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# Biomechanics and Plaque Progression in Human Coronary Arteries

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# Biomechanics and Plaque Progression in Human Coronary Arteries

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# Study Overview

## *Methods: Subject Population*

Patients referred to Cath Lab  
for evaluation of CAD



Evaluation of coronary arteries by angiography,  
physiology, IVUS, and CFD



Atorvastatin 80mg a day  
for 6 months

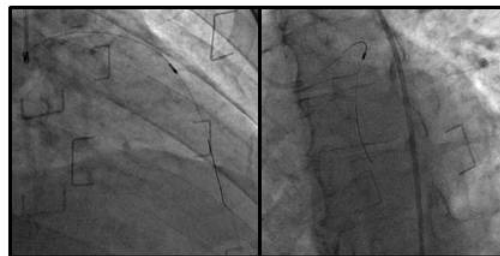


Repeat angiography, physiology, and IVUS  
at 6 months

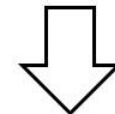
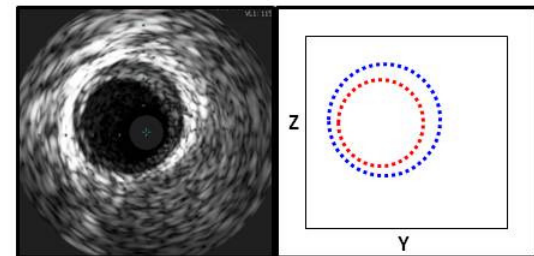
# Imaging Methods: Angiography, IVUS



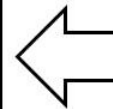
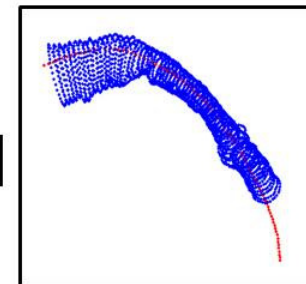
Biplane angiography



IVUS



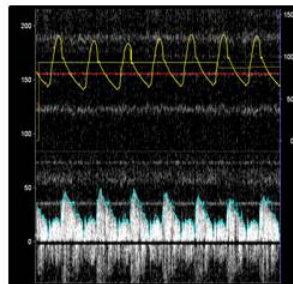
Stacking of IVUS on center line



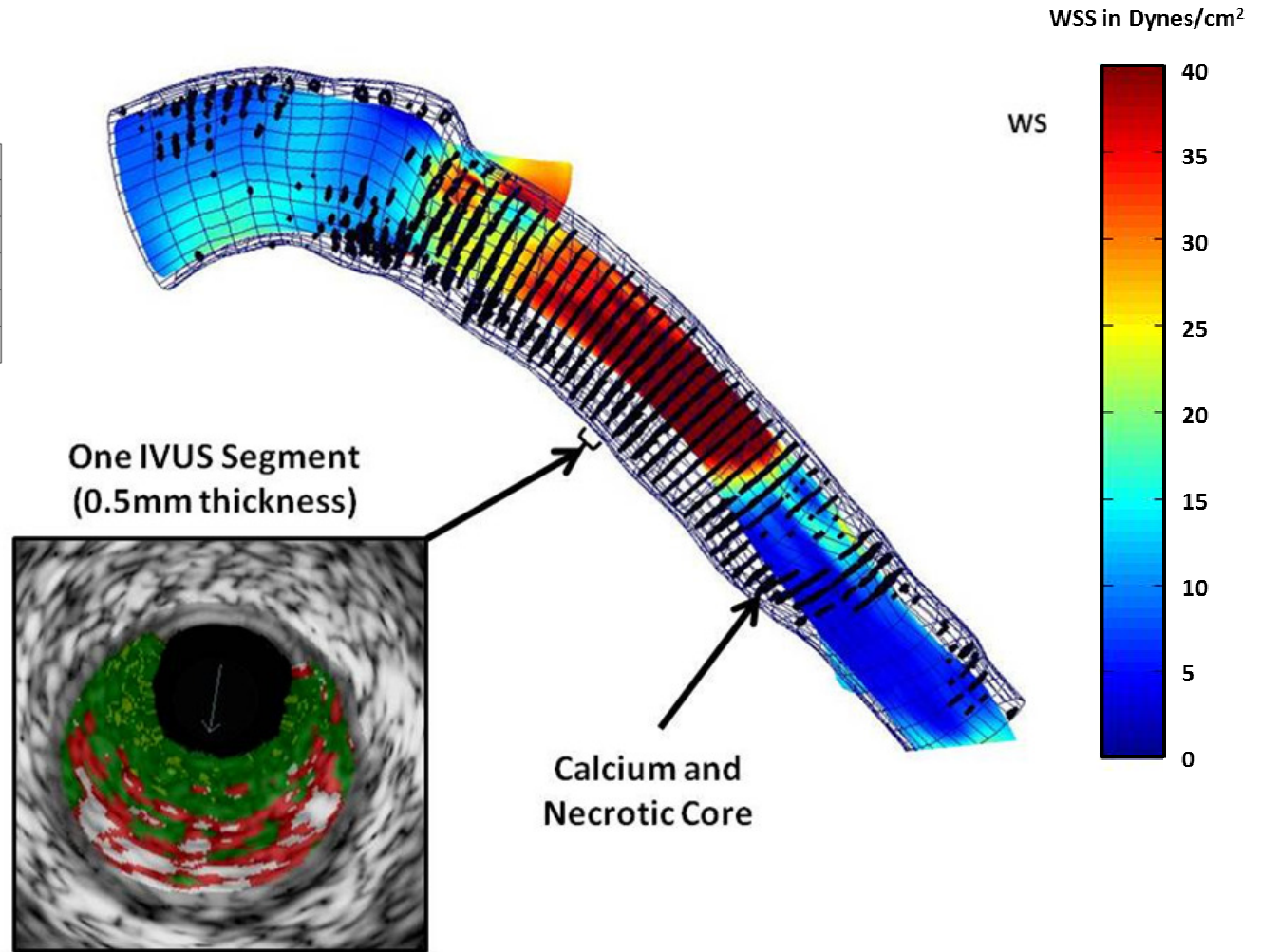
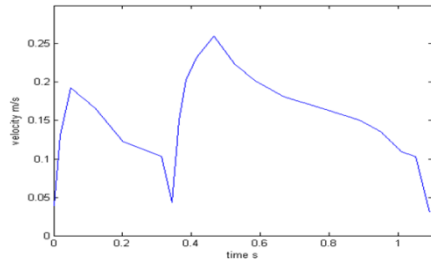
3D Reconstruction

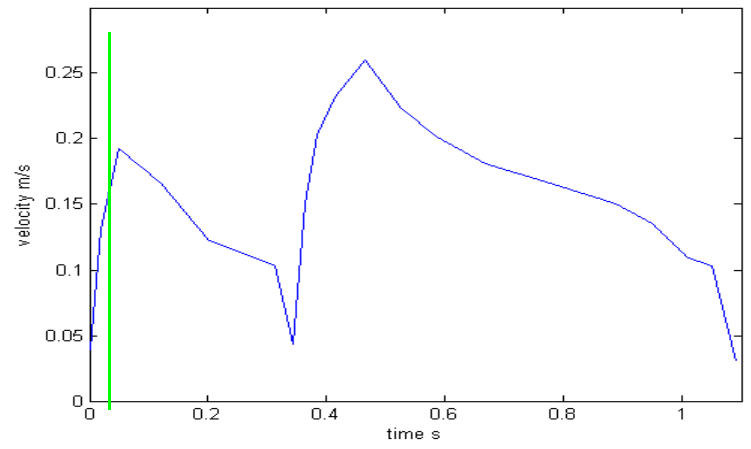
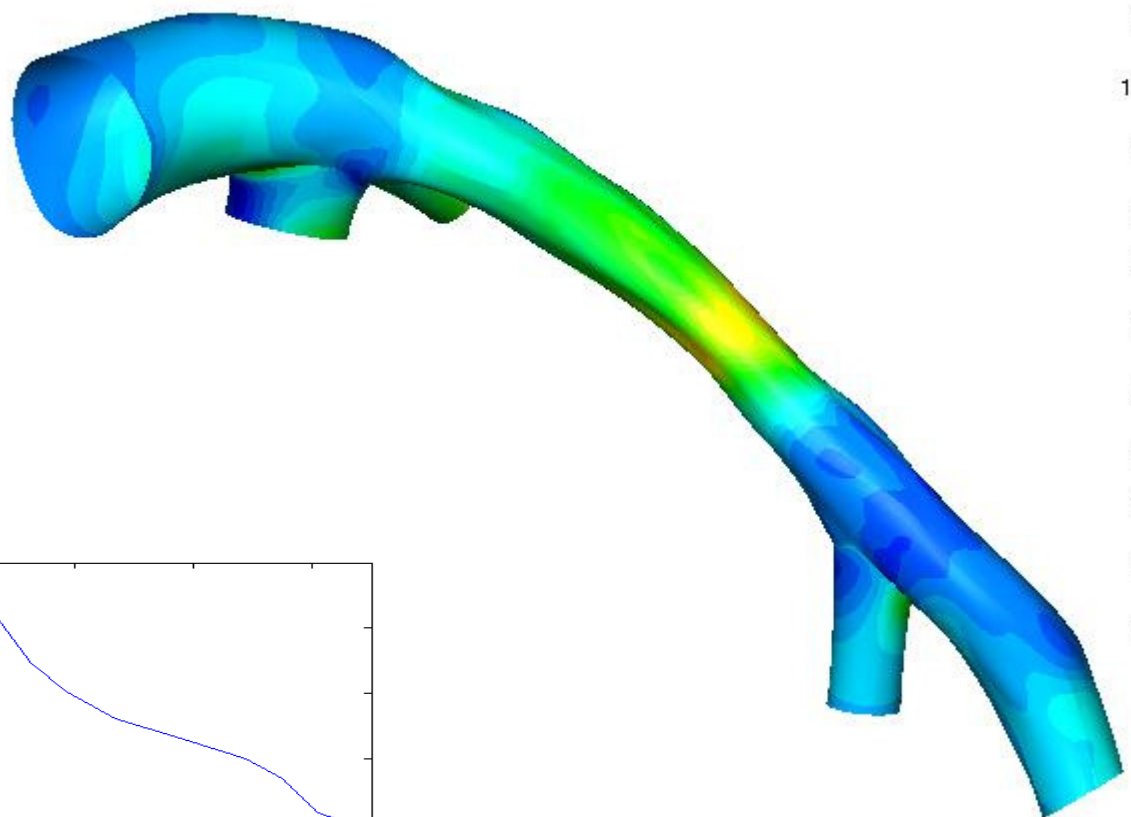


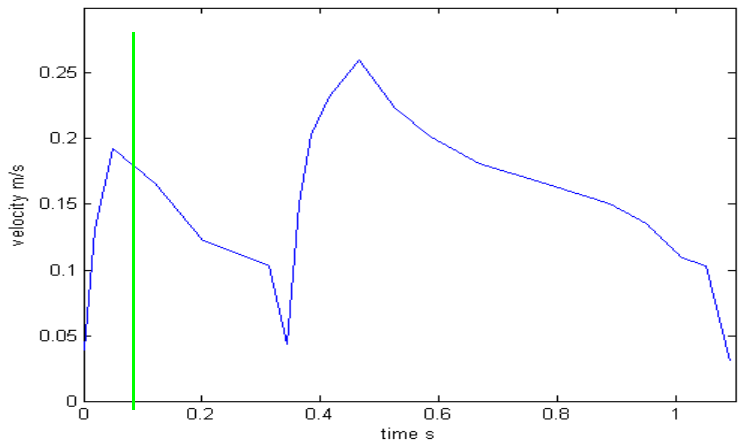
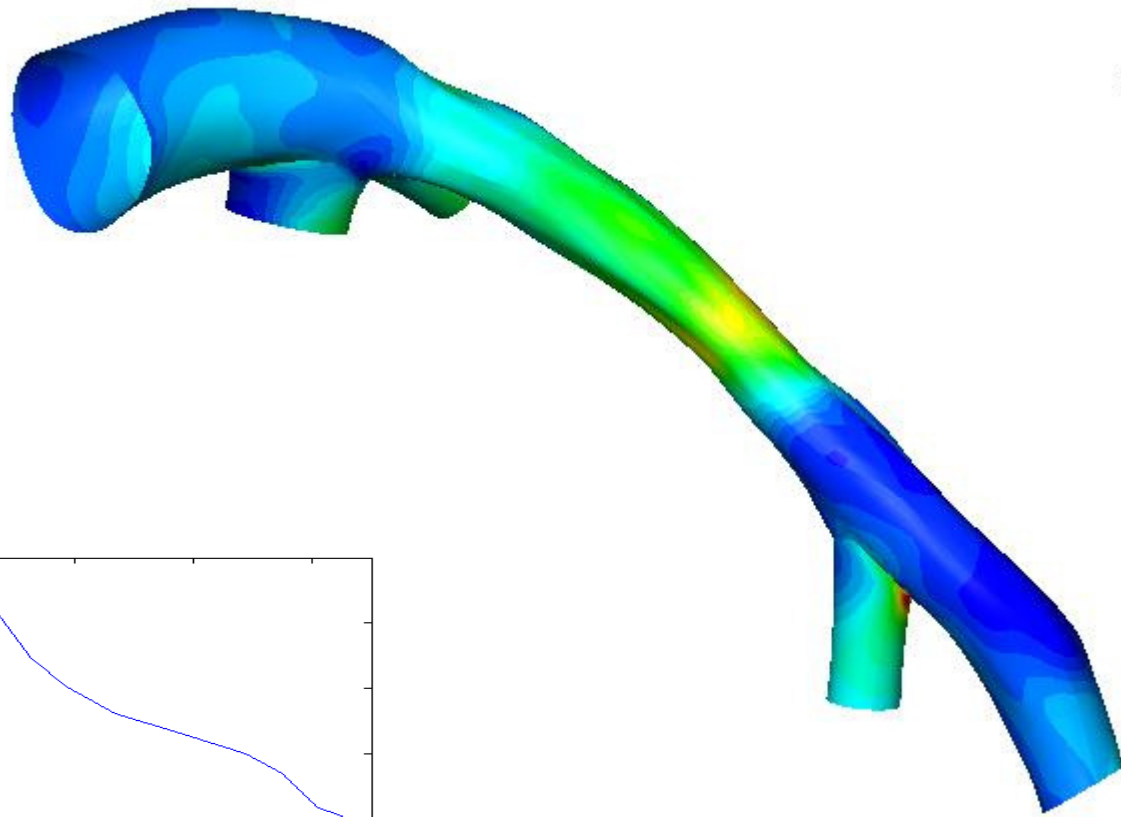
Velocity



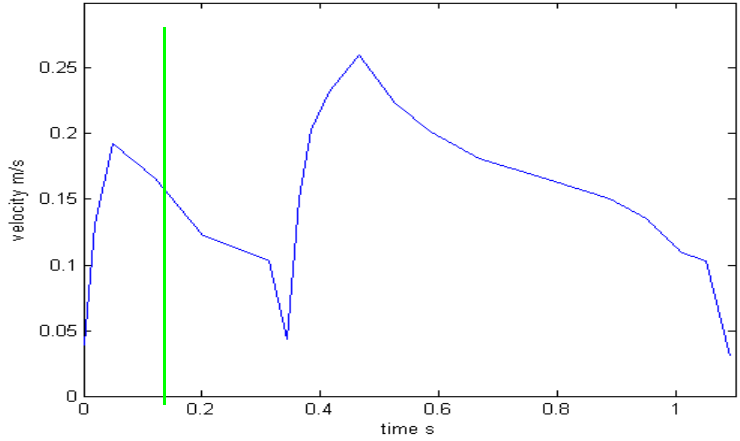
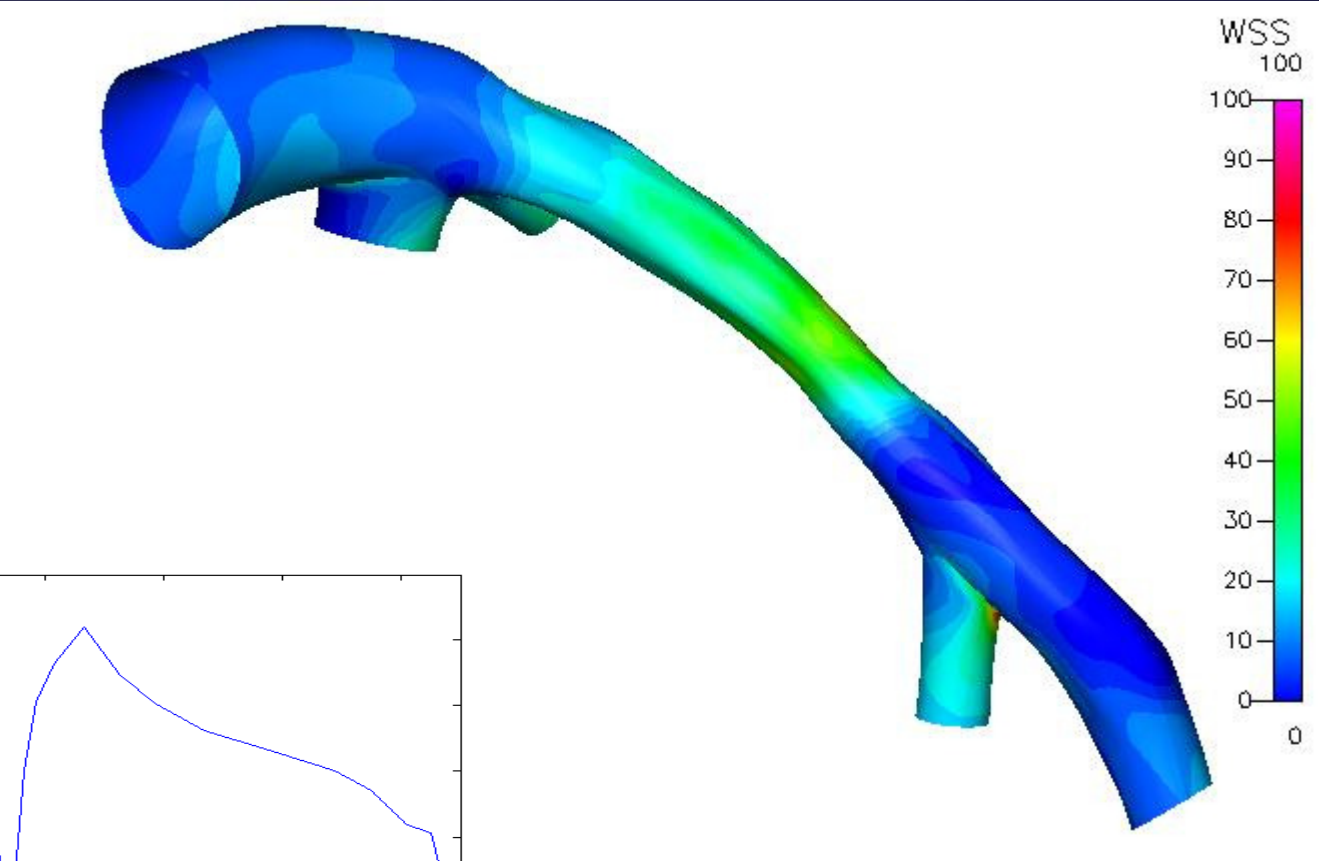
# Computational Methods

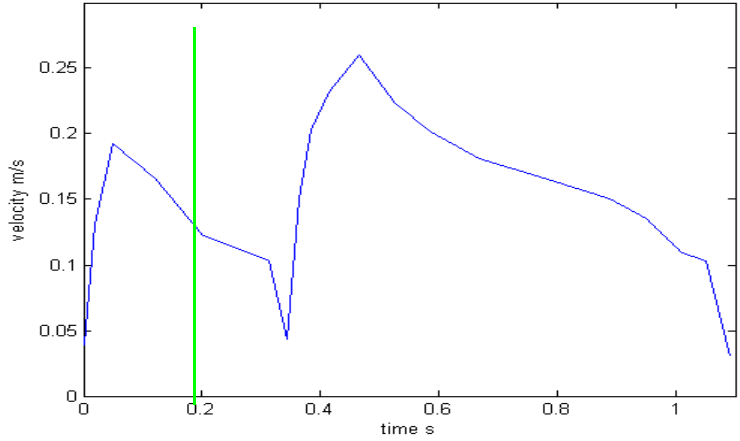
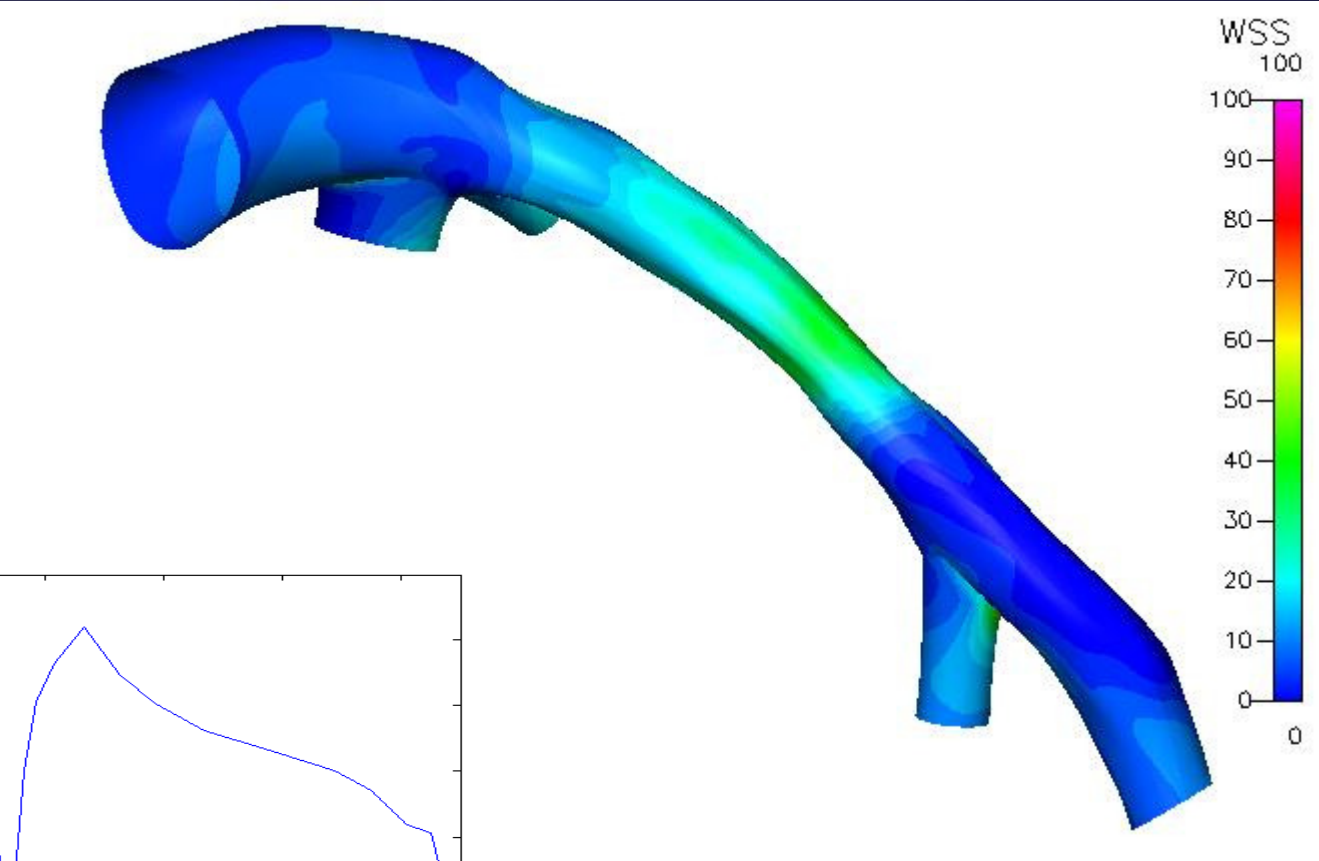


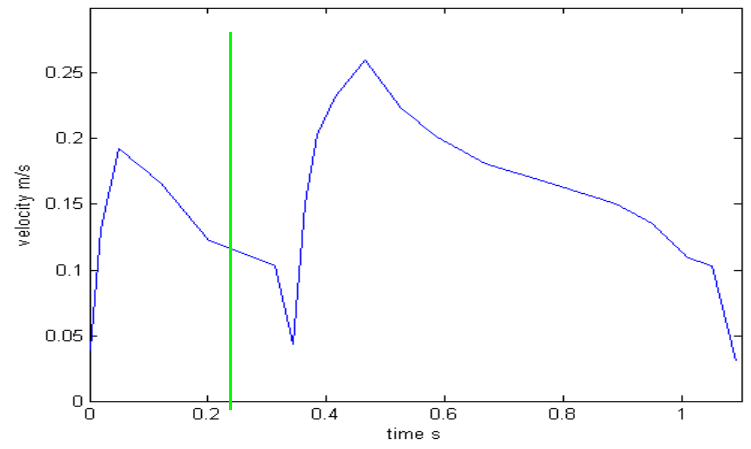
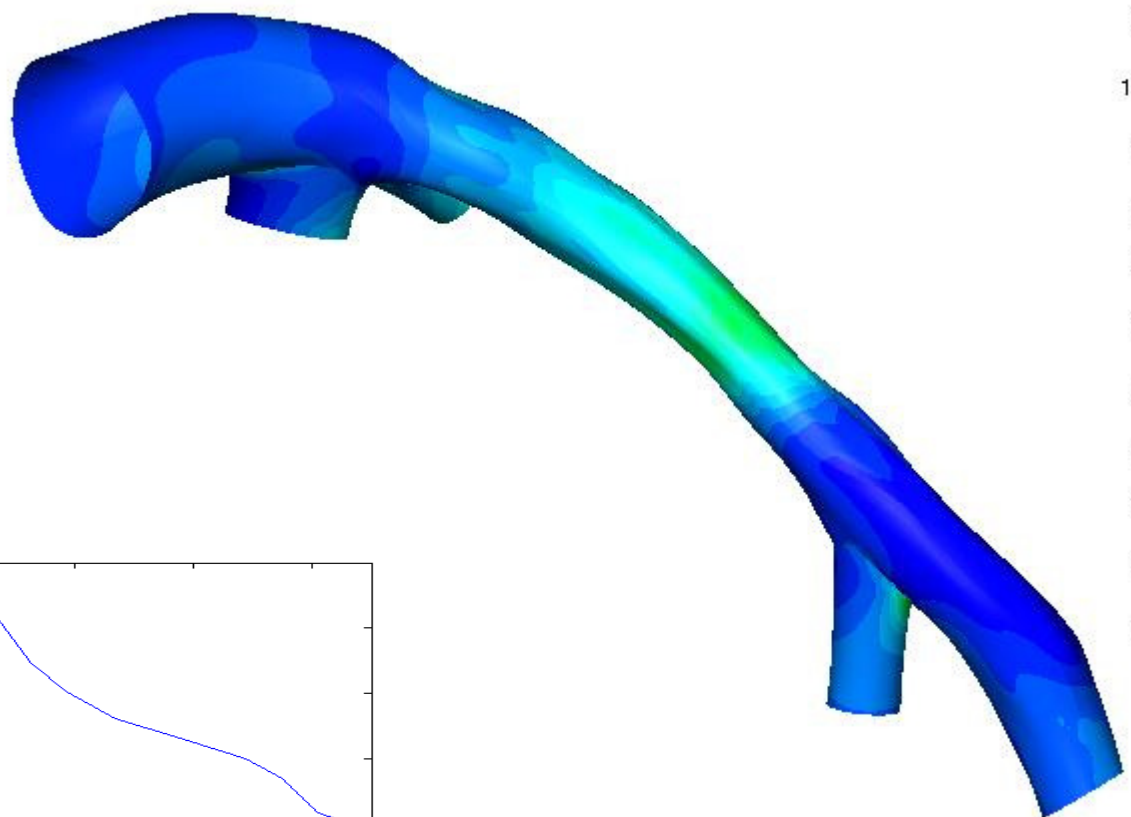


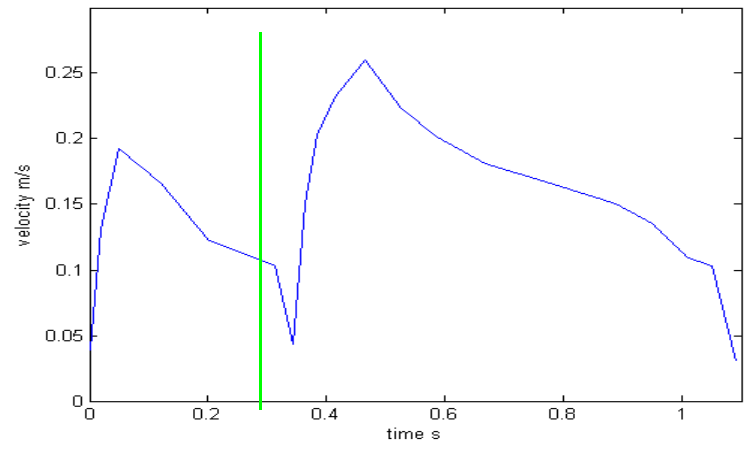
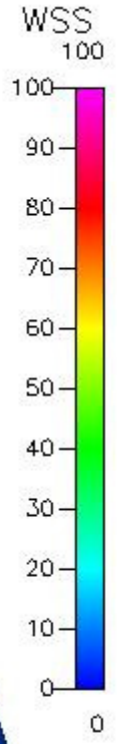
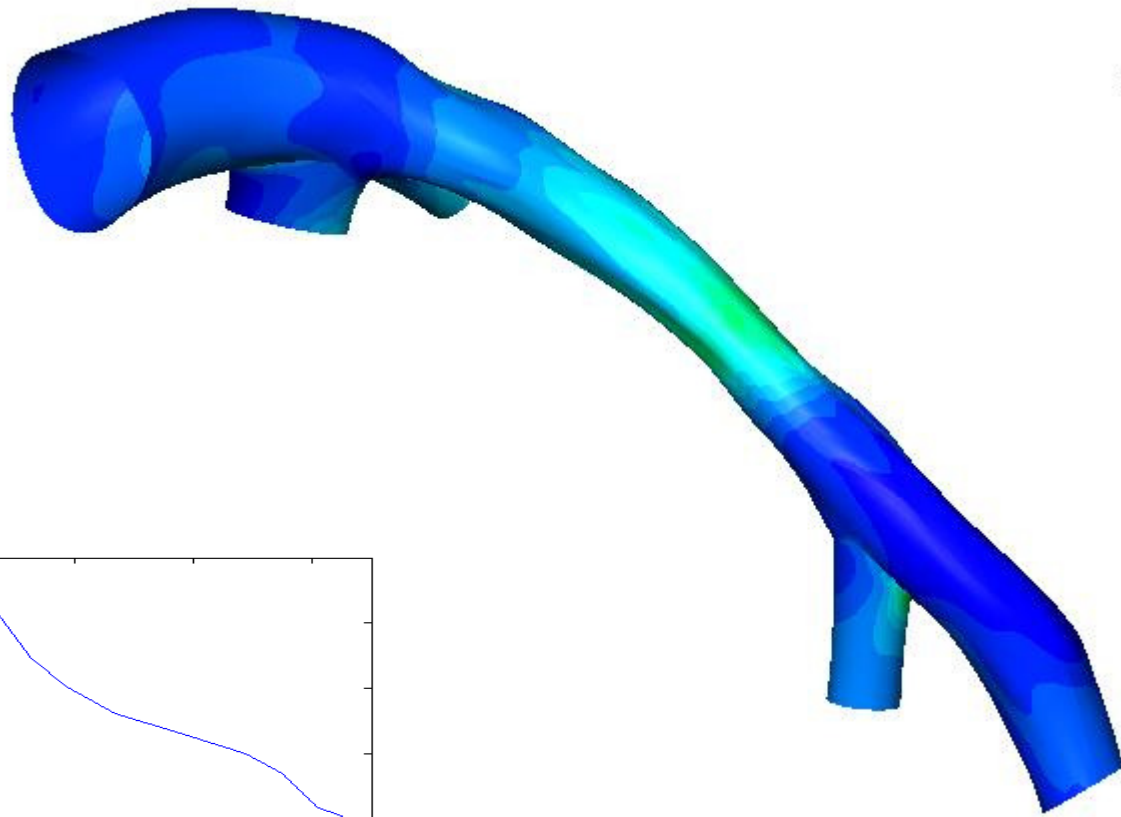


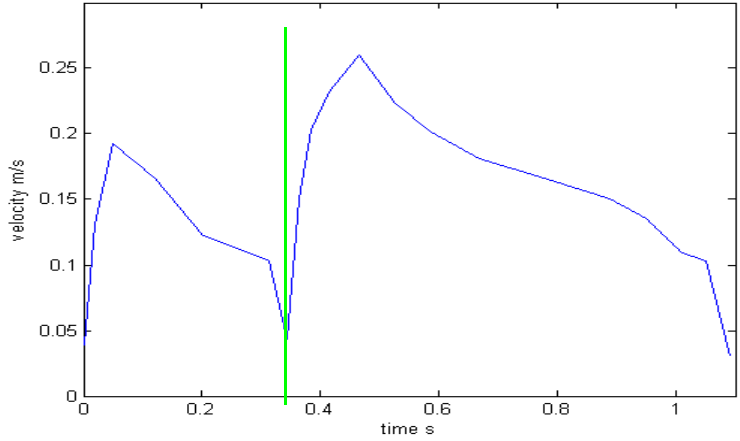
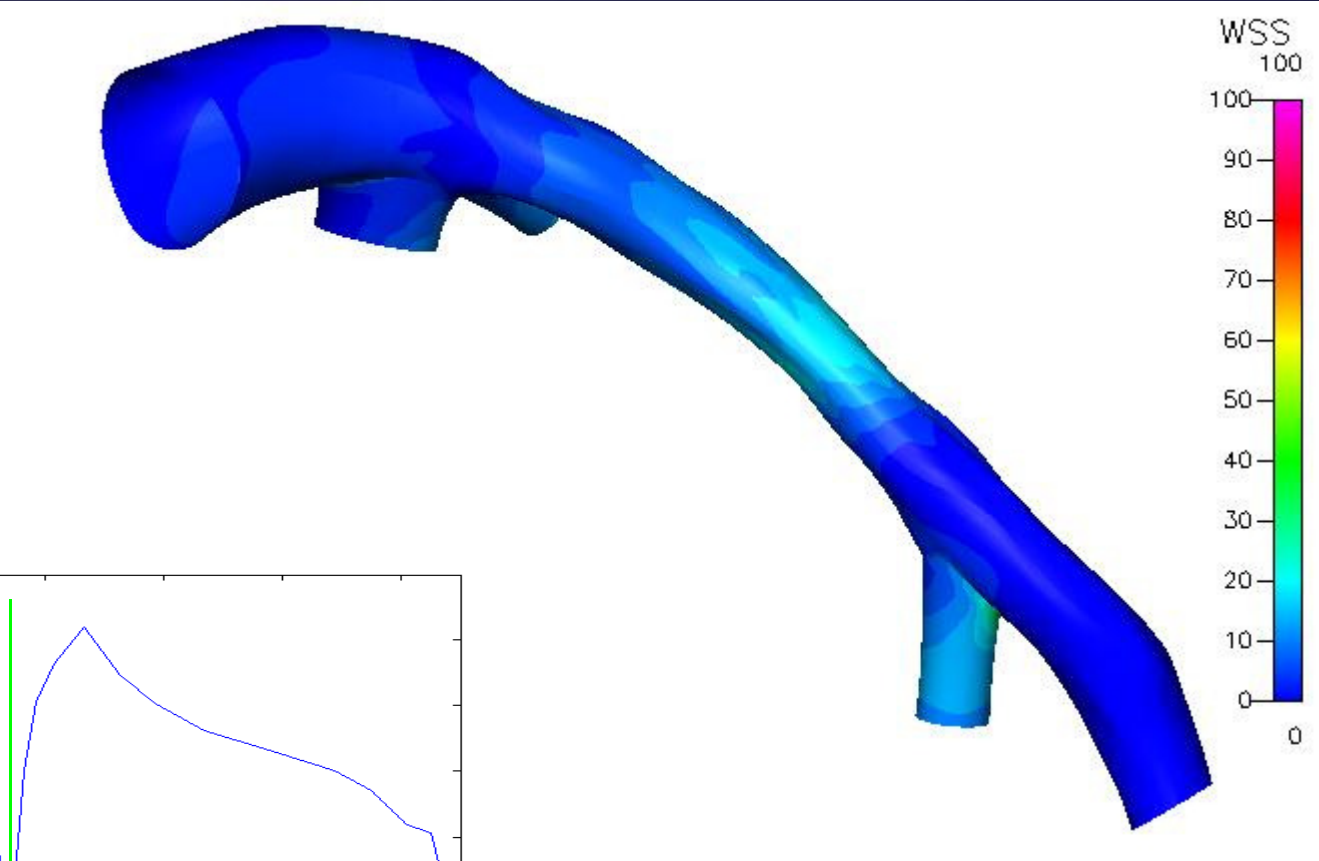


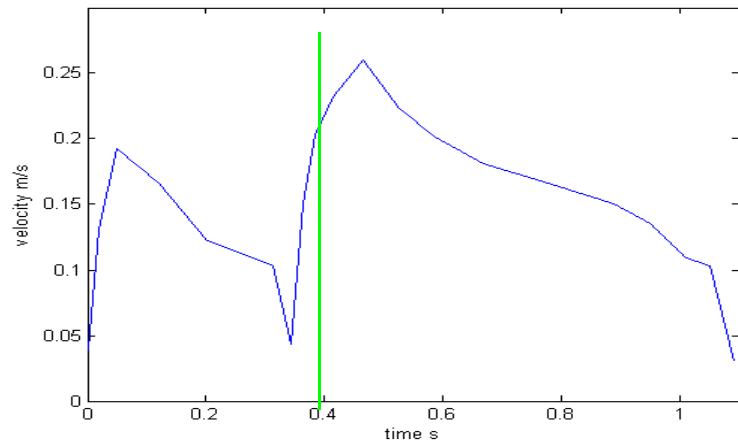
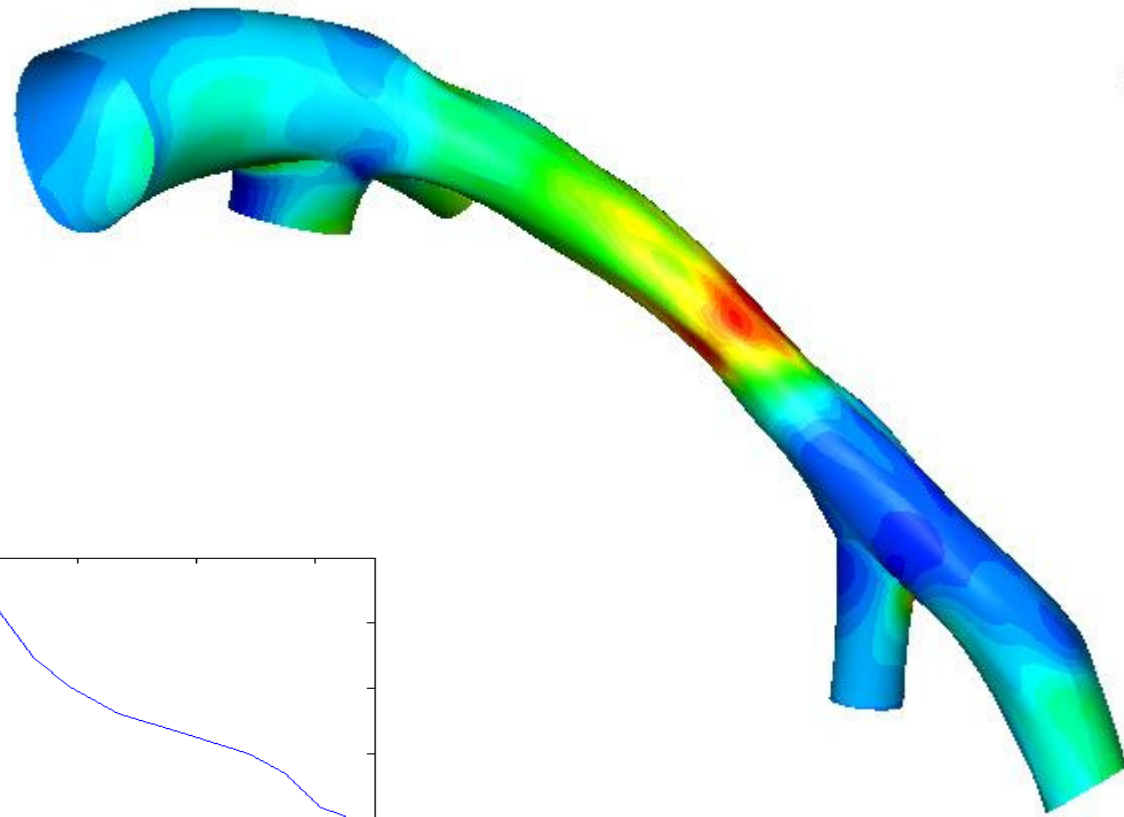


