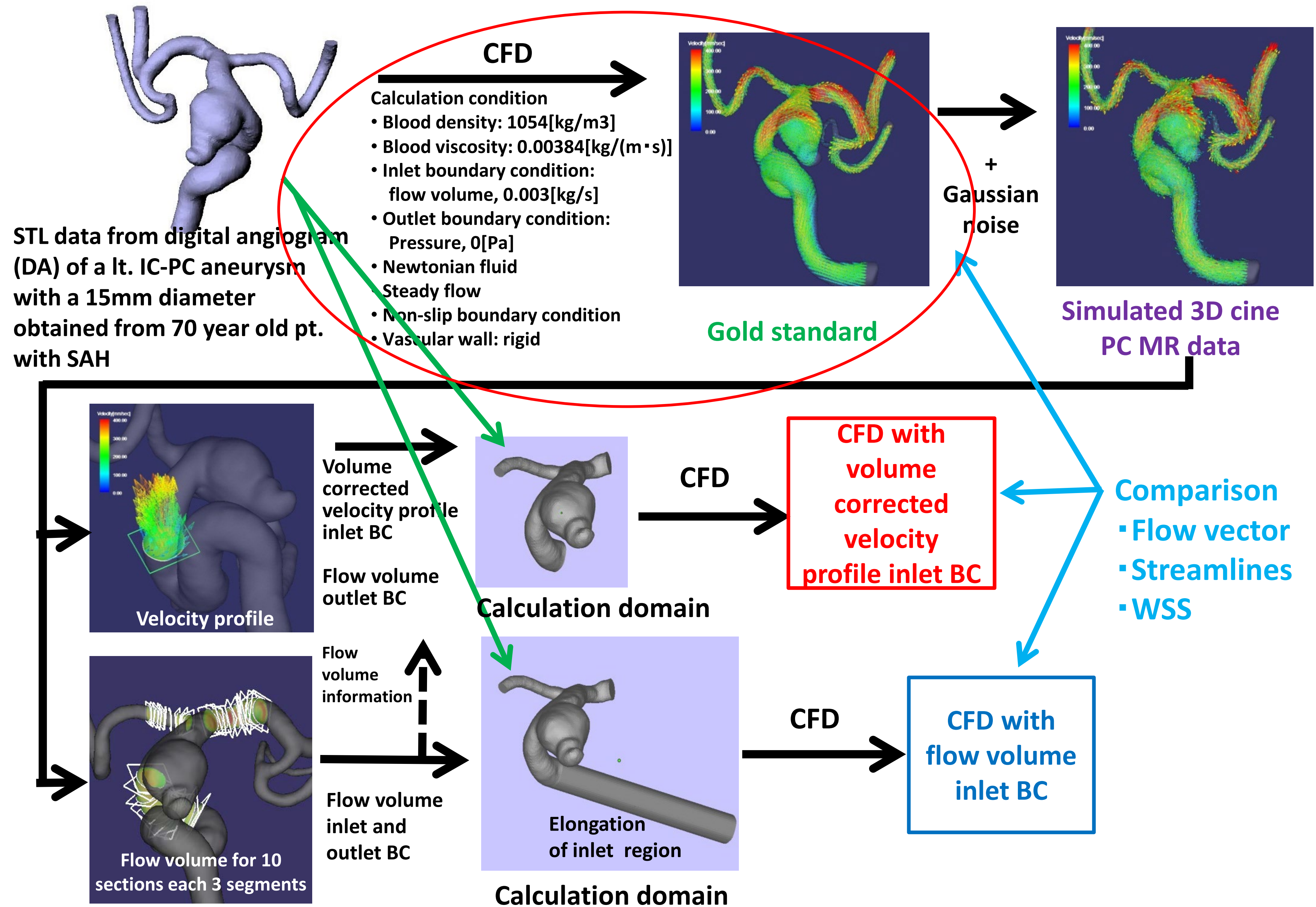

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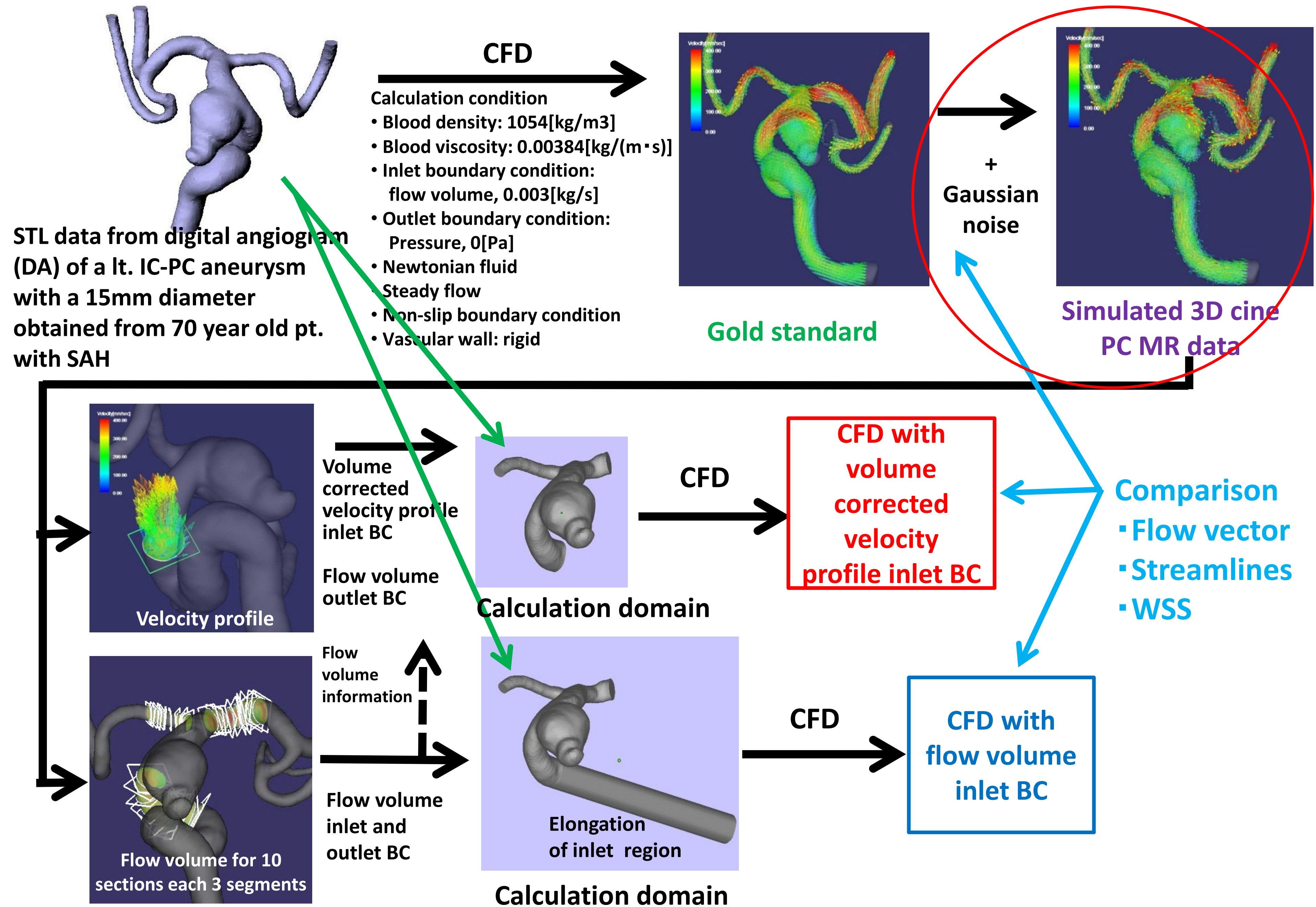

