Blood Fluid Dynamics Simulation in the Aorta-Heart System with Fluid-Structure Interaction (FSI) Methods

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Introduction

Blunt aortic injury in Motor Vehicle Crash Accidents (MVCs):

- Second-most common cause to death for victims of blunt chest trauma;
- Up to 15% of deaths related to MVCs;
- About 80% dead at the scene.

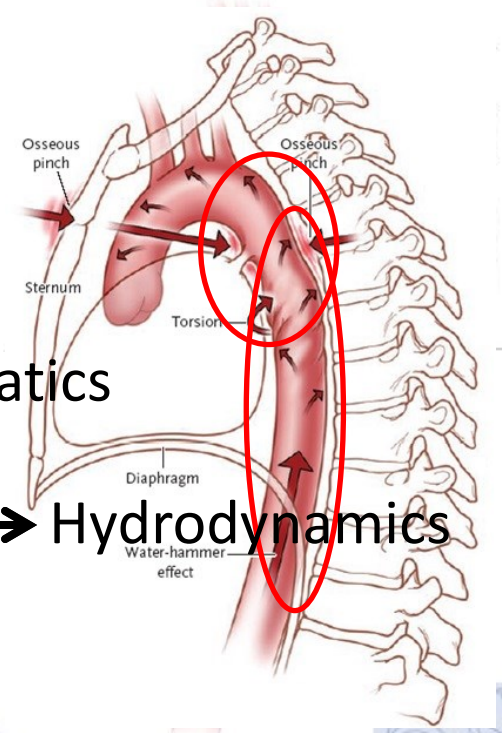
(Fox et al., 2015)

Uncertain injury mechanisms:

- Sudden stretch or shear of aorta;
- Entrapment by the surrounding organs;

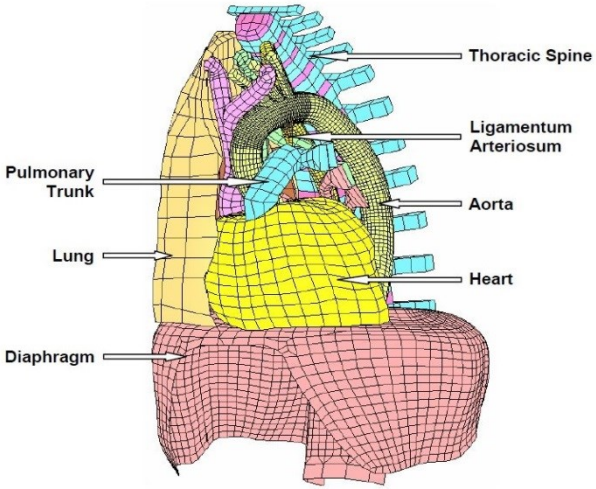
} Kinematics

- Sudden stroke of blood pressure (water hammer); → Hydrodynamics
- The comprehensive effects.



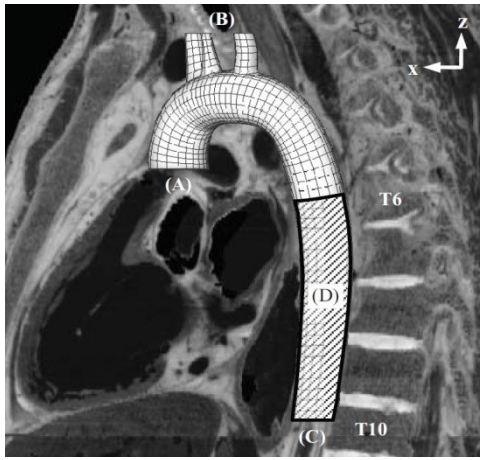
Previous models:

(1)