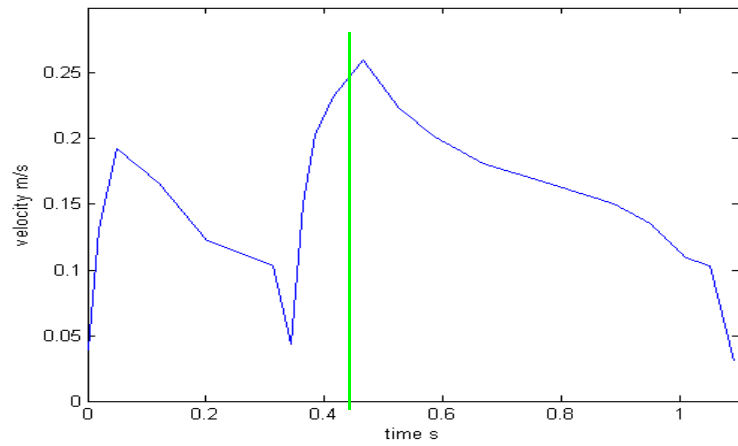
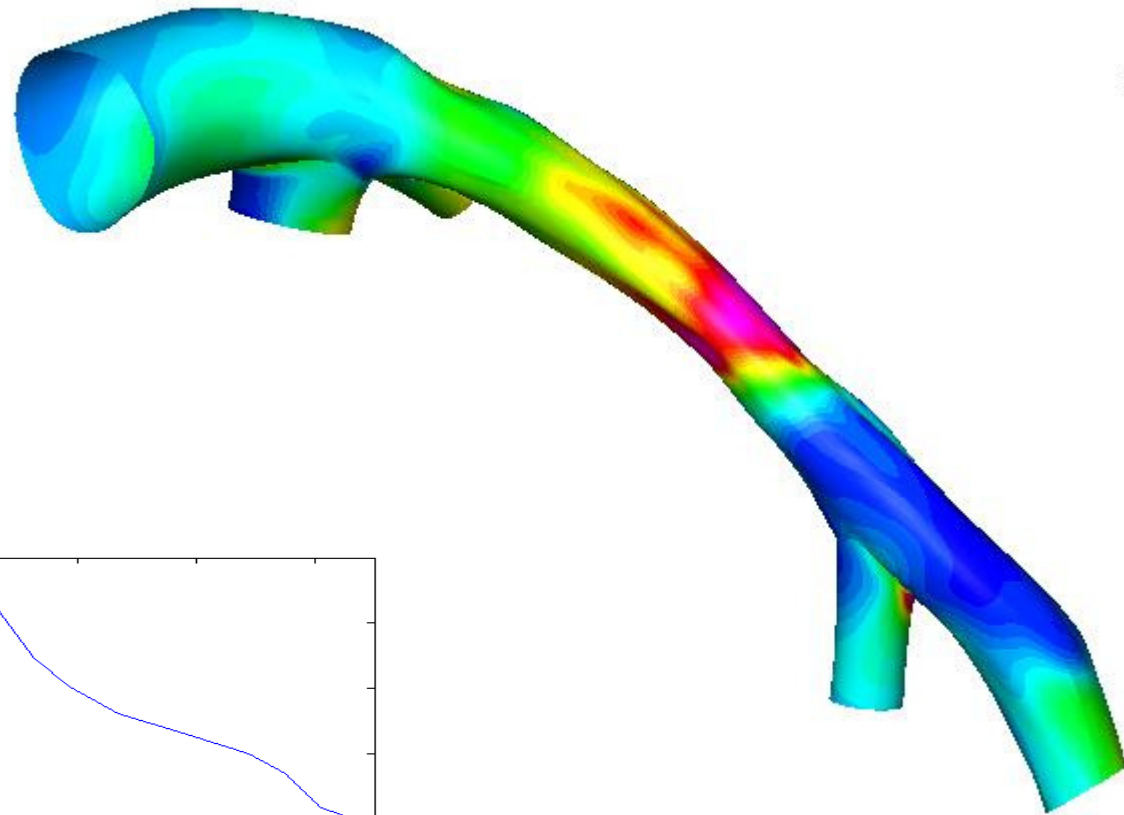


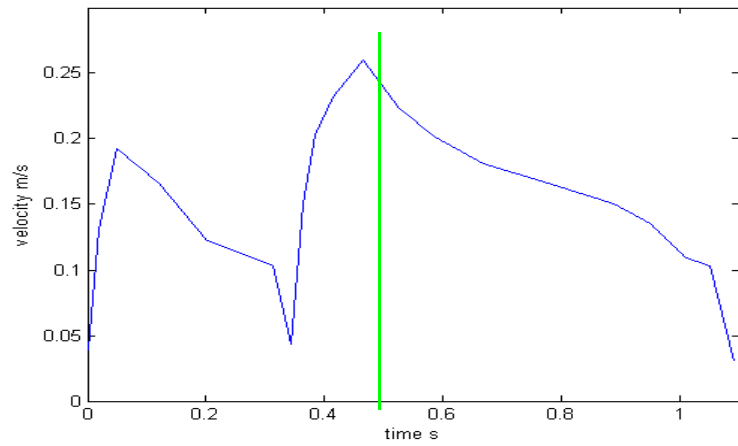
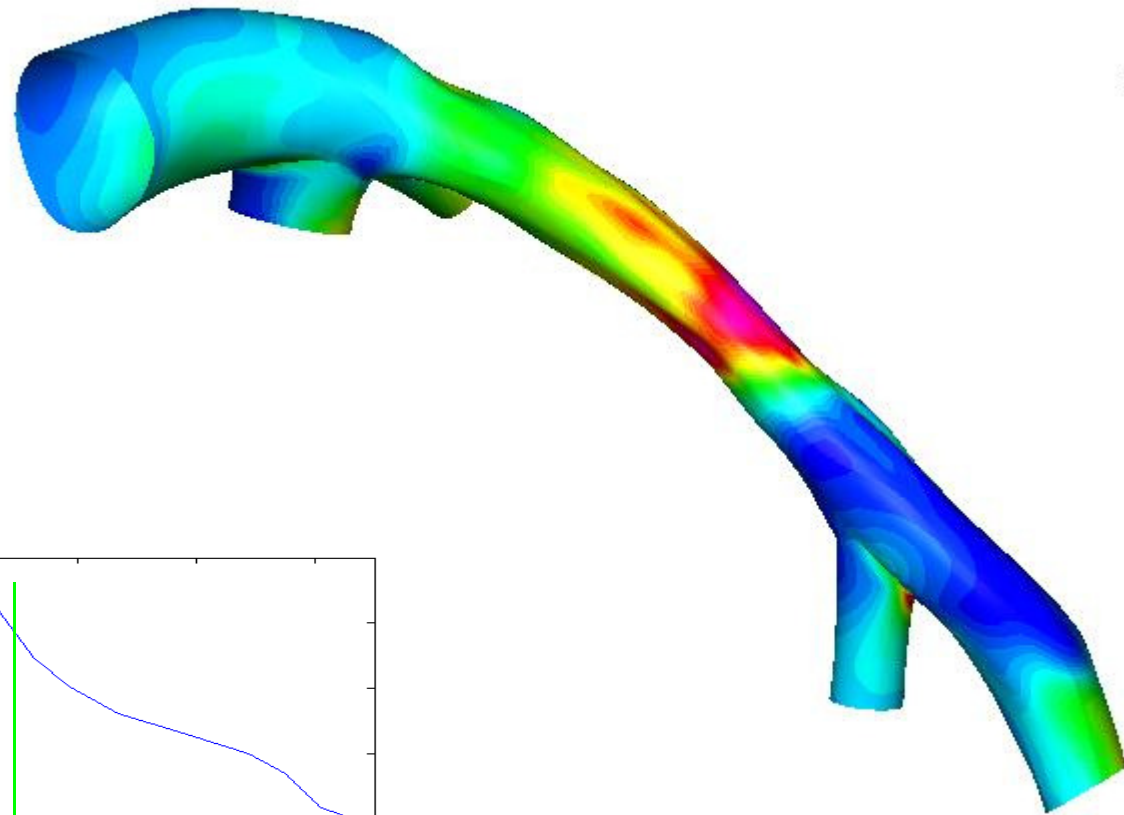




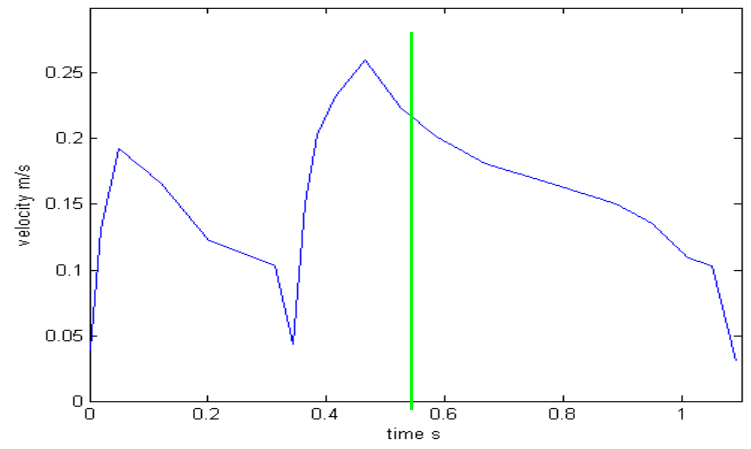
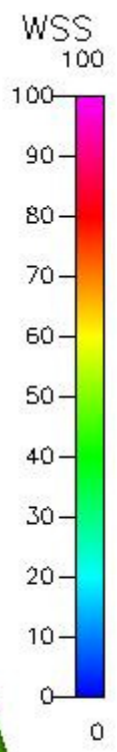
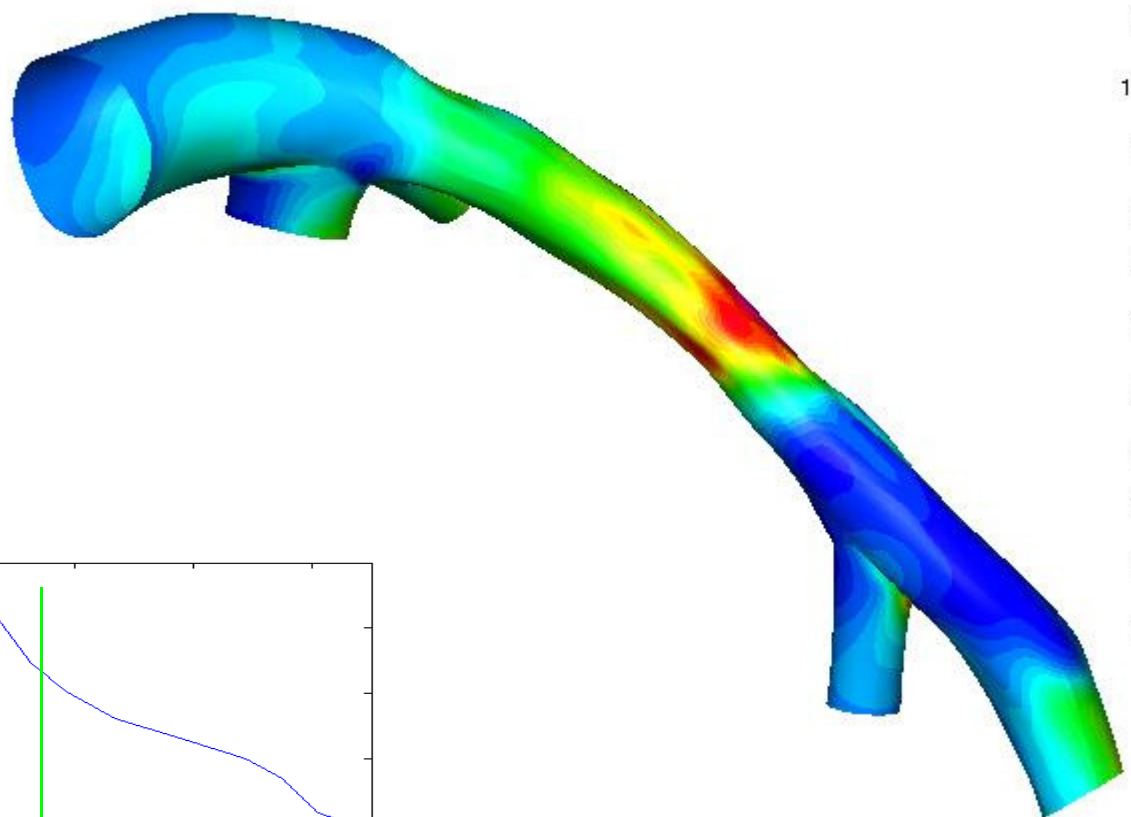


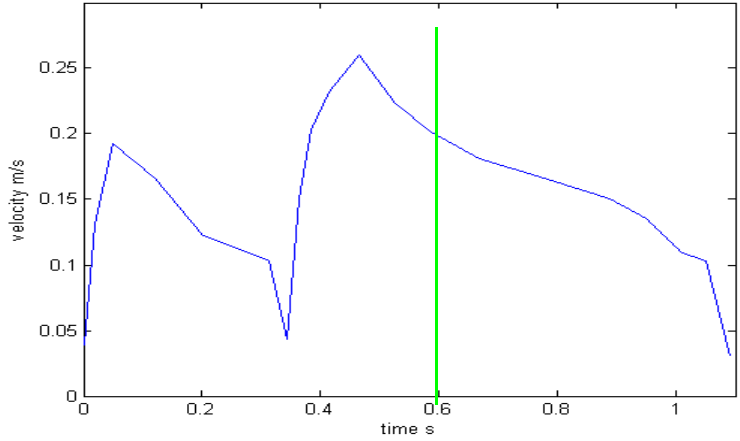
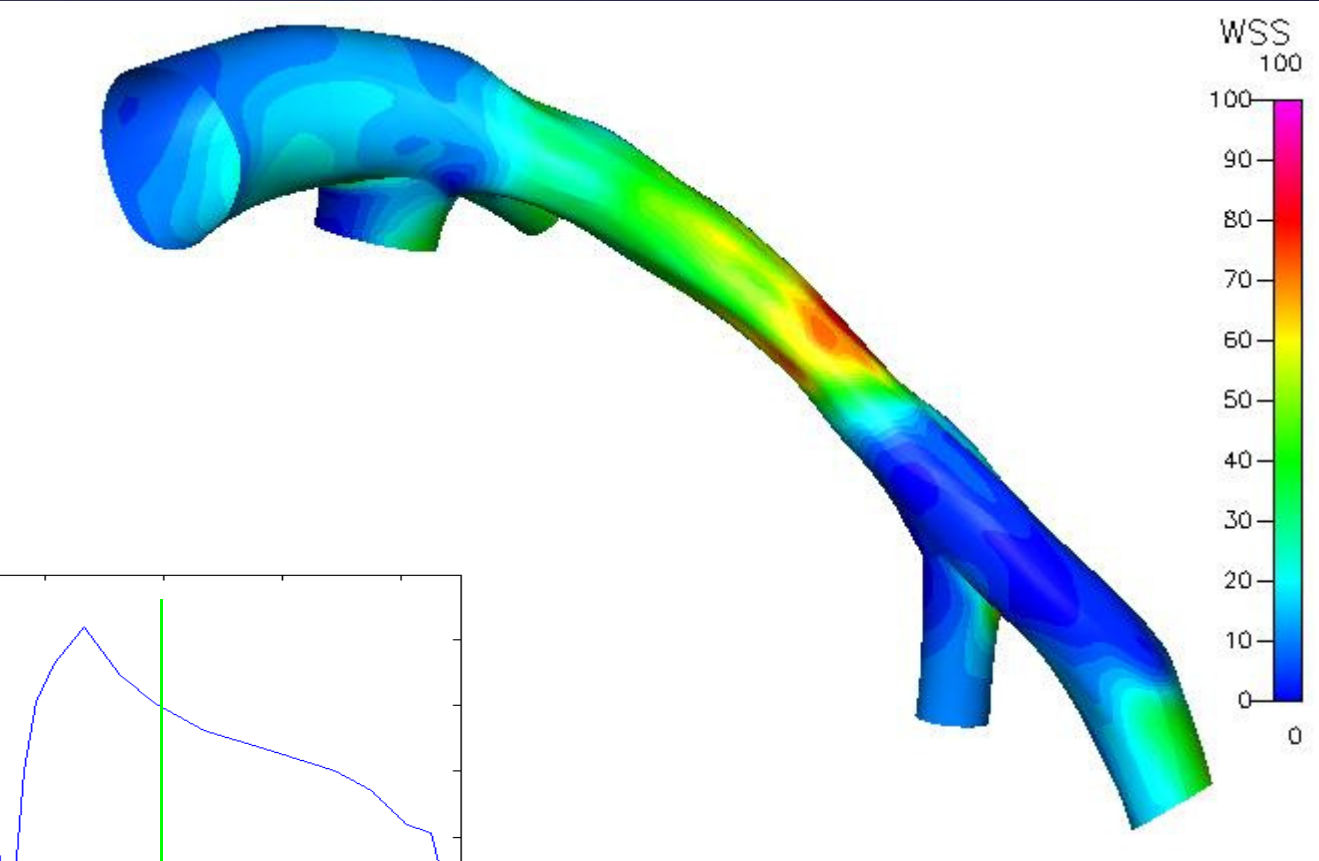


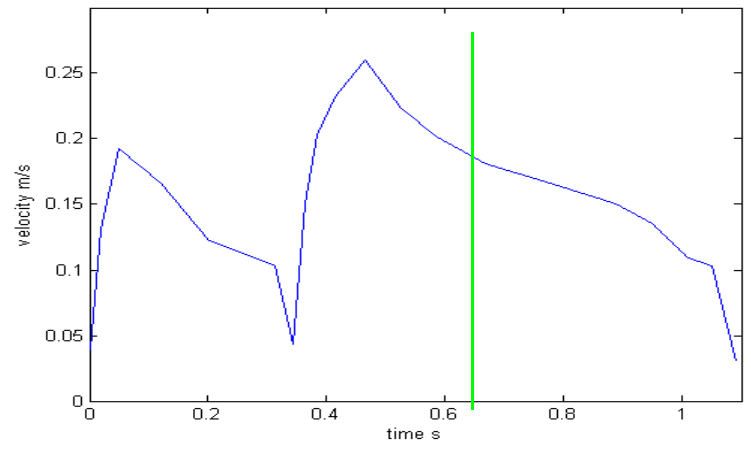
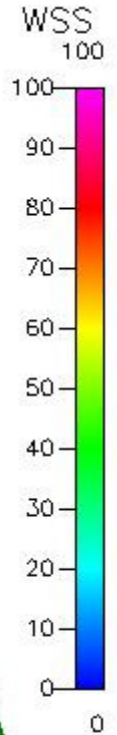
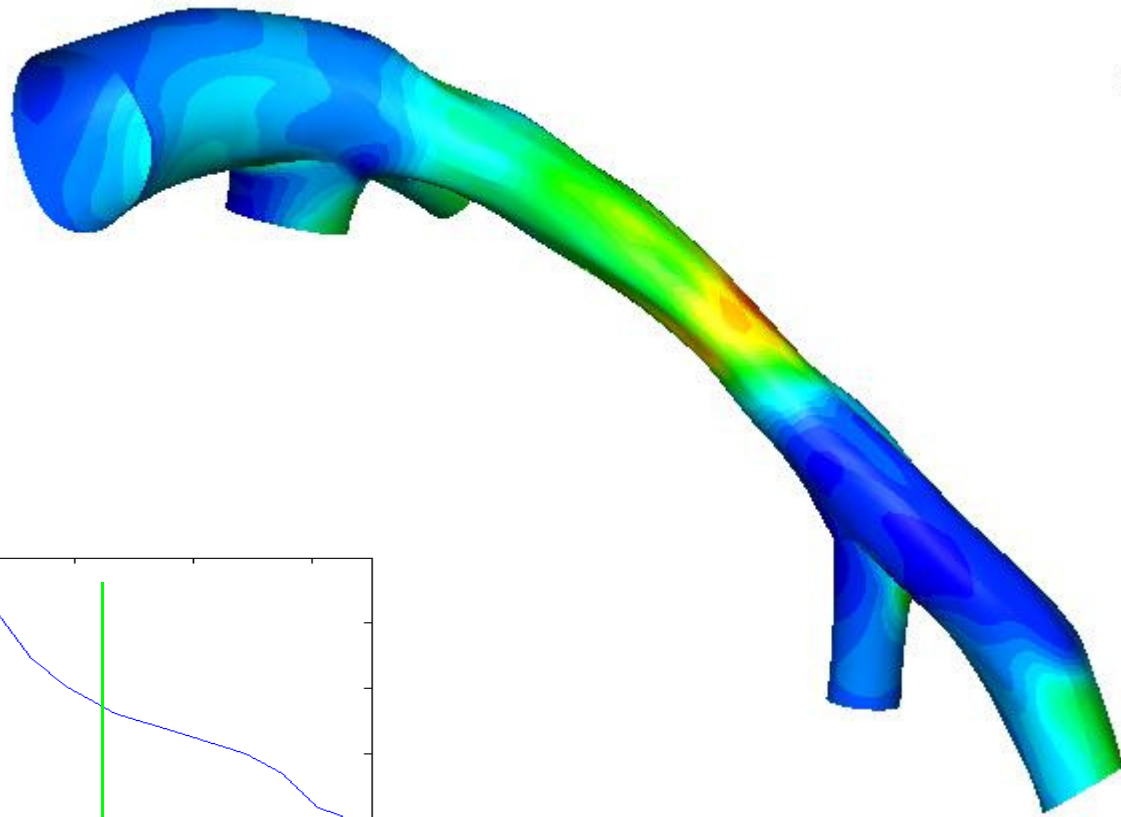


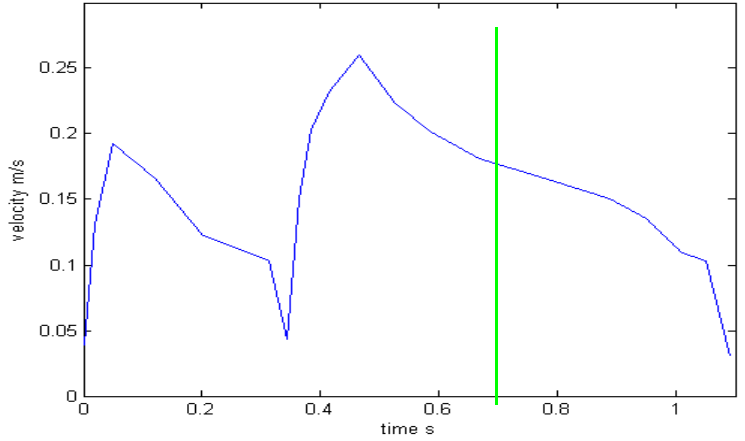
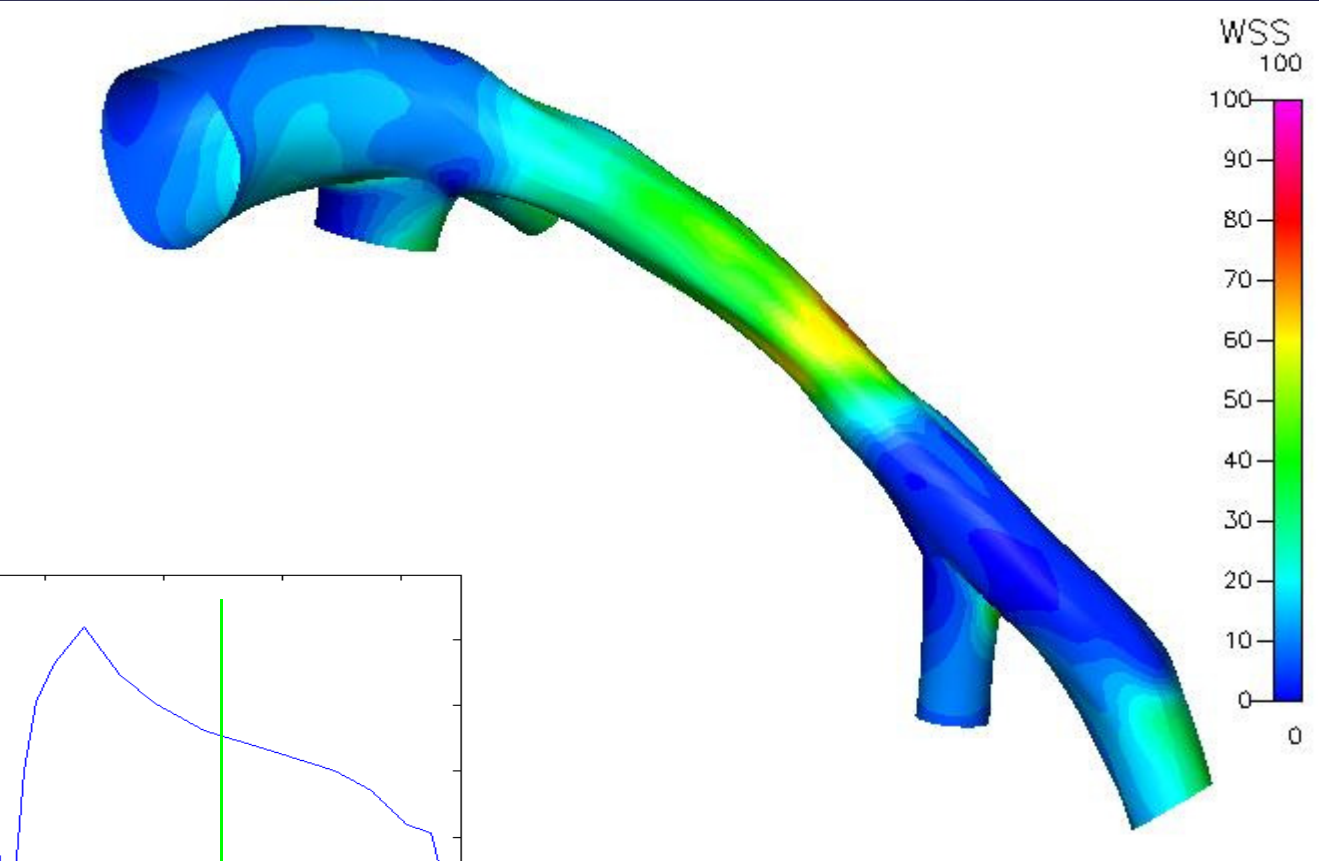


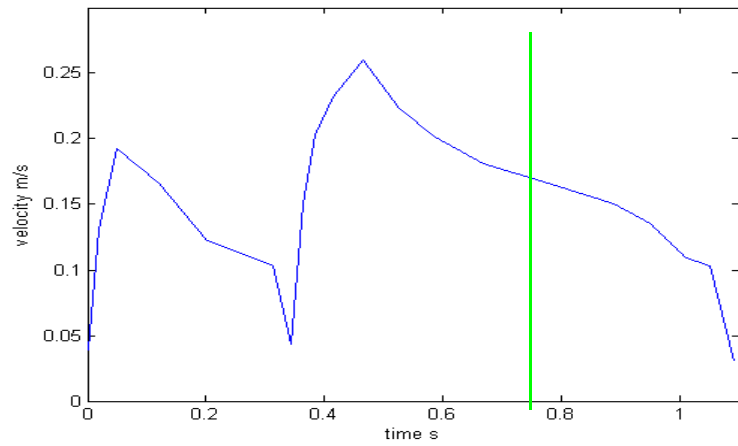
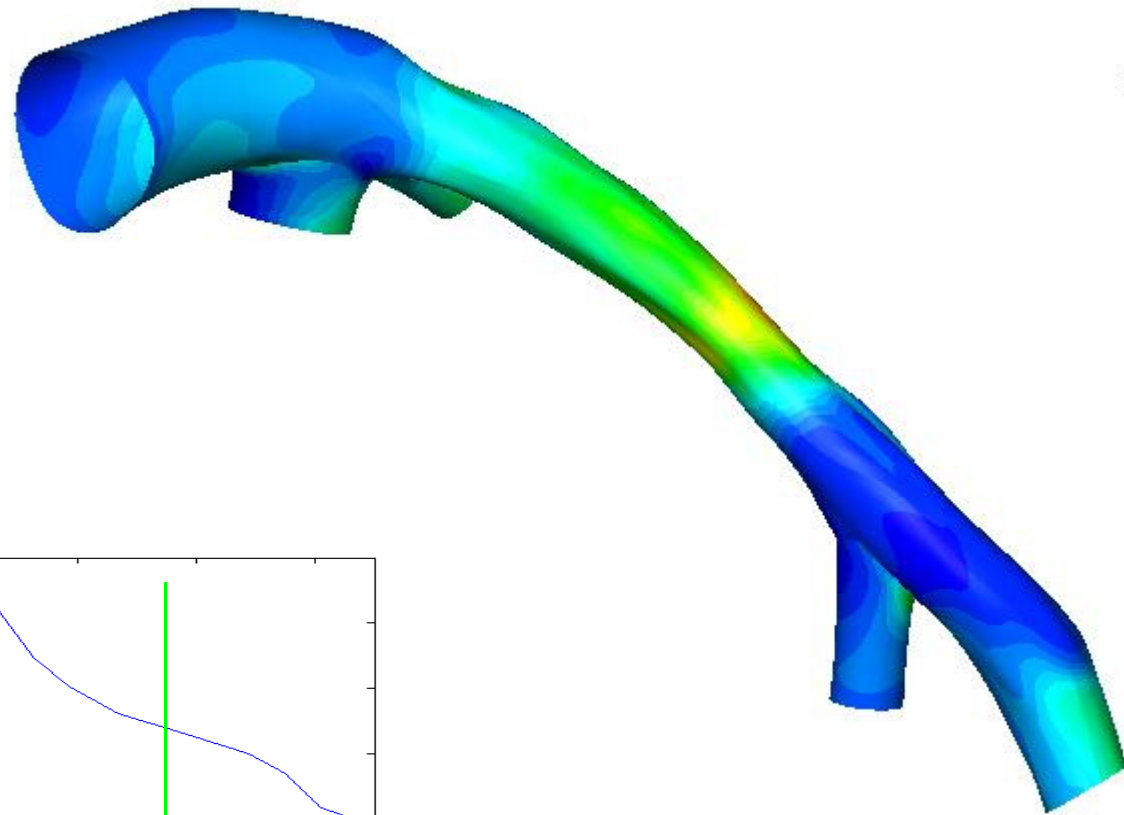


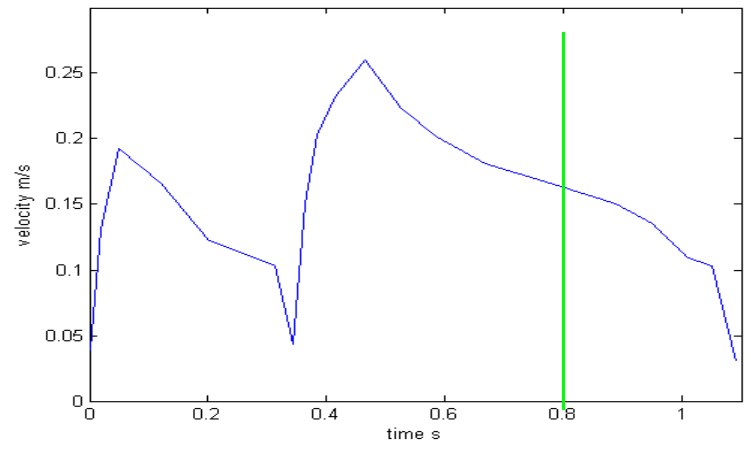
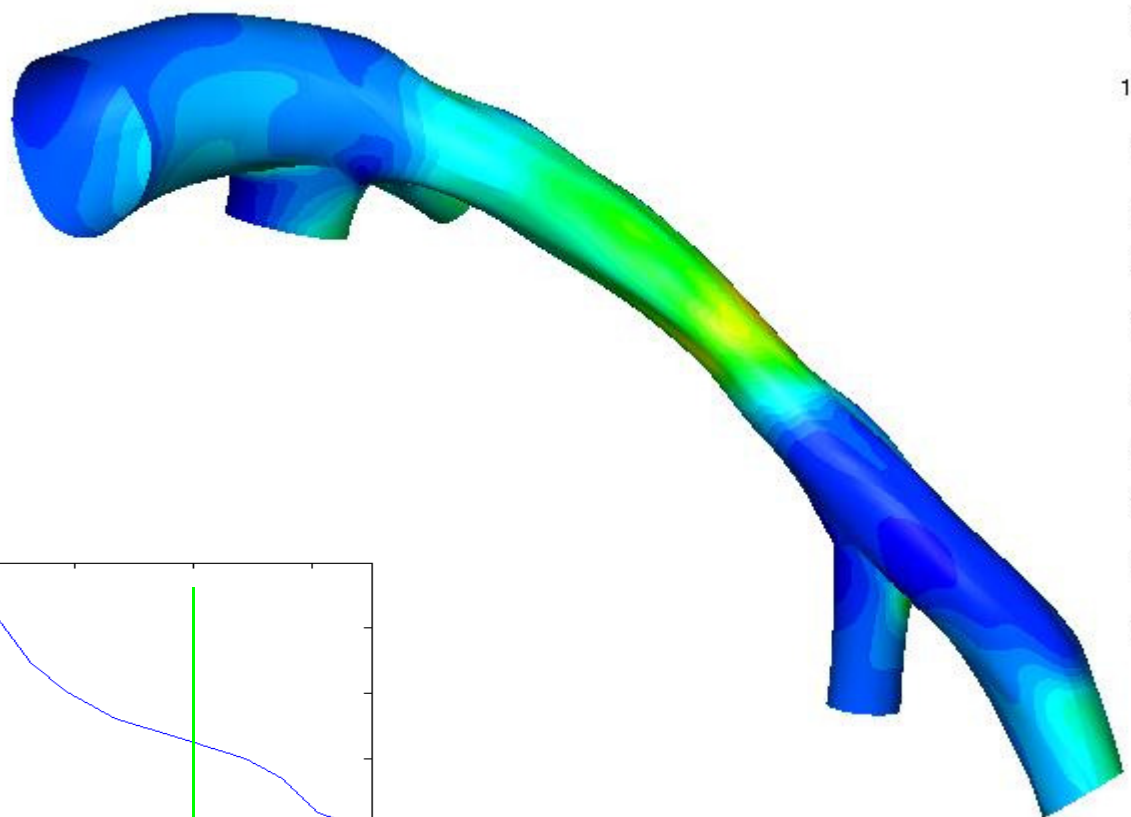


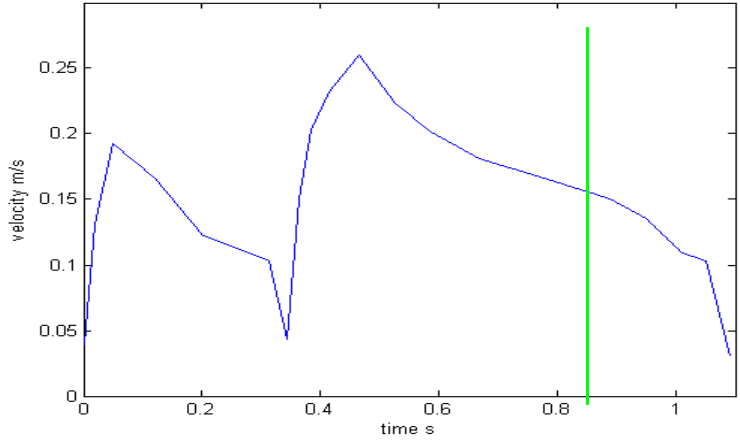
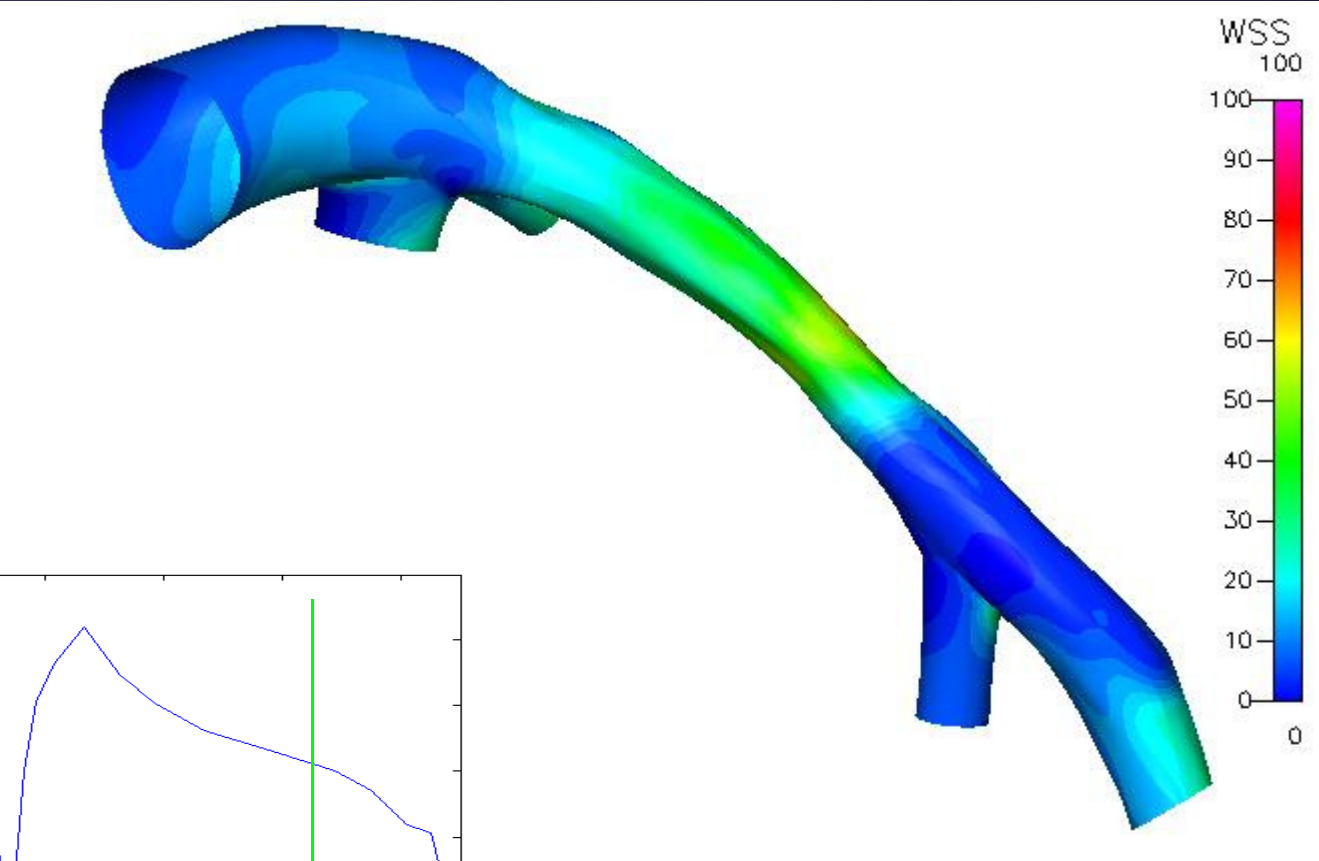


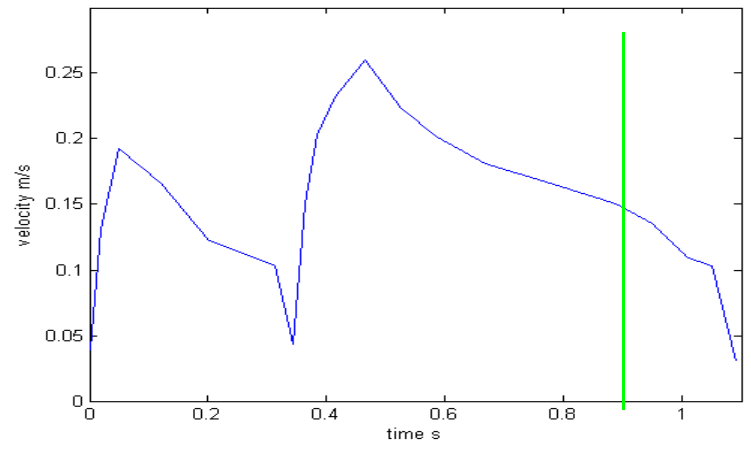
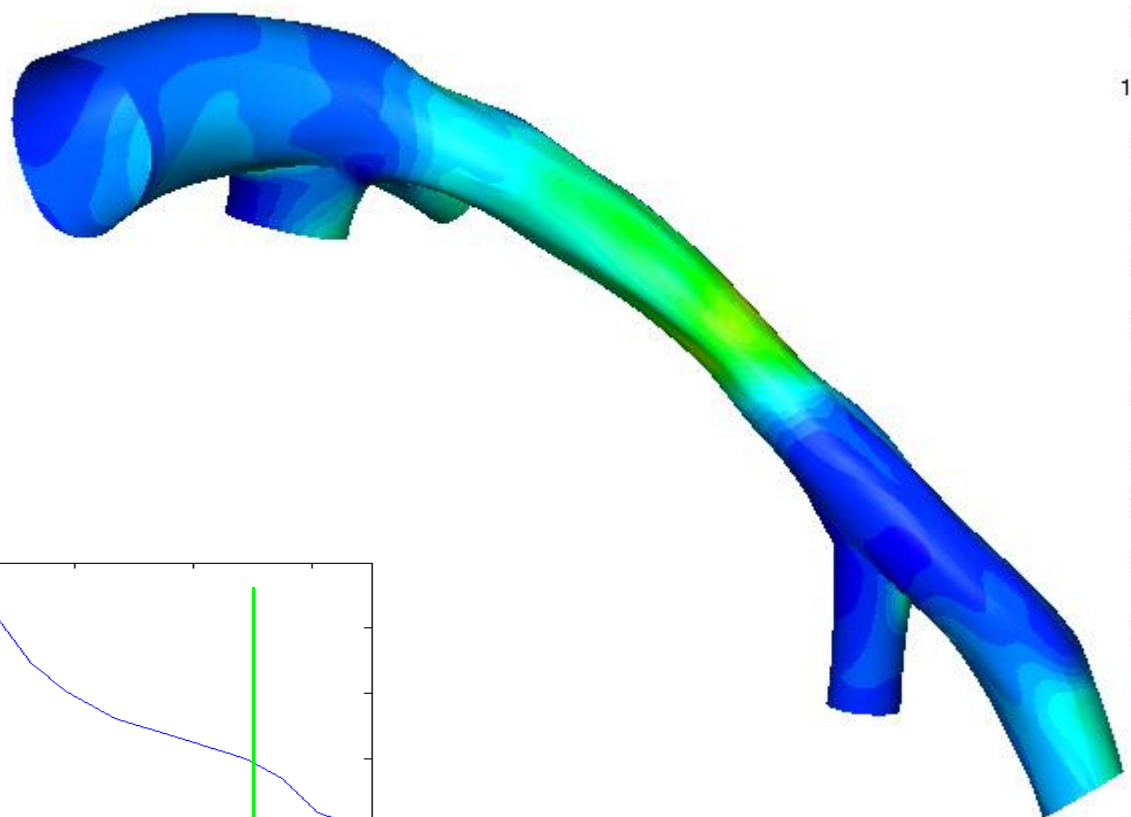