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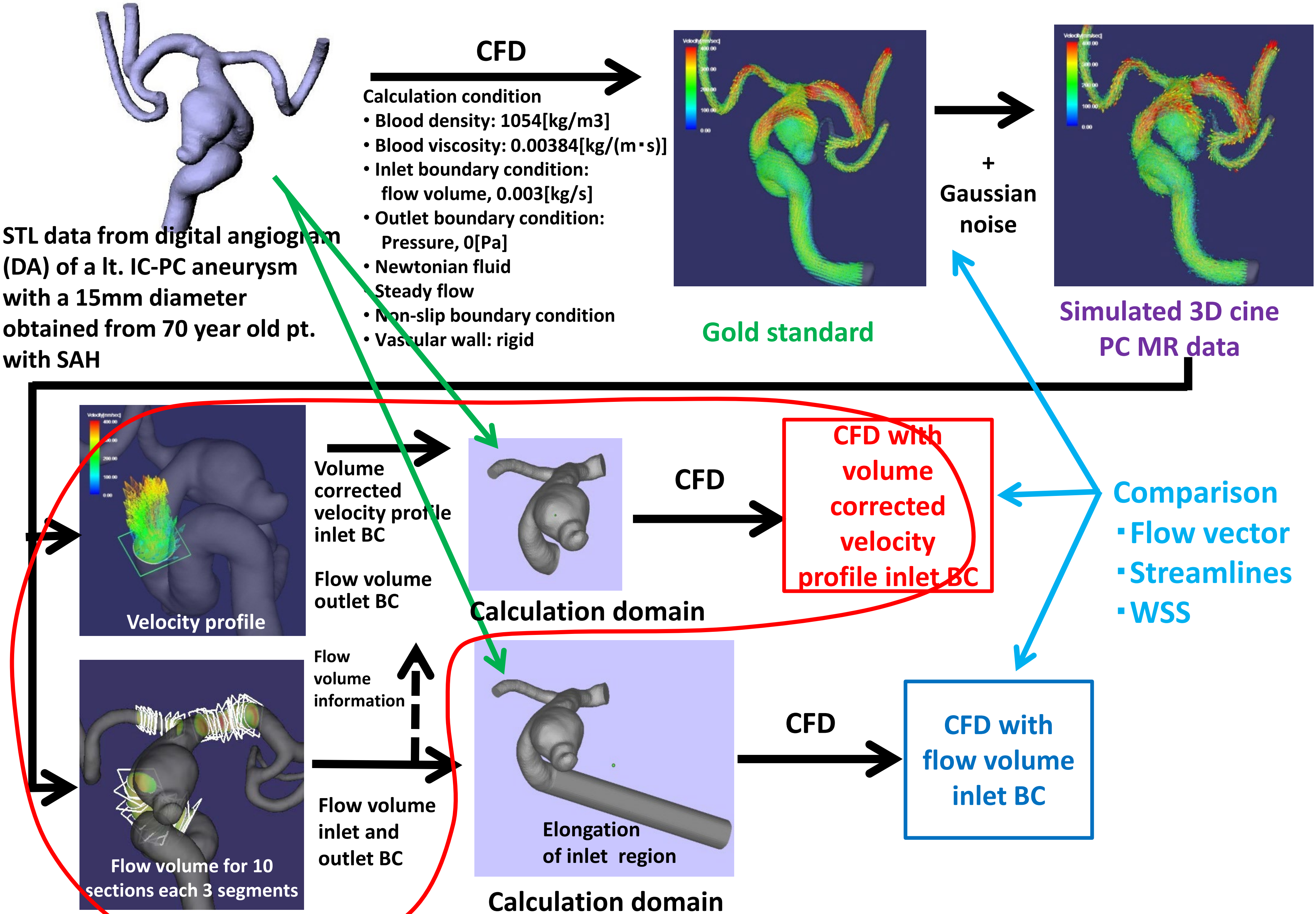

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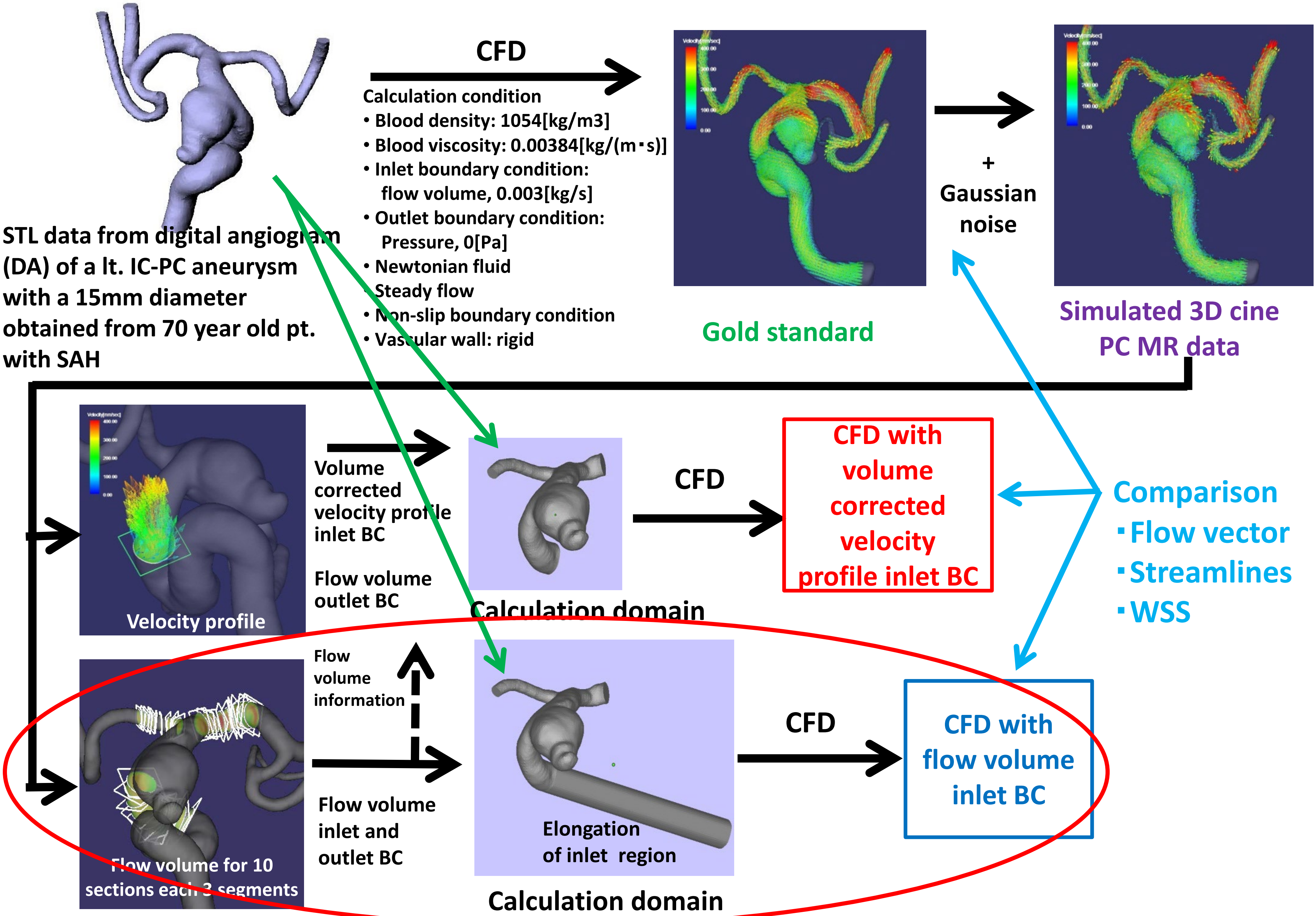

