

Shear Stress Analysis / 3 Dimensional Vessel and Scaffold: Reconstruction Methodology



European Bifurcation Club 2017
Porto, Portugal

BRS for bifurcation stenting: After thrombosis crisis

October 13th, 2017

Habib Samady MD

Professor of Medicine

Director, Interventional Cardiology, Emory University

Director, Cardiac Catheterization Laboratory Emory University Hospital

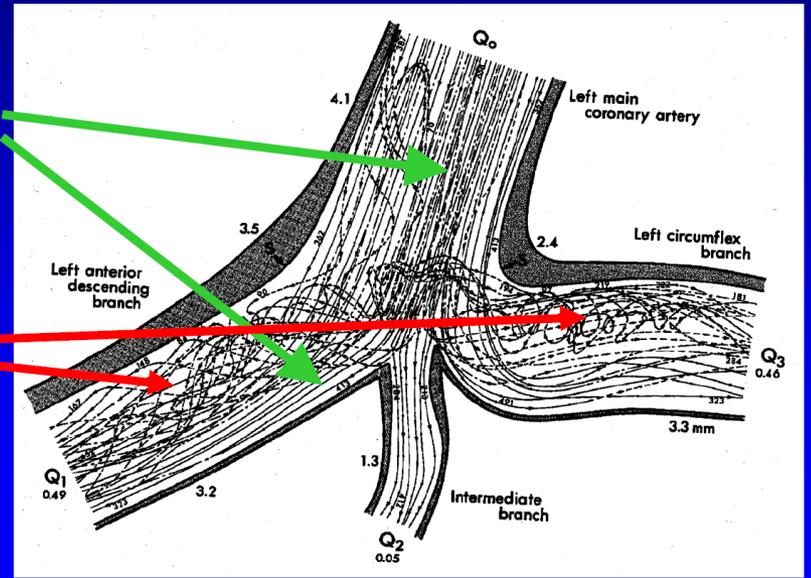
Disclosures

- **Medtronic:** PI SHEAR STENT Trial
- **Abbott Vascular:** PI Restoration Study (Subanalysis of ABSORB III Img.)
- **Gilead:** PI MARINA Trial
- **Volcano Therapeutics:** Research Grants
Steering Comm ADVISE II and Define PCI
- **St. Jude Medical:** Research Grants
- **American Heart Association:** Mentor Fellowship Awards
- **National Institute of Health:** Co-I NIH ROI/PPG
- **American College of Cardiology:** Deputy Editor, JACC Interventions

Coronary Bifurcations

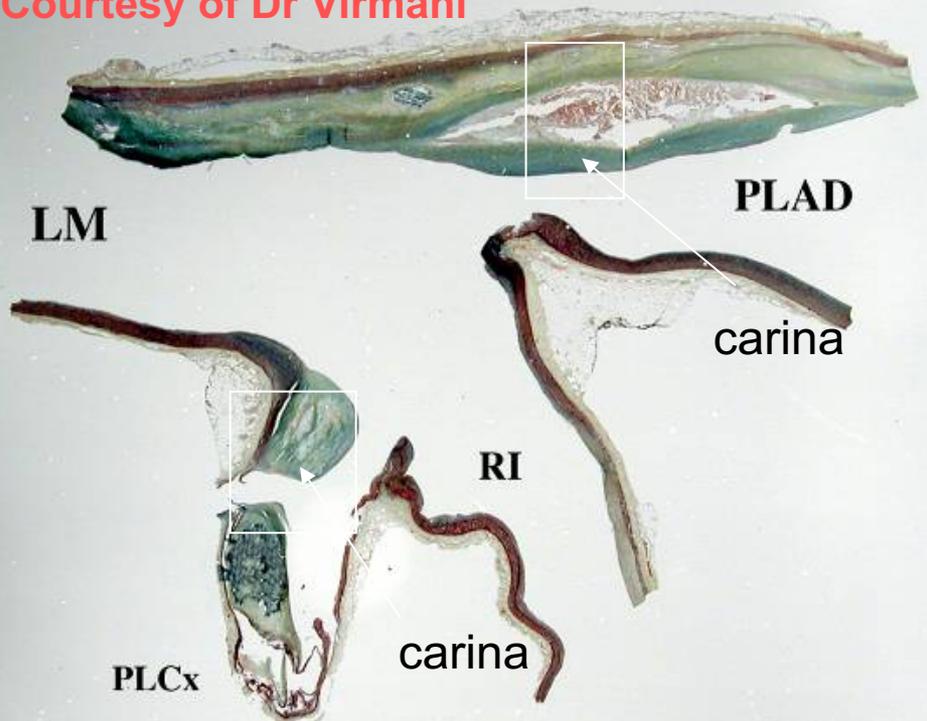
Undisturbed laminar flow
(vasculoprotective)