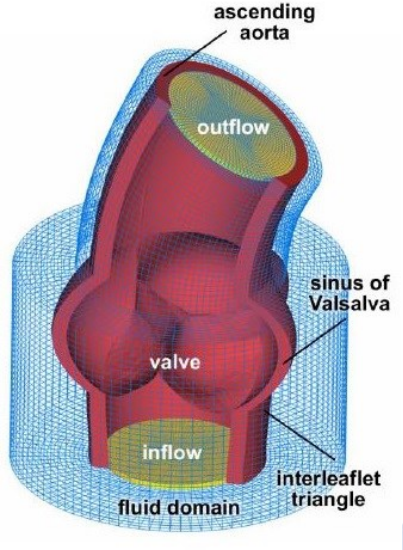
Shah et al., 2007

Richens et al., 2007

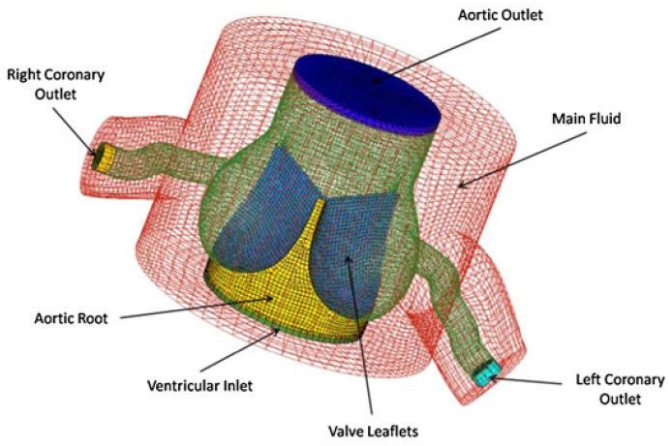


Lee et al., 2007

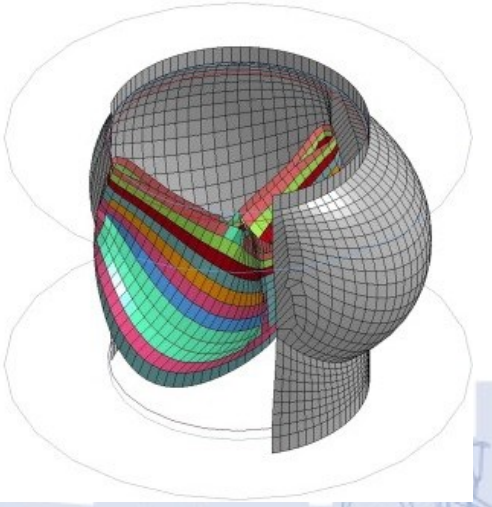
(2)



Sturla et al., 2013



Nobari et al., 2013



Sundaram et al., 2015

Objectives

Hydrodynamics study on blood flowing in the aorta-heart system

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--Isolated aorta-heart system
--Heart beating (contraction and relaxation)
--FSI coupling (LS-DYNA)
--Blood flowing validation

Kinematics study on the aorta interacting with the surrounding organs

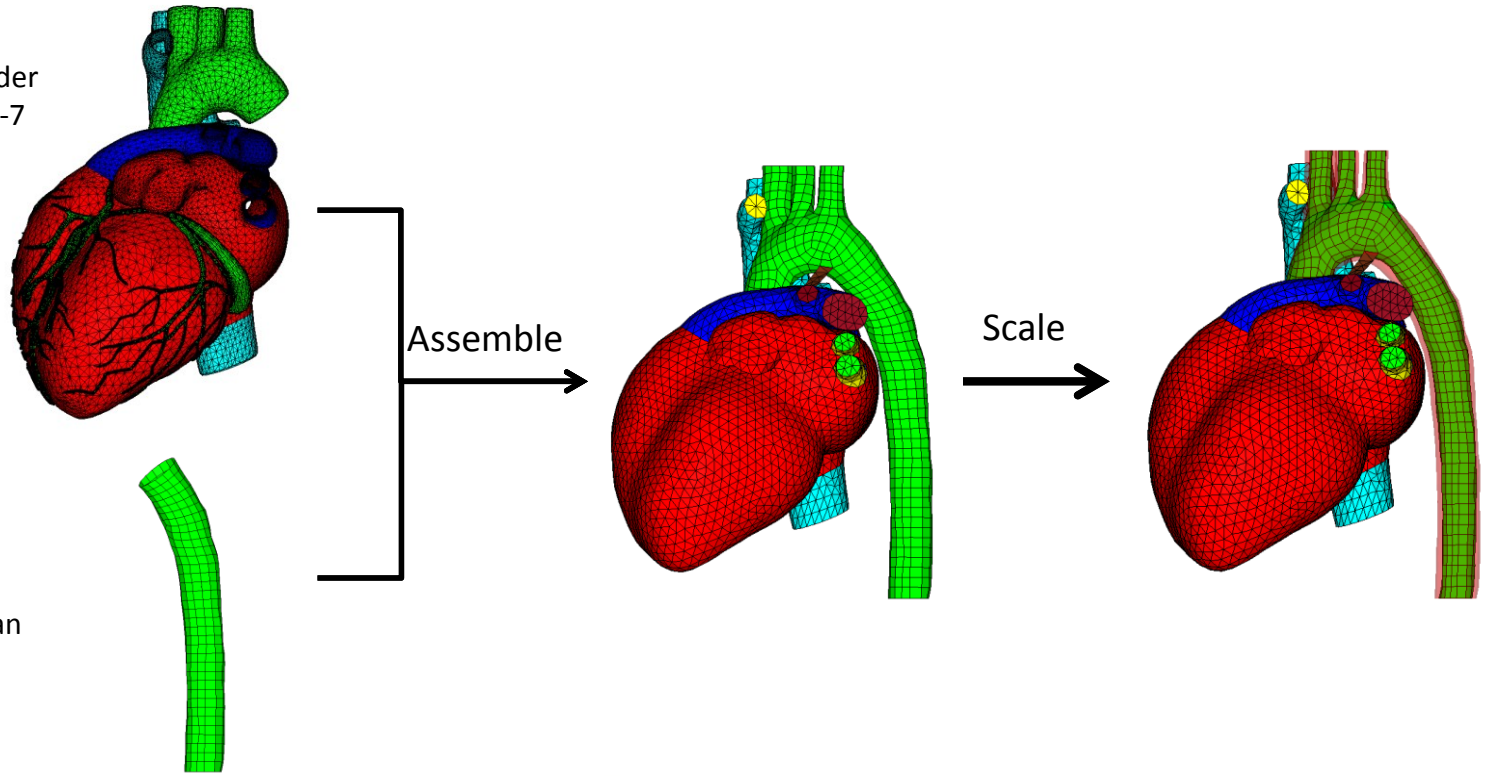
--Integrated with thoracic model
--Physiological or deceleration loading
--Kinematics validation (acceleration or relative movement)