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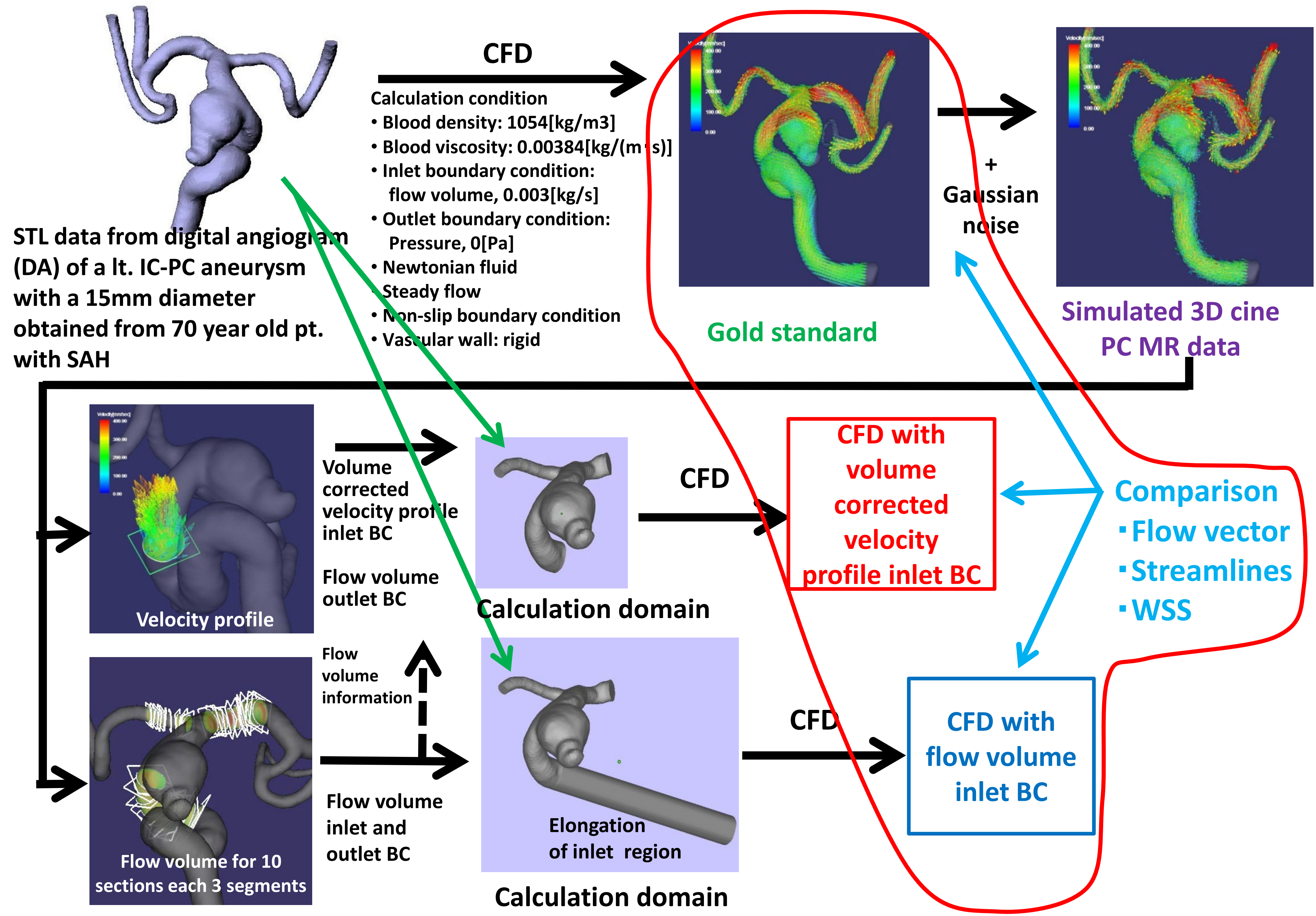
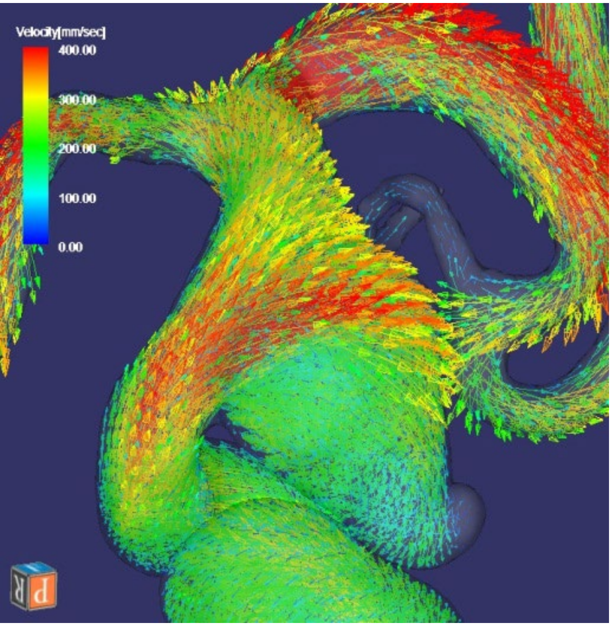
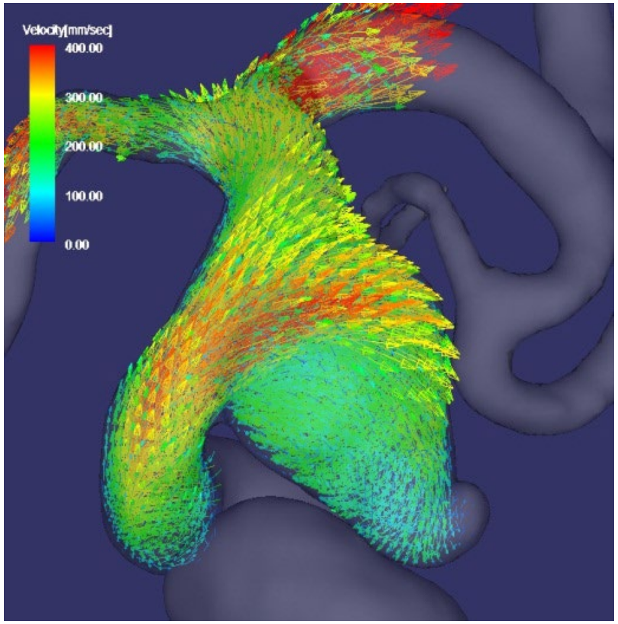
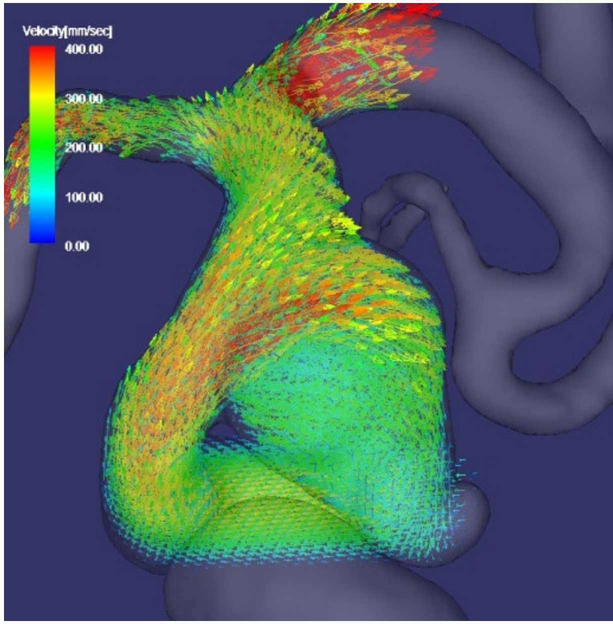