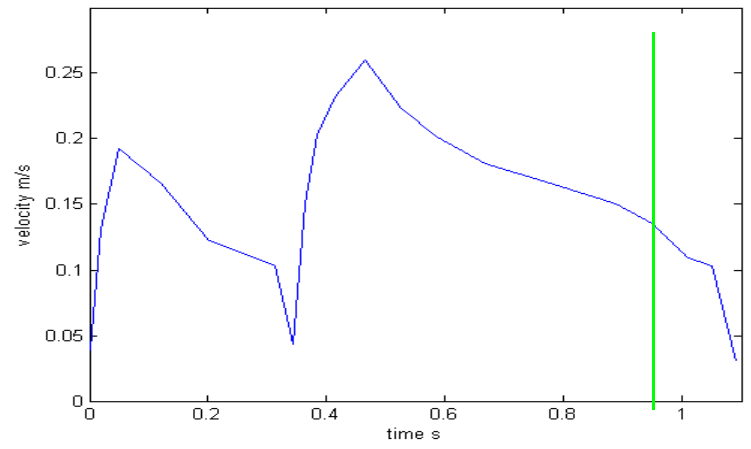
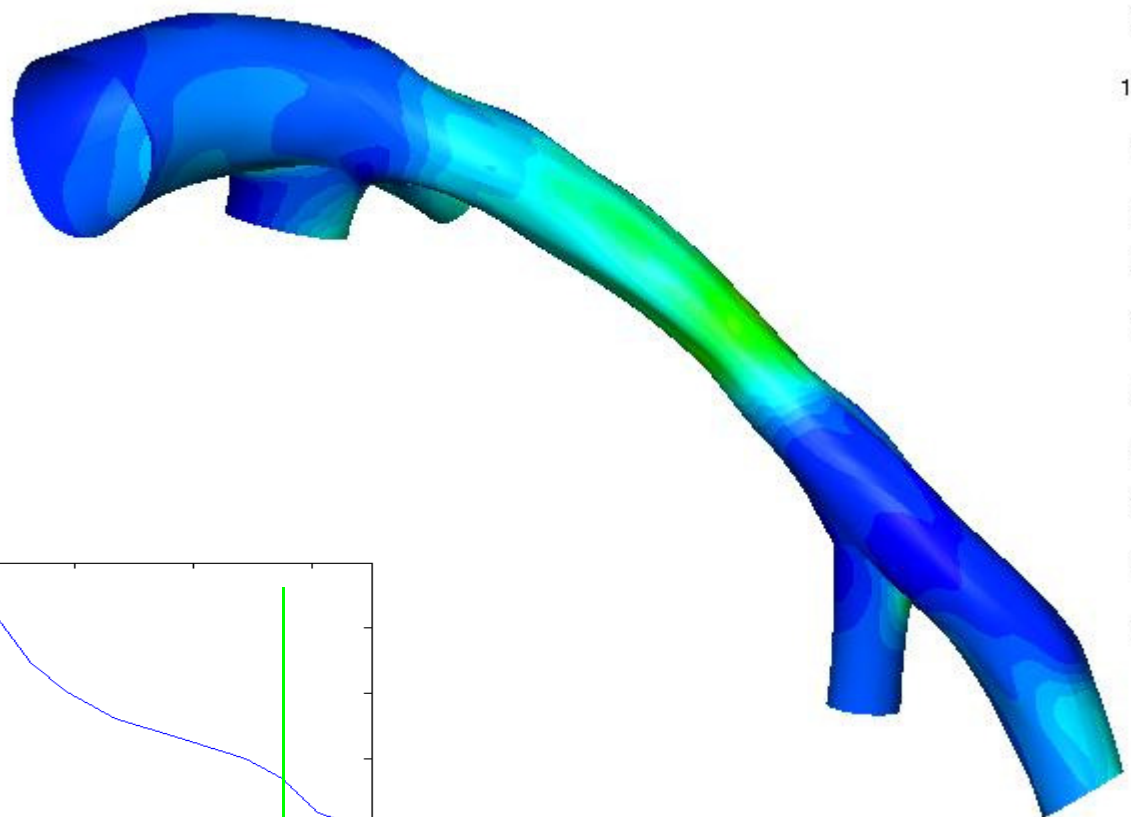


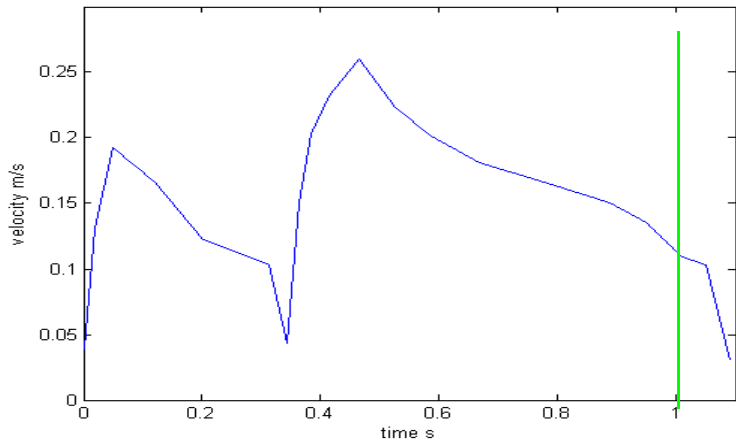
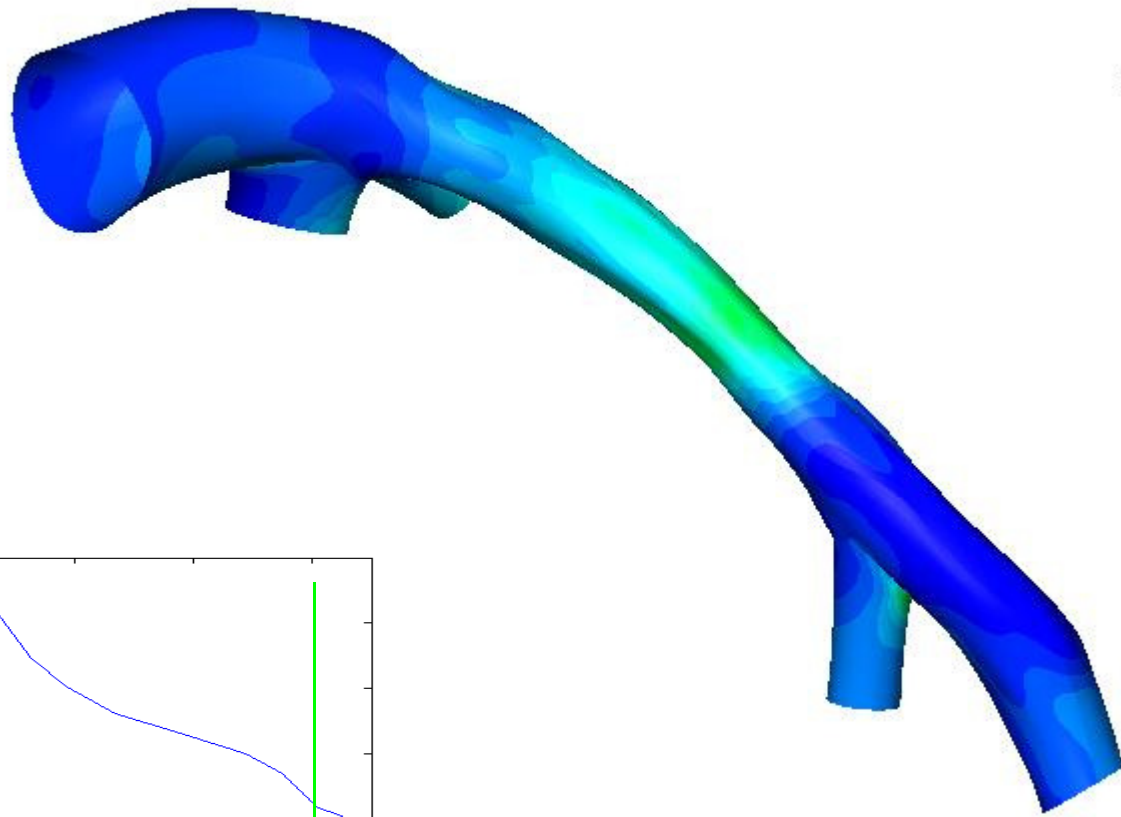


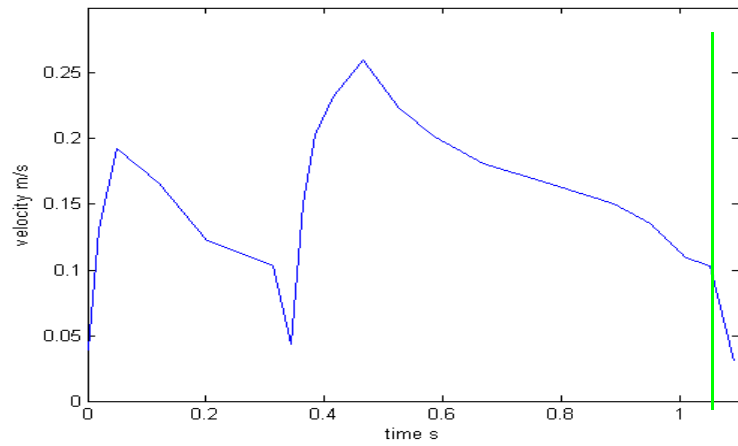
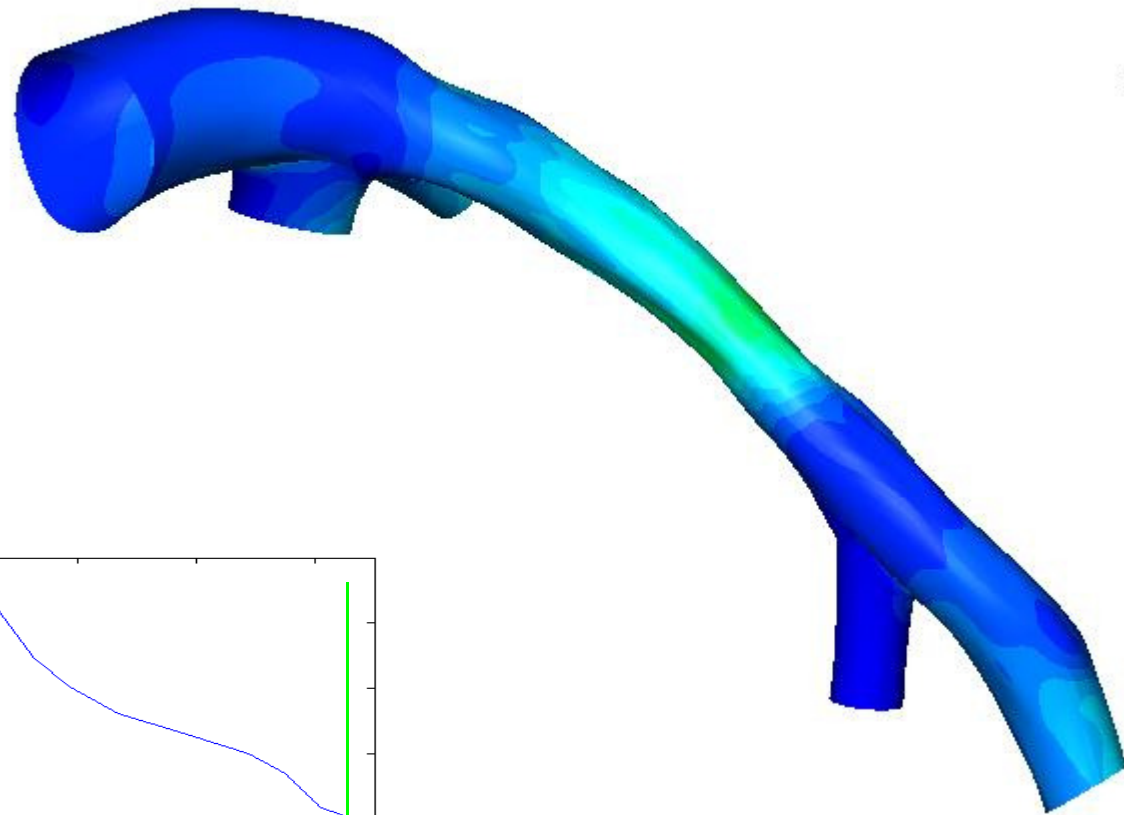


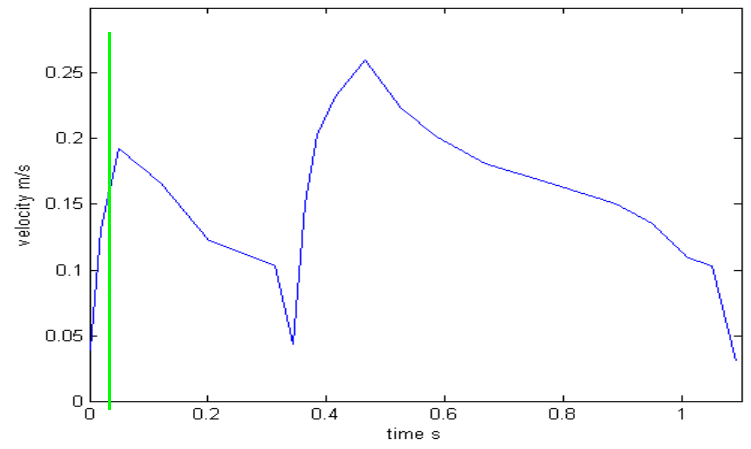
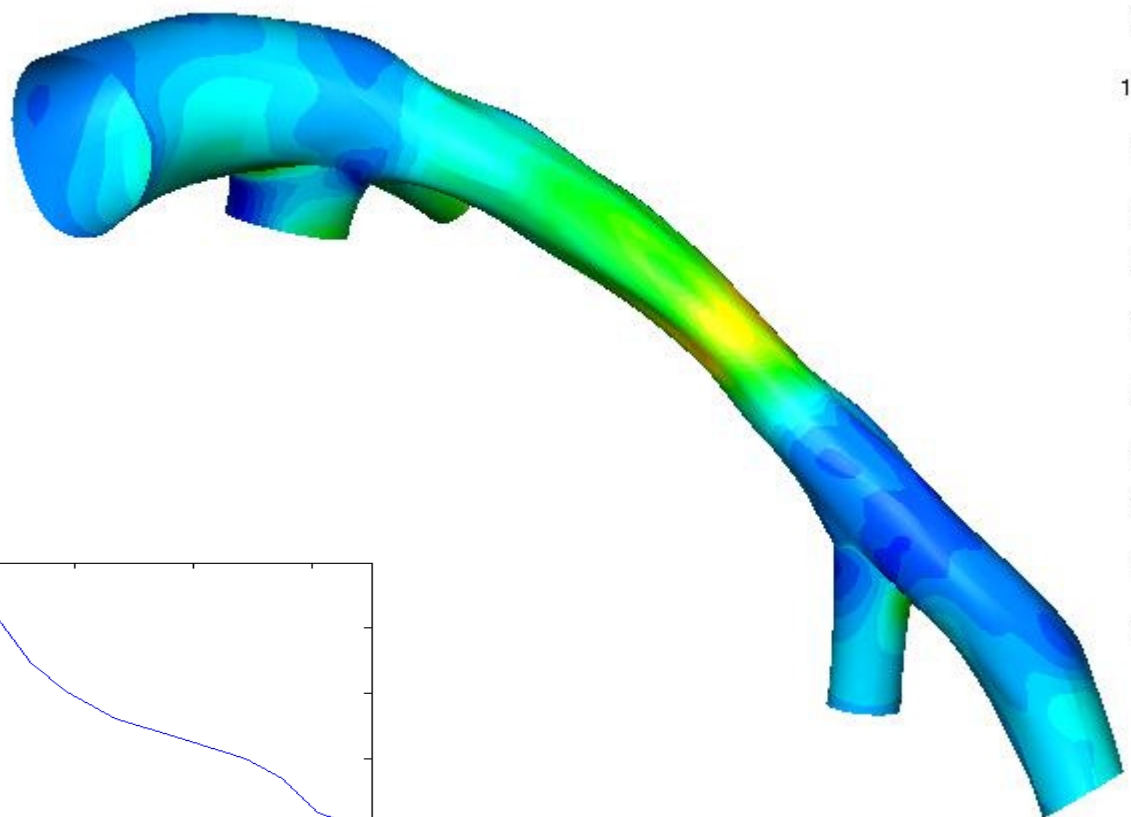


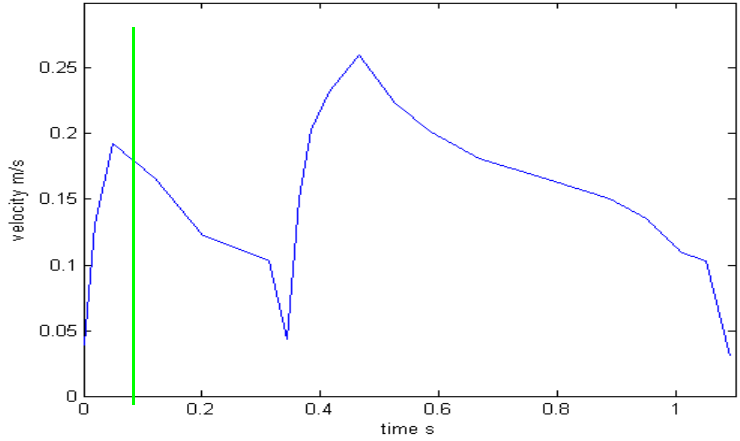
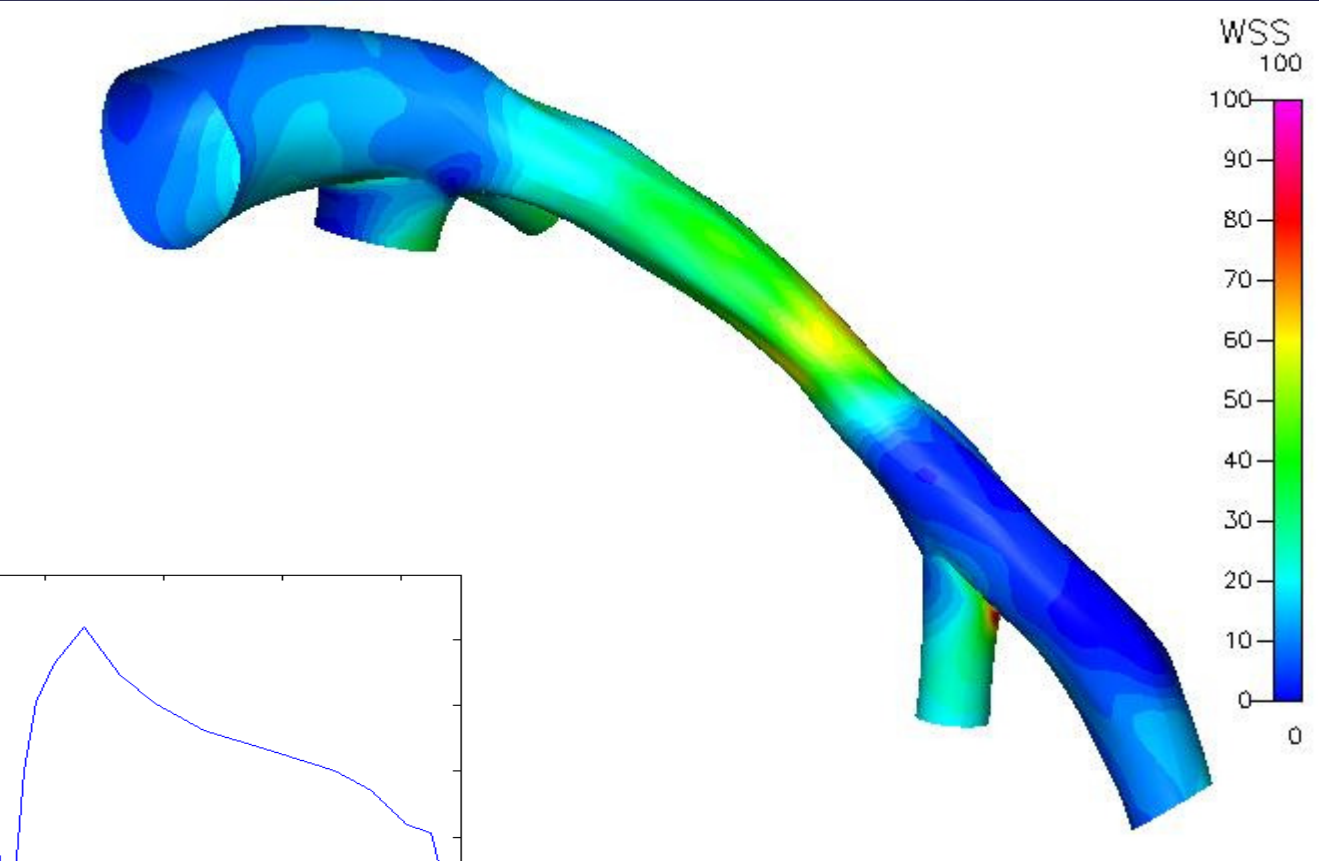


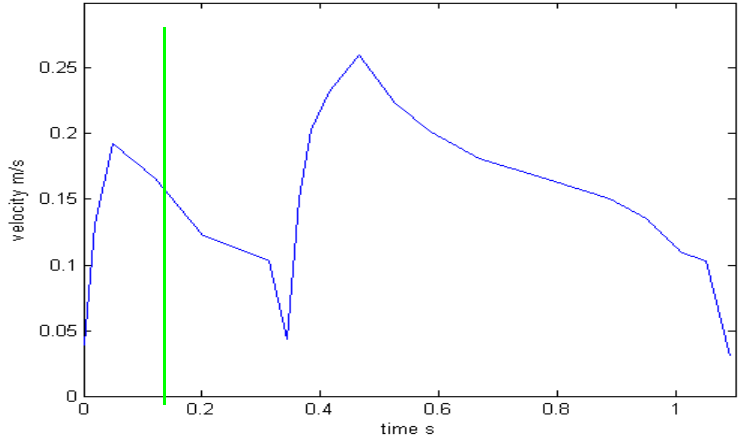
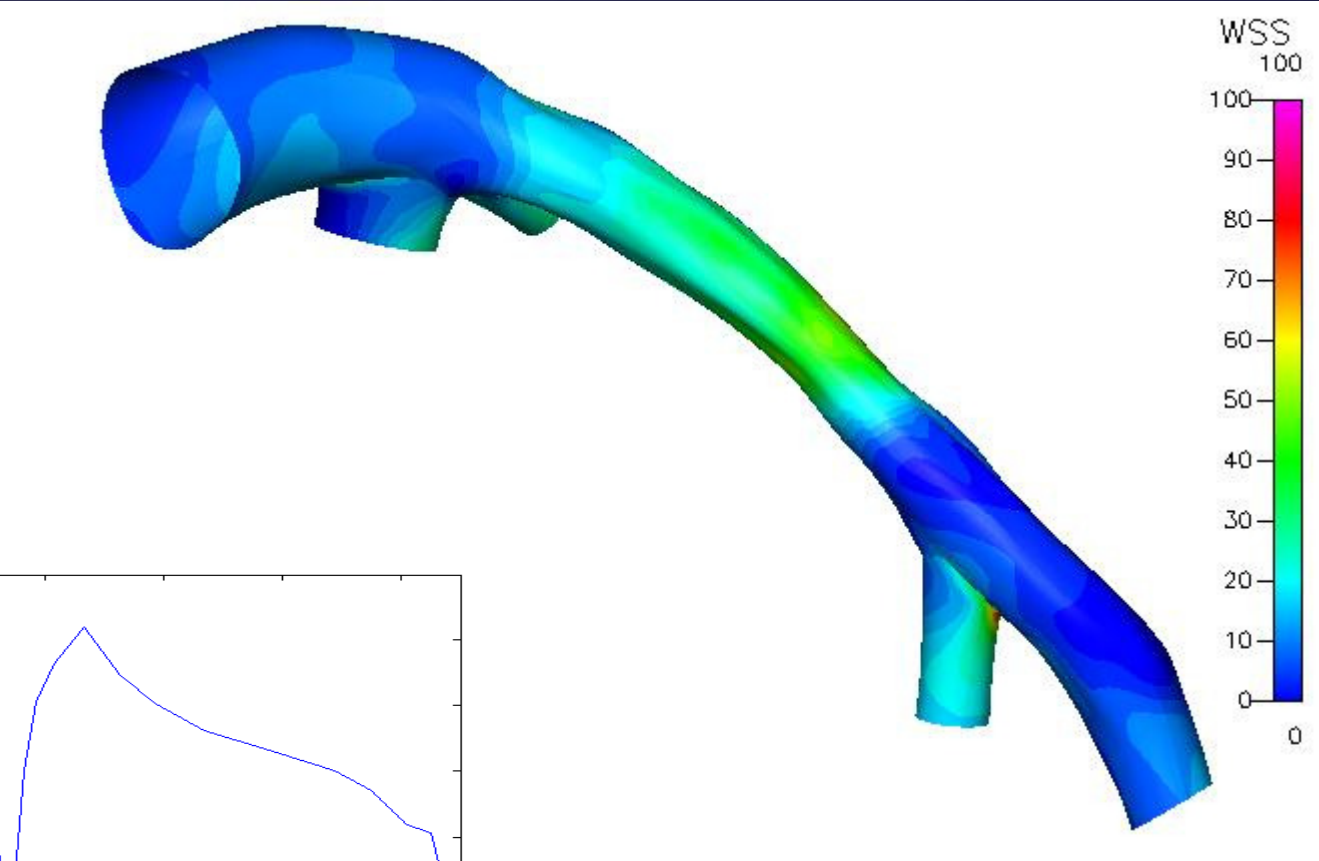


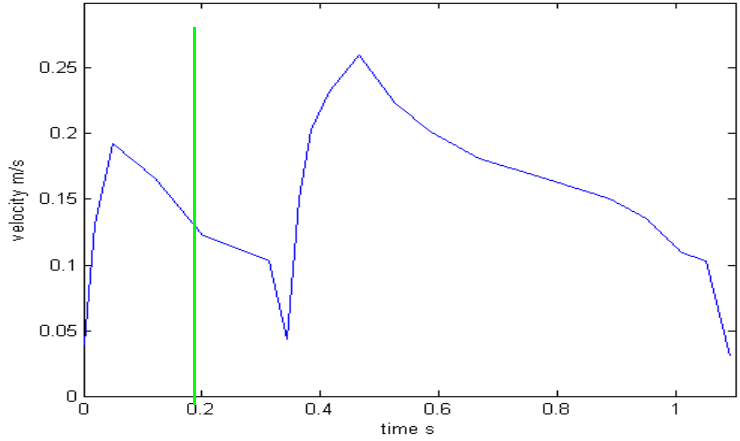
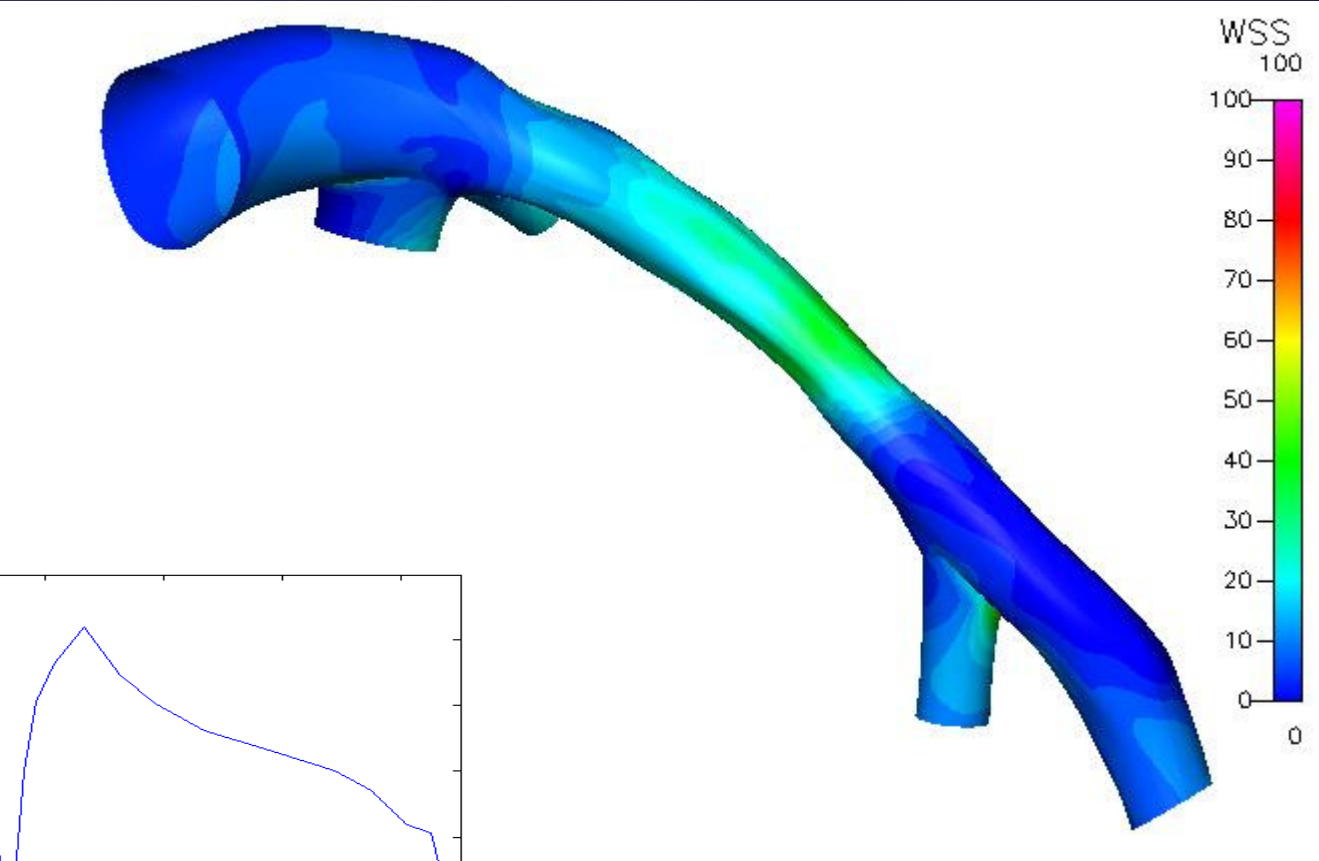


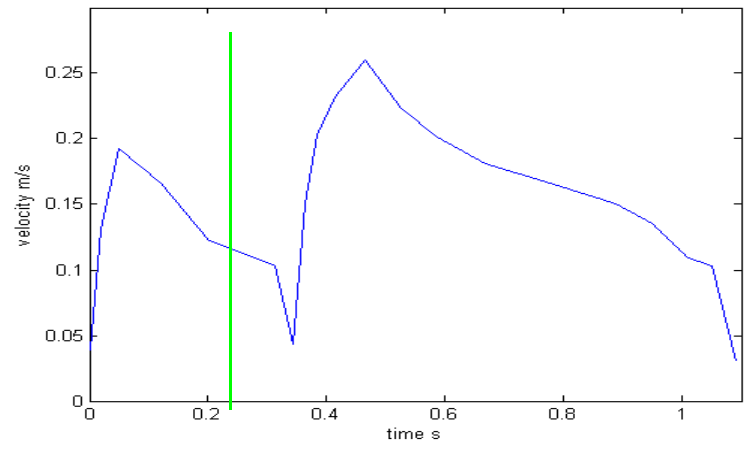
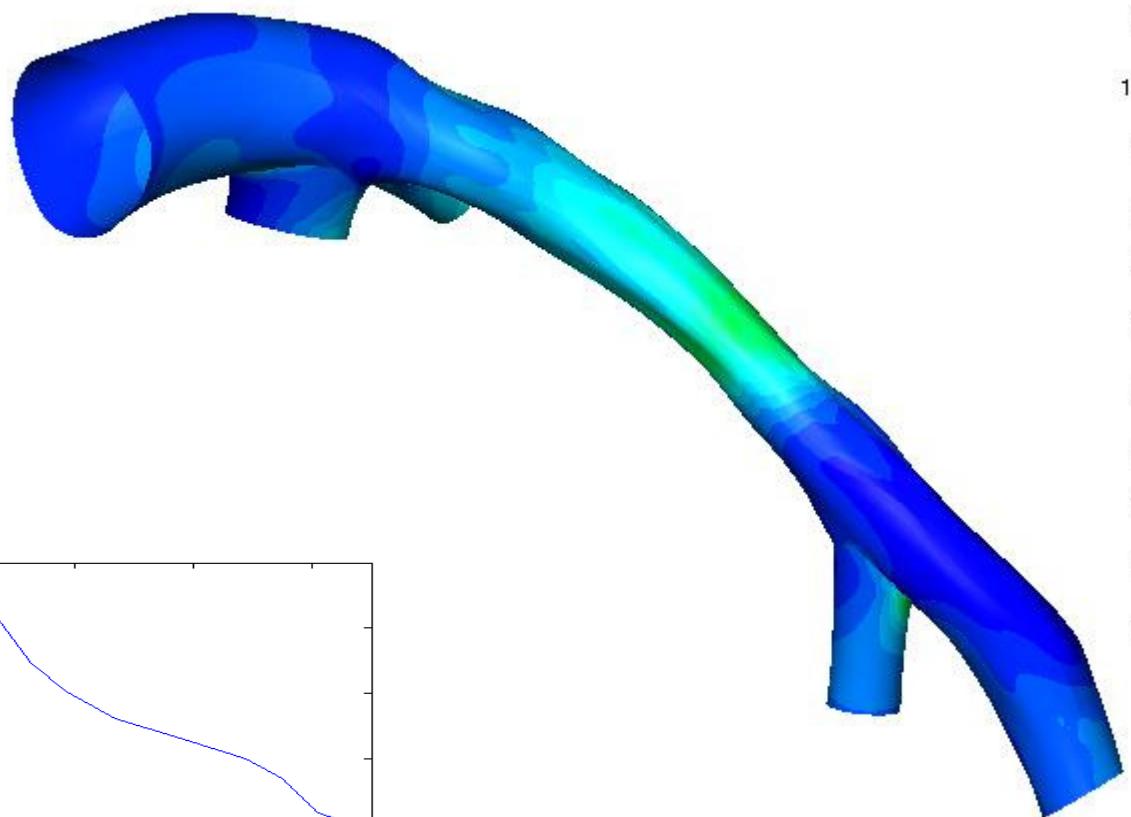




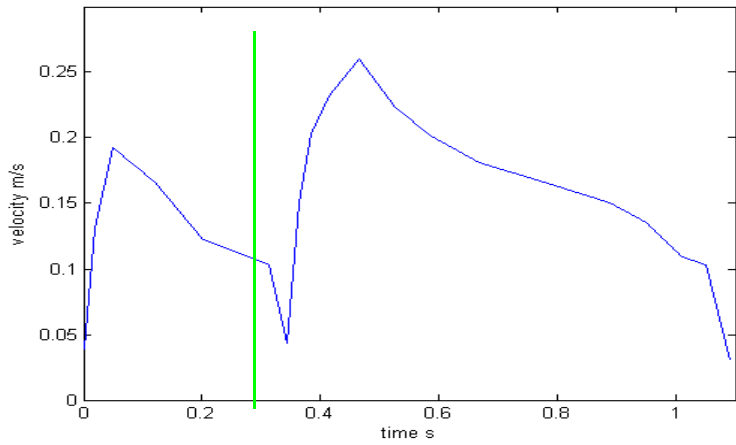
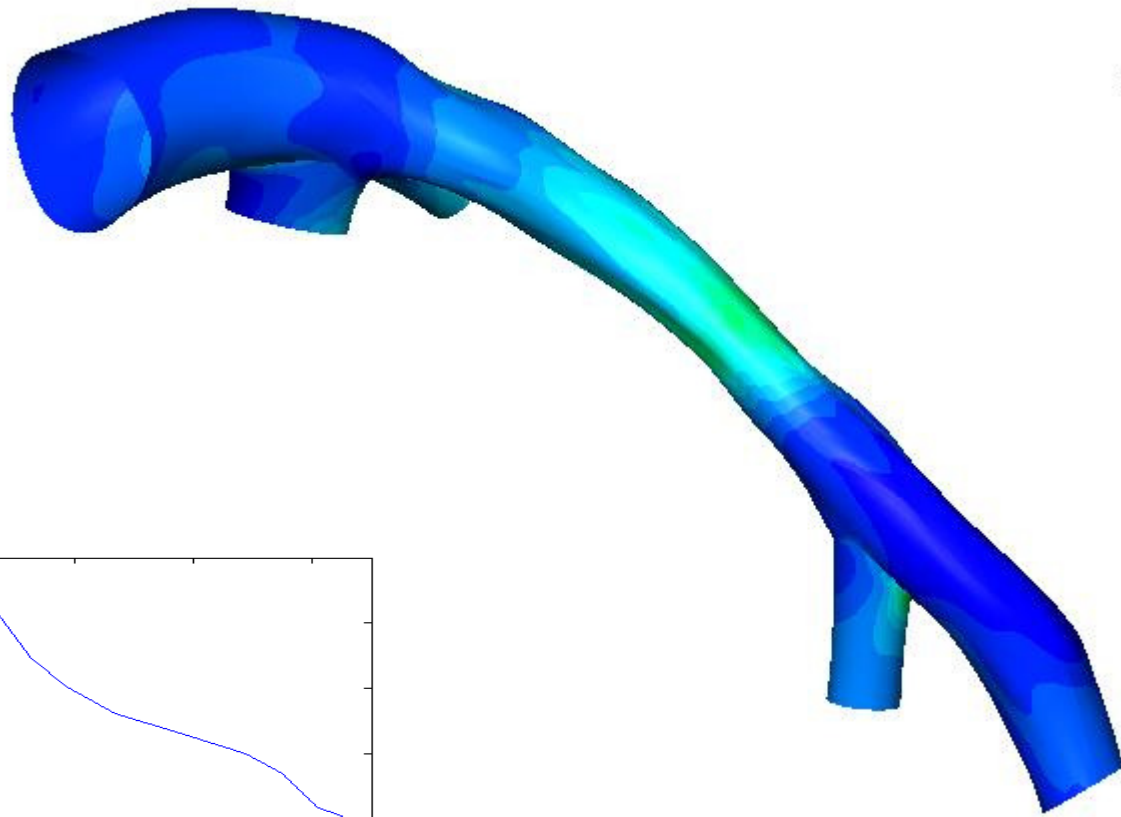


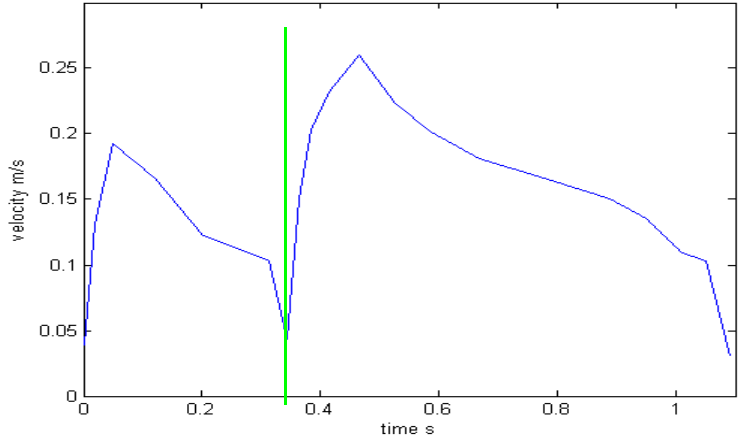
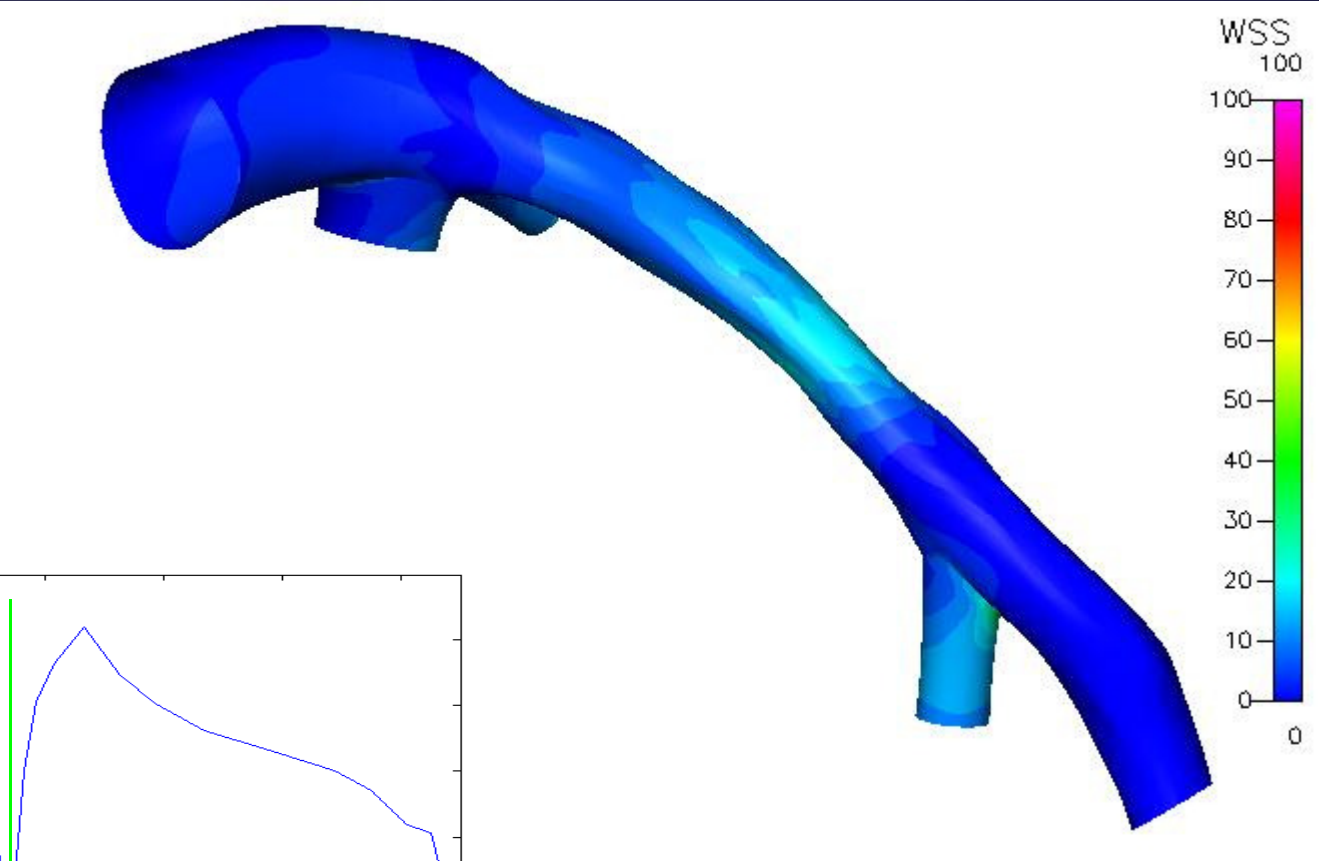