Low and oscillatory
disturbed laminar flow
(pro-inflammatory and
atherogenic)

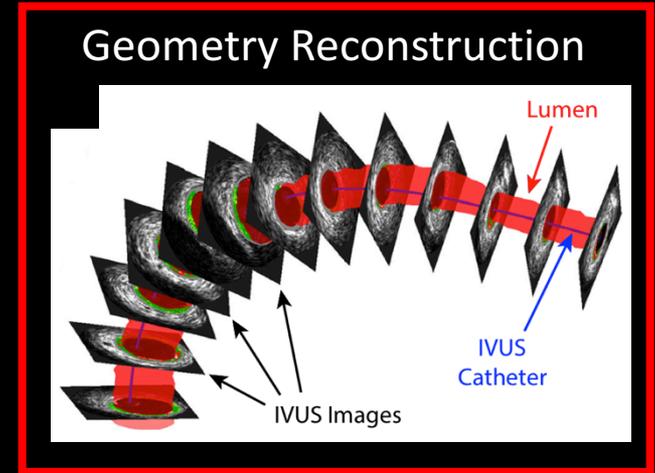
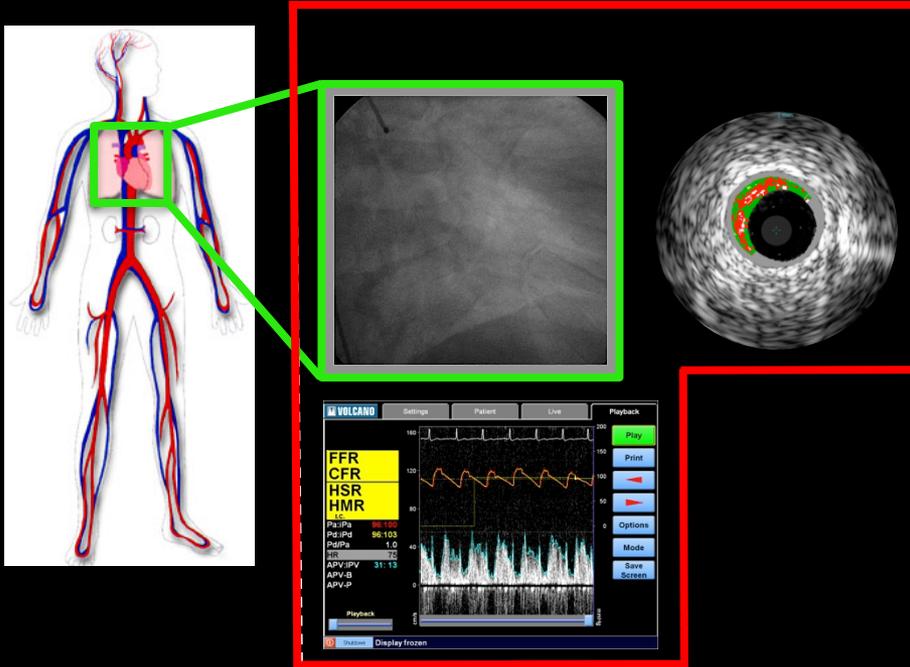


(Asakura and Karino. Circ Res 1990;66:1045)