Simultaneously study both kinds of mechanisms

--Impact simulation (car crash or thorax strike)
--Correlation analysis of aortic responses with kinematics and hydrodynamics

Geometric model

Source: http: //www.stlfinder .com/model/human-heart-7



Source: CT scan

Geometric model

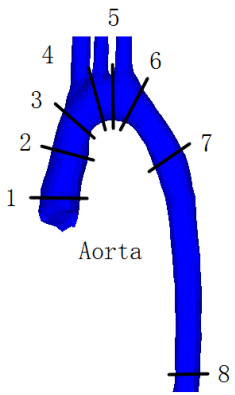


Table.1 Diameters of different aortic sections

Section	1	2	3	4	5	6	7	8
Diameter (mm)	27.4	27.8	27.1	24.8	24.0	21.9	20.8	18.1
Reference (mm)	26.8-28.7 (Nevsky et al., 2011)	27.2-29.1 (Nevsky et al., 2011)		24.4-26.4 (Isnard et al., 1989)		20.3-22.1 (Nevsky et al., 2011)		19.3-20.8 (Nevsky et al., 2011)

Table. 2 the Volume of LV

	Model	Reference
Volume (ml)	123.2	121-163 (Maceira et al., 2006)

FE model

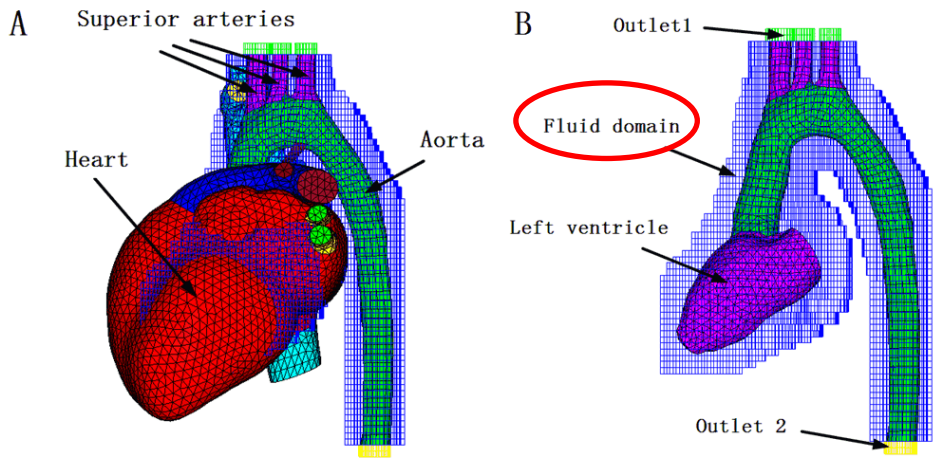


Table. 3 Number of element

Type of element	4-node shell	3-node shell	Tetrahedral	Hexahedral
Number	1,164	11,132	85,035	106,739

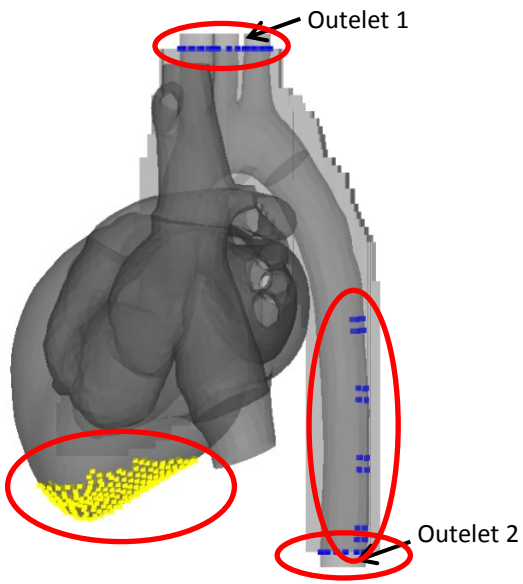
Materials (LS-DYNA)

Component	Material law	Material properties	References
Aorta	Orthotropic-elastic	E_a=6.111MPa, E_b=6.111MPa, E_c=6.111MPa, $\gamma_a = \gamma_b = \gamma_c$=2.056MPa, μ=0.4	Shah, 2007
Heart	Elastic	E=10.0MPa, μ=0.4	Shah, 2007
Other vessels and arteries	Elastic	E=10.0MPa, μ=0.4	Shah, 2007
Blood	Null and Gruneisen equation of state	ρ=1050kg/m^3, Dynamic viscosity=4.5E2 Pa·s, K=2.5GPa	Einstein et al., 2005 Sundaram et al., 2015

Boundary and loading conditions

SPCs:

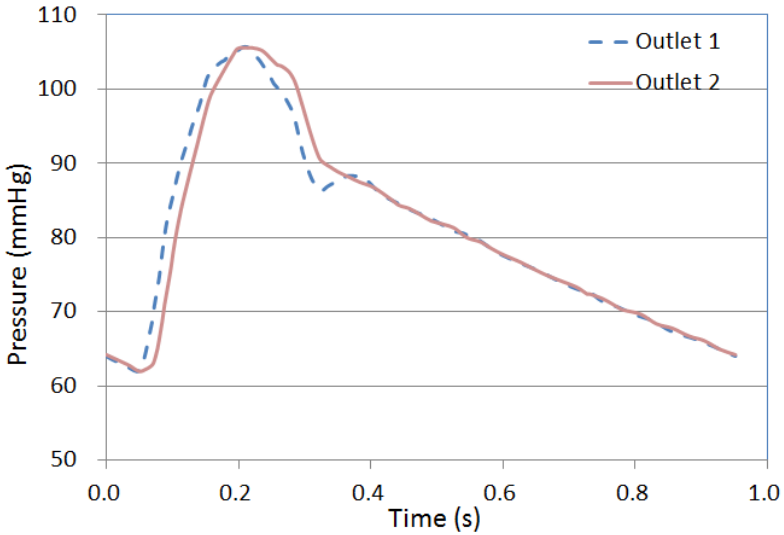
- Inferior nodes of heart (yellow);
- Posterior nodes of DA (blue);
- Superior nodes of superior arteries (blue).



SPC boundaries

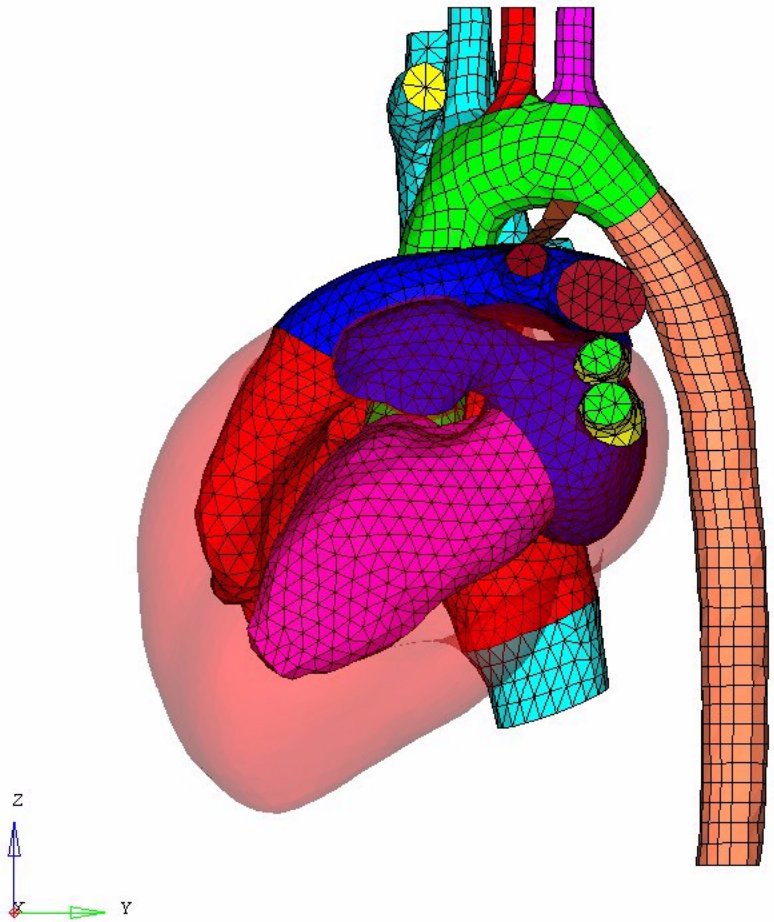
Loadings:

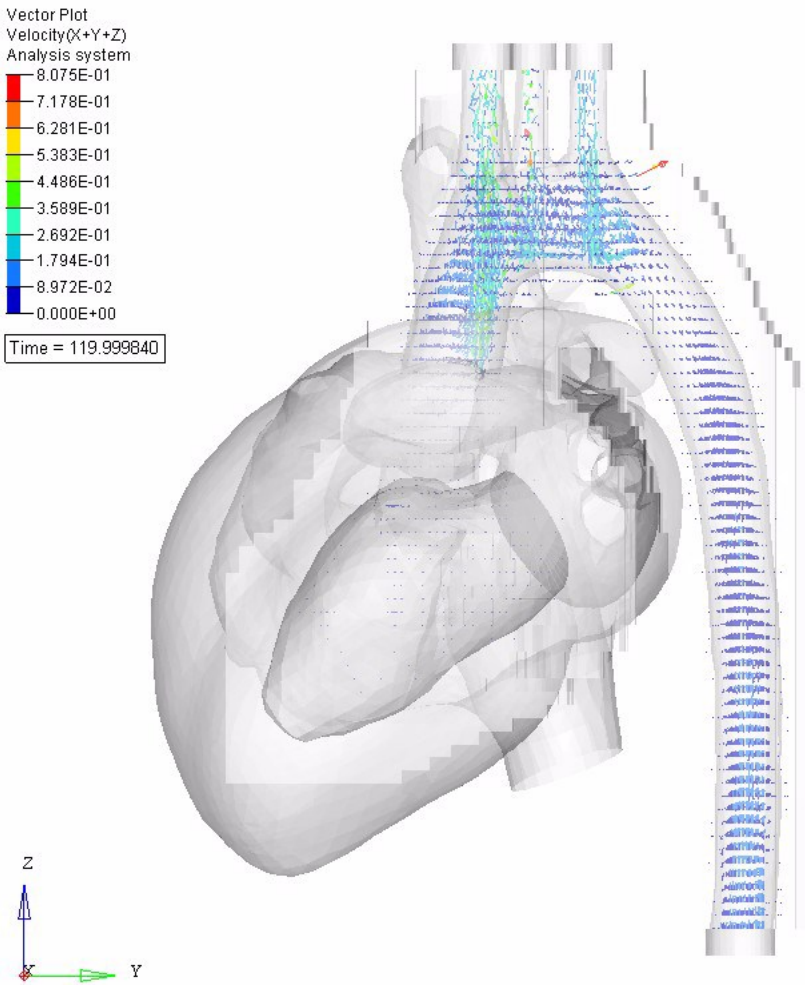
- Physiological pressure imposed to outlet 1 and 2
- Surface-distributed force applied to LV inner surface (**LV volume change**)