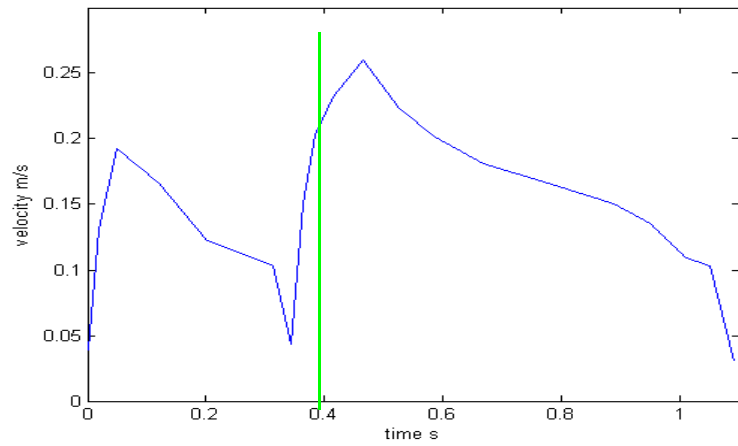
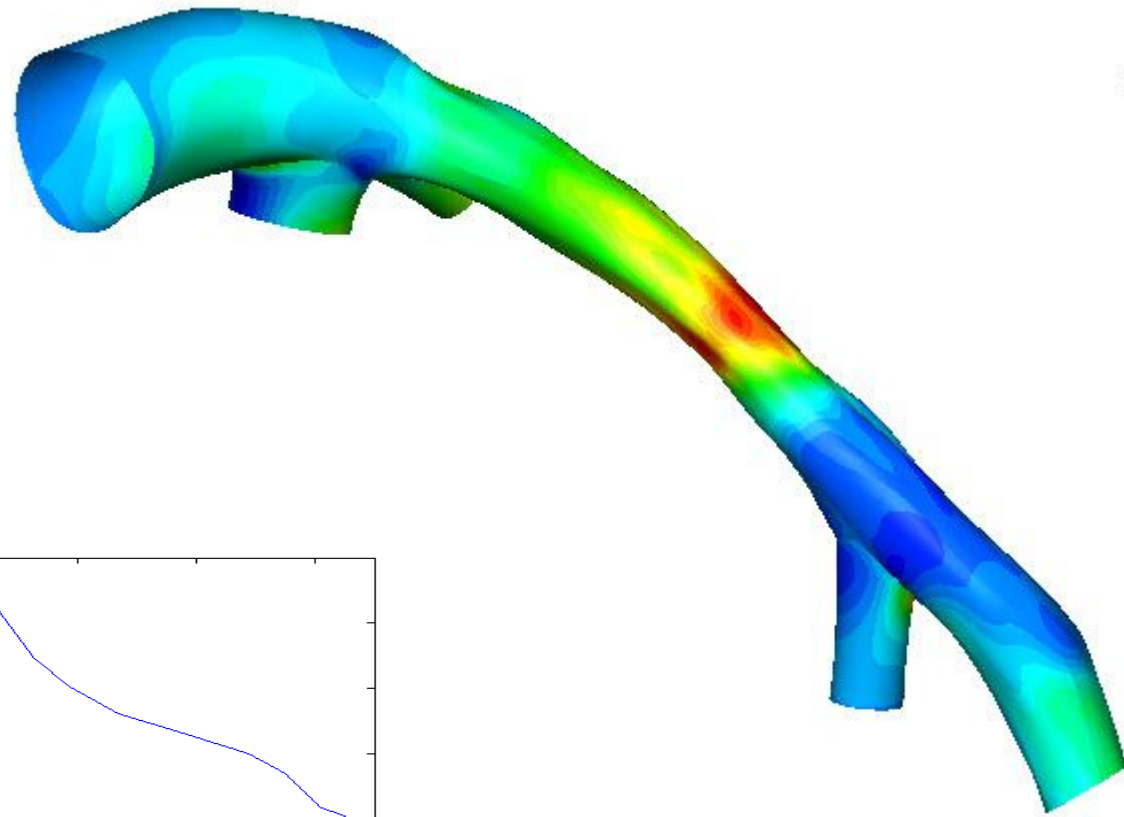


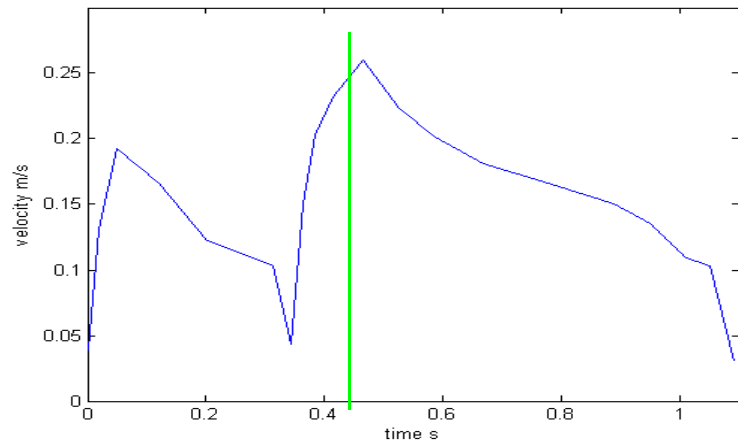
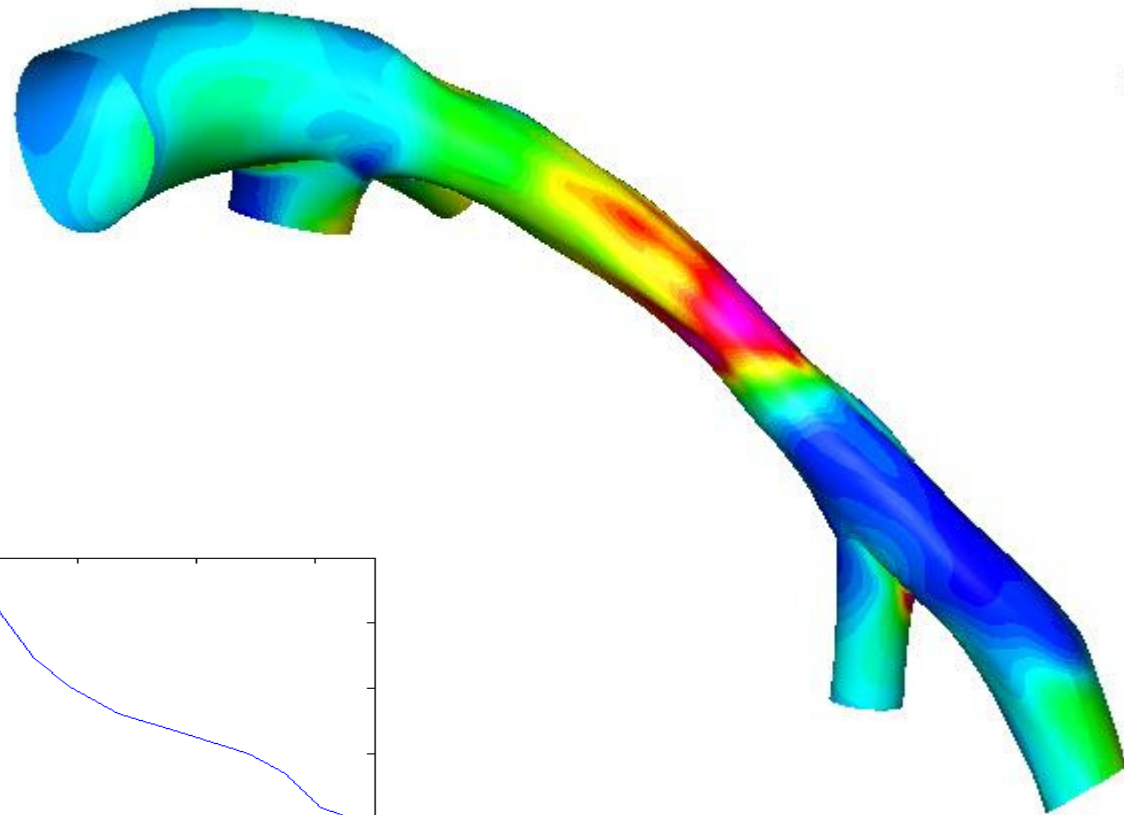


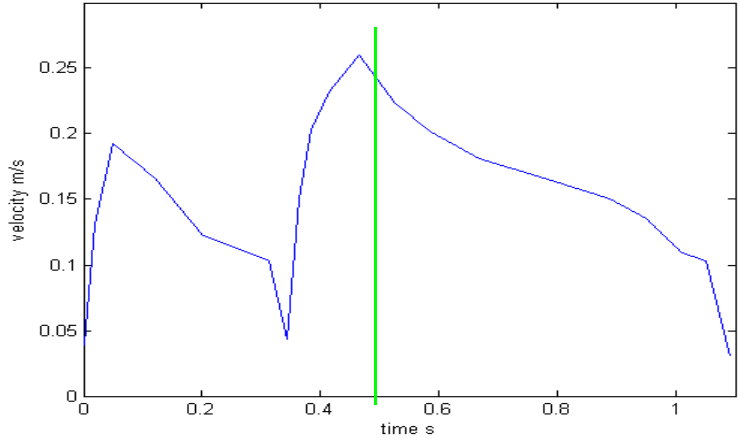
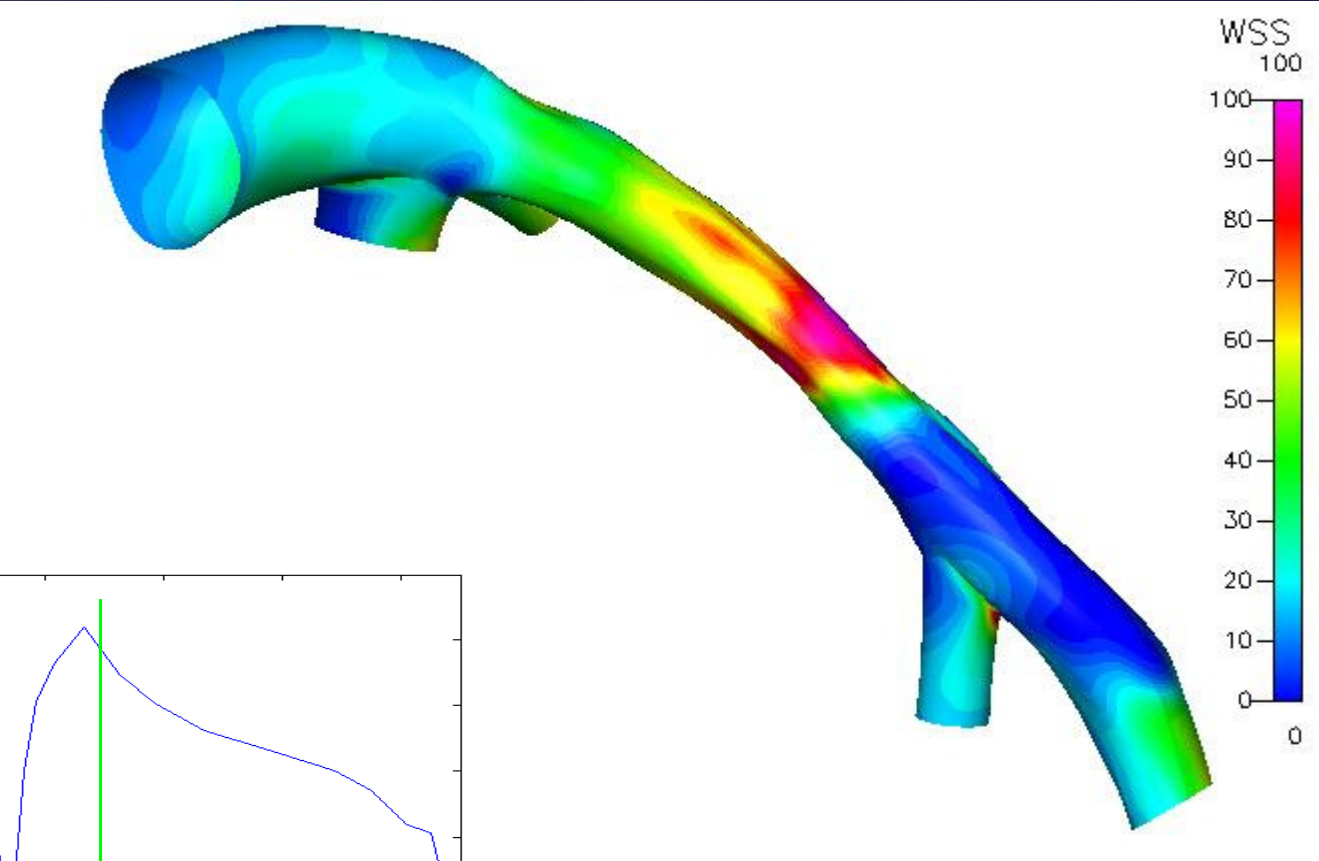


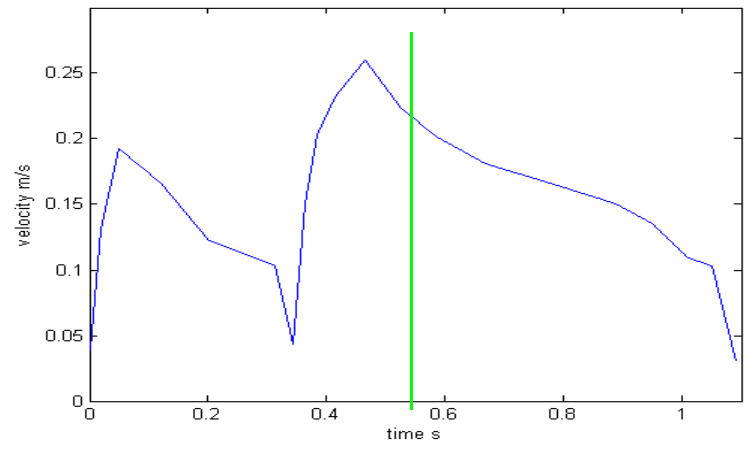
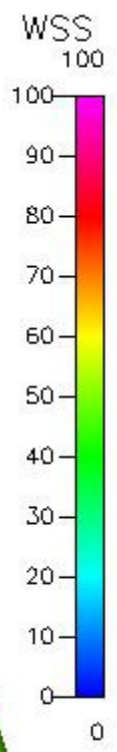
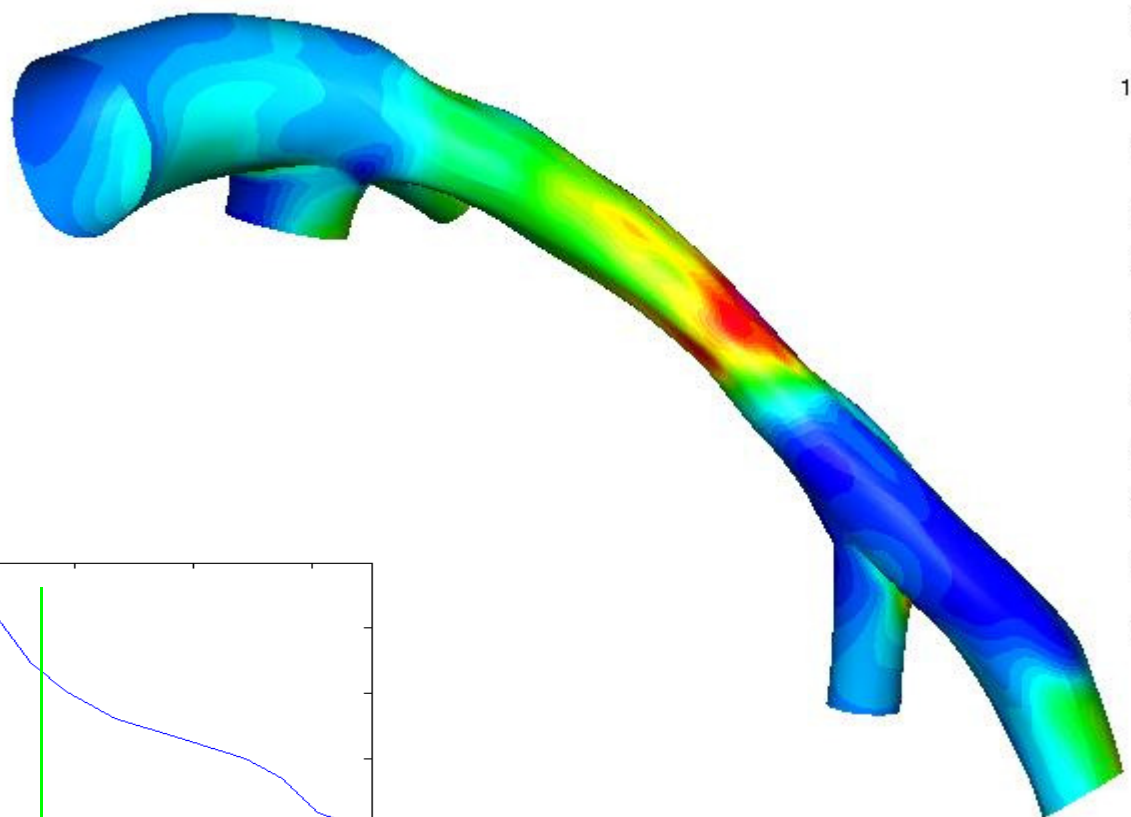


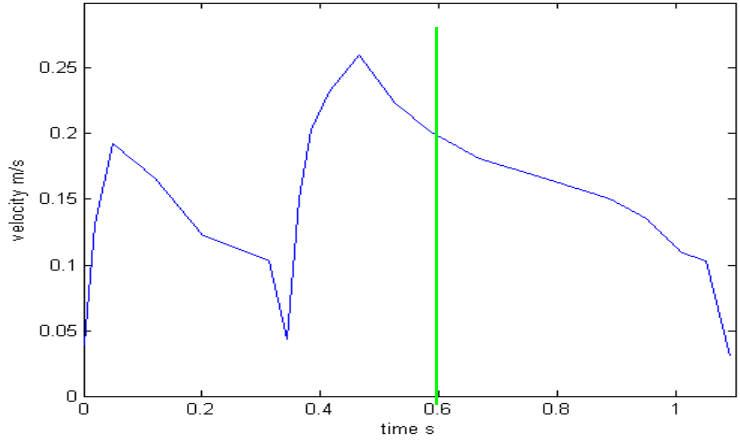
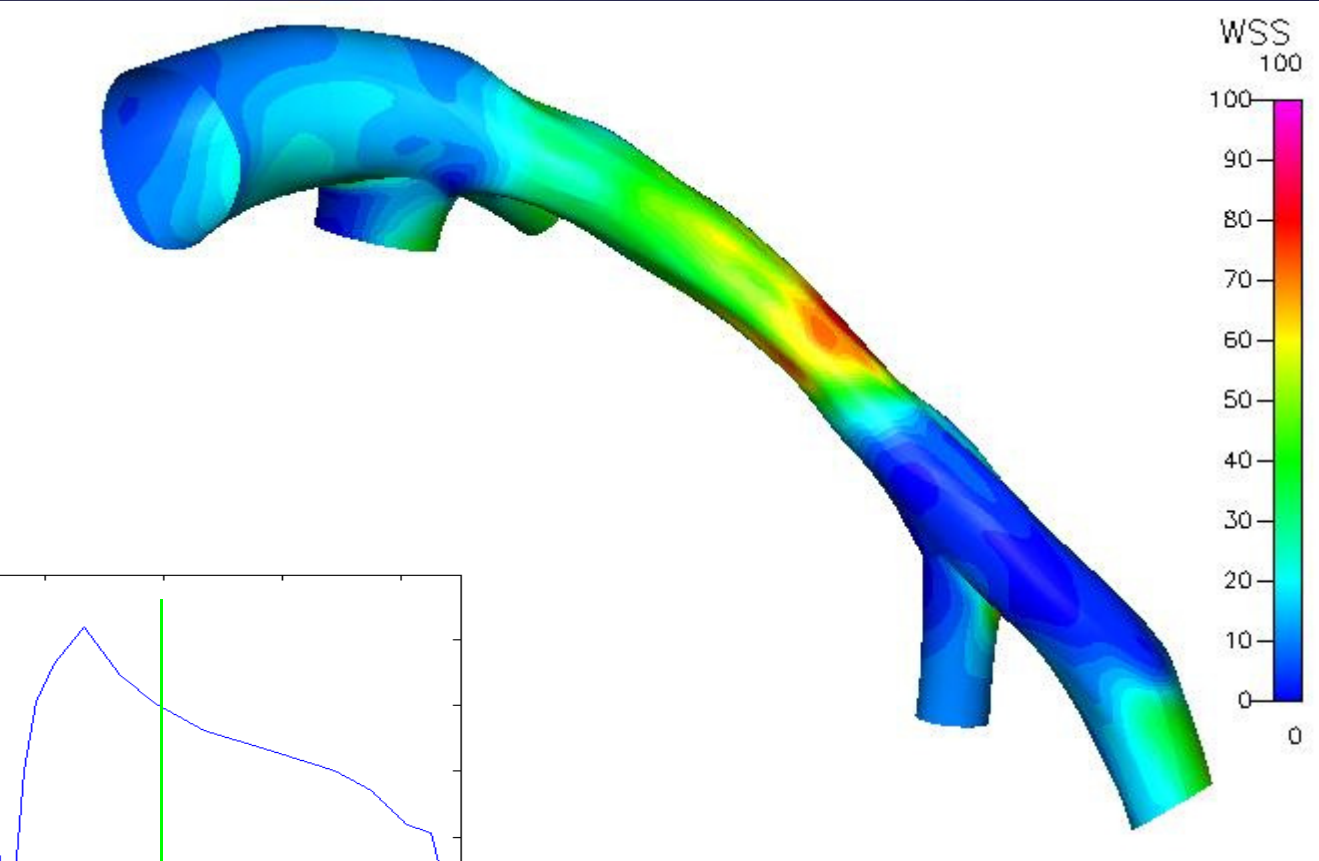


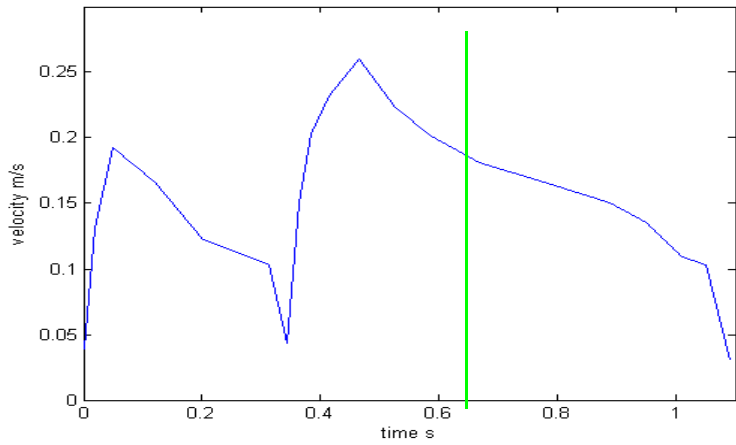
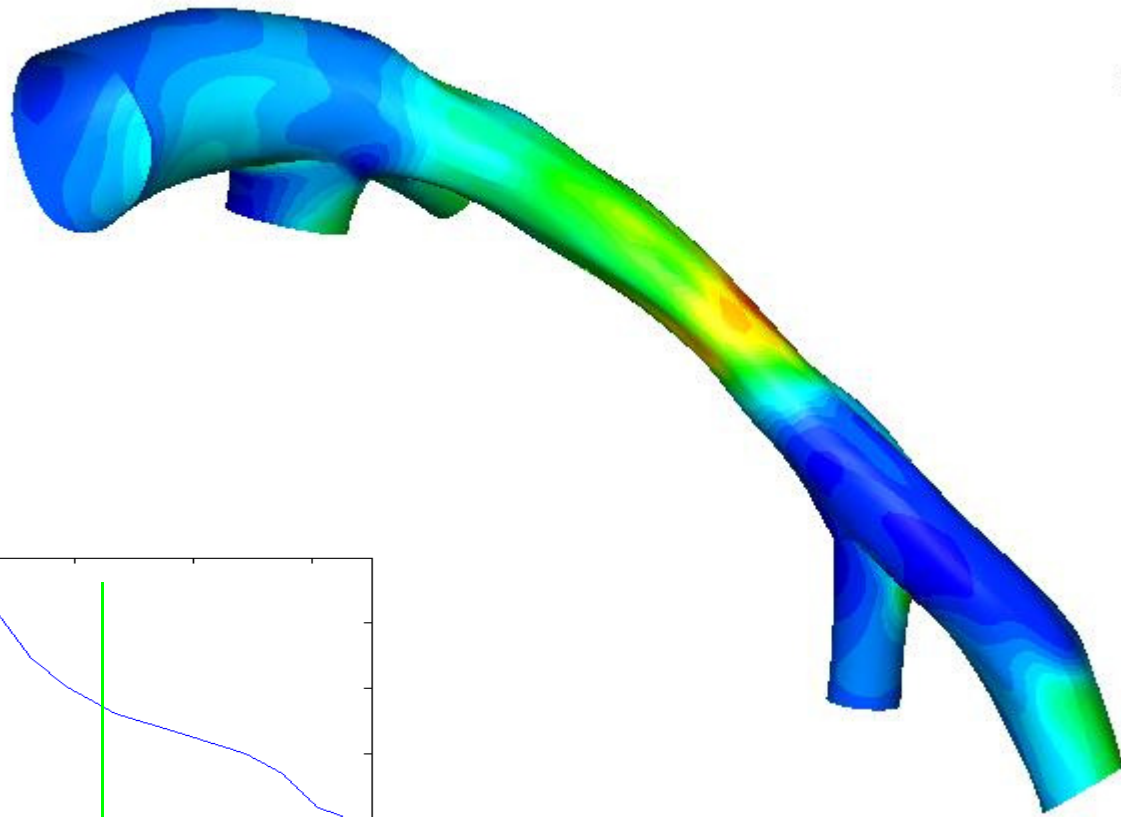




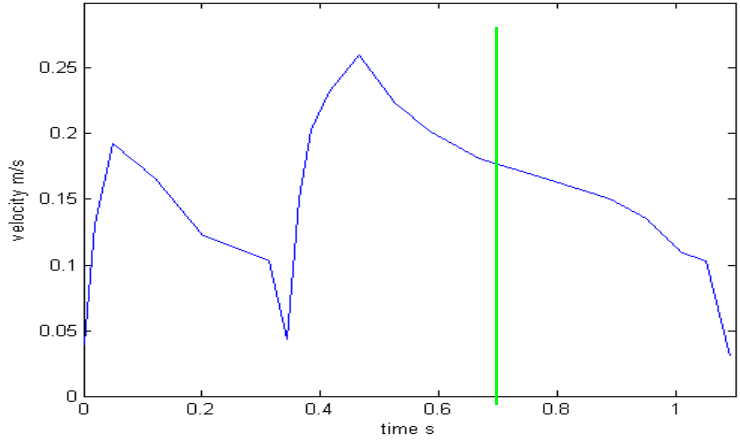
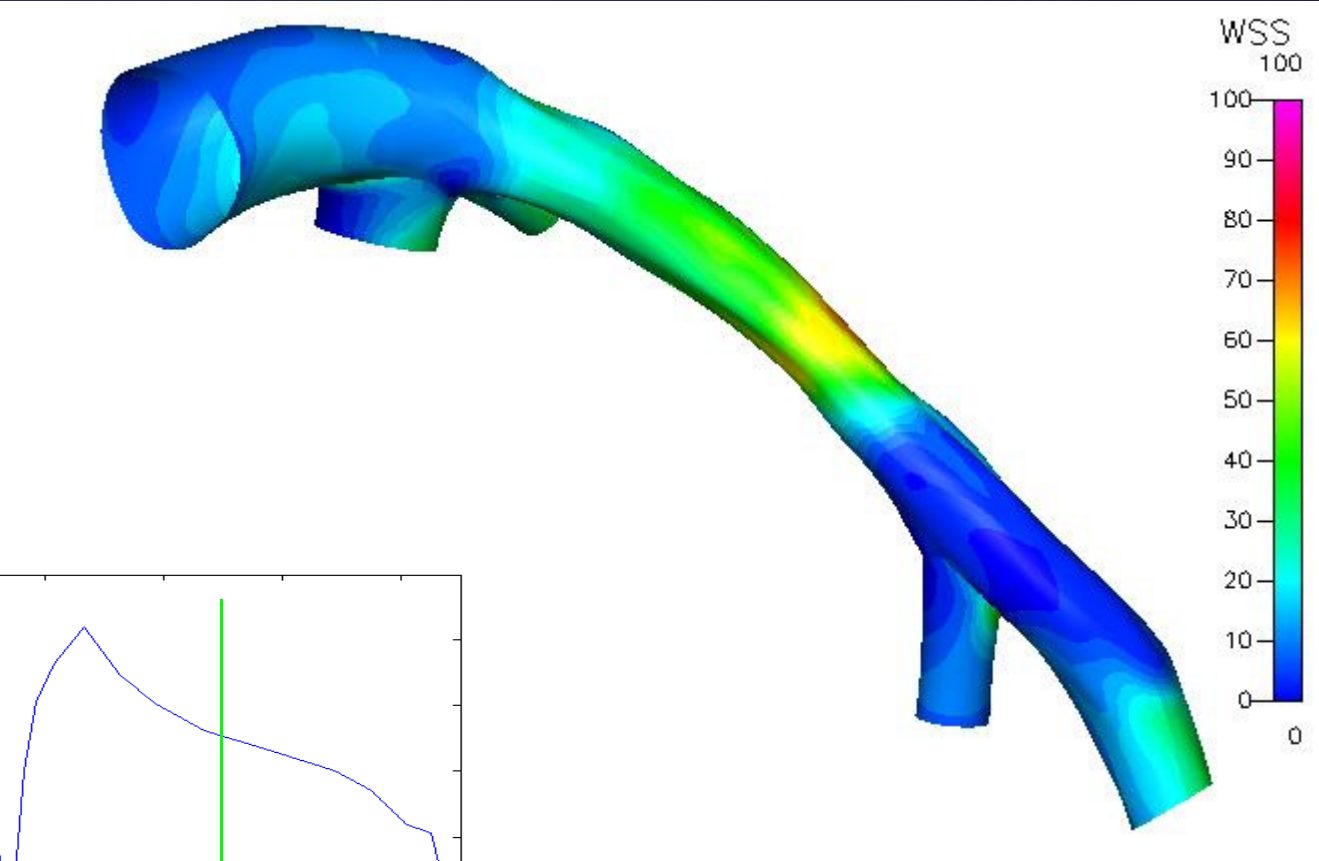


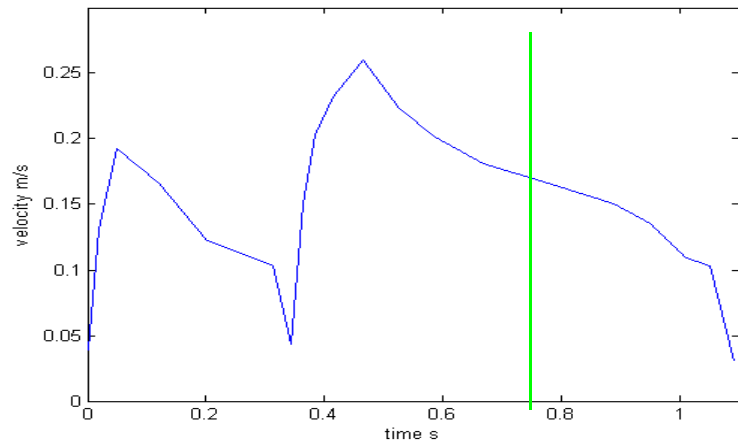
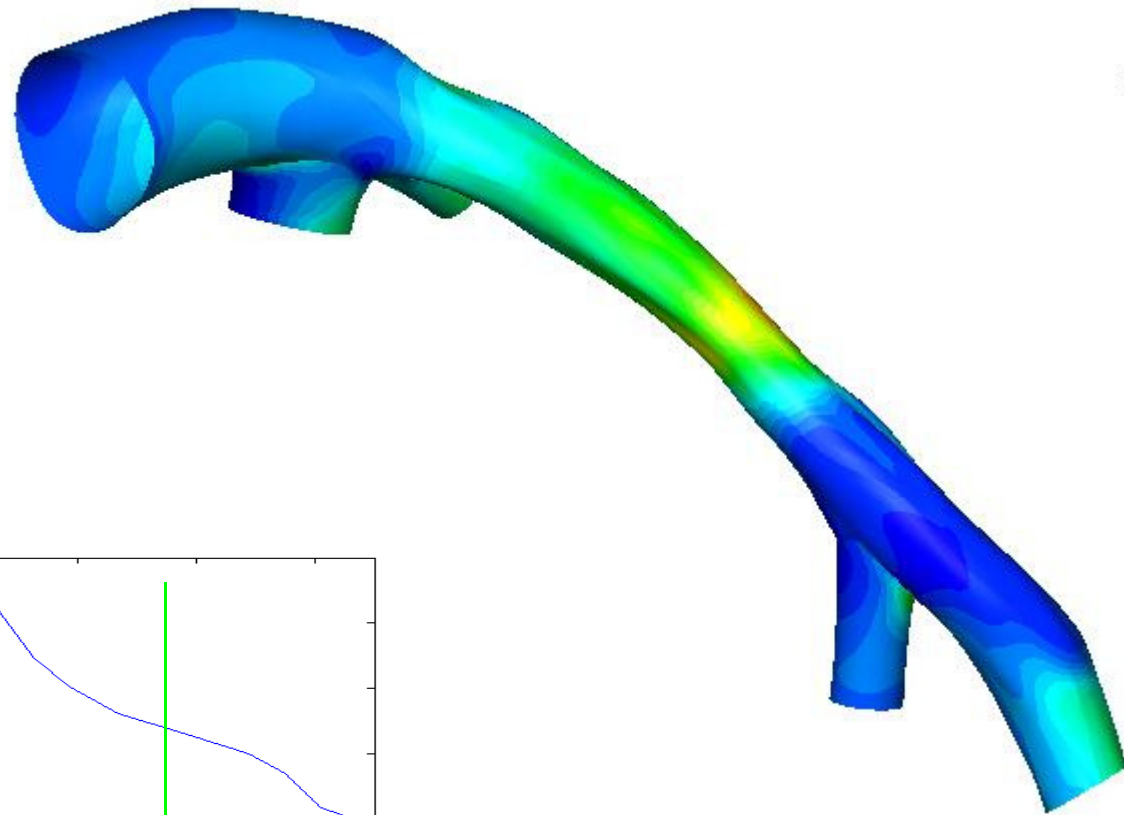


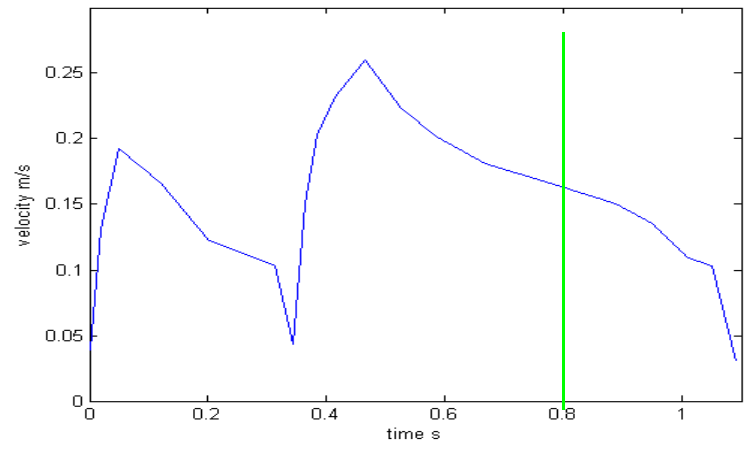
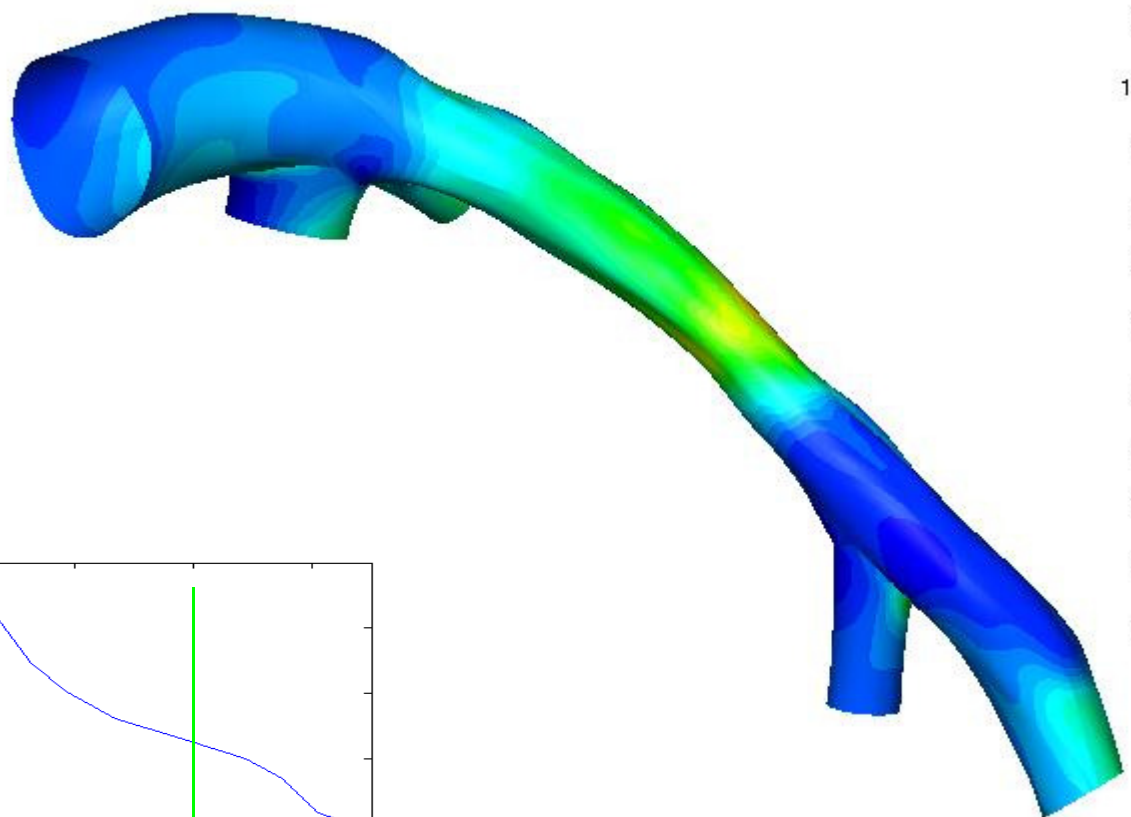


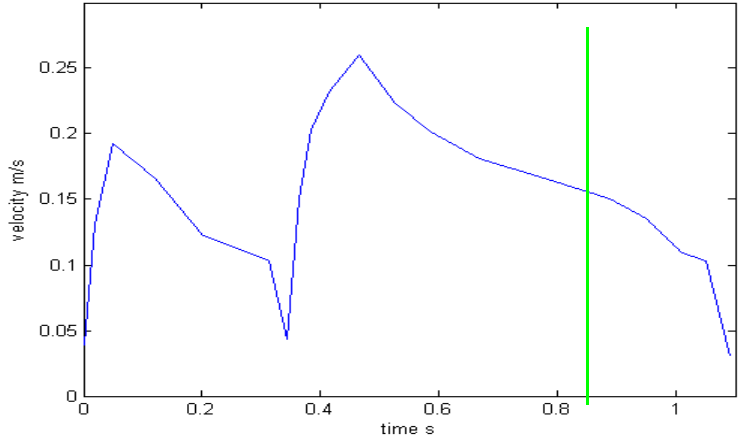
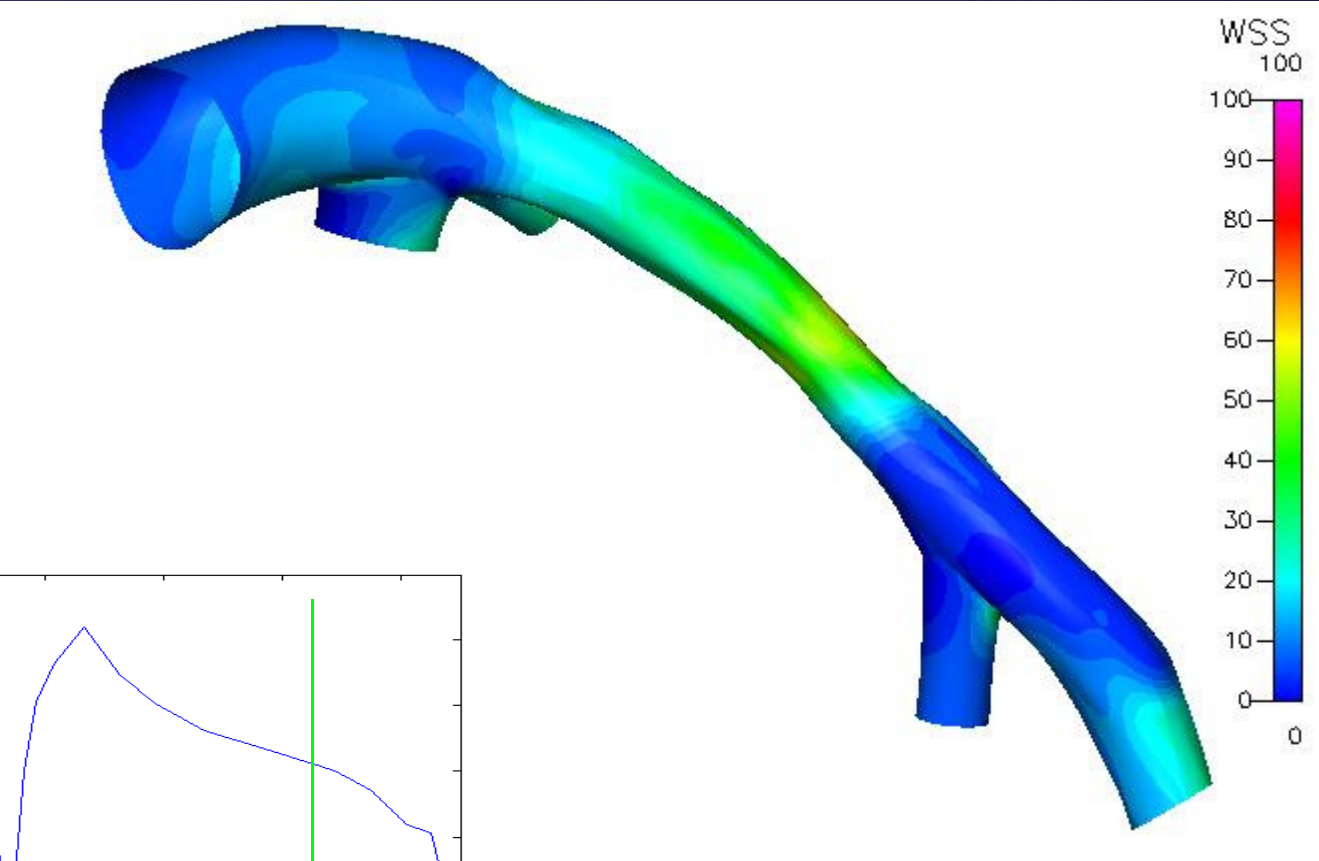