Courtesy of Dr Virmani



Overview of Computational Methods

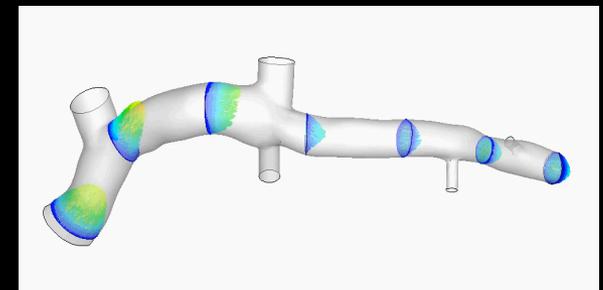
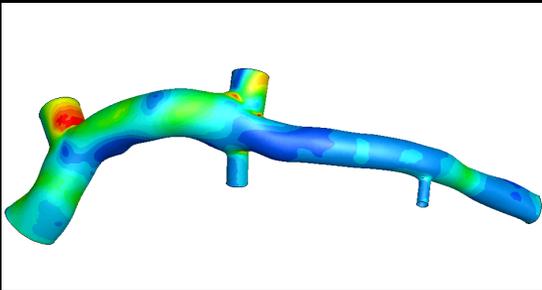


boundary conditions,
numerical methods

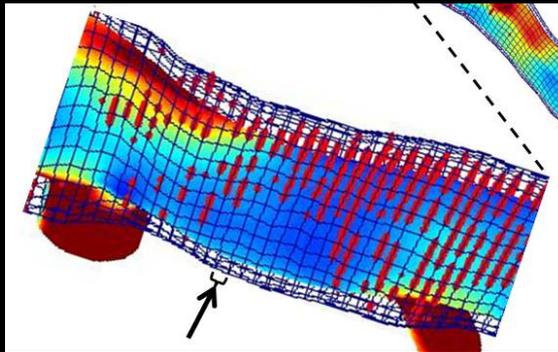
Verify
calculations

Hemodynamic Parameters

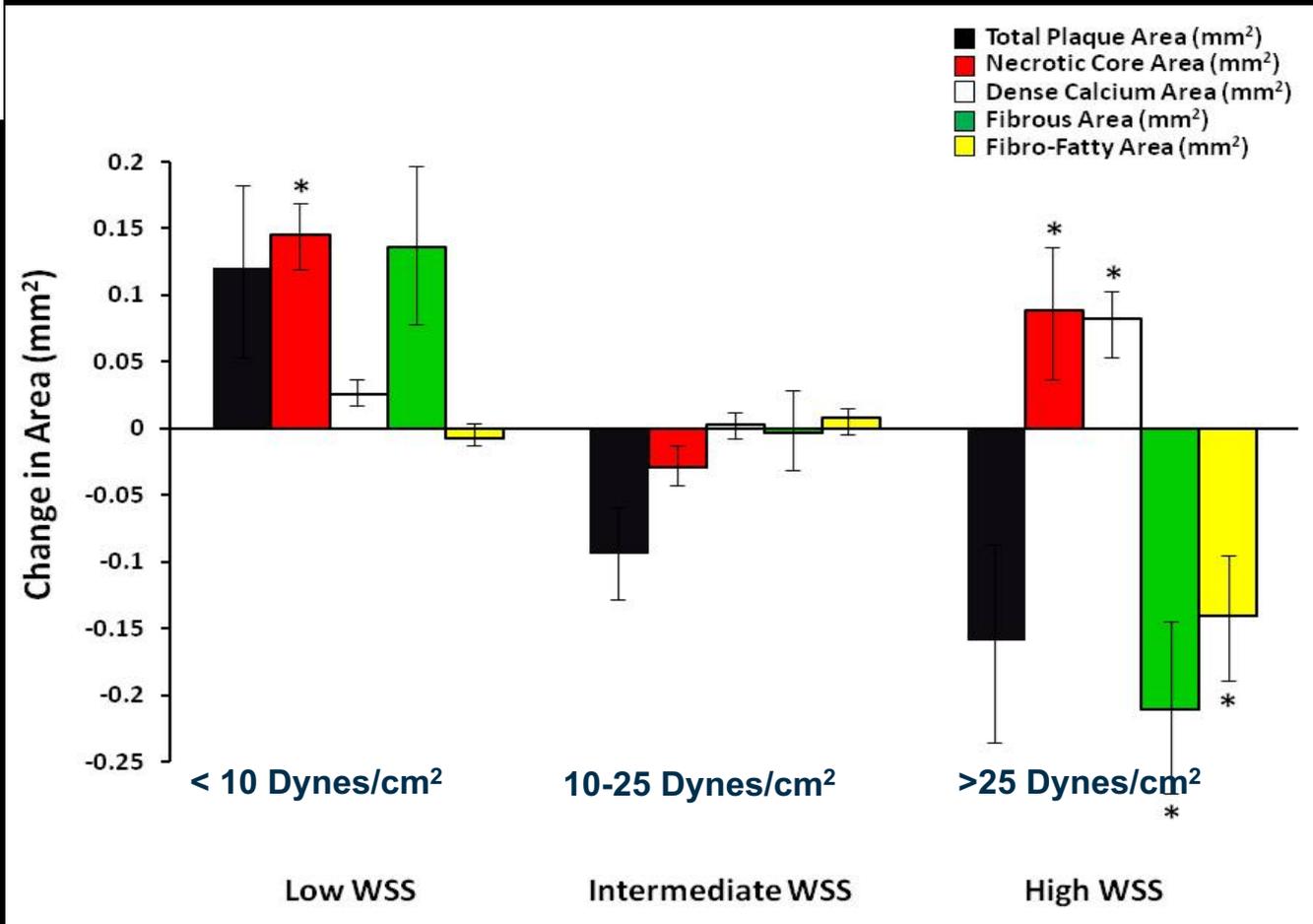
(e.g., WSS, oscillations, gradients)