Overview of this study

RESULTS 1







Gold standard

CFD with flow volume corrected velocity profile inlet BC

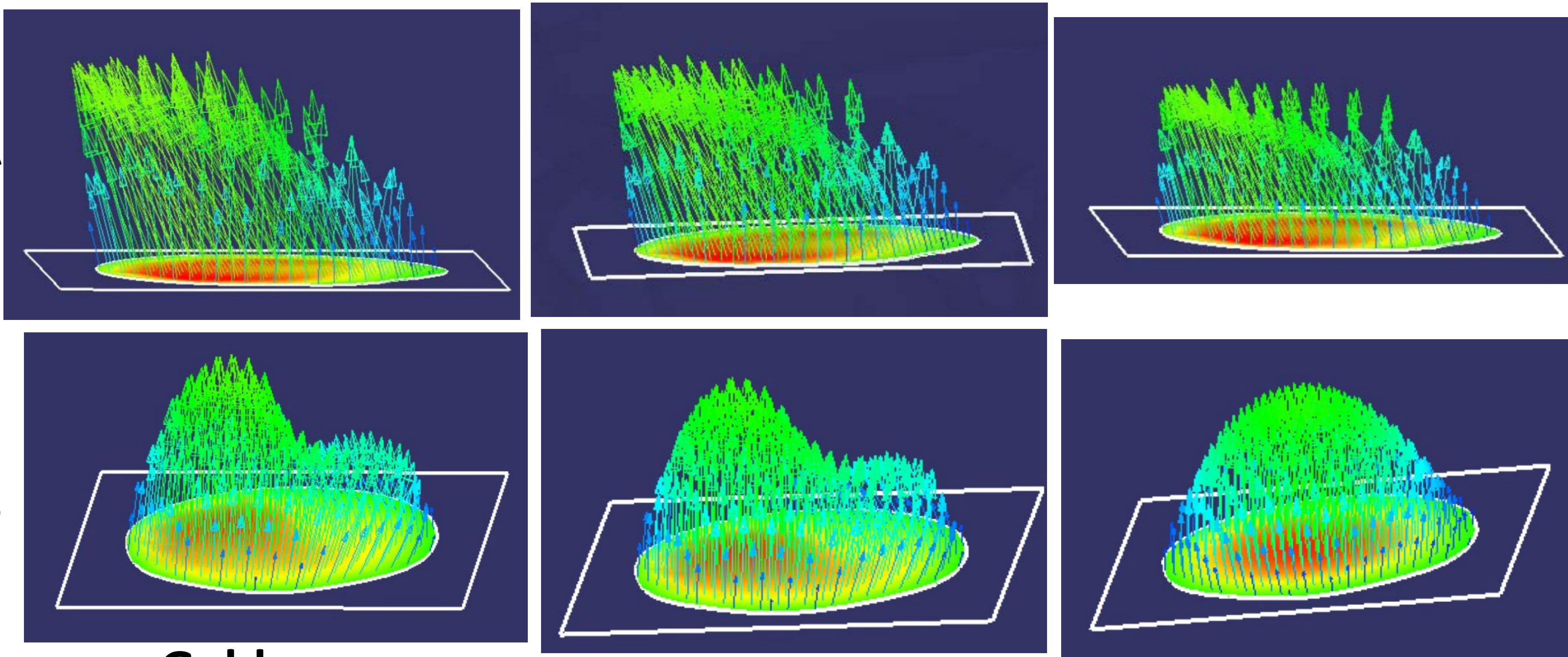
CFD with flow volume inlet BC

Comparison of velocity vector maps

RESULTS 2

A

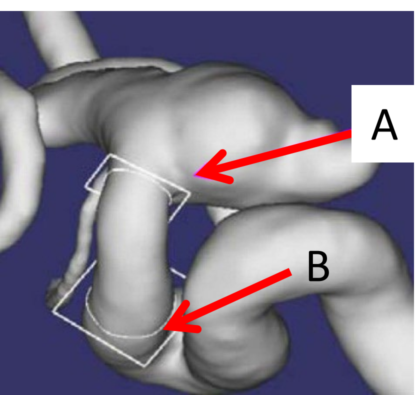
B



Gold standard

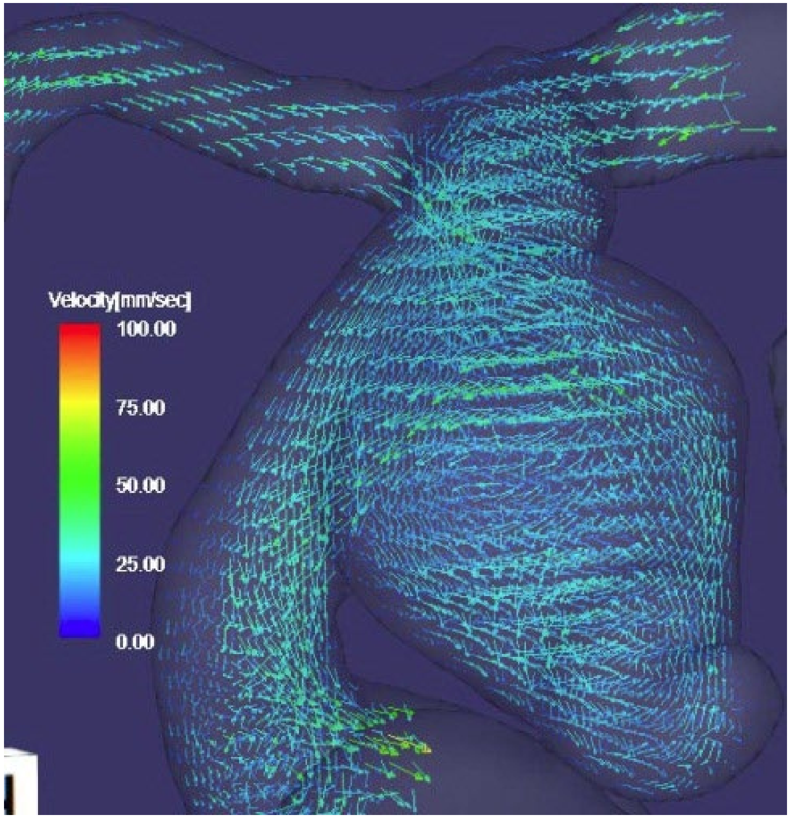
CFD with flow volume corrected velocity profile inlet BC

CFD with flow volume inlet BC

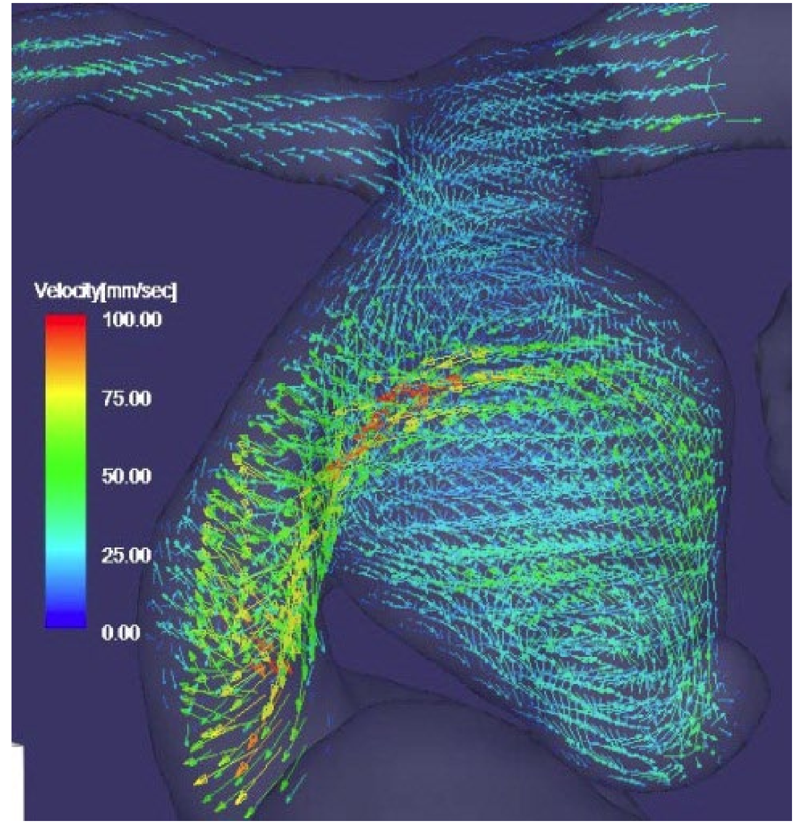


Comparison of flow velocities at the inlet and at the portion 11mm down stream from the inlet