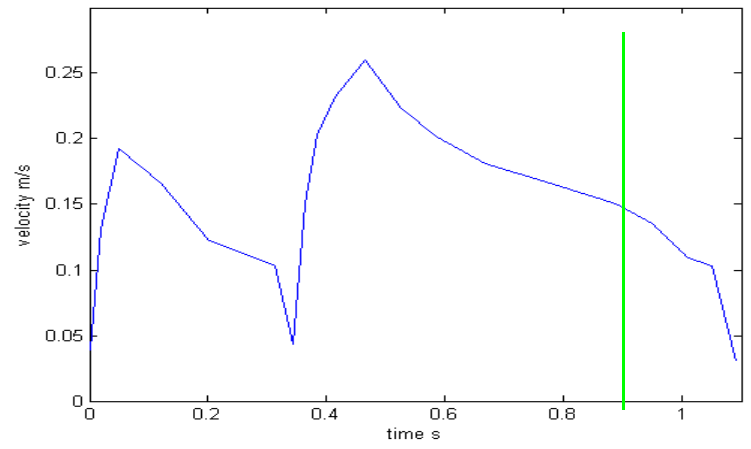
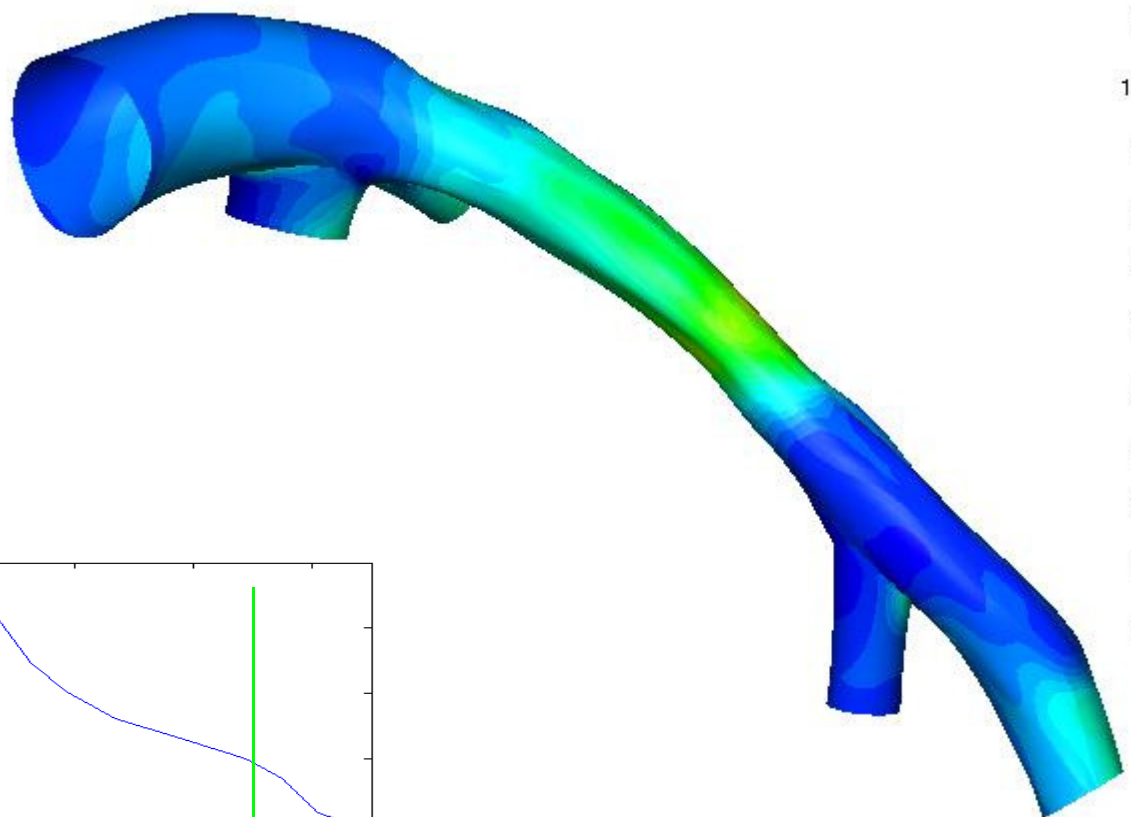


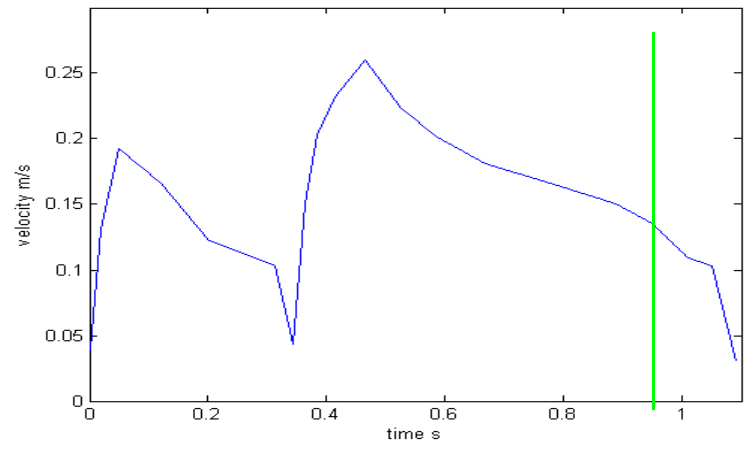
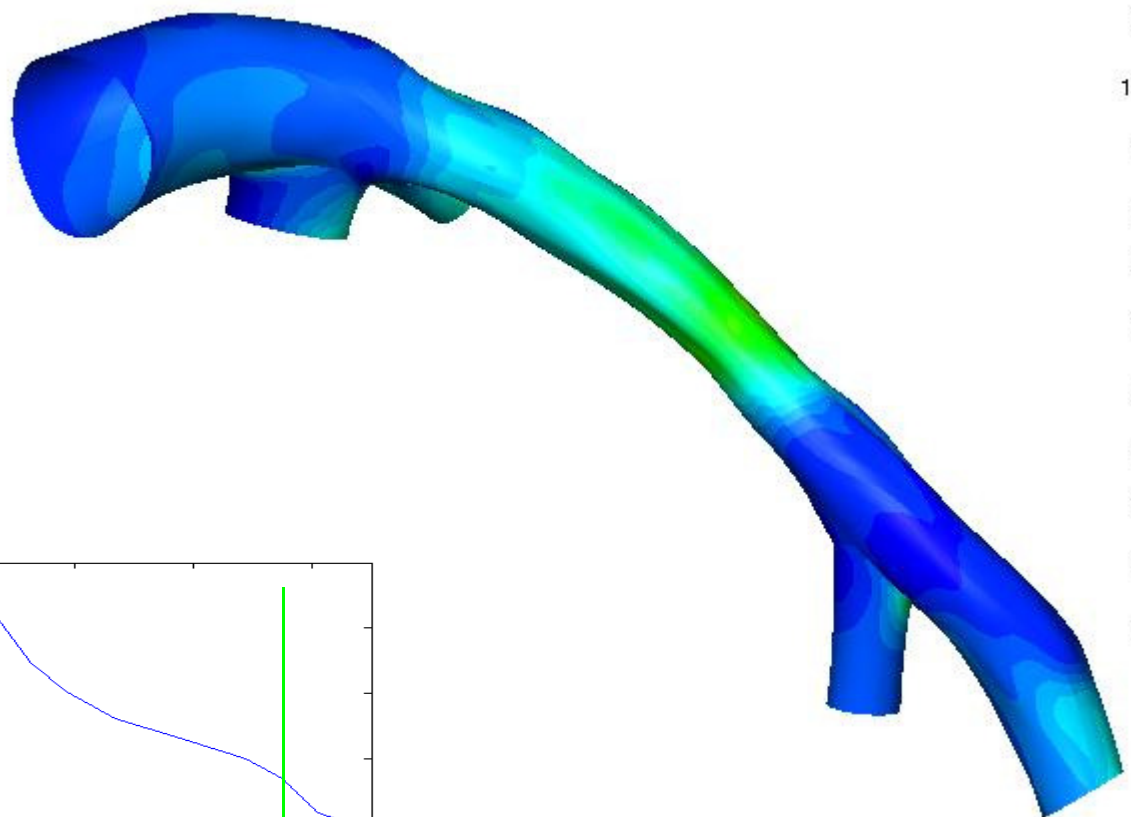


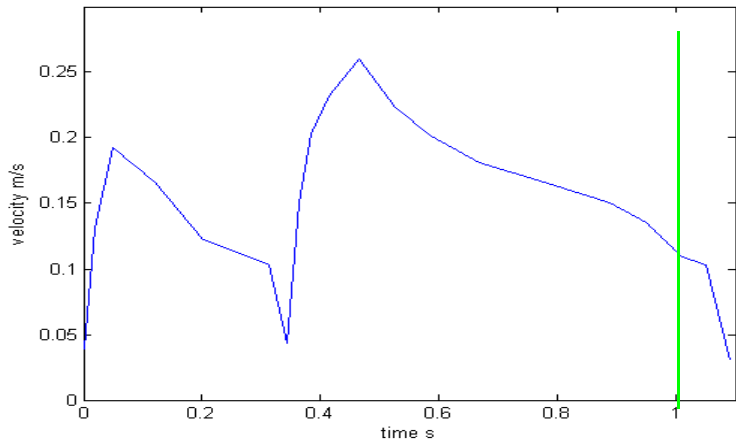
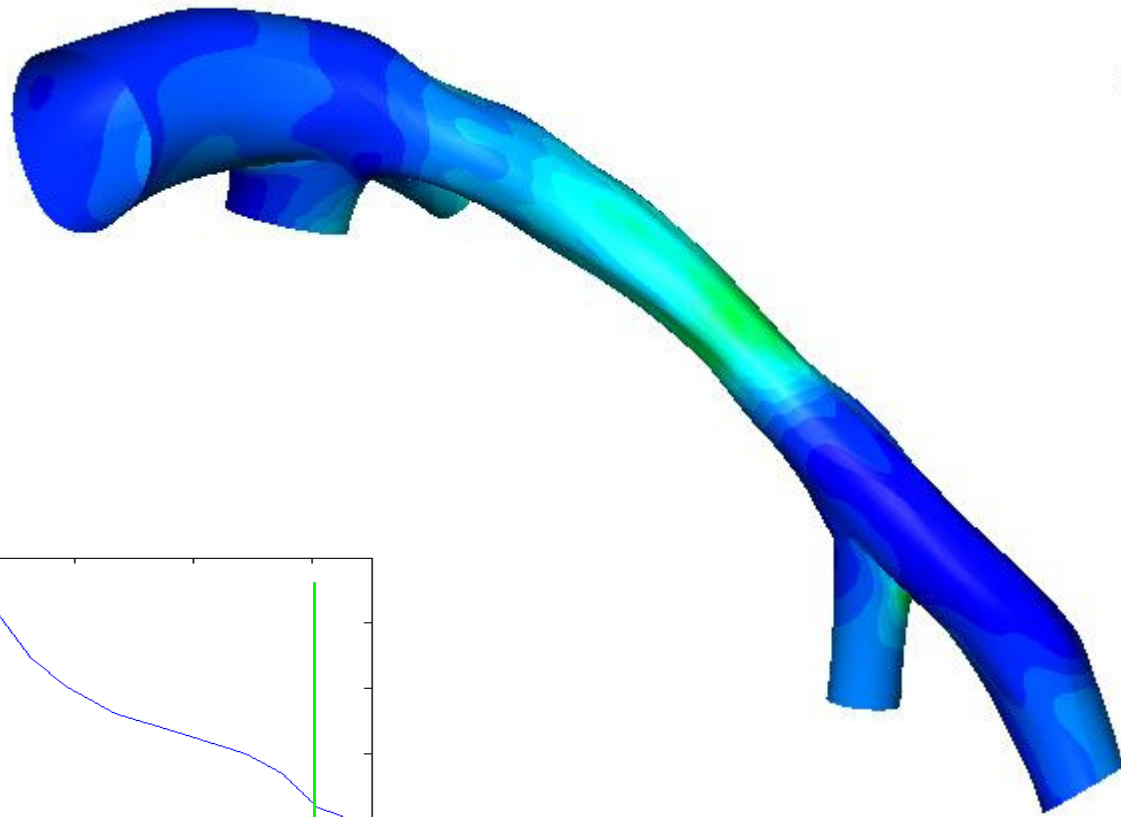


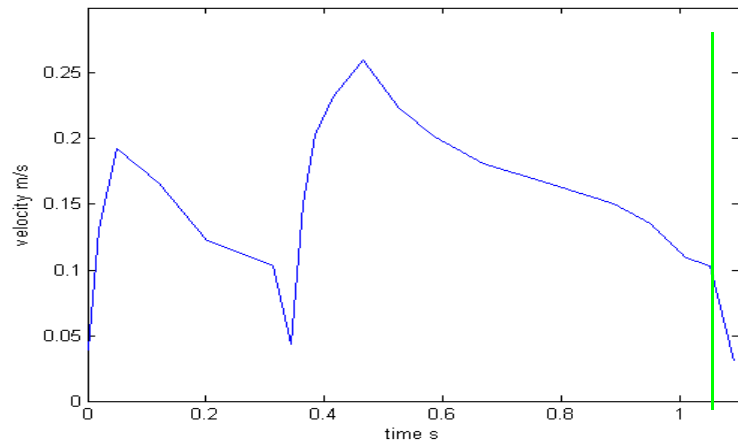
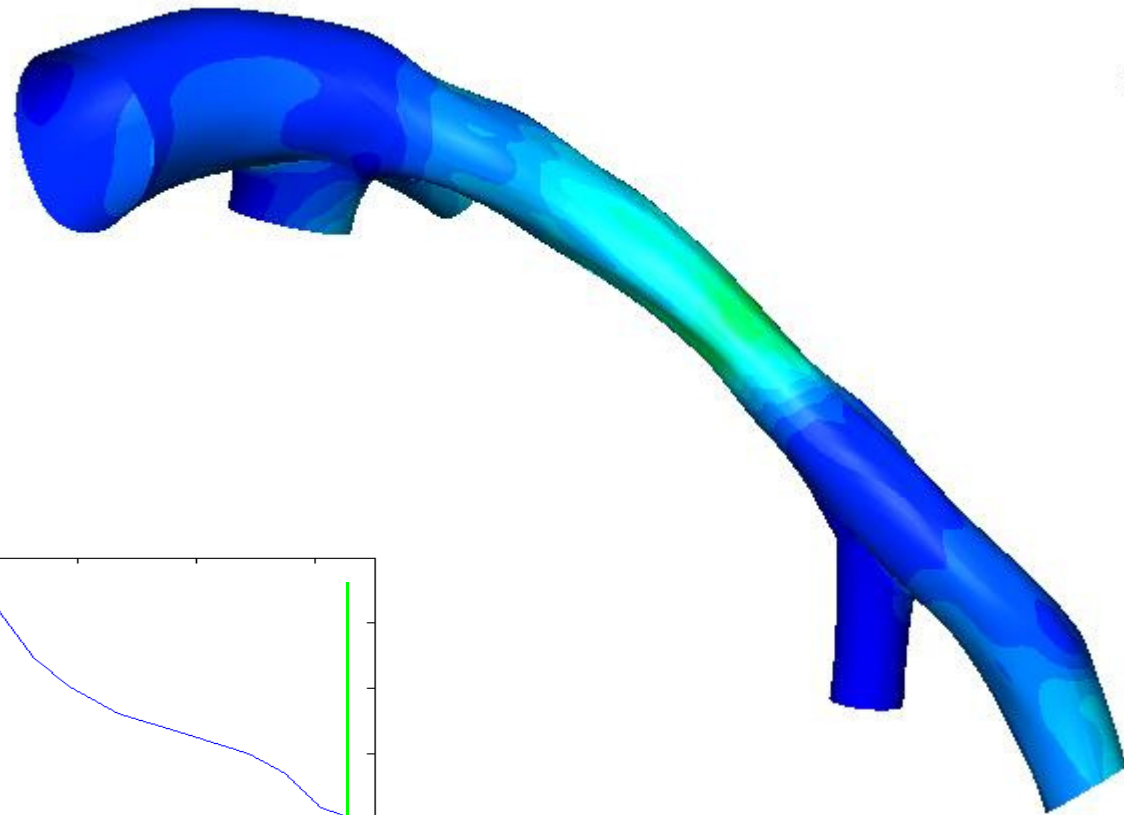




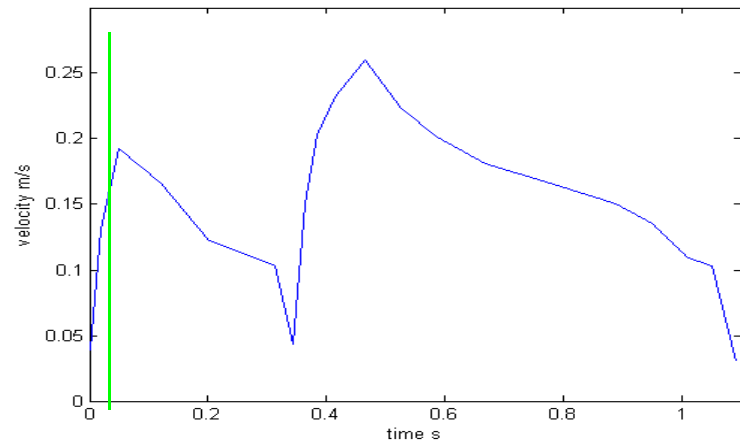
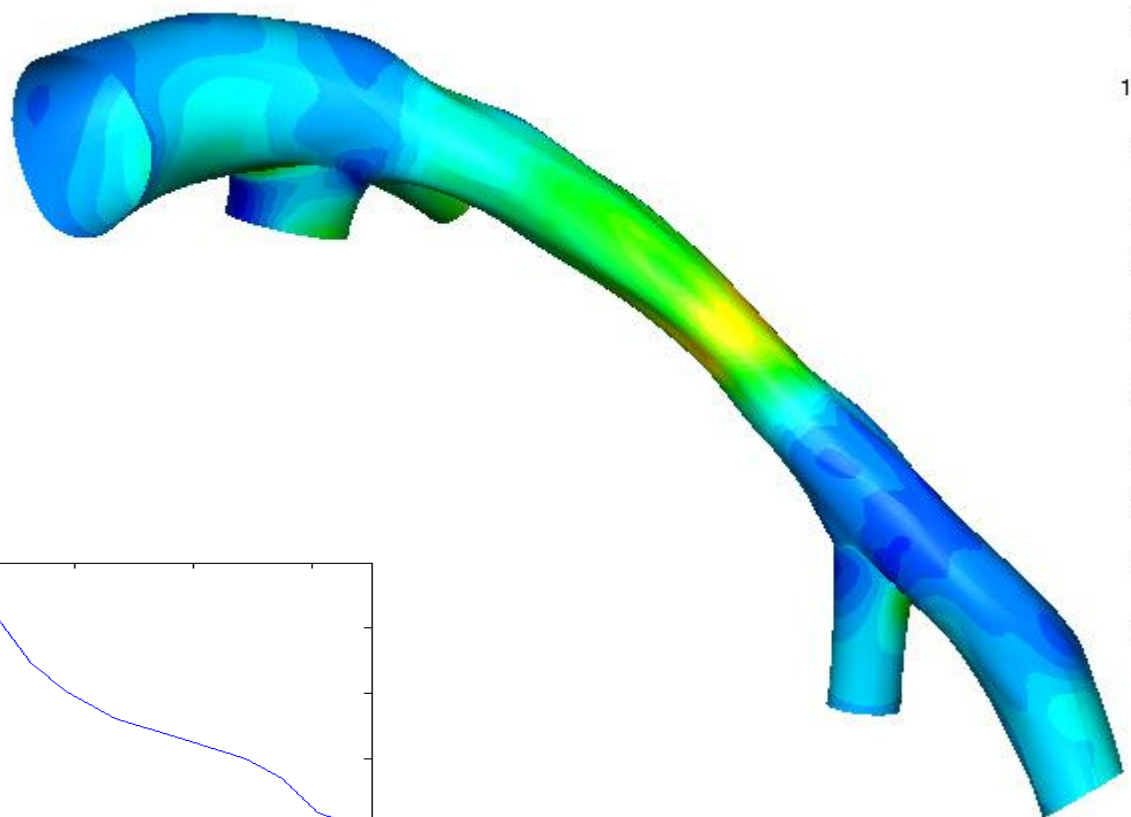


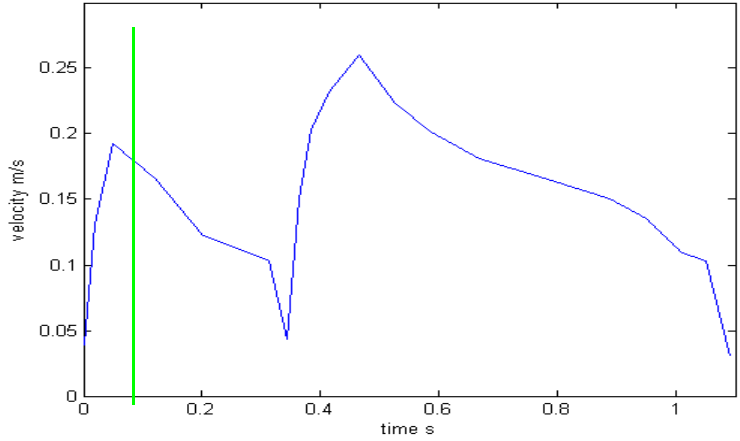
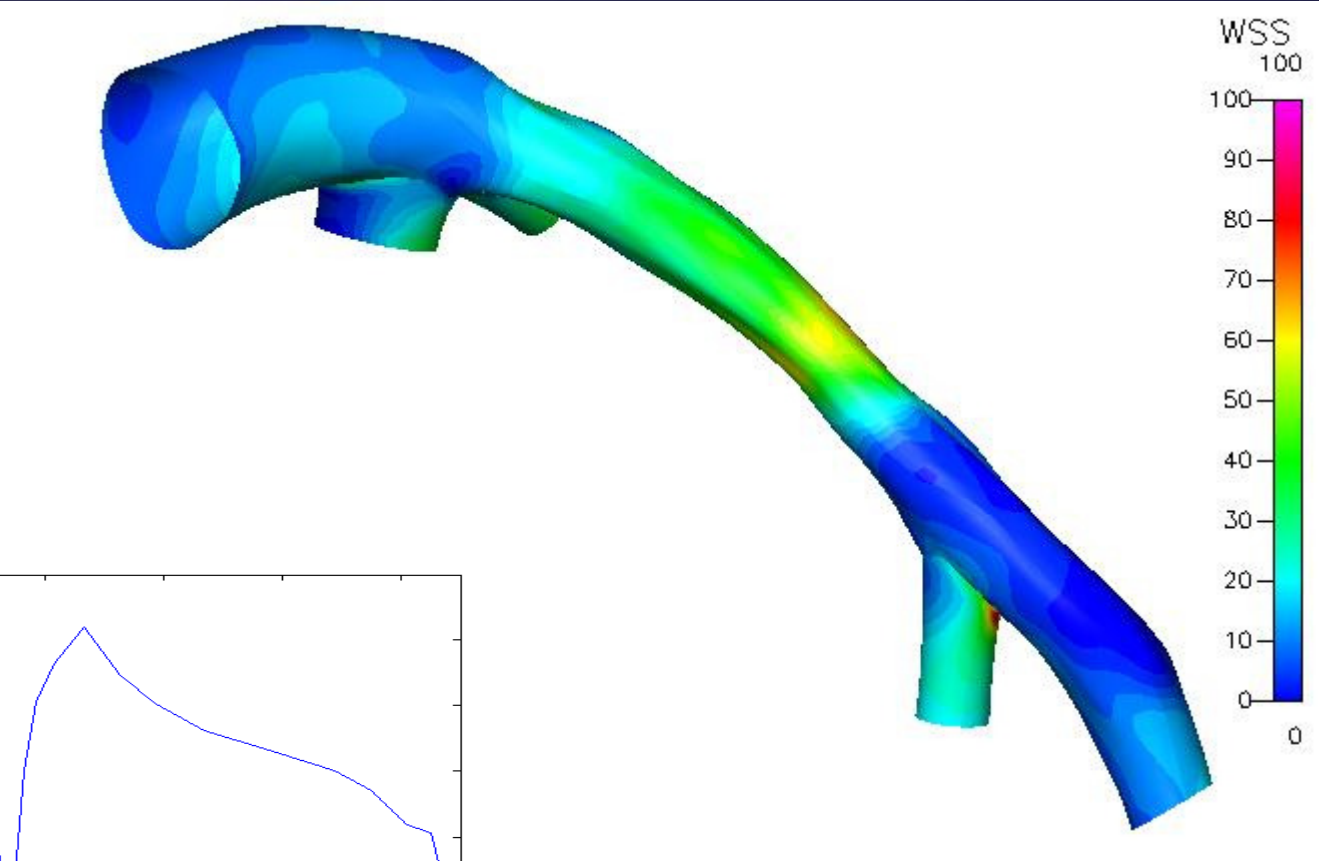


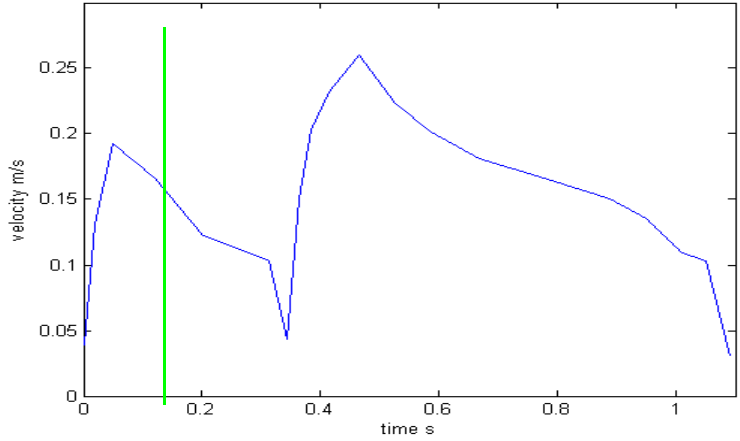
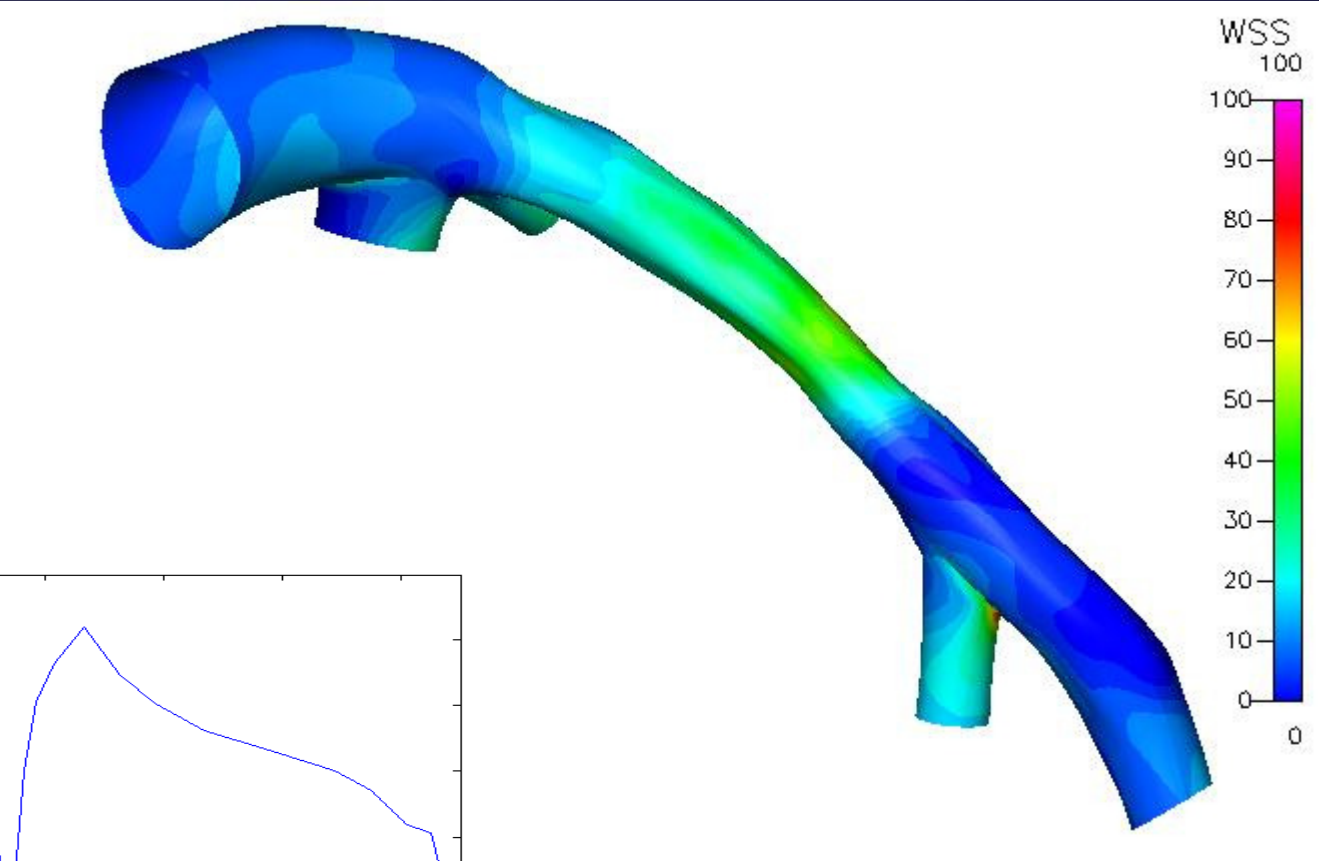


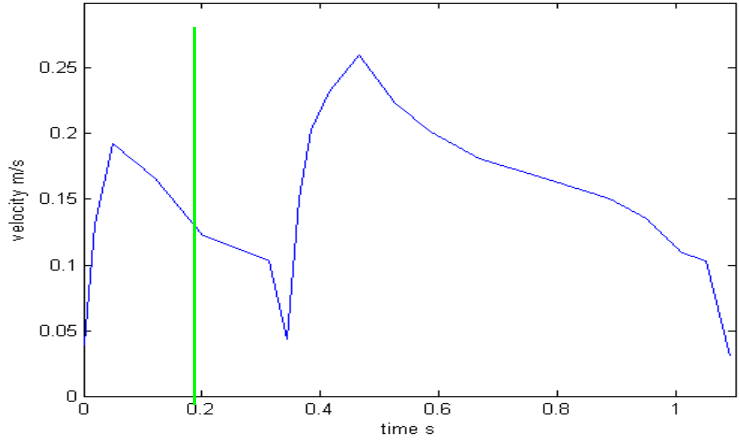
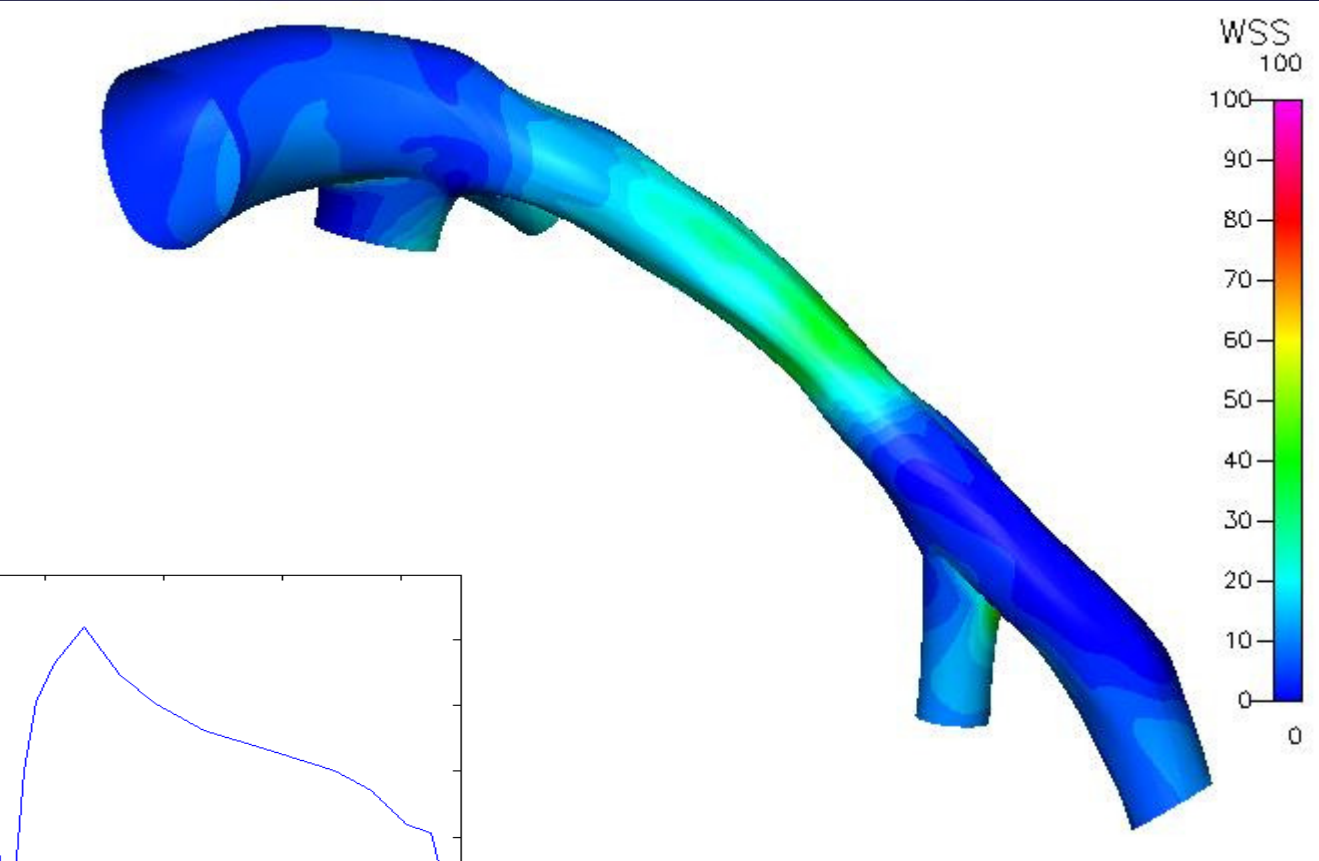


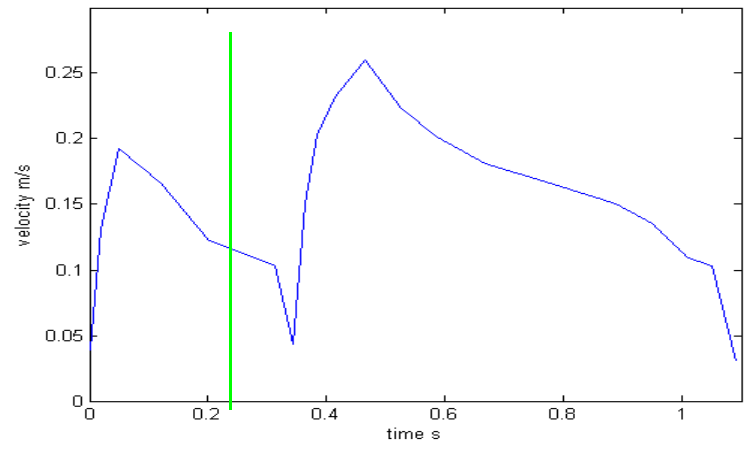
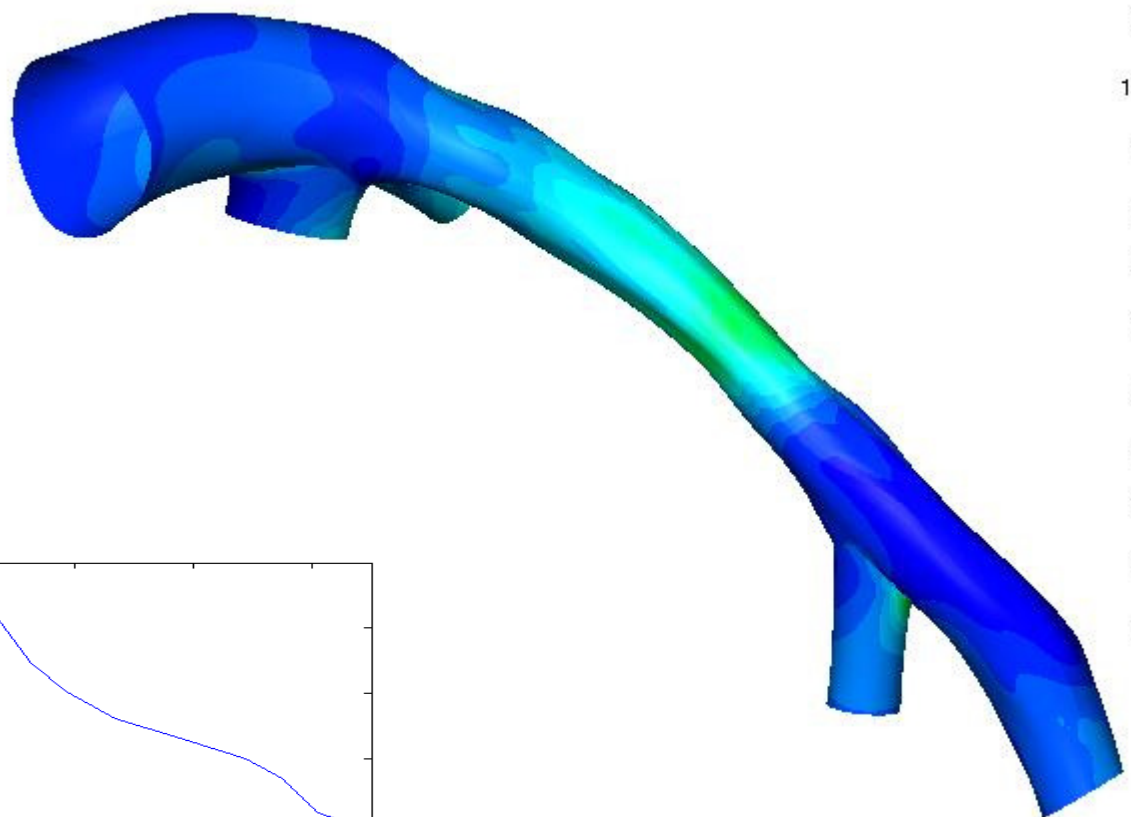


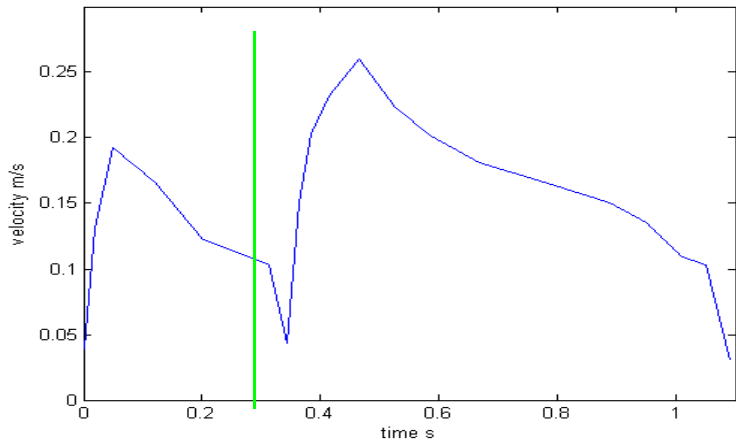
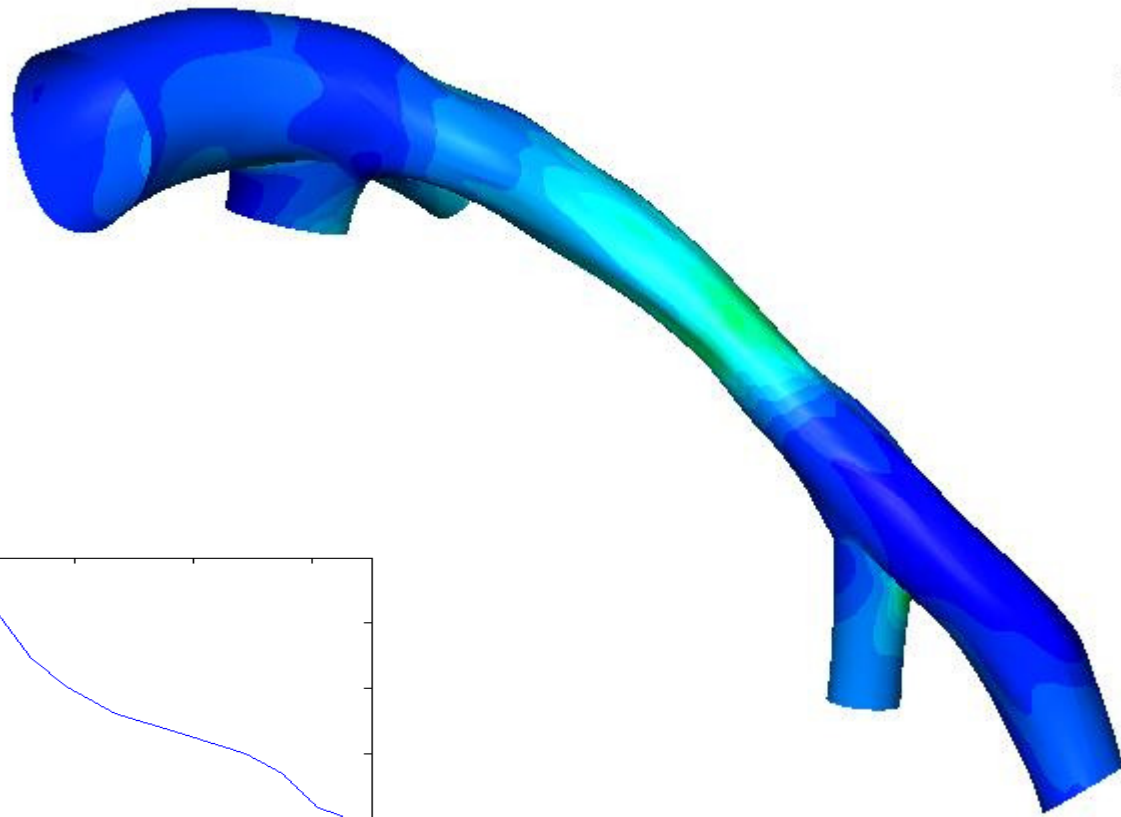