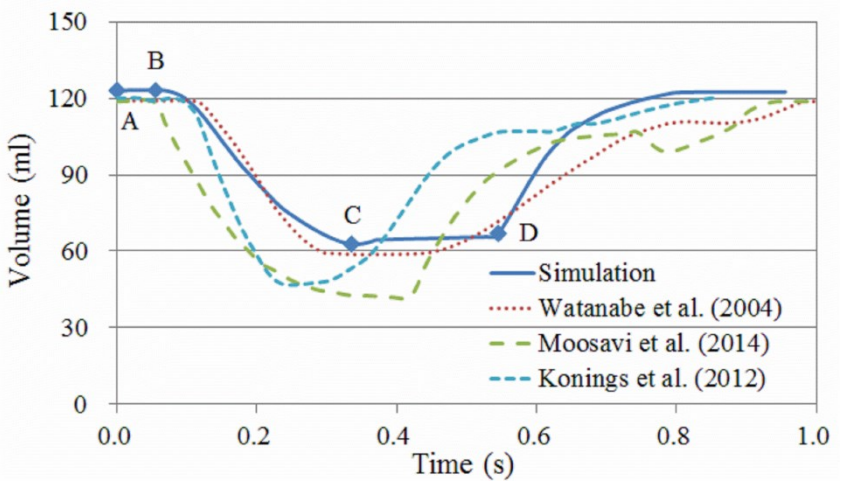
Pressure input for outlet 1 and 2 (Kim et al., 2009)