REAULTS 3



Subtraction vector map of CFD with flow volume corrected flow velocity inlet BC from Gold standard

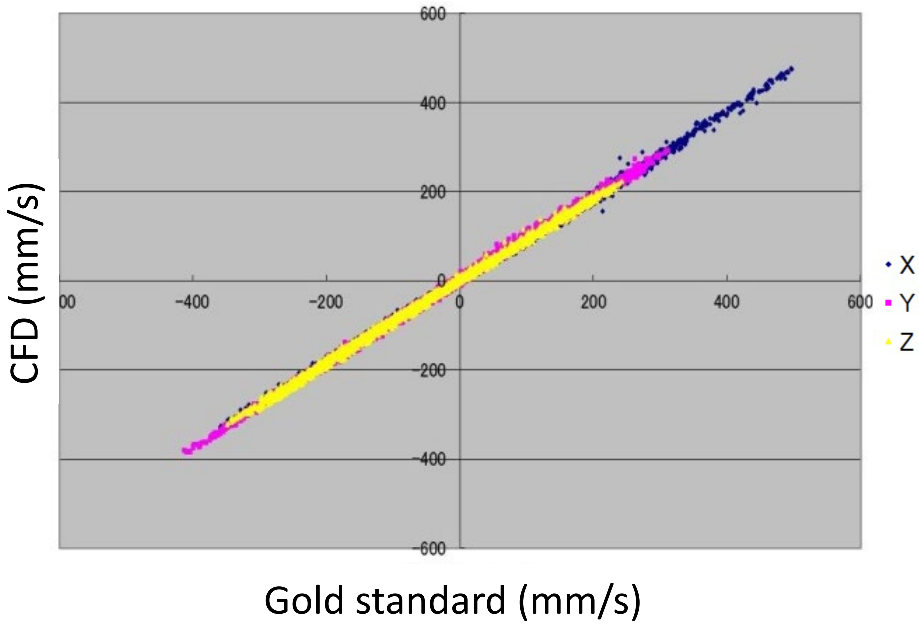


Subtraction vector map of CFD with flow volume inlet BC from Gold standard

Comparison of the velocity differences between two types of CFD and gold standard

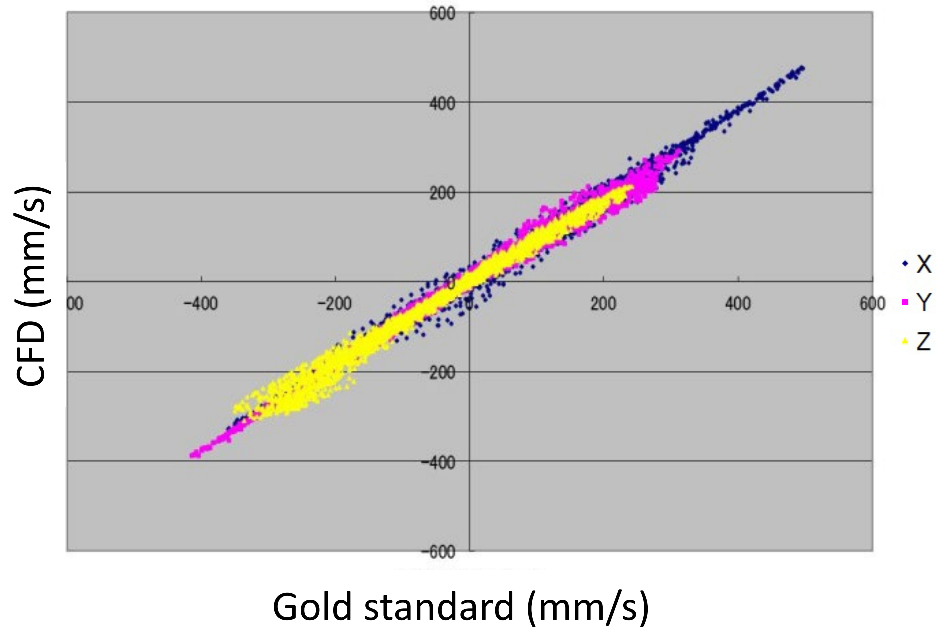
RESULTS 4

Correlation coefficients in three velocity components
X: 0.99929
Y: 0.999175
Z: 0.998979



Correlation chart between gold standard and CFD with flow volume corrected velocity profile inlet BC

Correlation coefficients in three velocity components
X: 0.999317
Y: 0.996258
Z: 0.995104

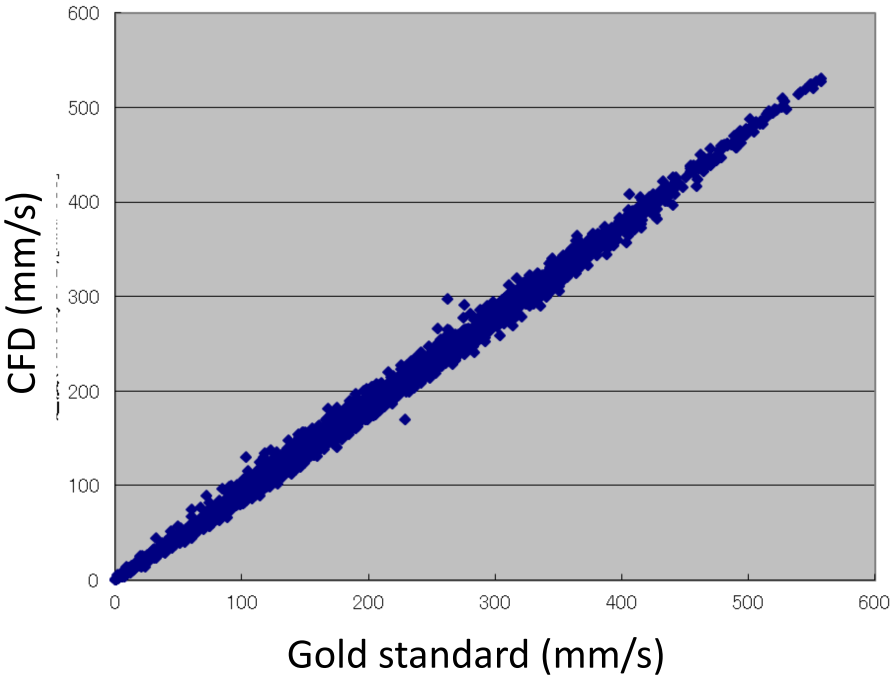


Correlation chart between gold standard and CFD with flow volume inlet BC

Comparison of correlation coefficients of velocities in in three velocity components between gold standard and two types of CFD