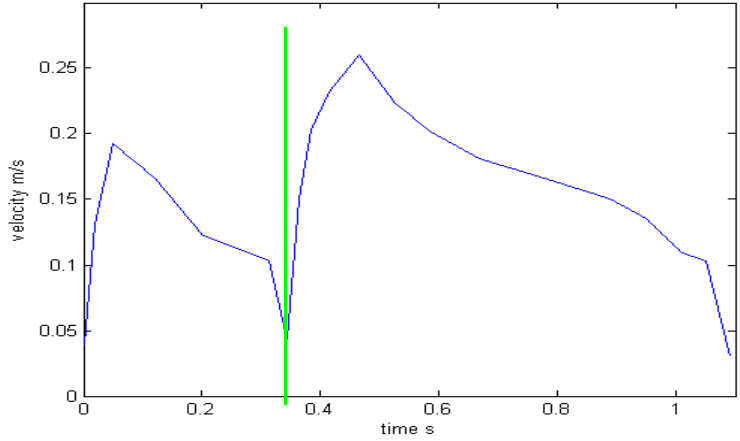
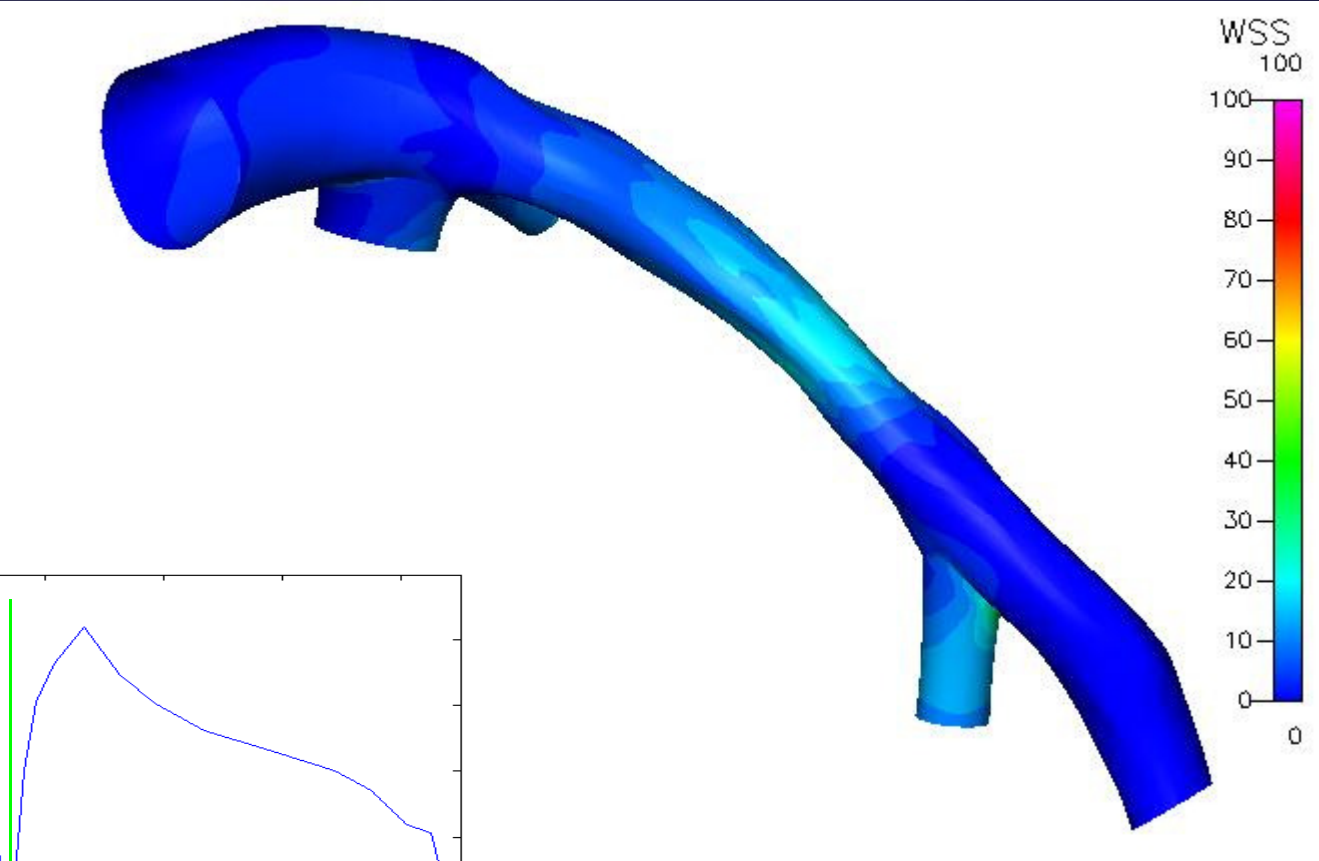


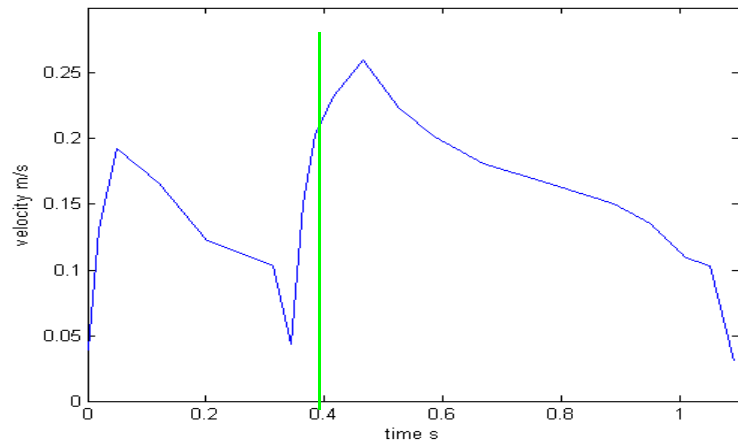
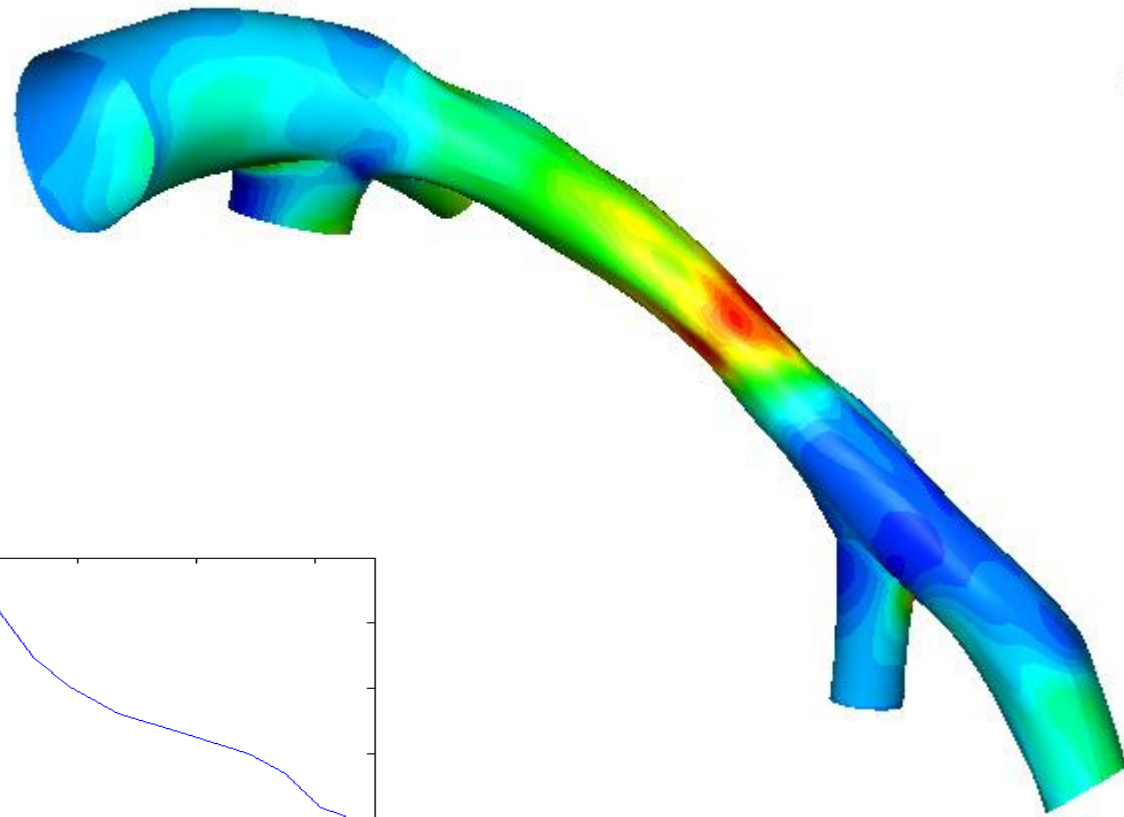




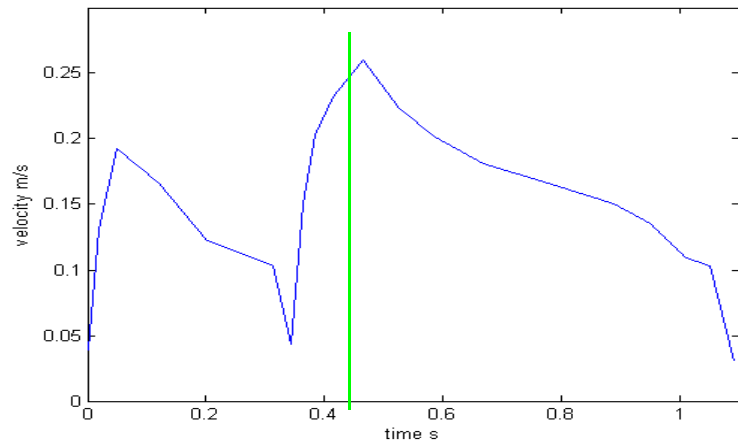
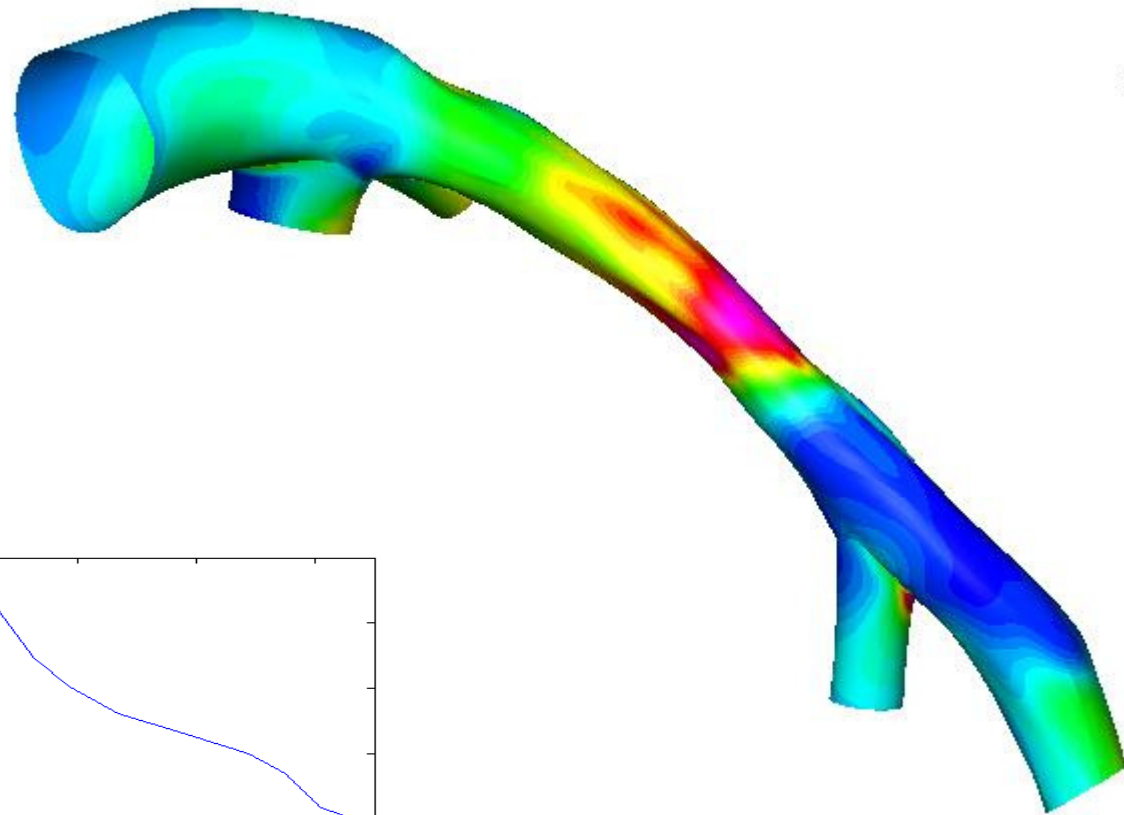


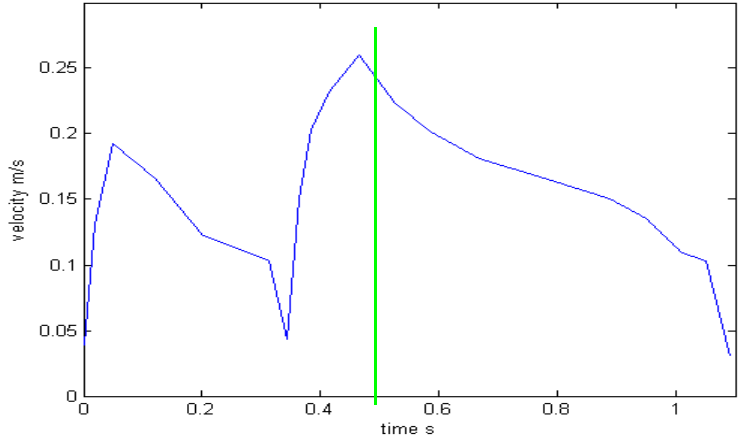
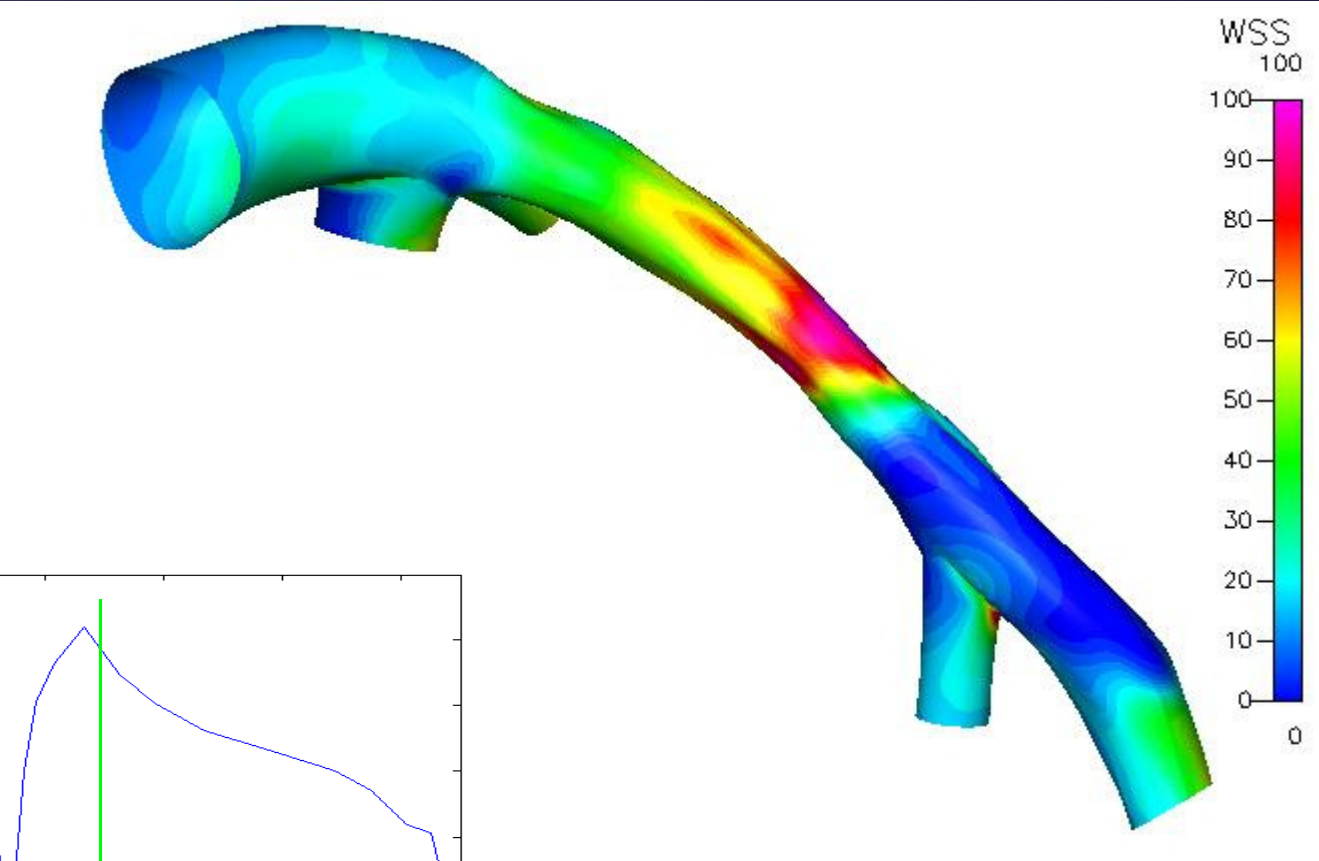


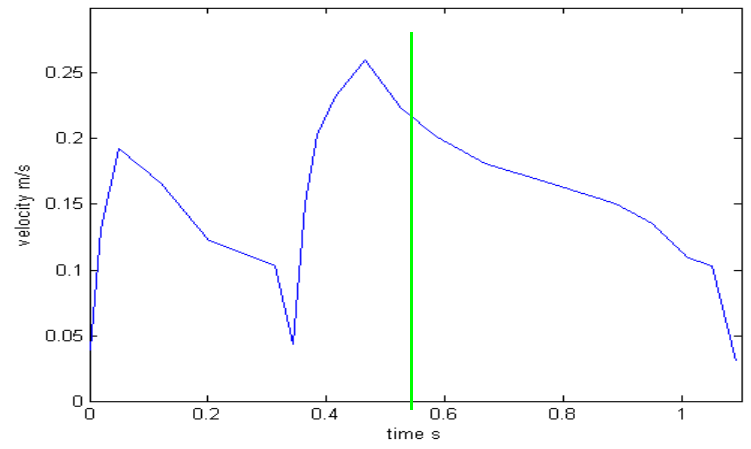
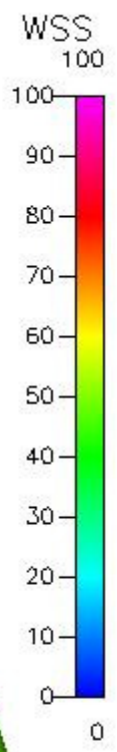
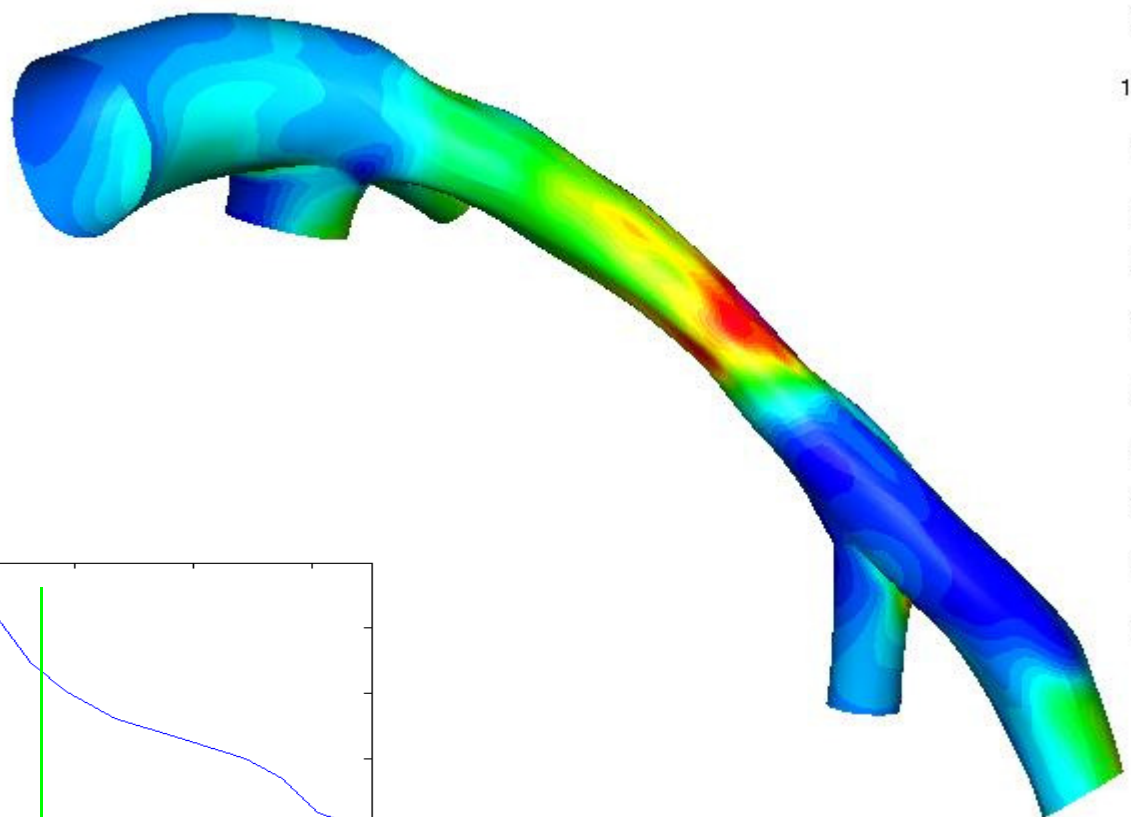


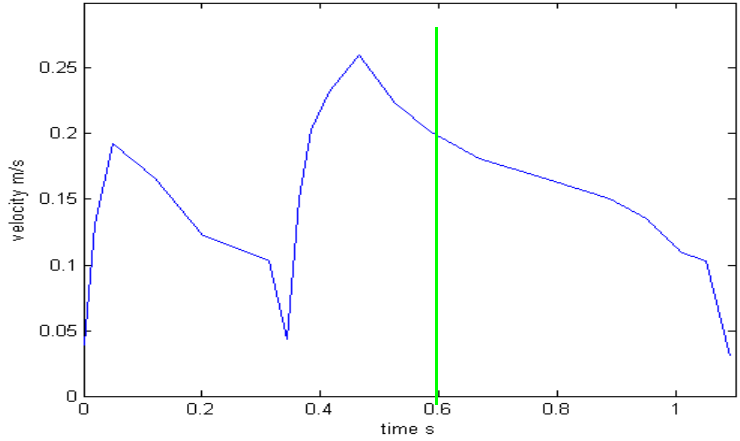
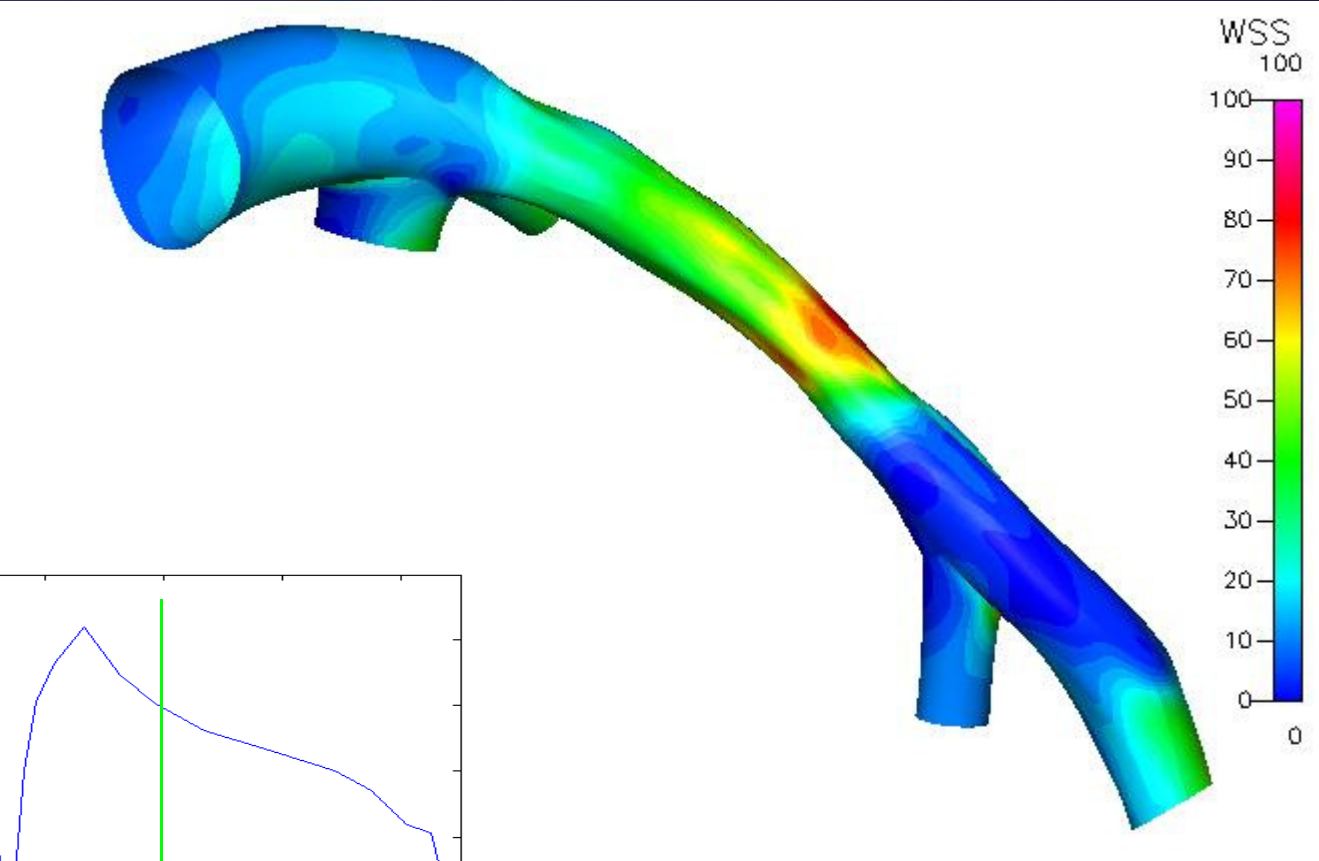


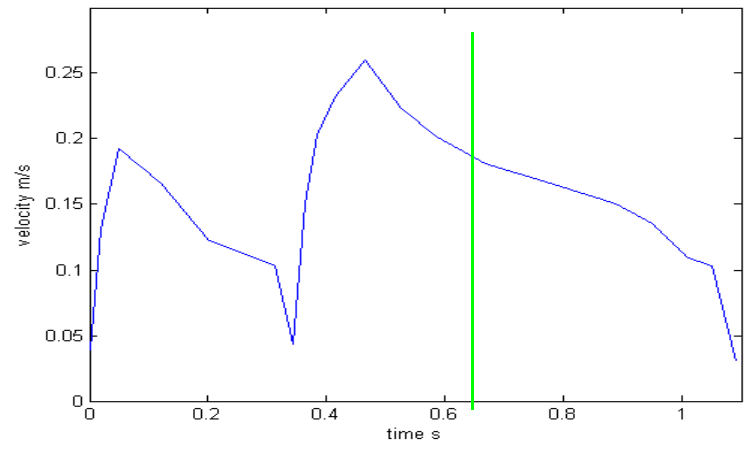
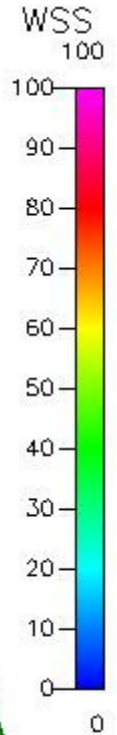
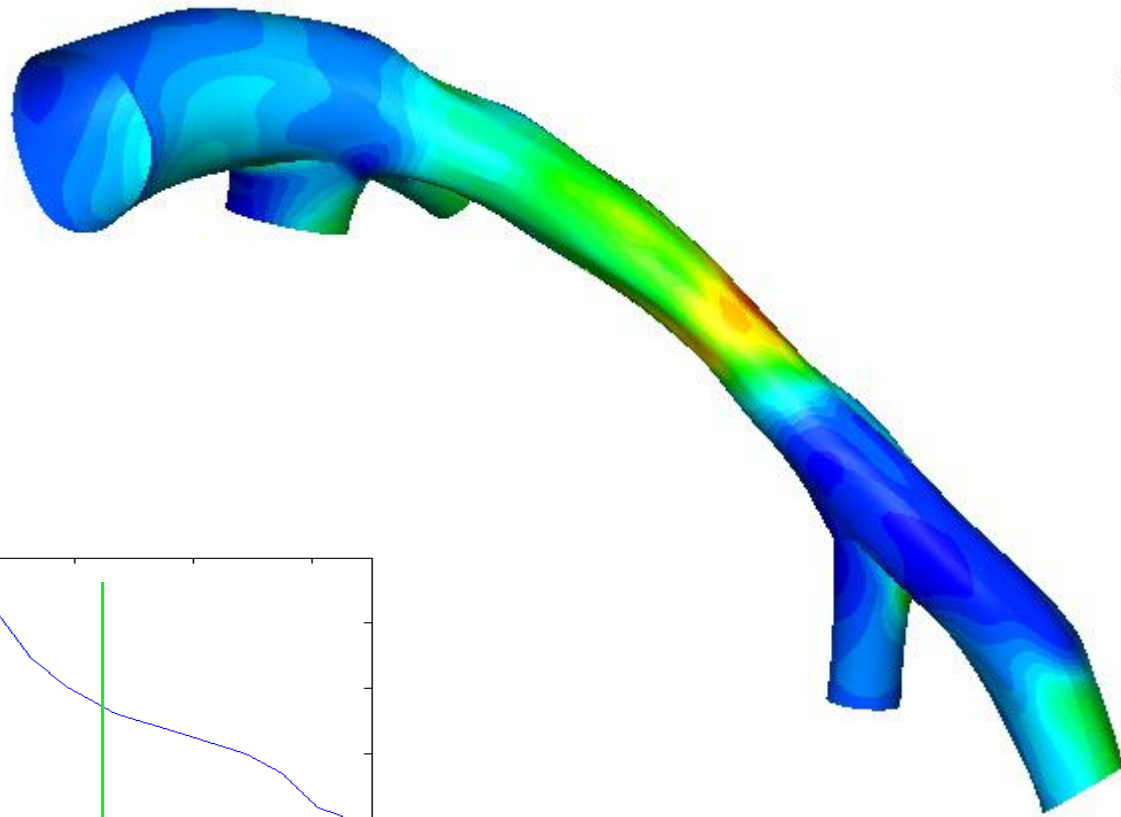


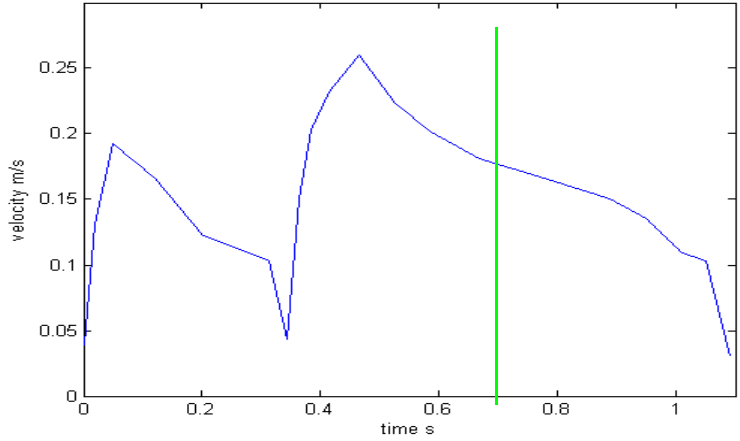
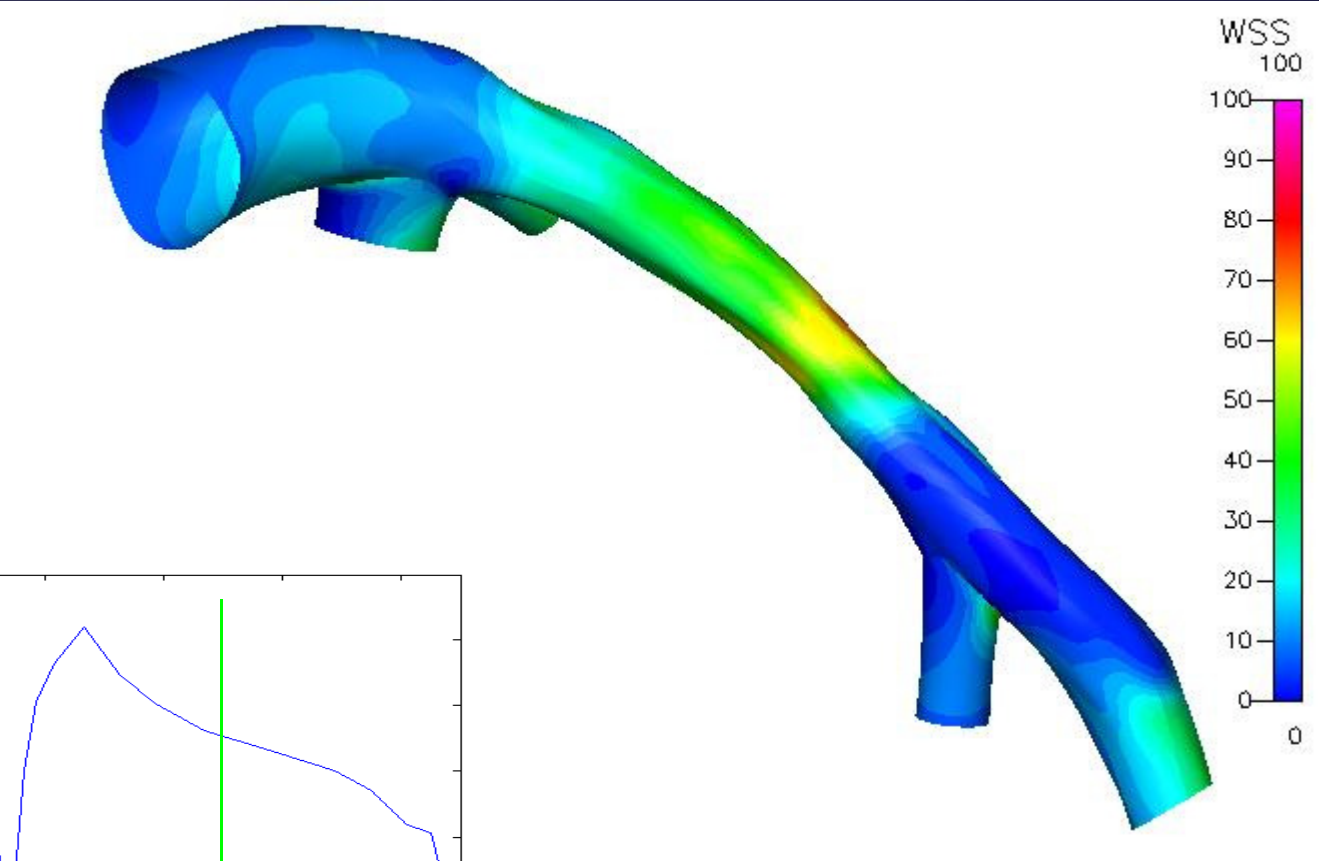


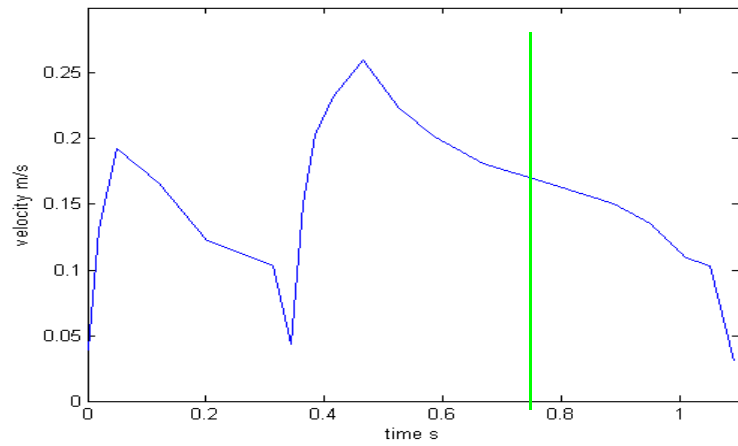
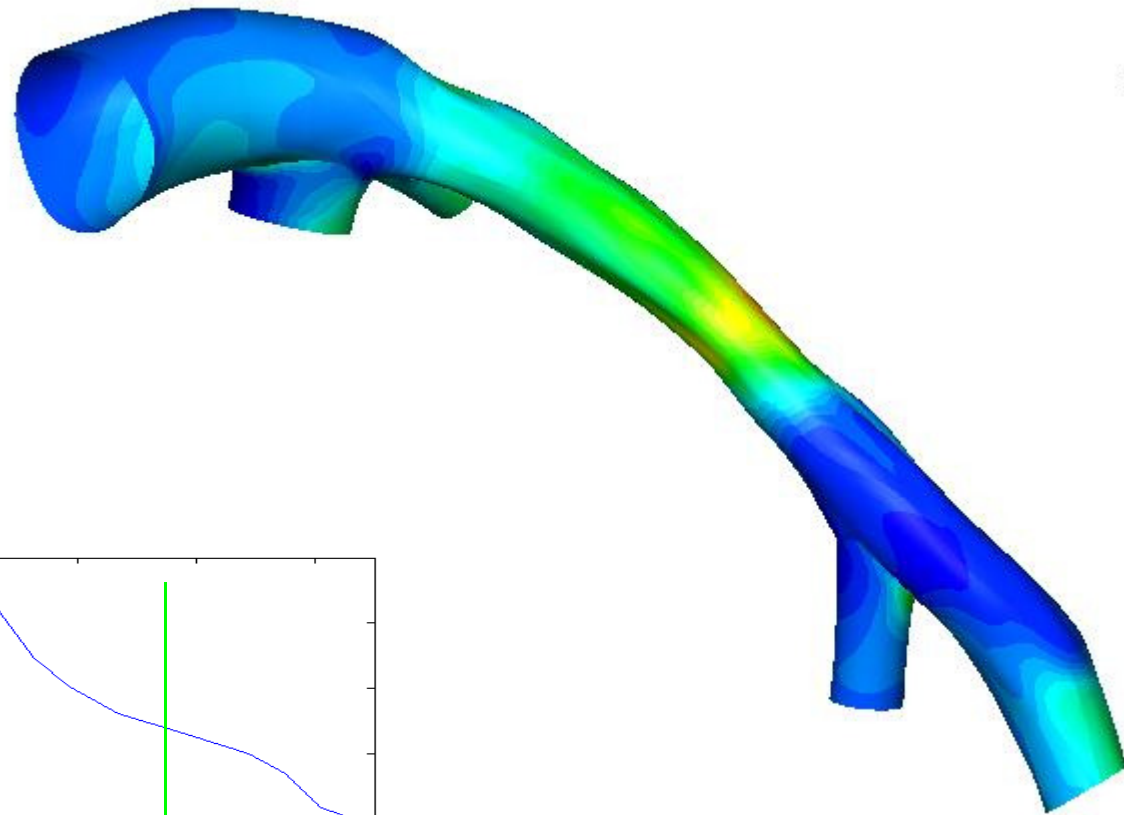


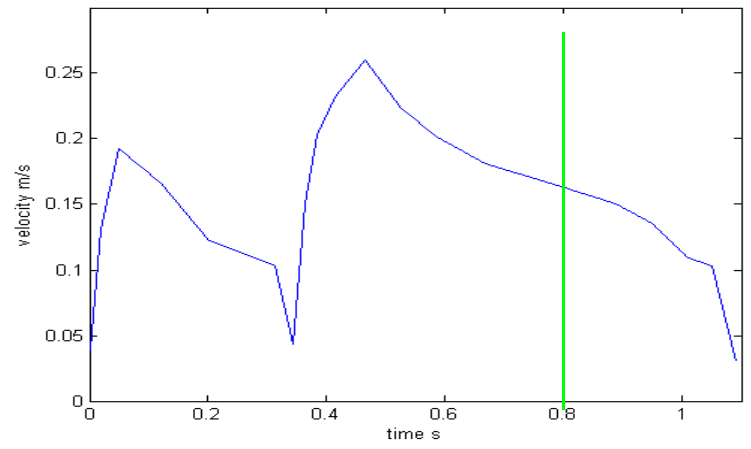
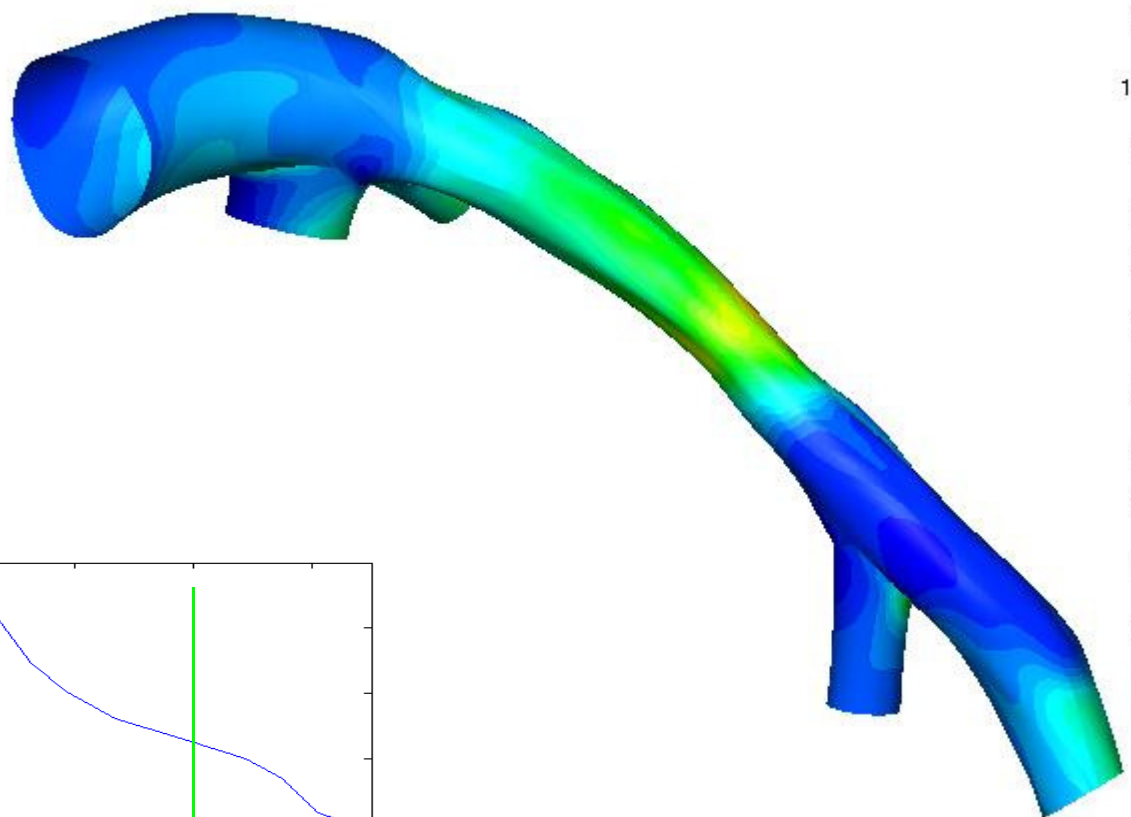