Results and discussion

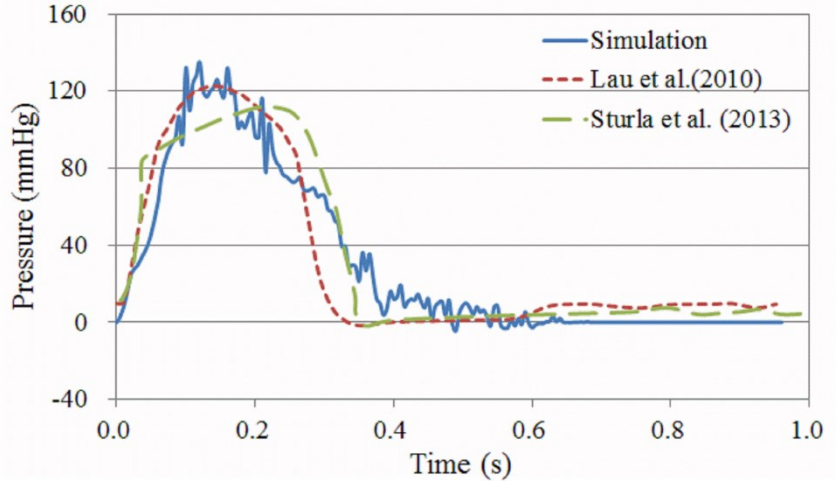




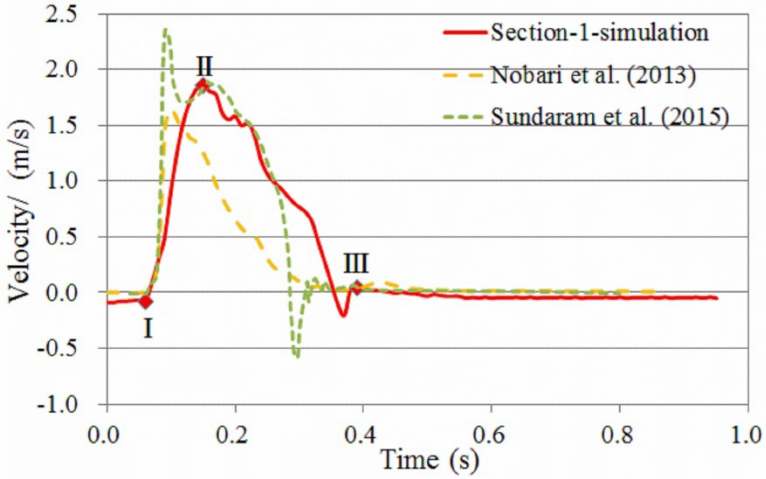
Results and discussion



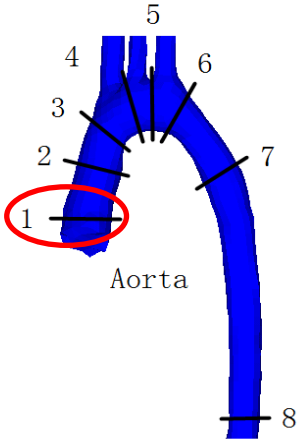
Left ventricle volume time-history

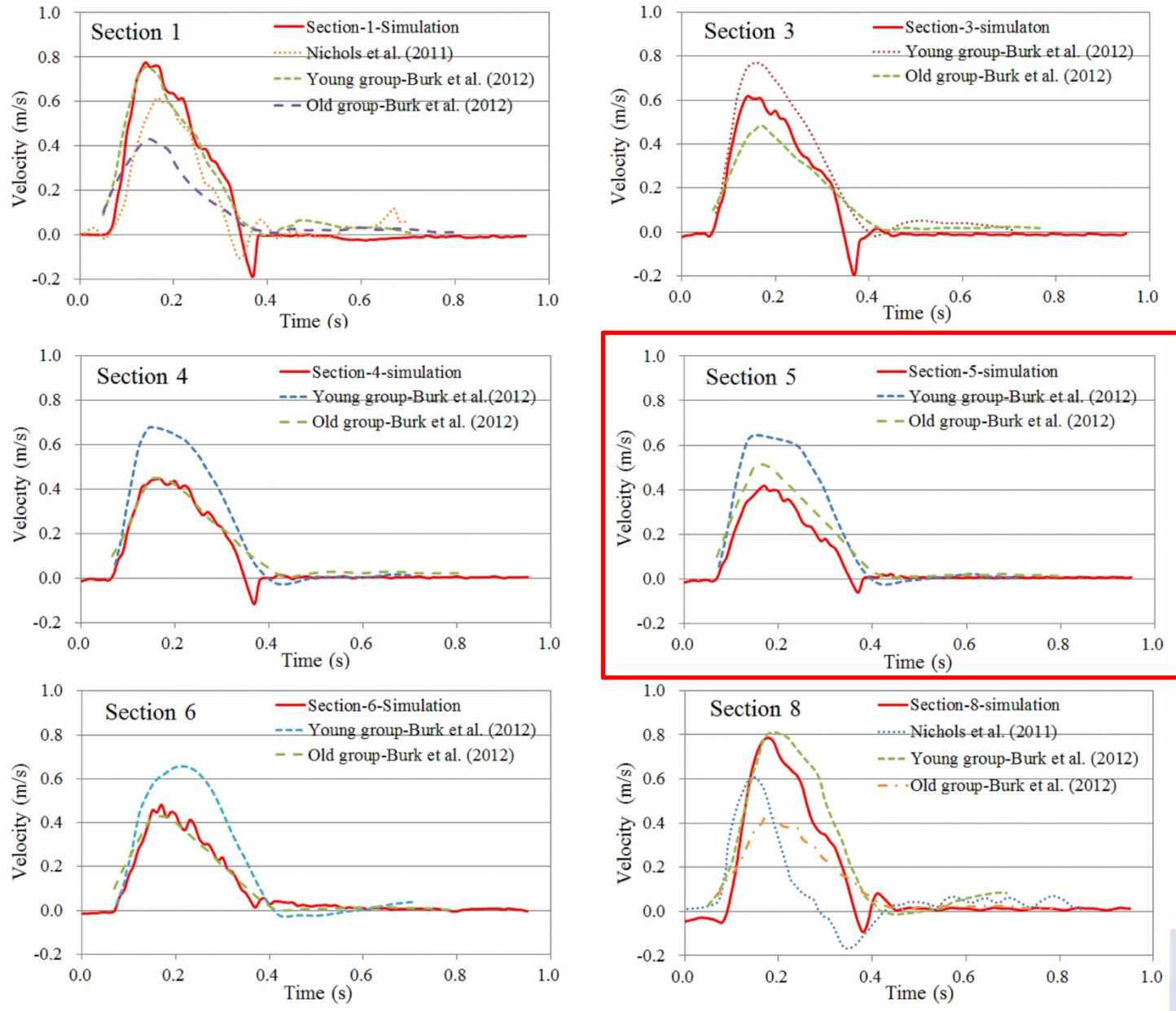


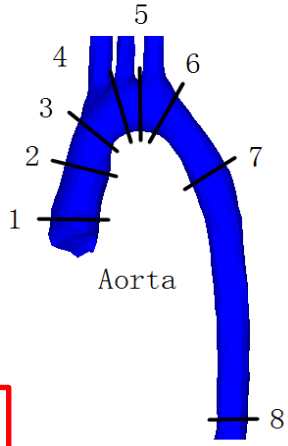
Left ventricle blood pressure time-history