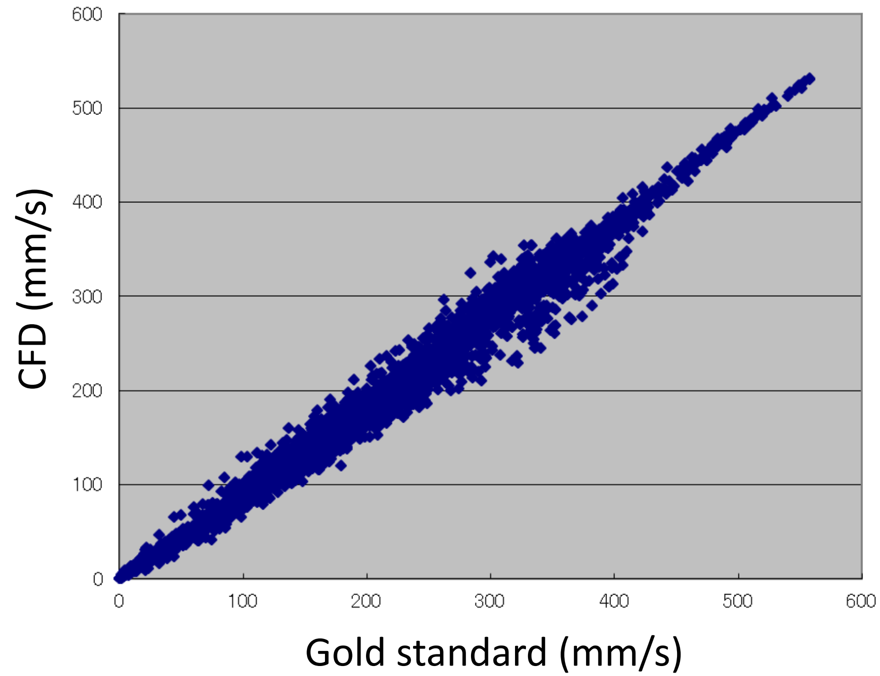
RESULTS 5

Correlation coefficient in vector length, 0.998213



Correlation chart between gold standard and CFD with flow volume corrected velocity profile inlet BC

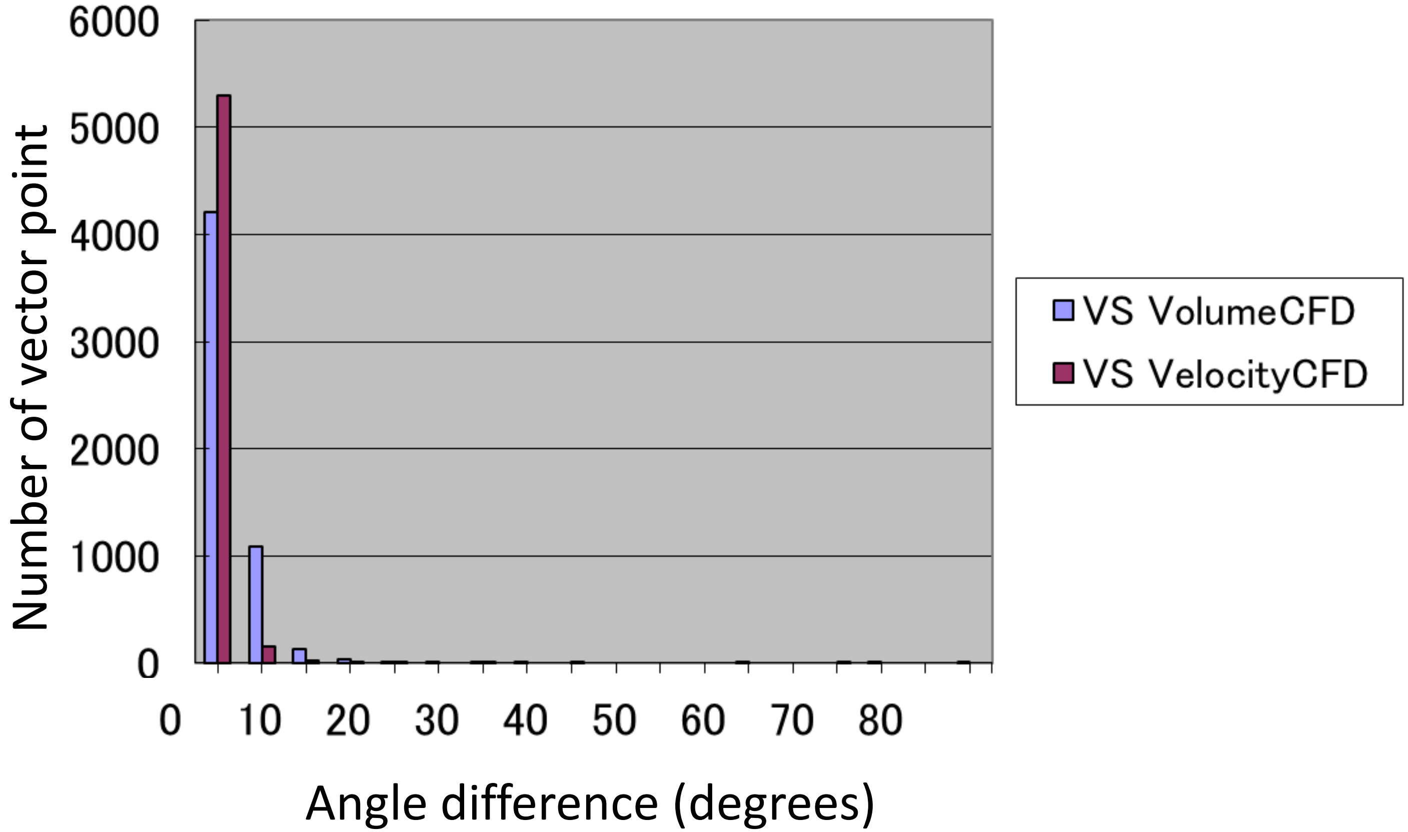
Correlation coefficient in vector length, 0.992992



Correlation chart between gold standard and CFD with flow volume inlet BC

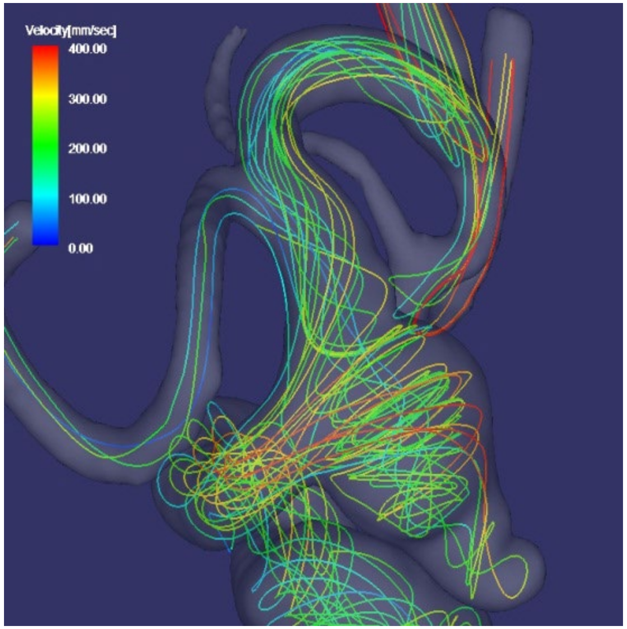
Comparison of correlation coefficients of **vector length** between gold standard and two types of CFD

RESULTS 6

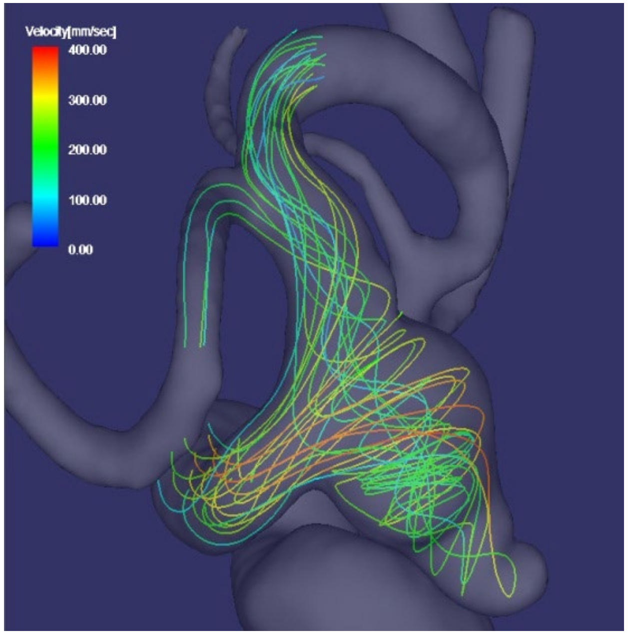


Angle differences of vectors of two types of CFD from those of gold standard at each corresponding point