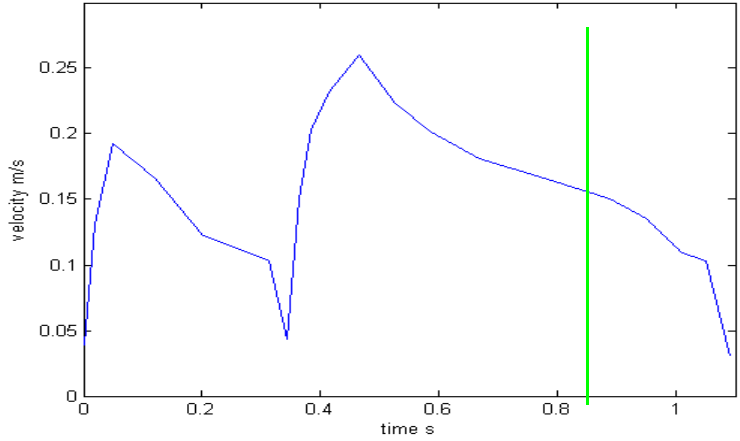
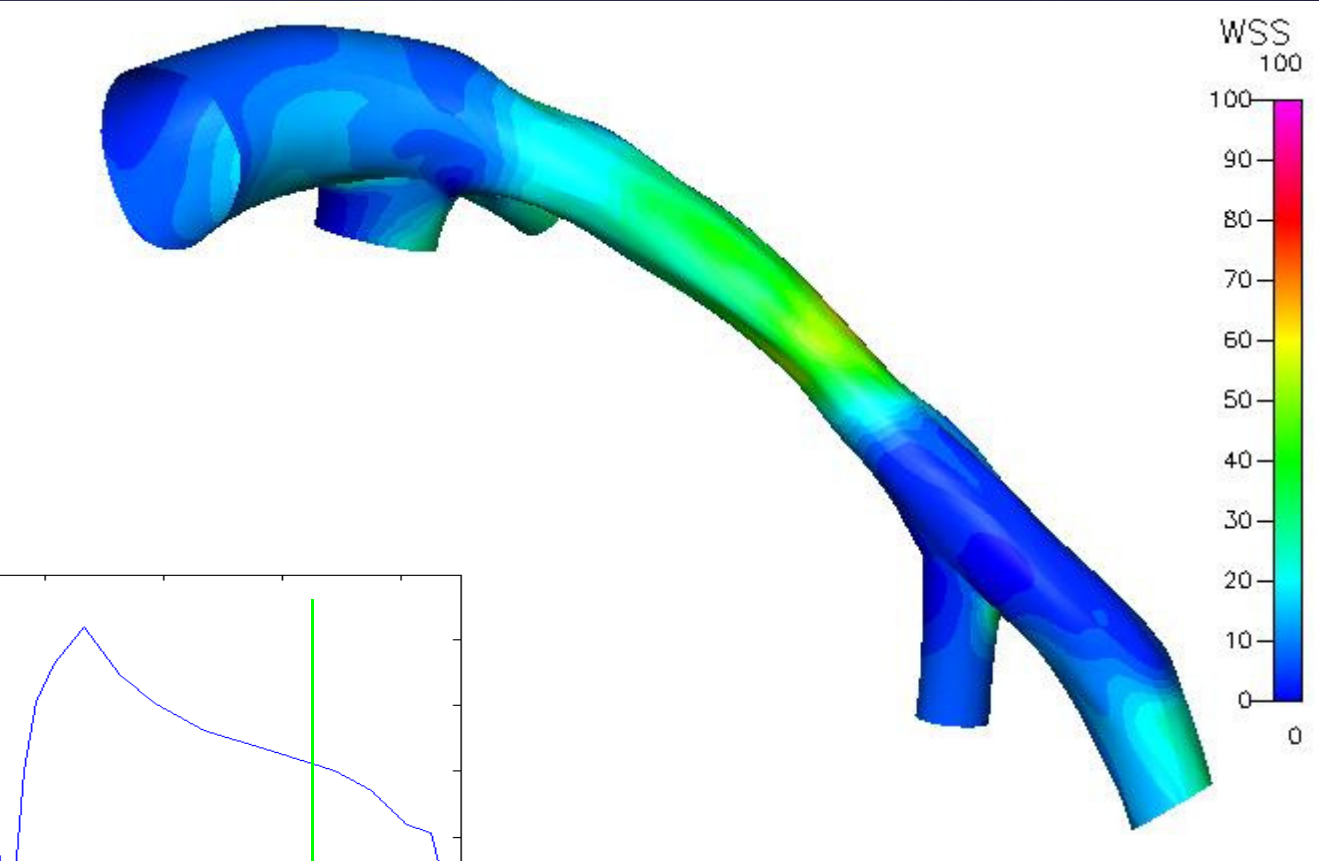


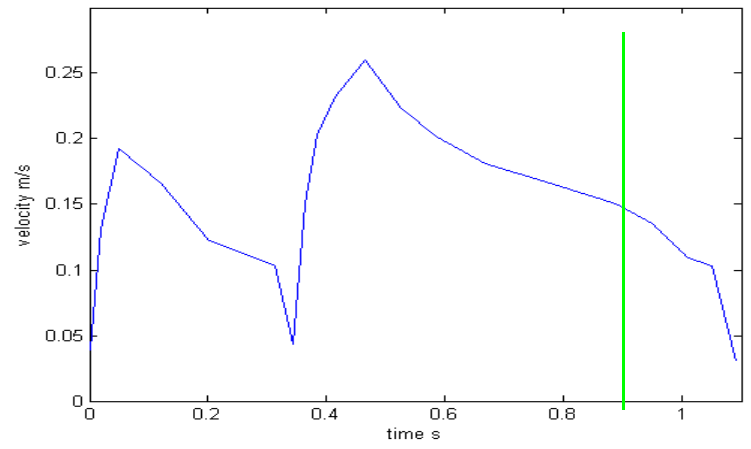
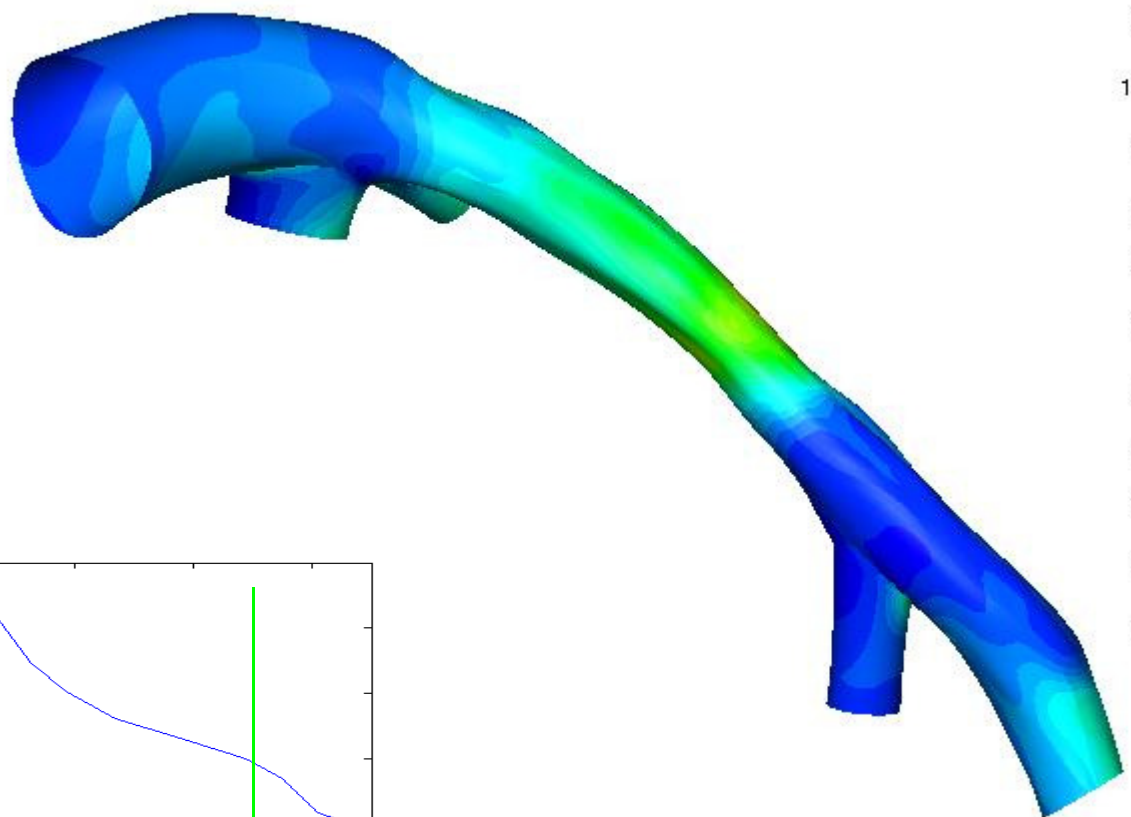


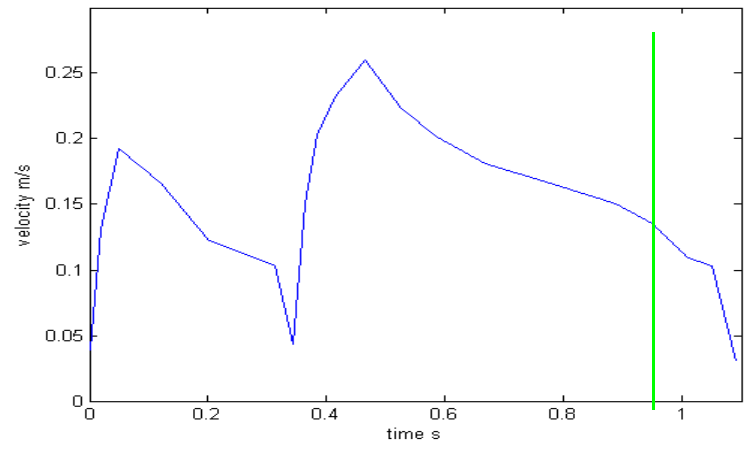
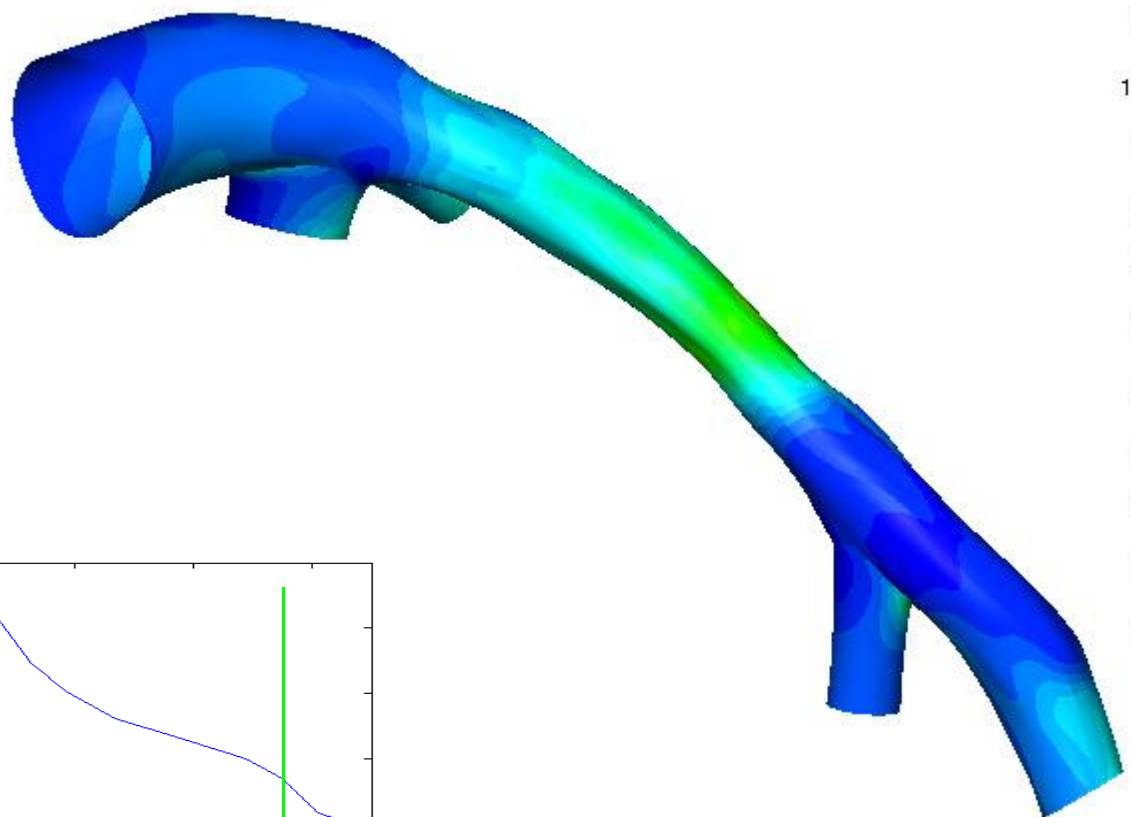


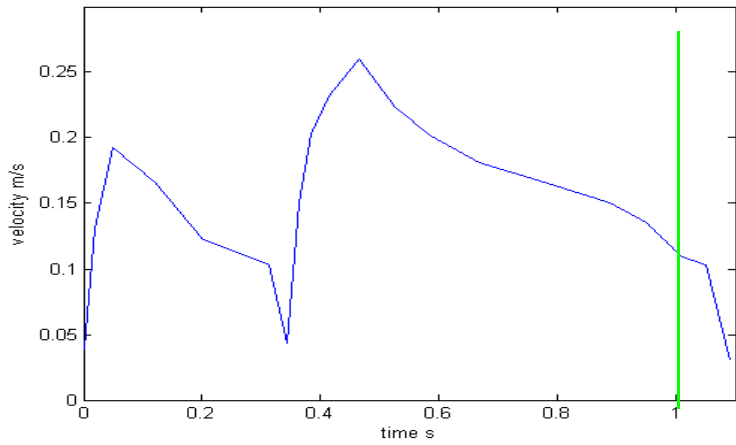
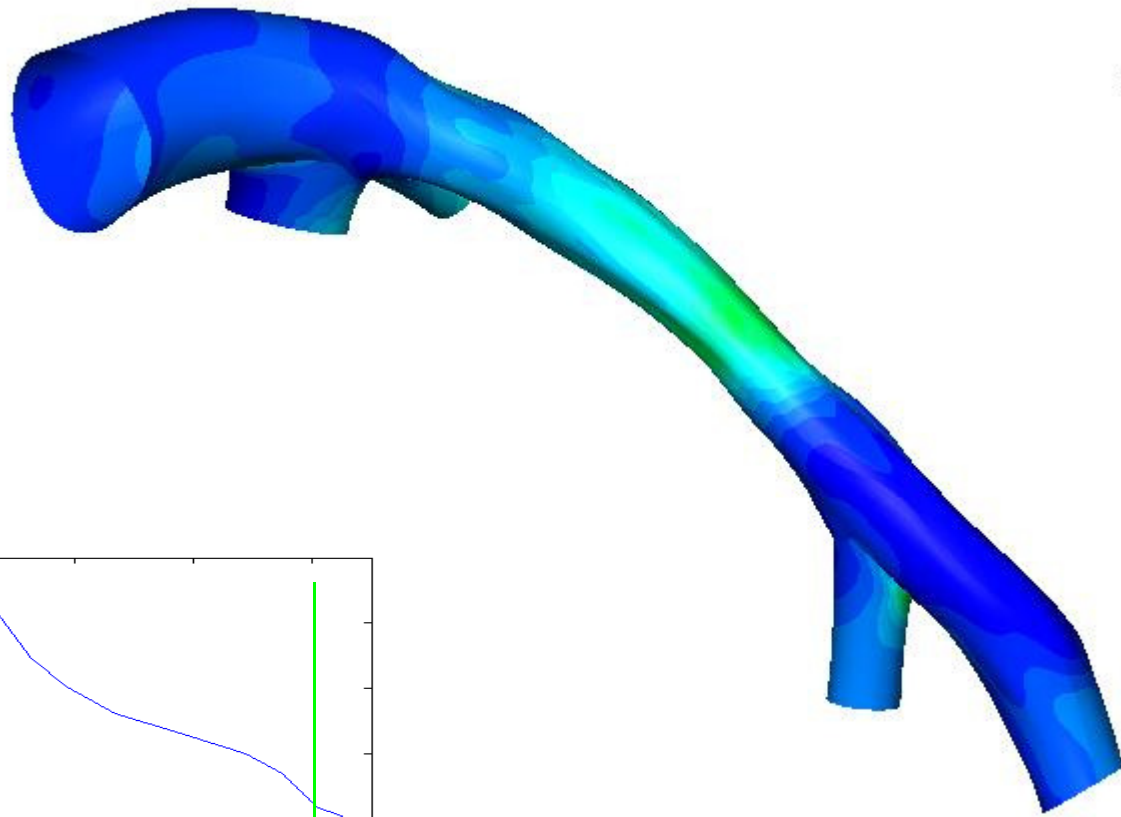


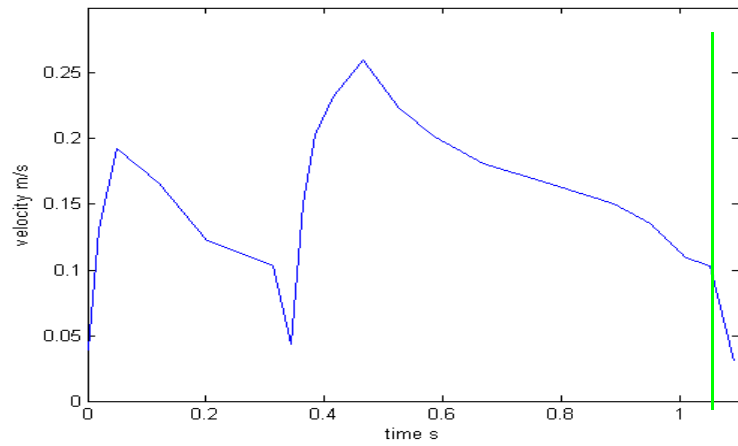
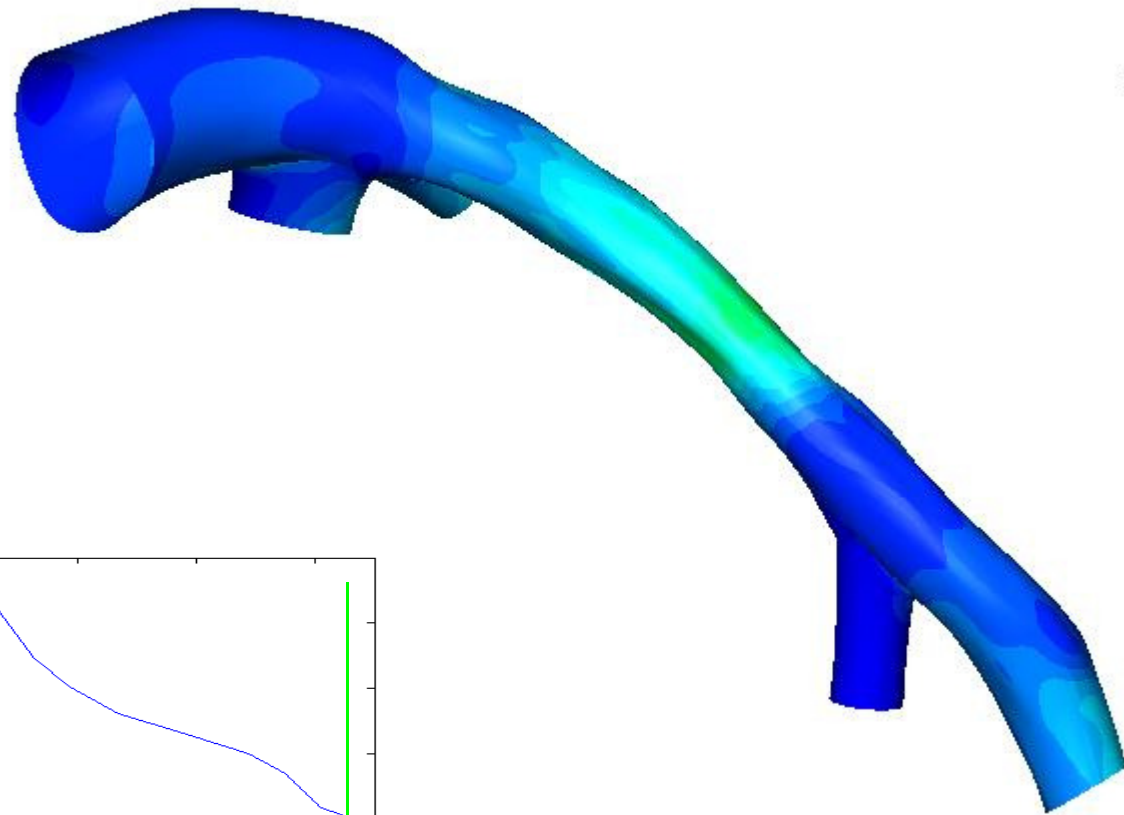




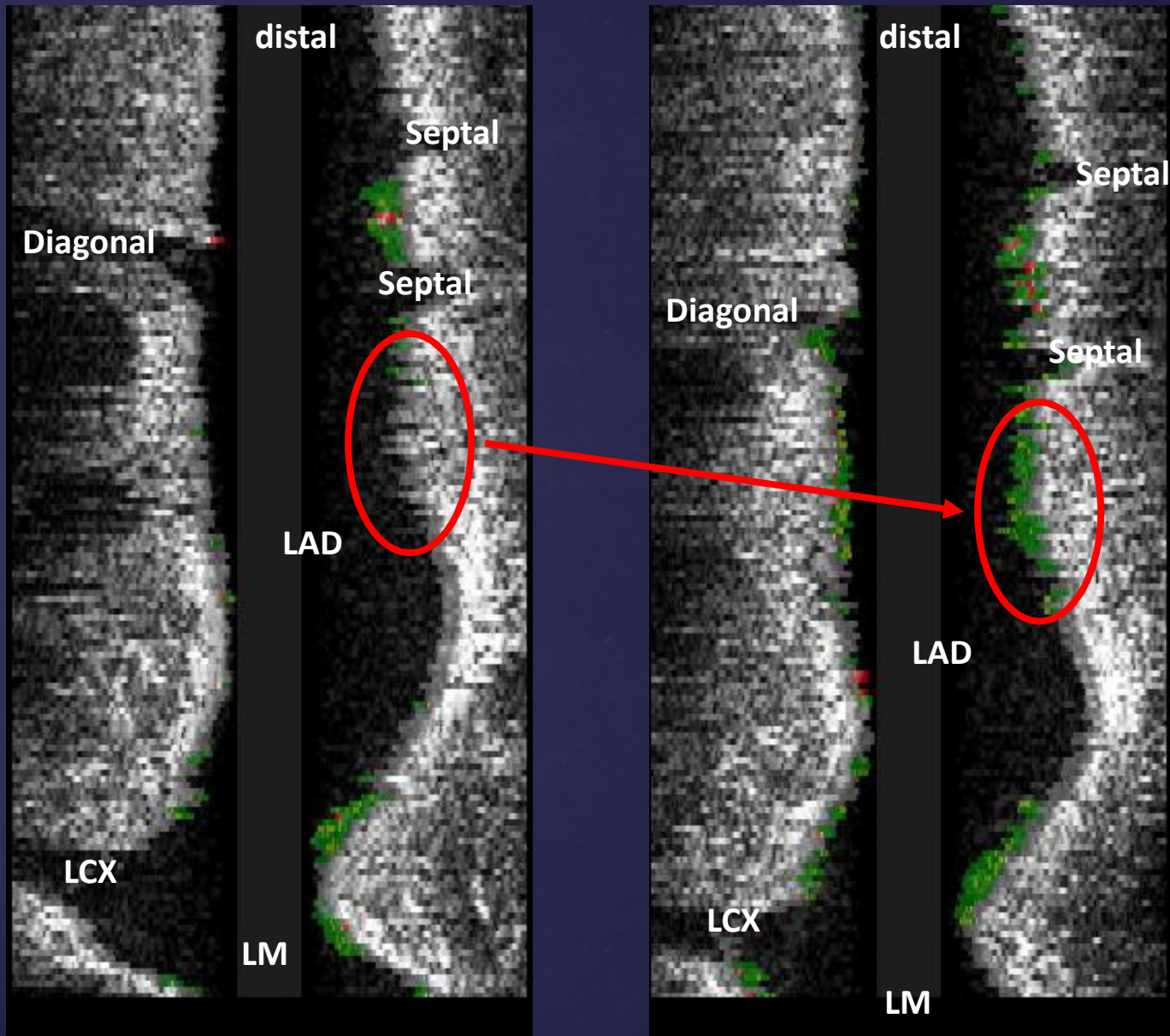








# Atherosclerosis Progression by Virtual Histology IVUS



Baseline

6 months Later

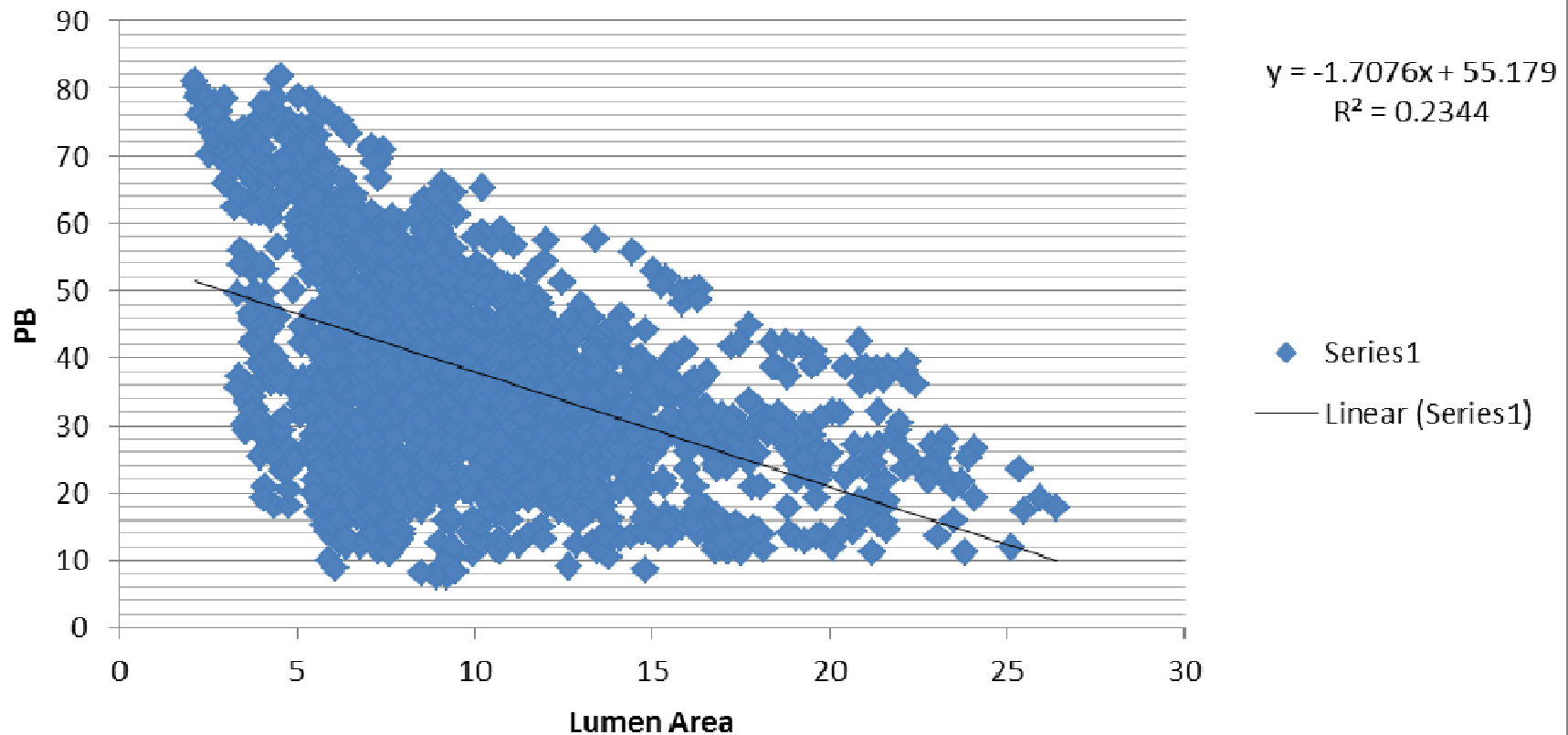
# Analysis of Pooled Baseline Data

- WSS averaged over cardiac cycle to obtain mean WSS on surface
- WSS then averaged around circumference to obtain WSS as a function of axial location
- Image data for each slice were obtained to show lumen area (LA), plaque area (PA), vessel area (area within IEL), and plaque burden (PB)

# Lumen Area vs Plaque Burden

Pooled Baseline Data – 18 Subjects

## Lumen Area vs PB - ALL

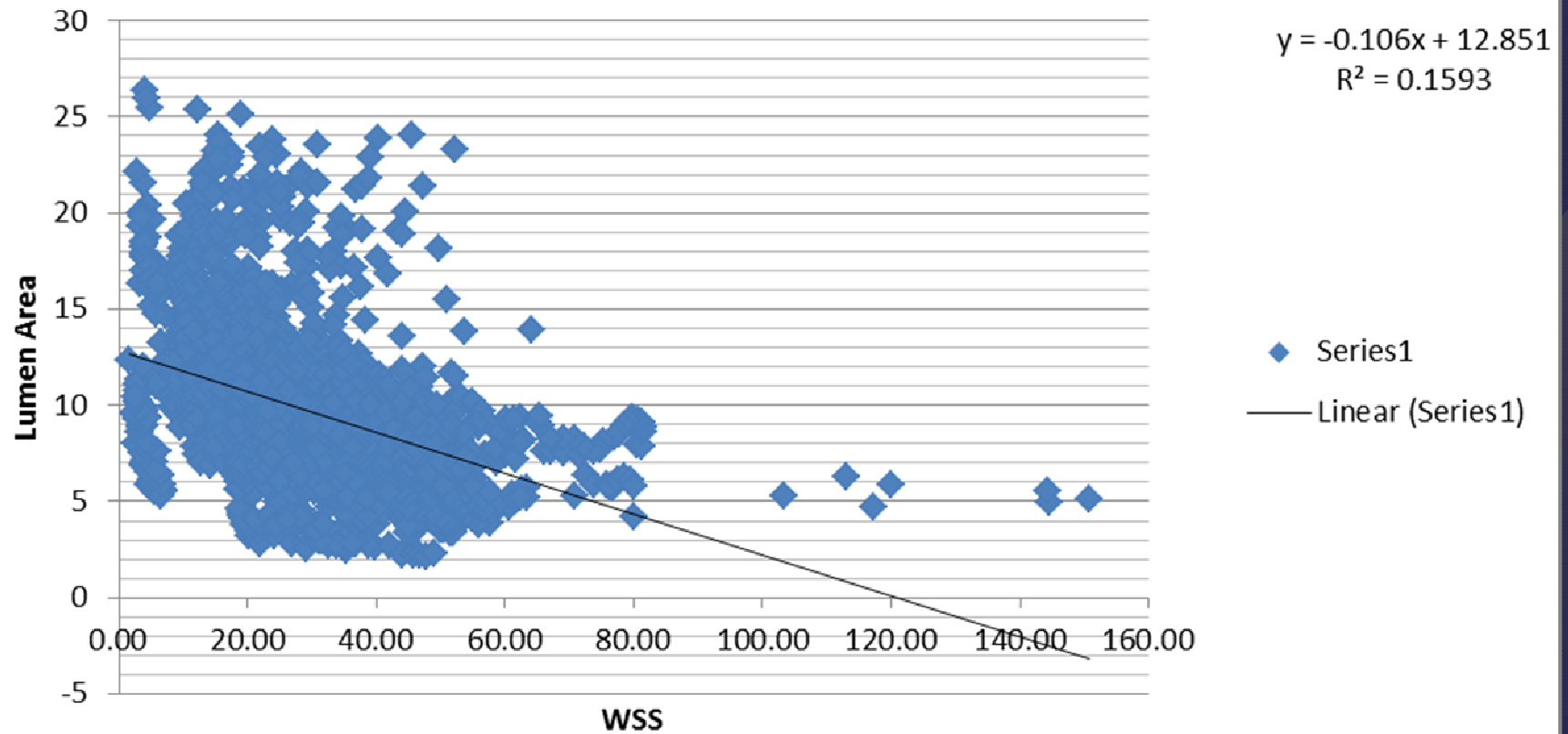




# WSS vs Lumen Area

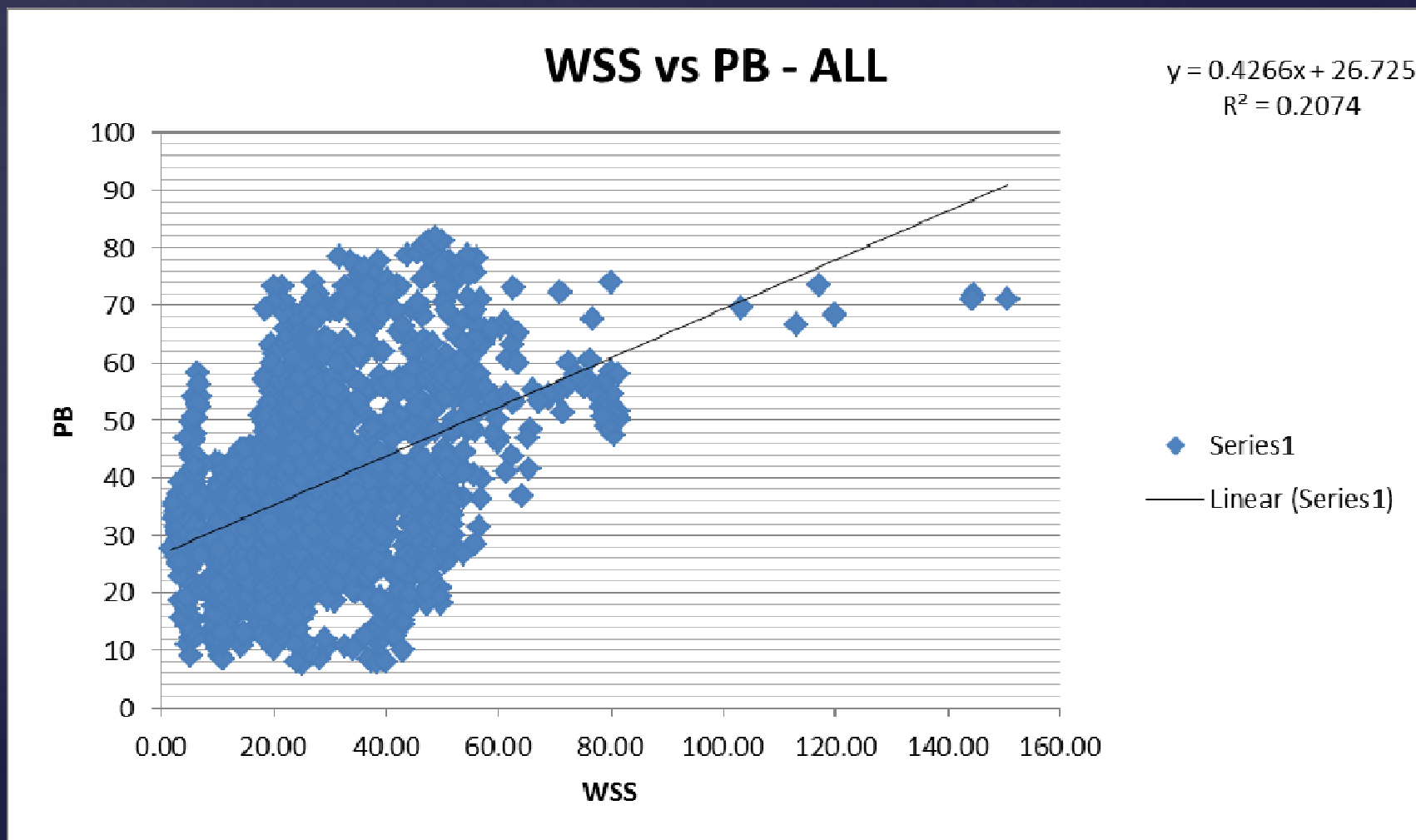
Pooled Baseline Data – 18 Subjects

## WSS vs Lumen Area - ALL



# WSS vs Plaque Burden

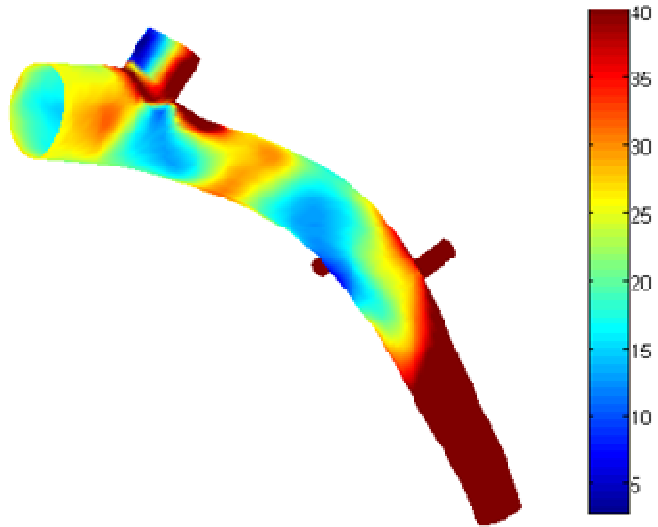
Pooled Baseline Data – 18 Subjects



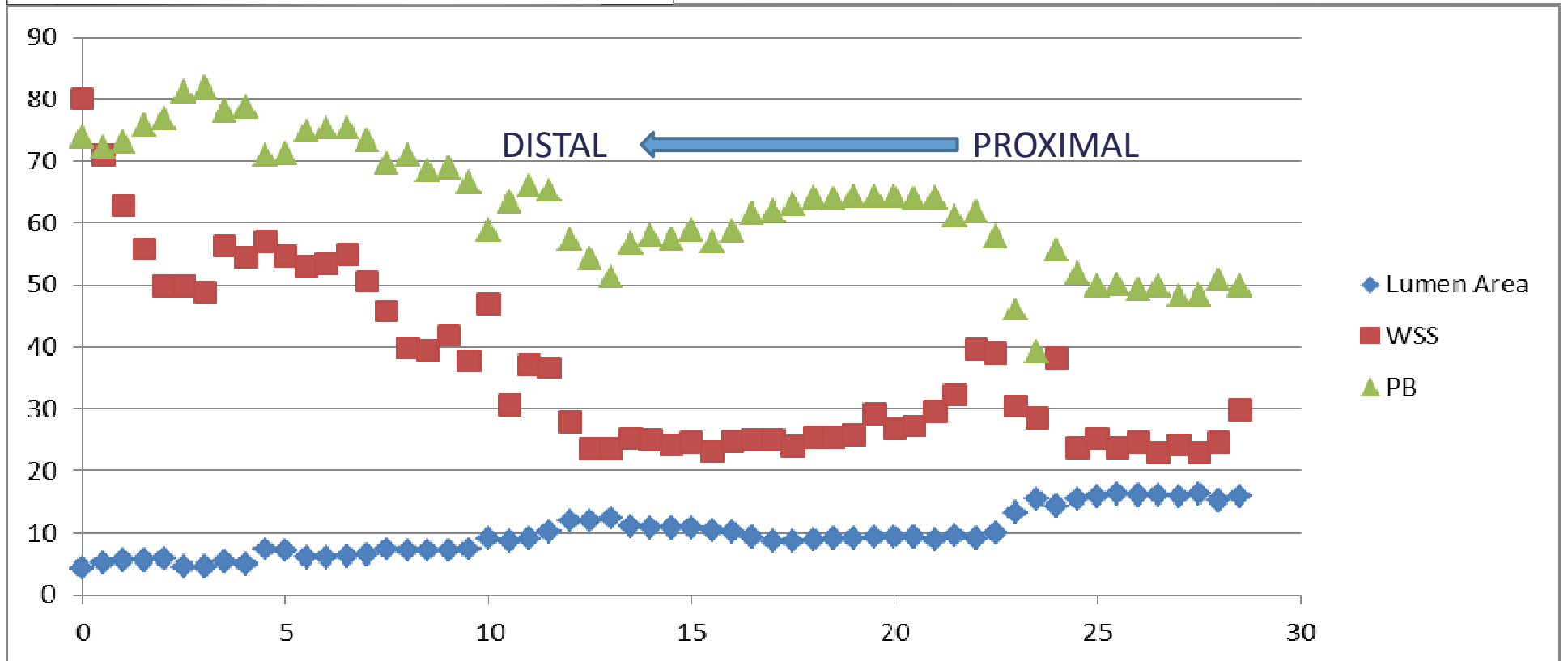
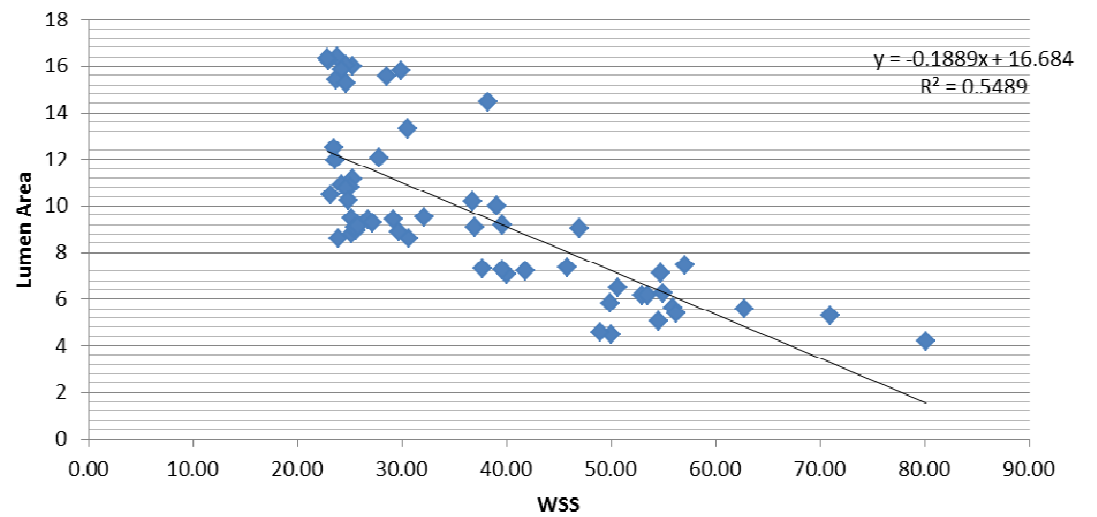
# Conclusions – Baseline