Peak ejection velocity at section 1

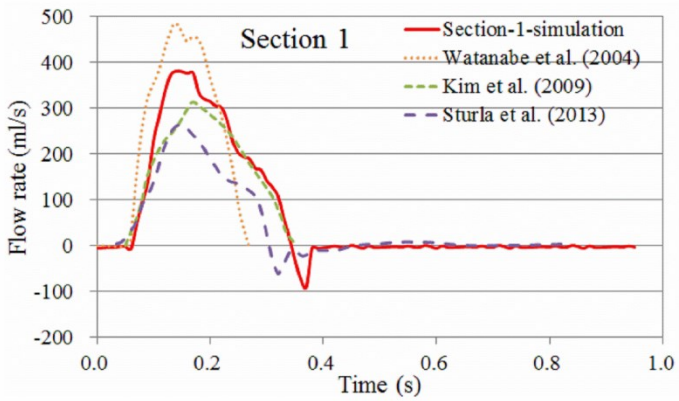


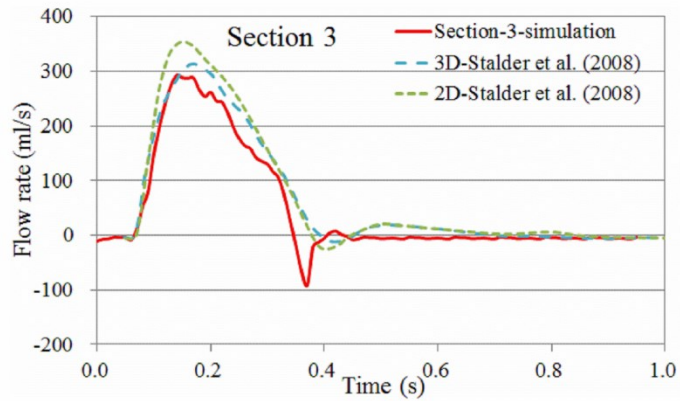


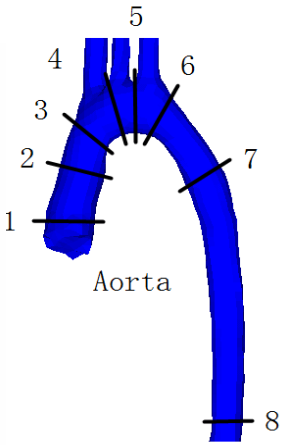


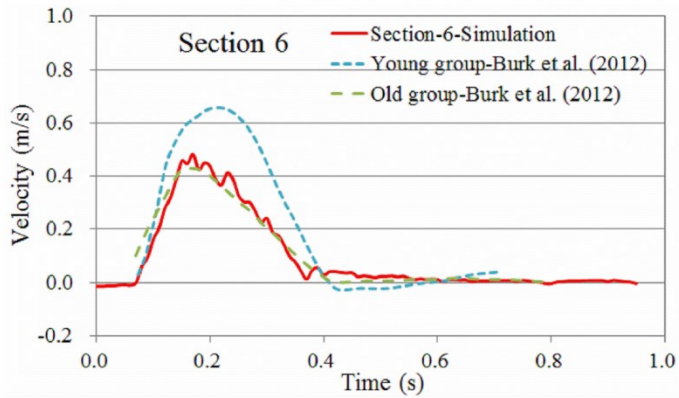
Average blood velocity for different aortic sections