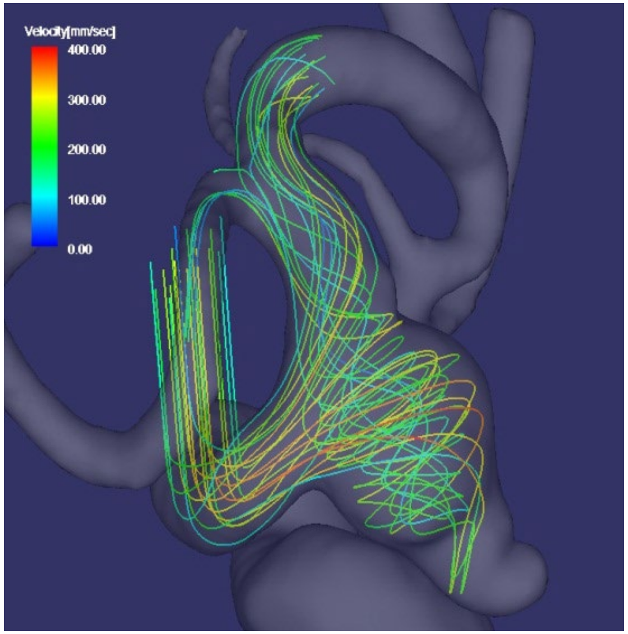
RESULTS 7



Gold standard



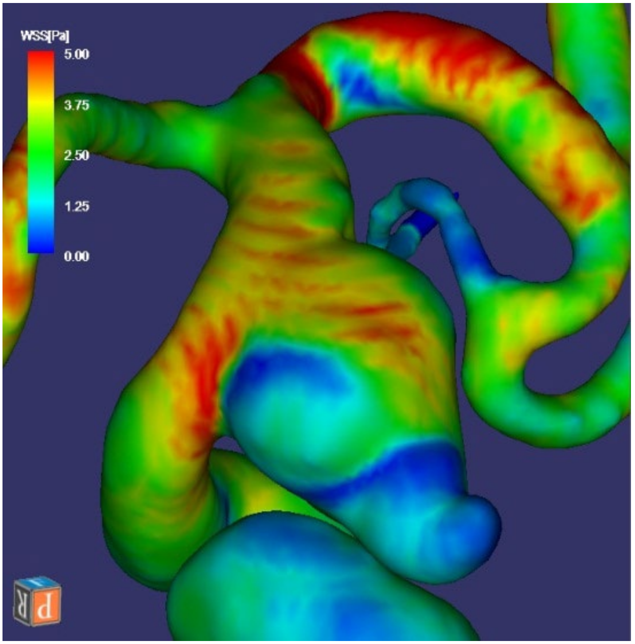
CFD with flow volume corrected velocity profile inlet BC



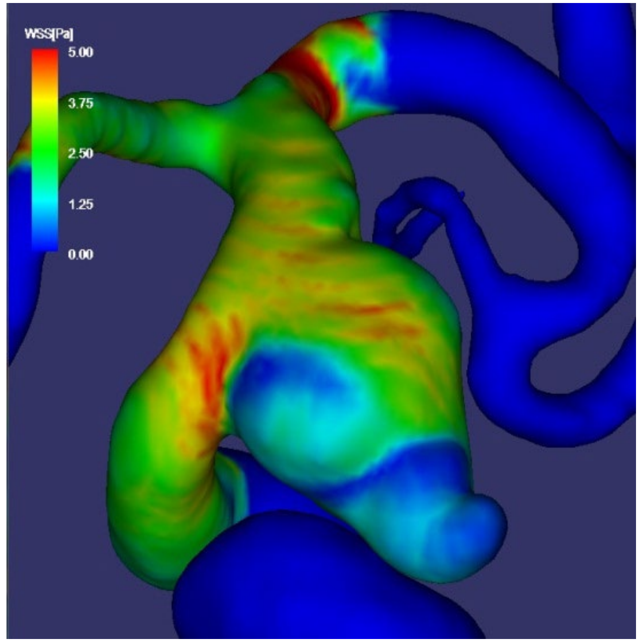
CFD with flow volume inlet BC

Comparison of streamlines

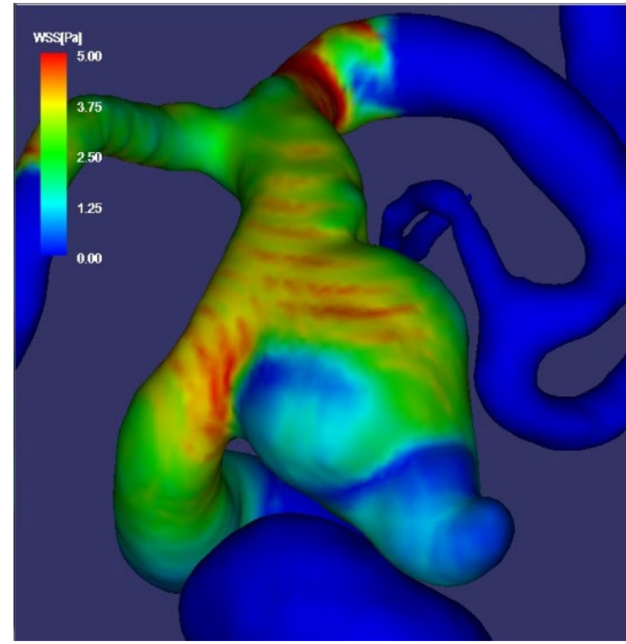
RESULTS 8



Gold standard



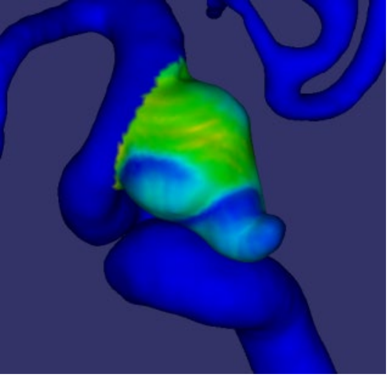
CFD with flow volume corrected velocity profile inlet BC