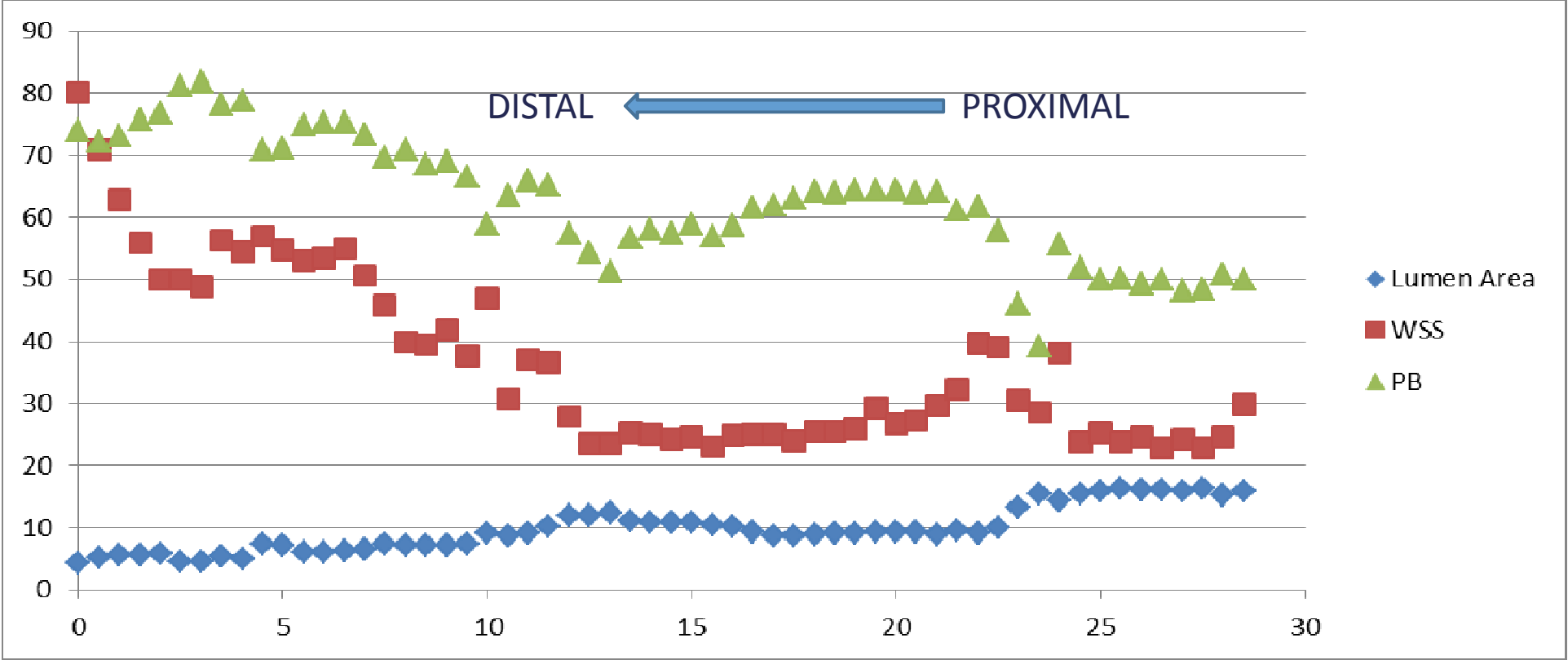
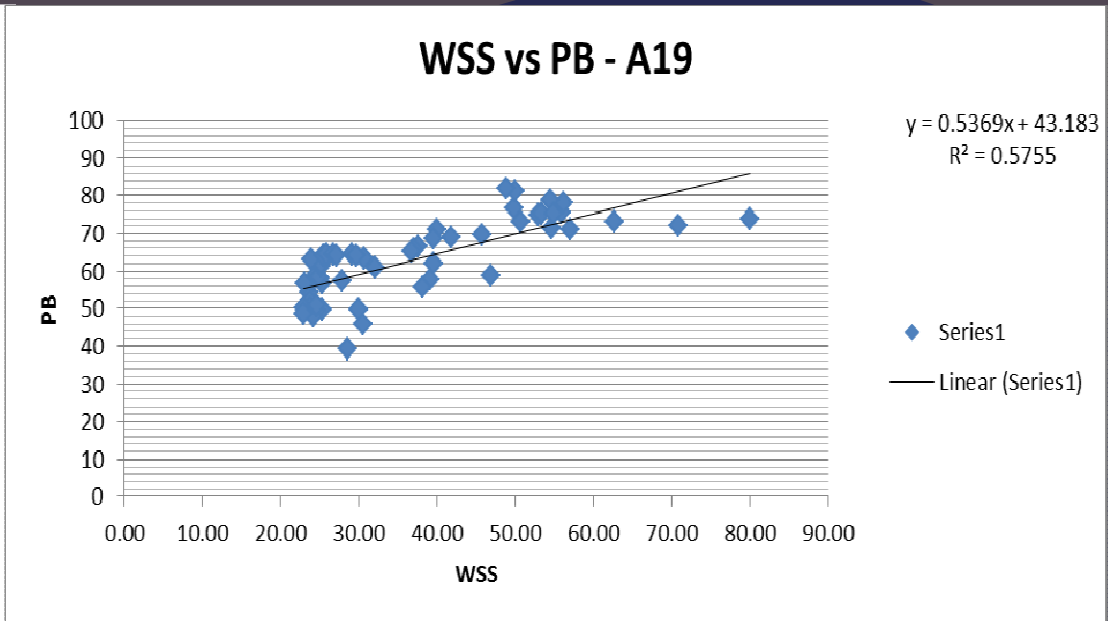
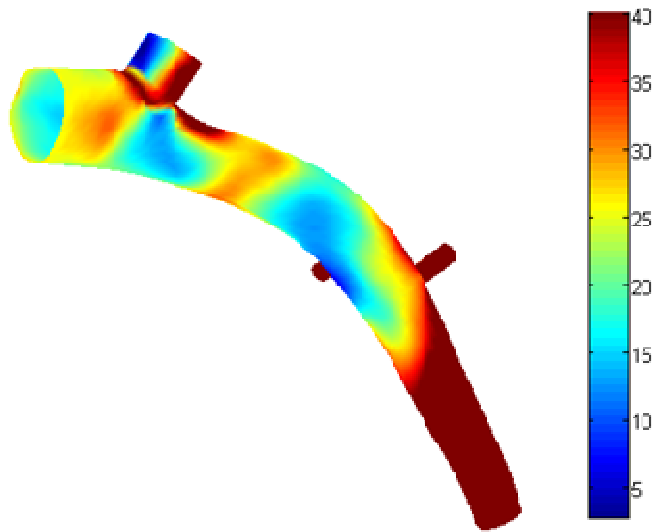
In patients with symptomatic coronary artery disease, population data show:

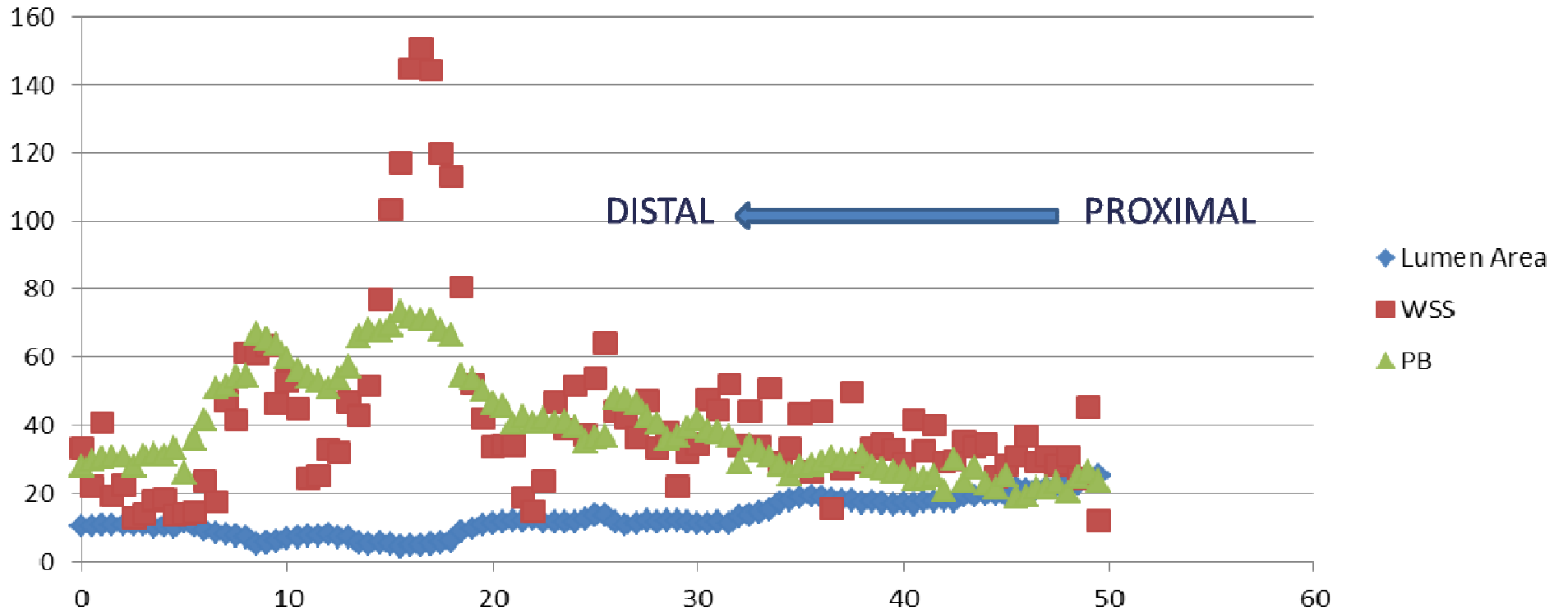
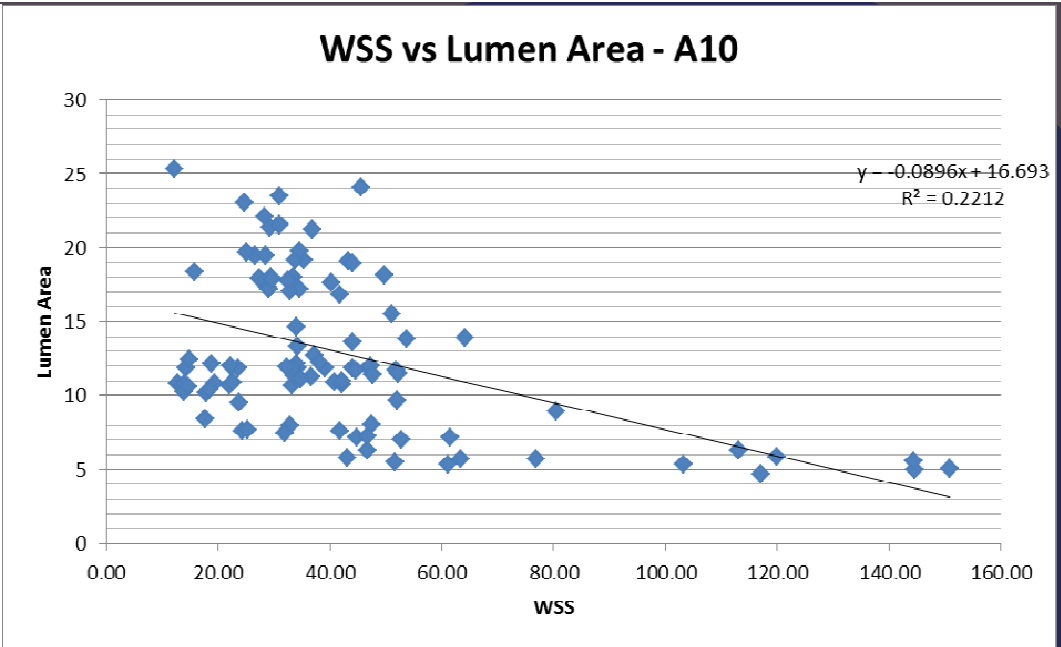
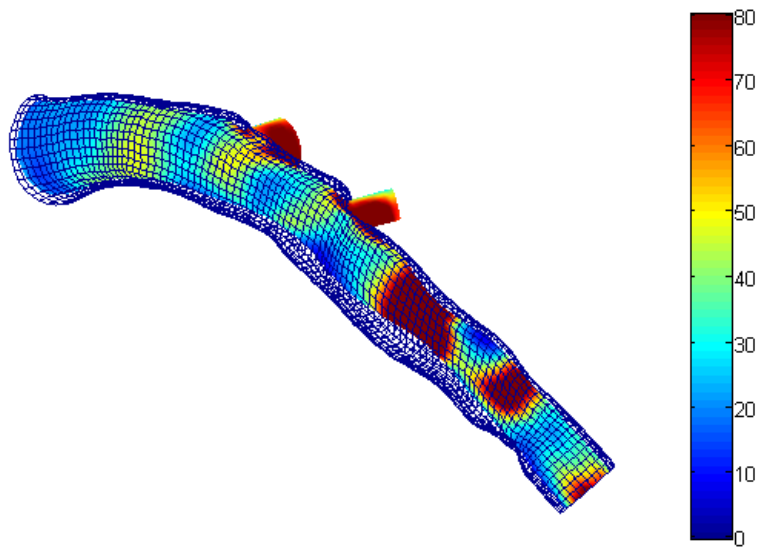
- Trends between WSS, lumen area, and plaque burden follow intuition
- Statistical work ongoing to determine significance, etc.
- **Considerable individual variability**

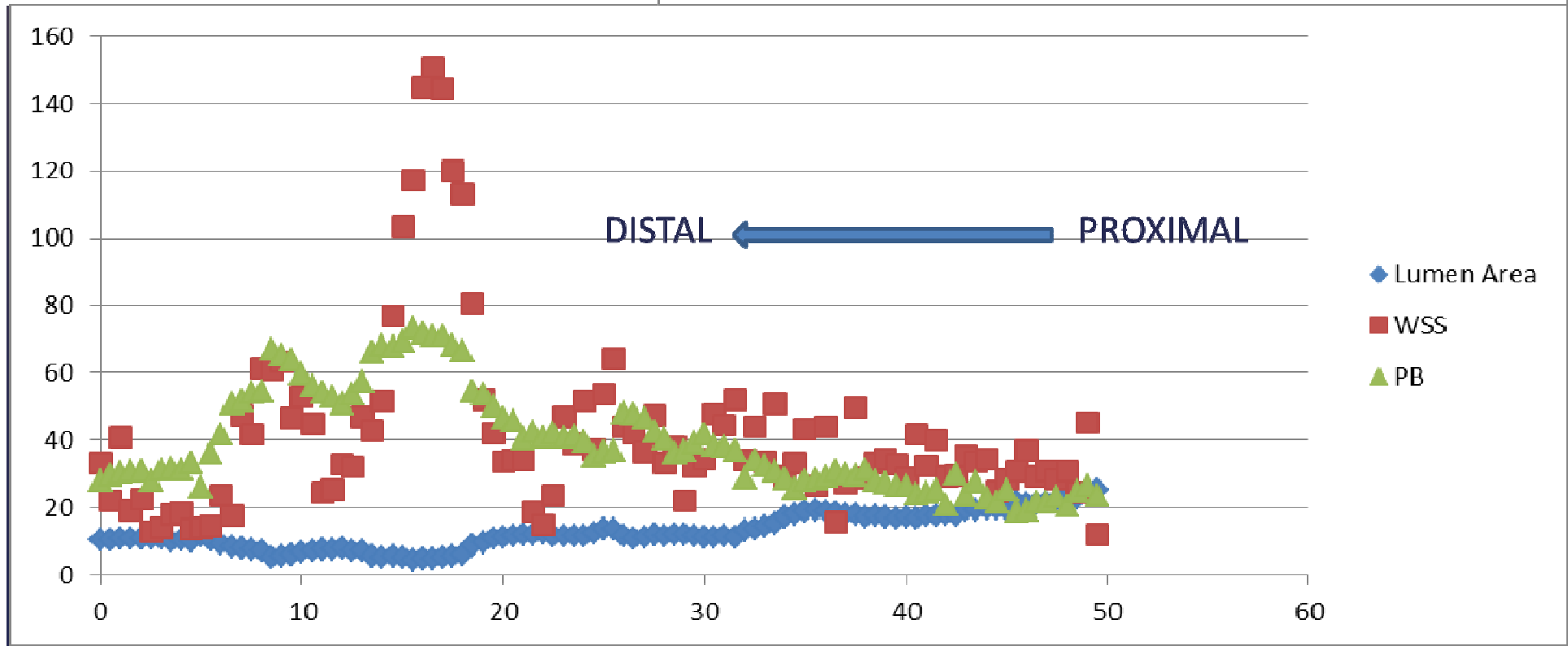
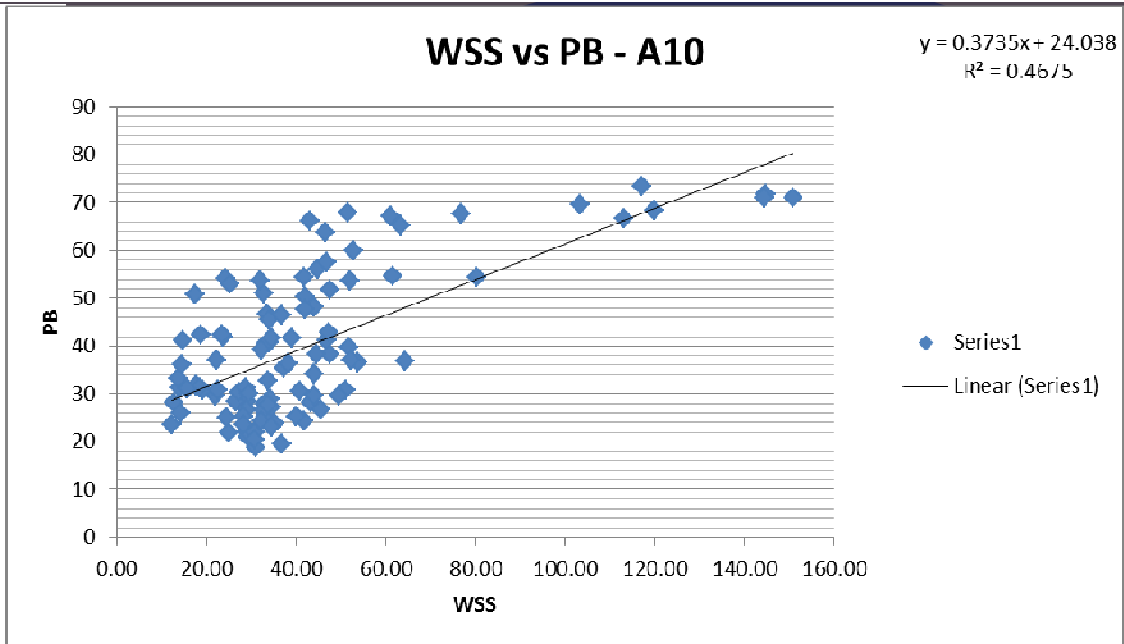
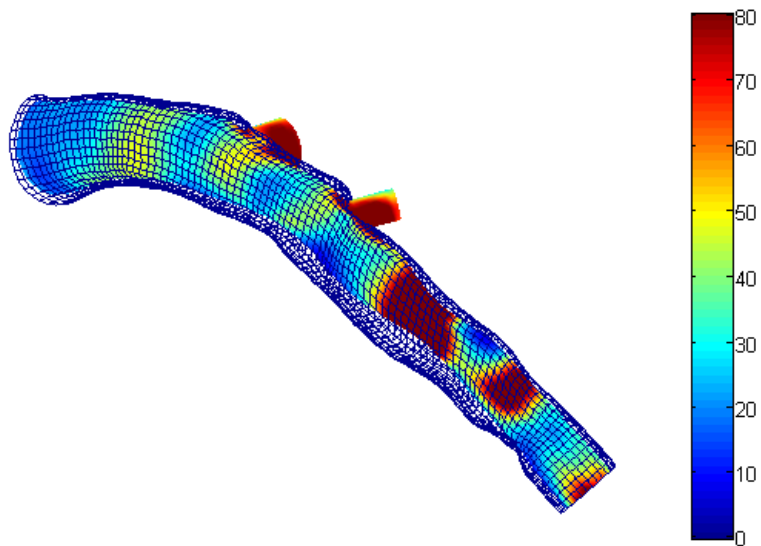


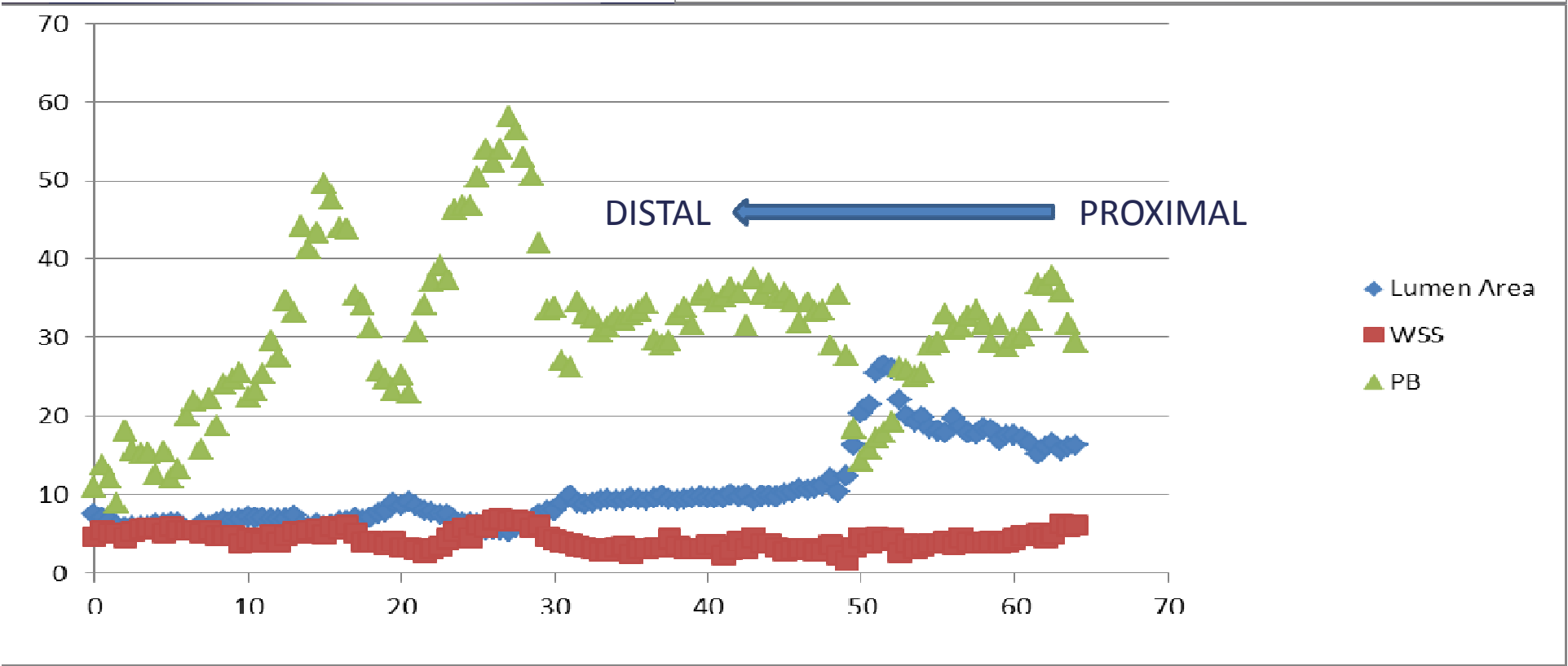
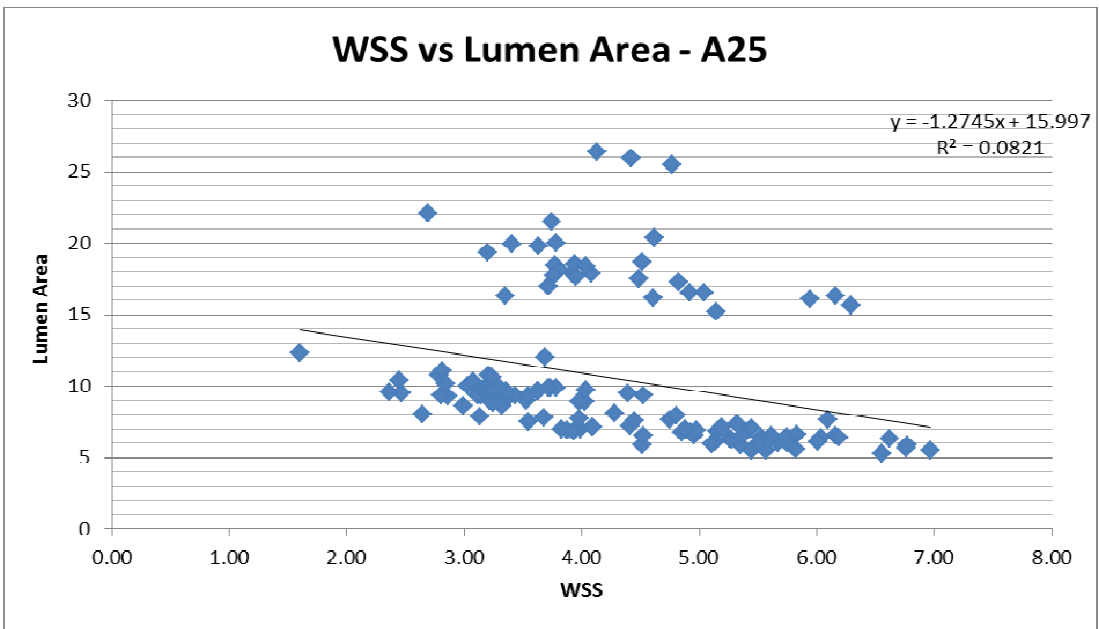
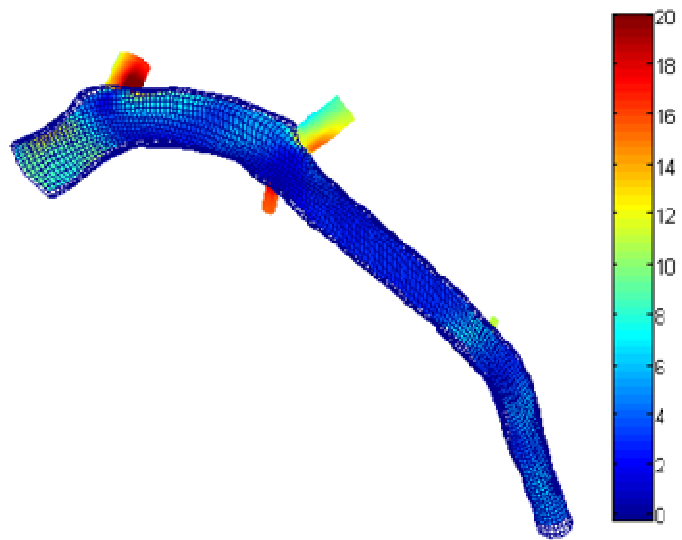
WSS vs Lumen Area - A19



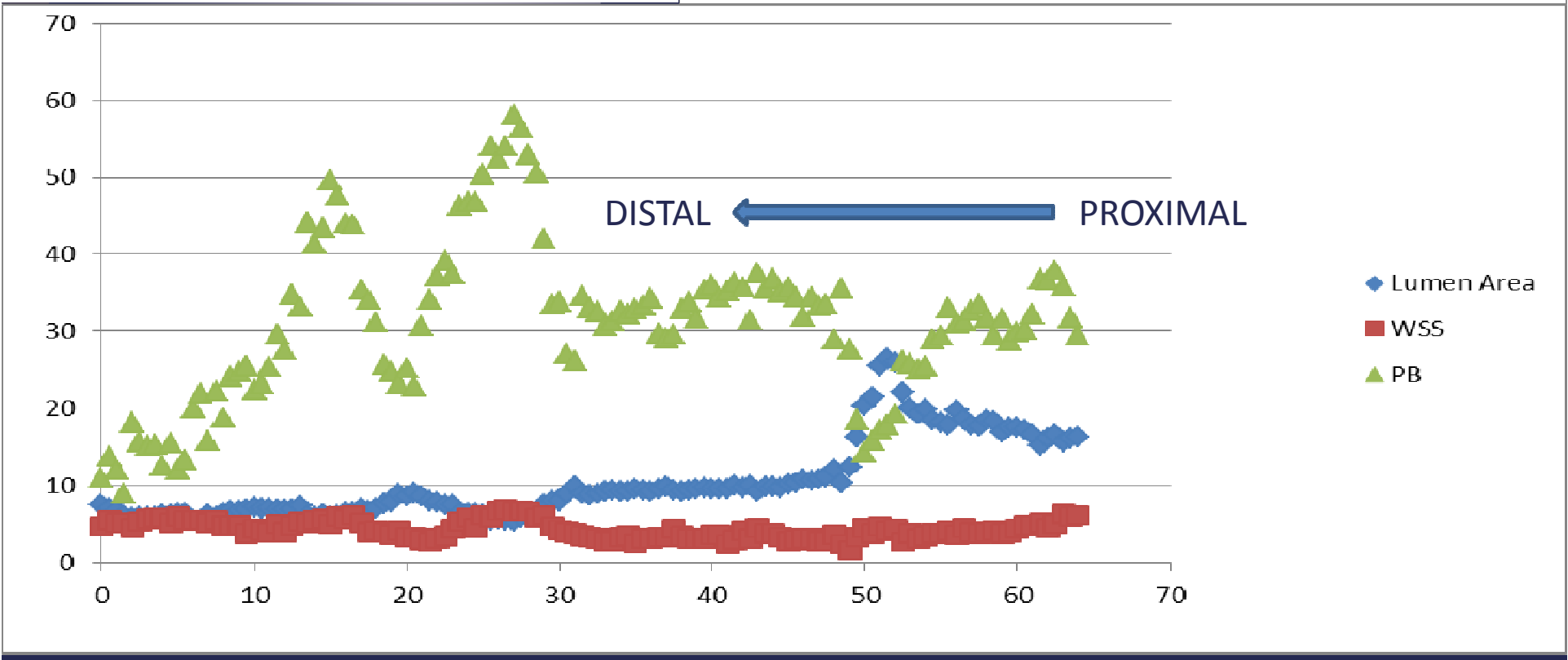
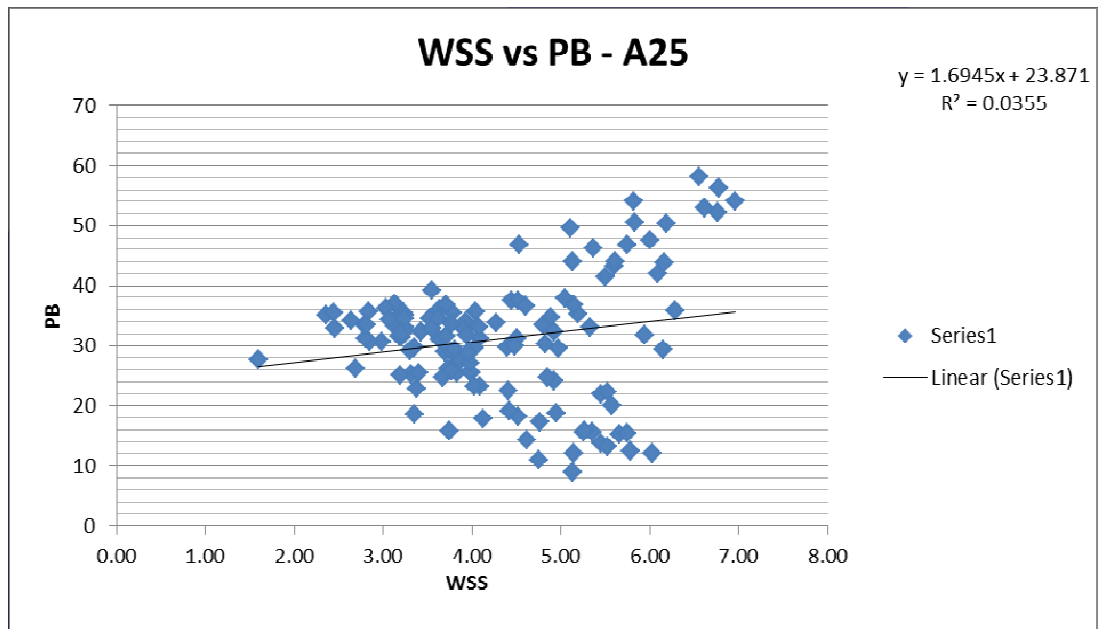
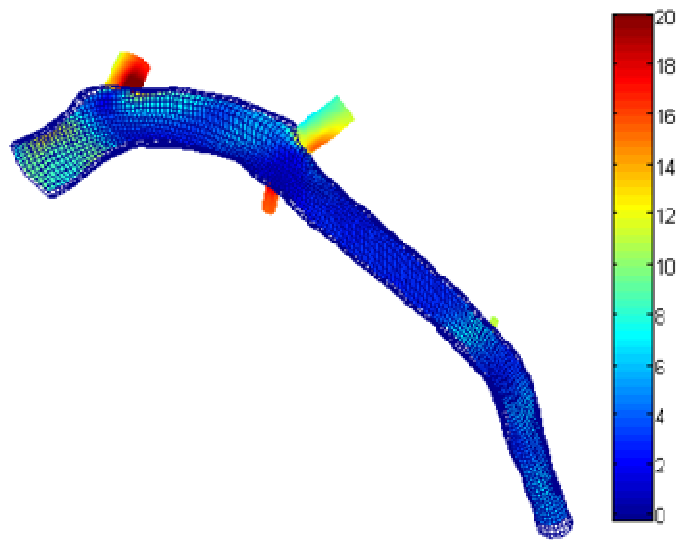






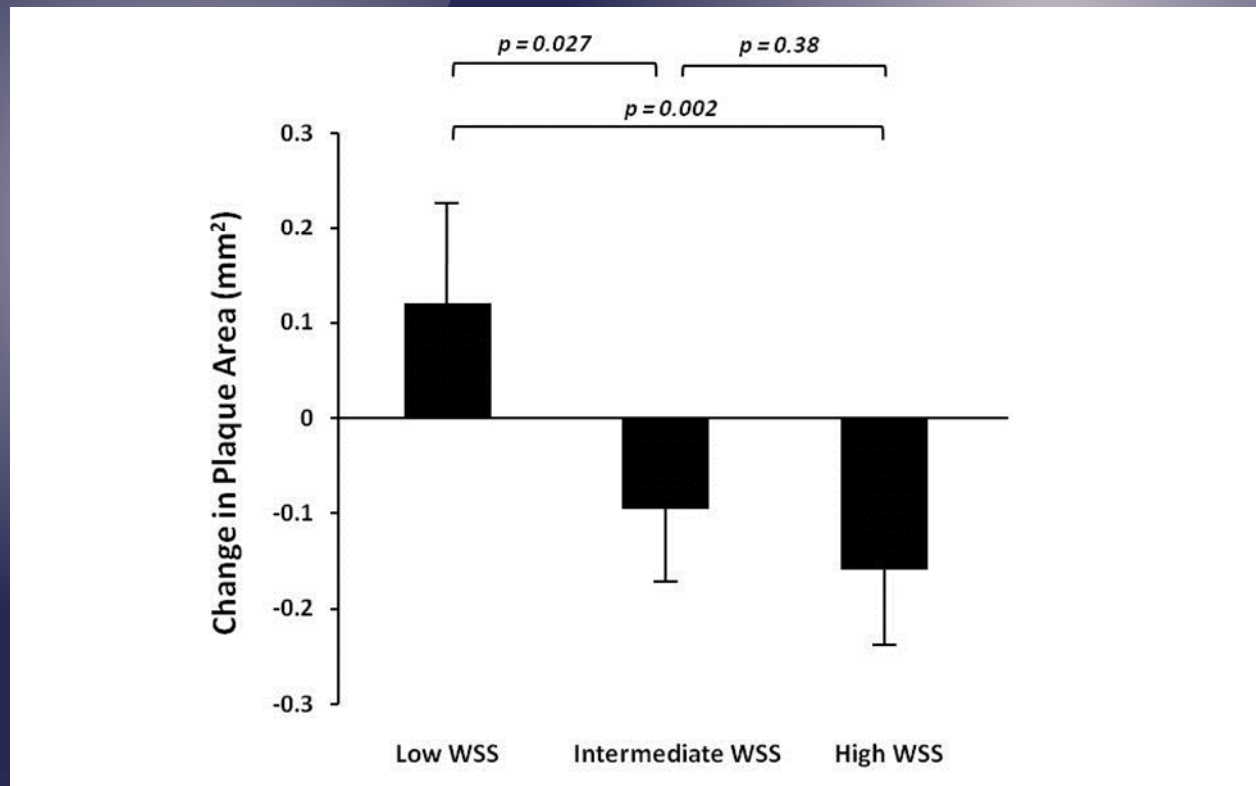






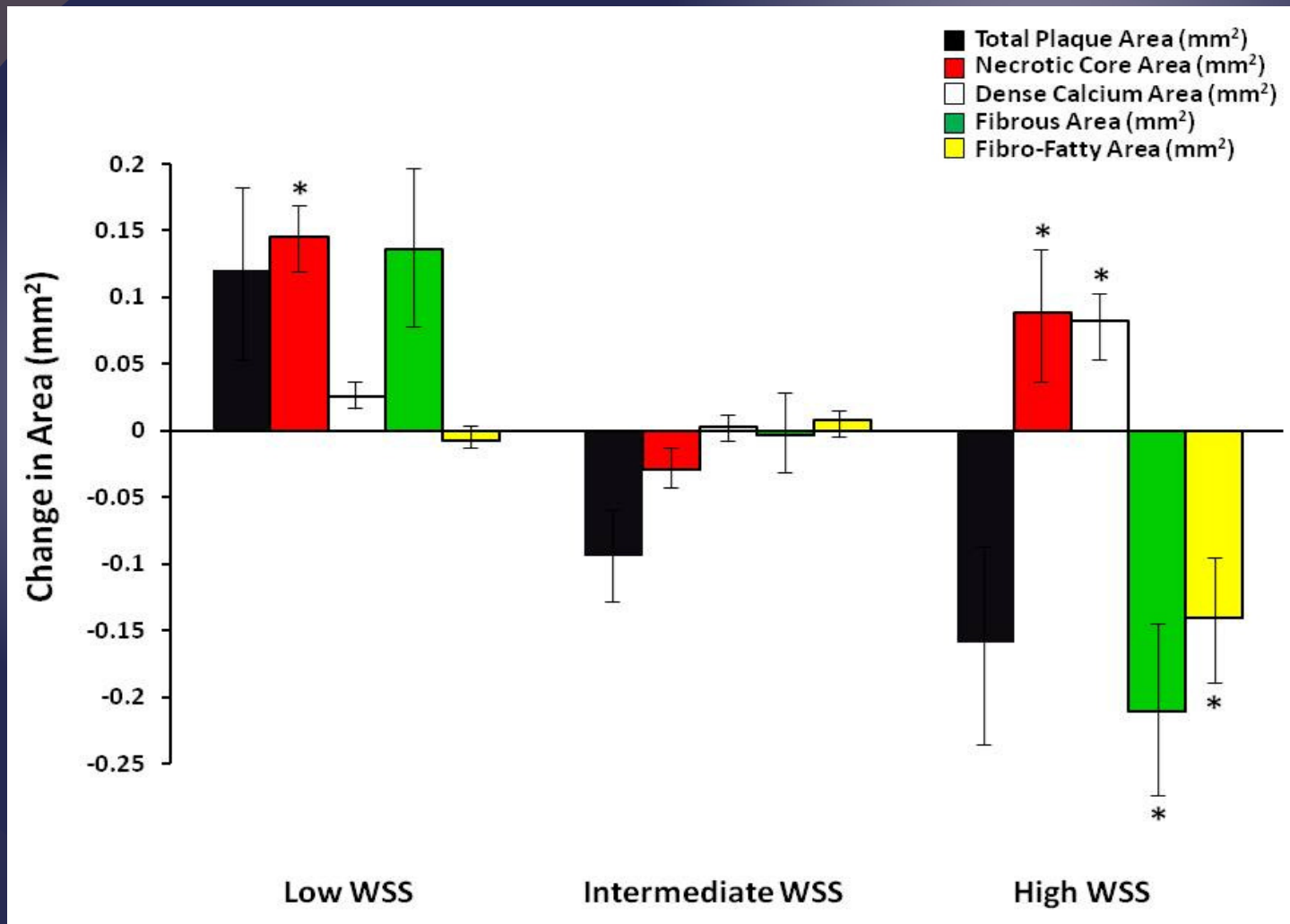
# Results – Longitudinal

Change in Plaque Area Over Six Months  
Low WSS (<10 dynes/cm<sup>2</sup>); Intermediate (10-25); High (>25)



# Results – Longitudinal

Change in Plaque Composition in Low (<10), Intermediate (10-25), and High (>25) WSS Segments over 6 Months



# Conclusions - Longitudinal

In patients with coronary artery disease:

- Coronary segments with *low WSS* develop greater total plaque progression as well as more constrictive remodeling compared to intermediate or high WSS segments.
- Coronary segments with *intermediate (physiologic) WSS* show overall plaque regression.
- Coronary segments with *high WSS* demonstrate no significant change in total plaque area, but suggest a plaque phenotype transformation (increase in necrotic core and calcium, and decrease in fibrous and fibro-fatty tissue).

# Some Common Misconceptions

- WSS can be estimated from looking at angiographic images so why do CFD?
- Blood pressure, viscosity and non-Newtonian rheology matter a lot
- IVUS, angiography, CFD are very accurate
- A correlation shows a cause-effect relationship
- Data taken at a single time point can be generalized

## So why bother with WSS anyway?

- Evidence that WSS relates to atherogenesis
- Evidence that WSS relates to plaque progression
- WSS, along with the intravascular pressure field, creates mechanical forces on plaques
- Knowing an **individual's** WSS patterns may suggest pre-emptive and/or therapeutic measures

# Acknowledgements and Disclosures

- Pfizer Inc.
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A Big Happy Birthday to  
Shmuel  
and  
A Big Thank You to  
David!