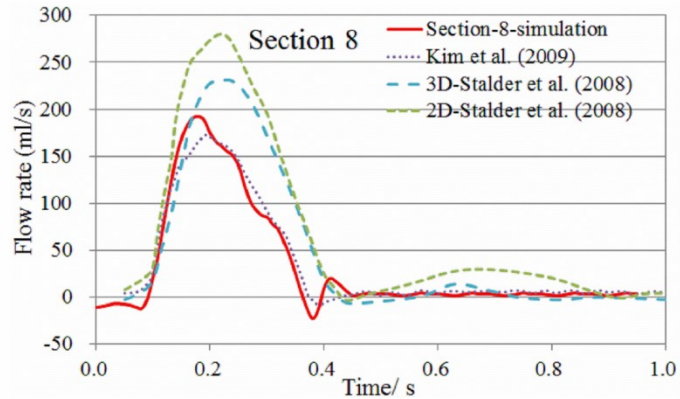
Results and discussion



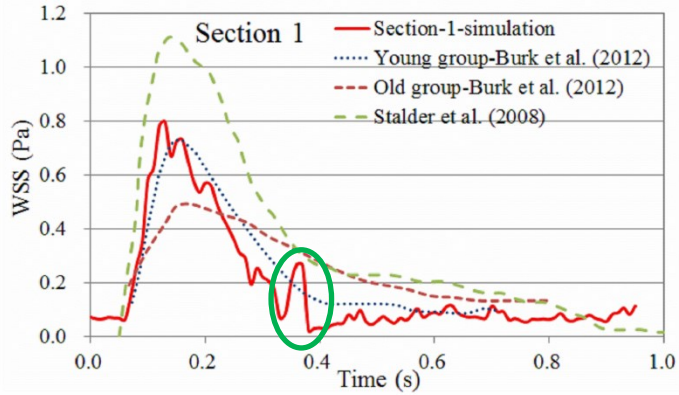


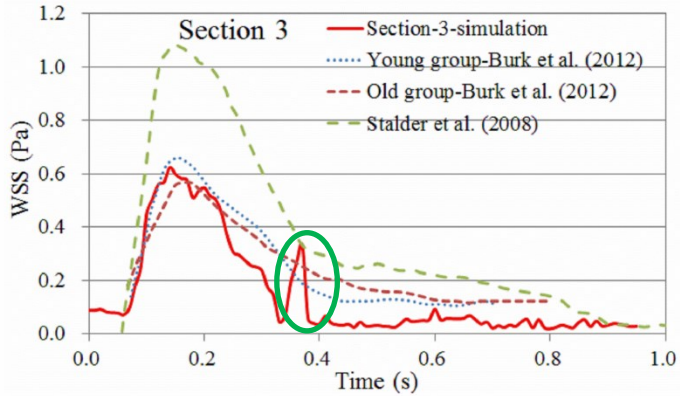


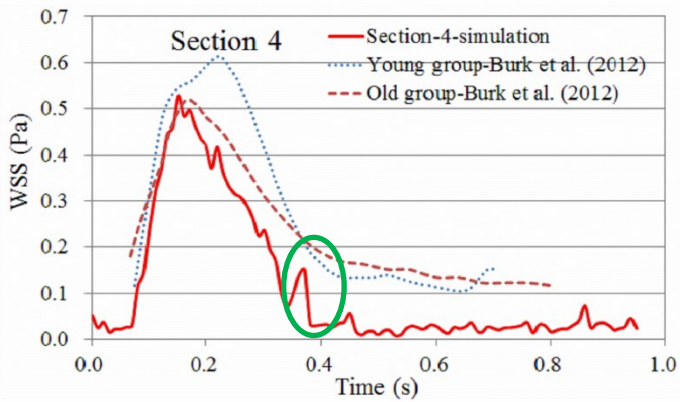


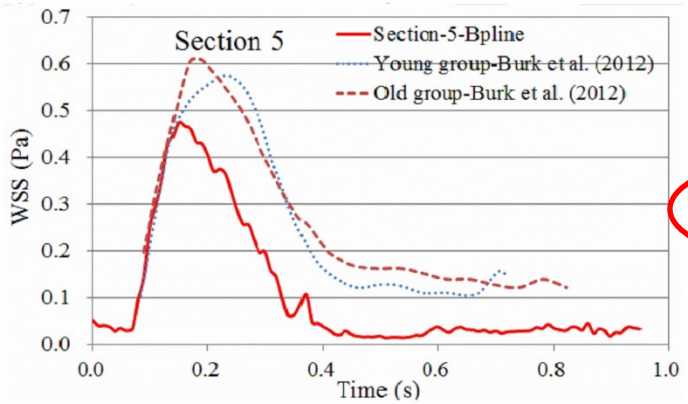


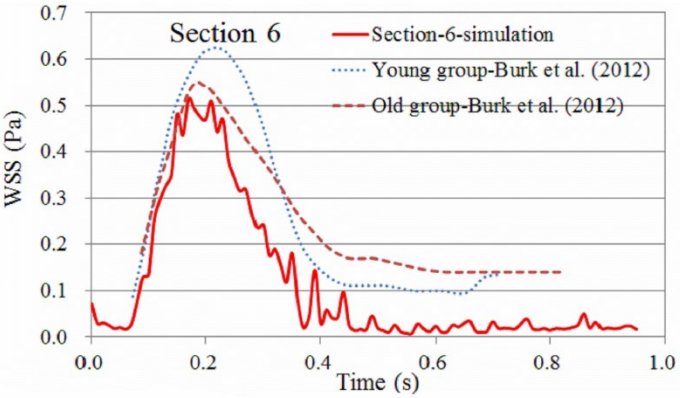
Flow rate for different aortic sections

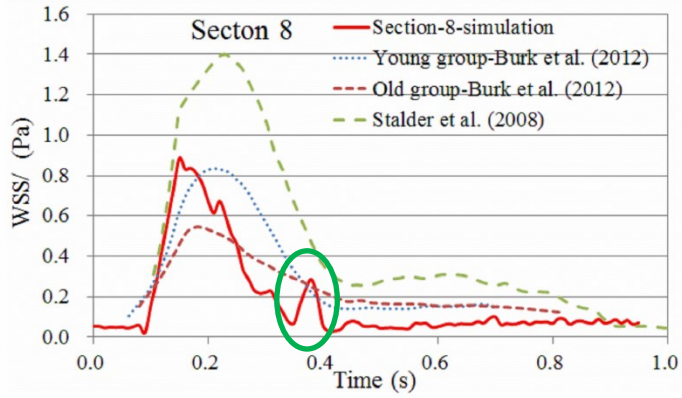


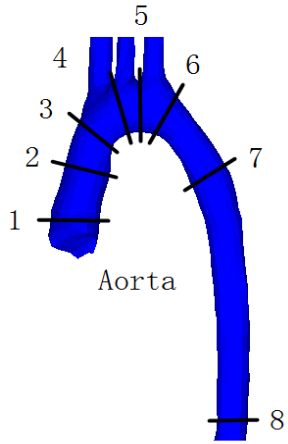












Wall shear stress (WSS)

$$WSS = \mu \left(\frac{\delta u}{\delta x}\right)_{x=0}$$

μ: dynamic viscosity

u: velocity

X: distance

Section averaged wall shear stress (WSS) time-history

Conclusion

LV volume and blood pressure → Enough blood into aorta within appropriate period

Blood velocity and flow rate → Feasibility of studying hydrodynamics with FSI

Section averaged WSS → Possibility of studying WSS effects on aortic pathologies and injuries with FSI

Future work

Integrating this isolated model with thoracic model;

Validating the relative movement of the aorta to the surrounding organs;

Simulation of car crash conditions or other scenarios;

Parameter analysis of the kinematics and hydrodynamics on aortic injury risks.

Thank you!