CFD with flow volume inlet BC

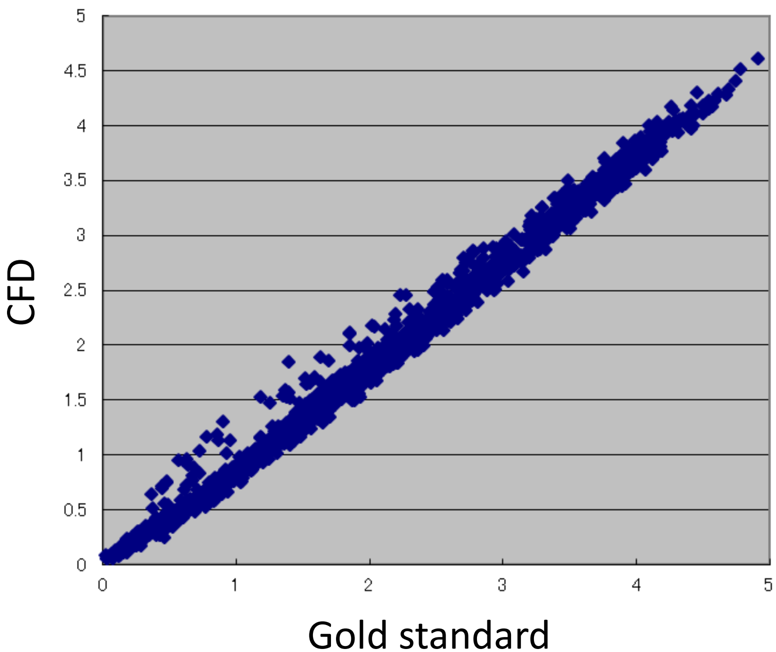
Comparison of WSS

RESULTS 9

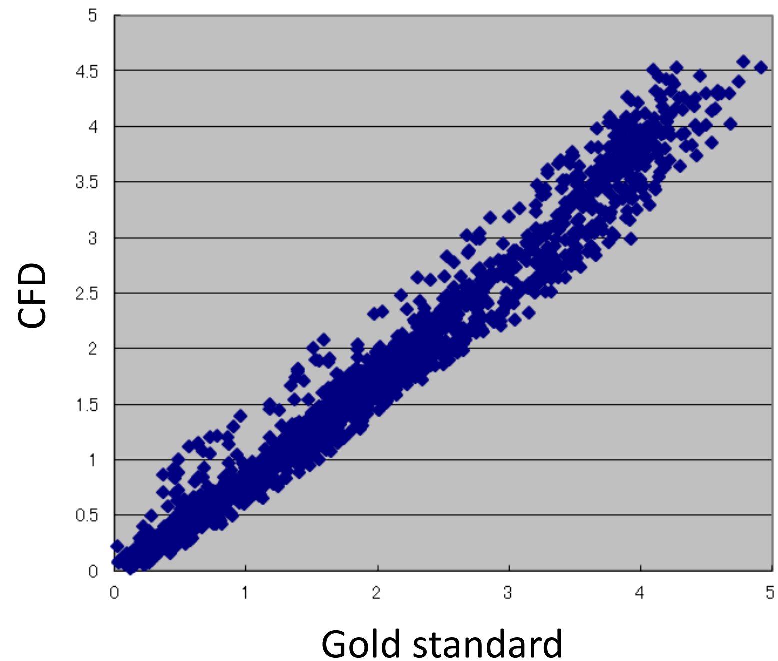


Correlation coefficient in WSS of the intracranial aneurysm, 0.995496

Correlation coefficient in WSS of the intracranial aneurysm, 0.981925



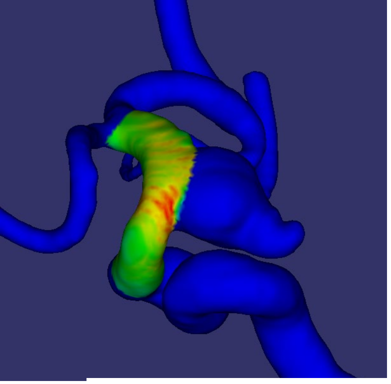
Correlation chart between gold standard and CFD with flow volume corrected velocity profile inlet BC



Correlation chart between gold standard and CFD with flow volume inlet BC

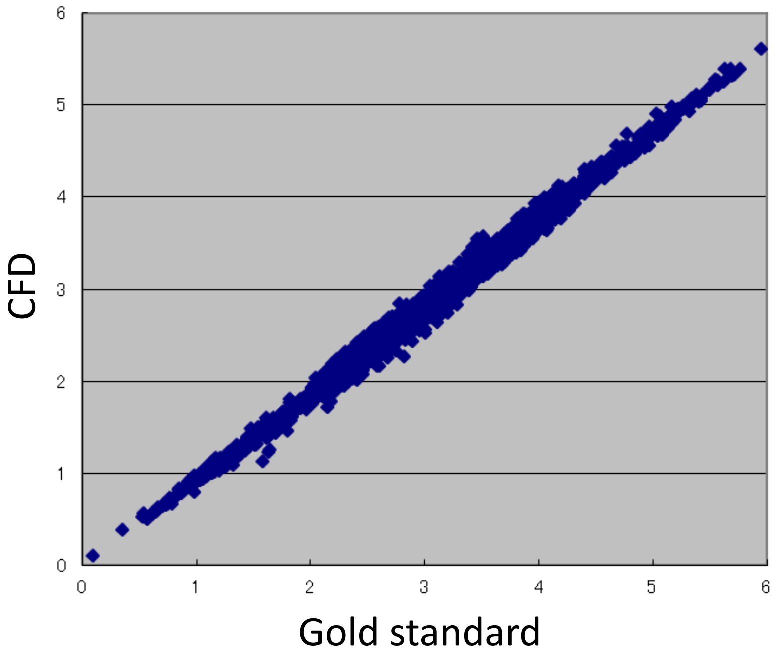
Comparison of correlation coefficients in WSS of the intracranial aneurysm between gold standard and two types of CFD

RESULTS 10

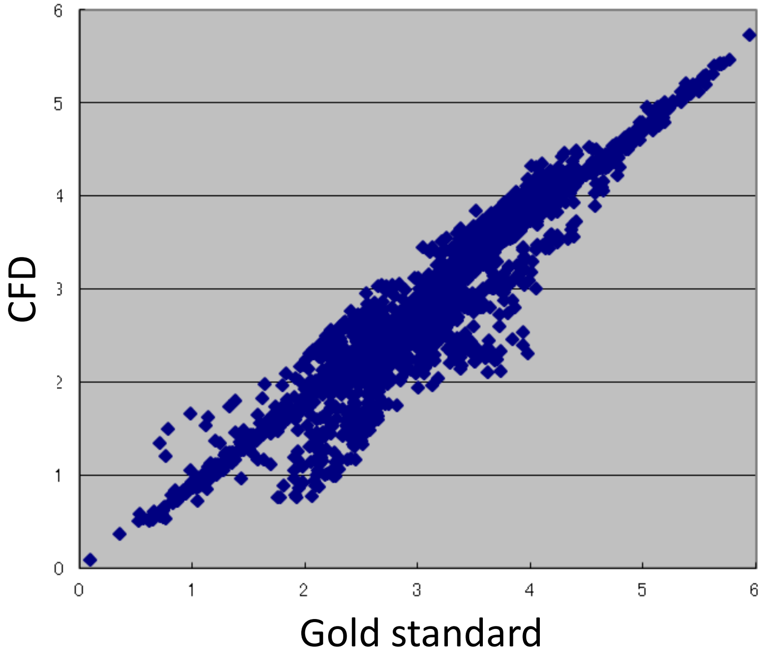


Correlation coefficient
in WSS of the parent artery,
0.996069

Correlation coefficient
in WSS of the parent artery,
0.952791



Correlation chart between gold standard and CFD with flow volume corrected velocity profile inlet BC



Correlation chart between gold standard and CFD with flow volume inlet BC

Comparison of correlation coefficients in WSS of the parent artery between gold standard and two types of CFD

DISCUSSION 1

- In practical MR-based CFD, adequate inlet region length can not be obtained, because imaging slab of 3D cine PC MR is limited due to relatively longer imaging time.
- In this simulation study, CFD with flow volume corrected velocity profile inlet BC was superior to CFD with flow volume inlet BC for accurate velocity vectors and WSS in and around the aneurysm.

DISCUSSION 2

- There were several limitations in this study.
  - Number of patients and the location of the inlet was limited.
  - Not pulsatile flow but steady flow
  - Intracranial aneurysmal geometry for simulated MR-based CFD calculation in this study was the same as the true geometry used for Gold standard. In practical CFD, we usually can’t help but use different geometry from true vascular shape. We thought that such geometric differences from the true may affect the CFD results much more than boundary conditions.

CONCLUSION

- CFD with flow volume corrected velocity profile inlet BC was superior to CFD with flow volume inlet BC in this simulation study for an intracranial aneurysm. Therefore, flow volume corrected velocity profile inlet BC should be used for MR-based CFD of intracranial aneurysms.
- According to our results, we can obtain accurate 3D velocity vector fields from MR-based CFD using flow volume corrected velocity profile inlet BC, whereas 3D cine PC MR data sets from the human body contain errors.