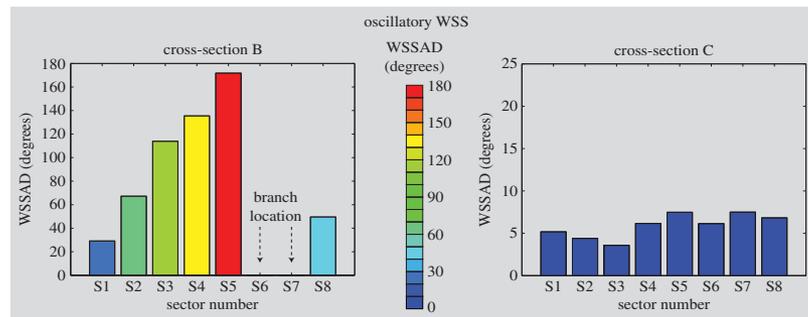
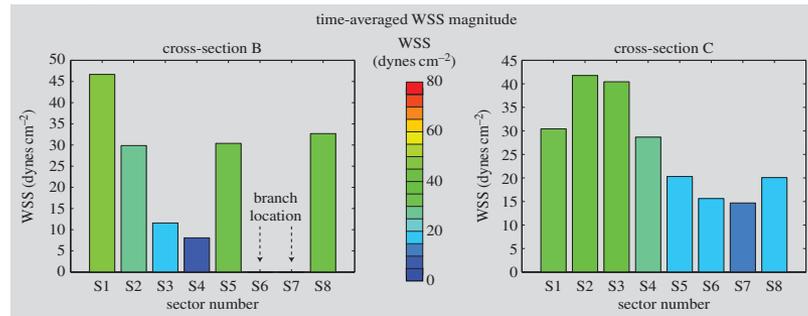
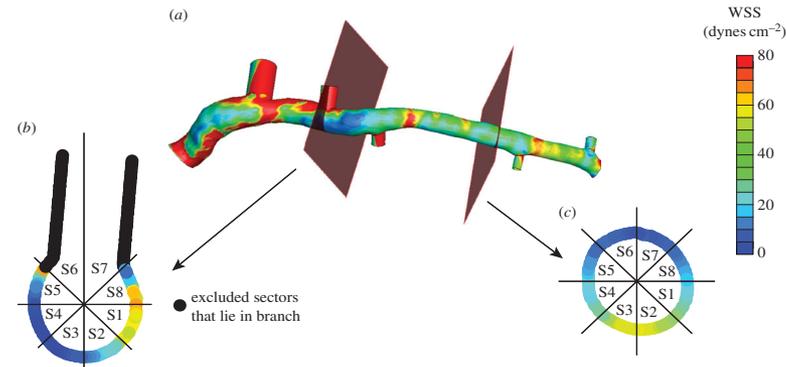
WSS and Plaque Progression



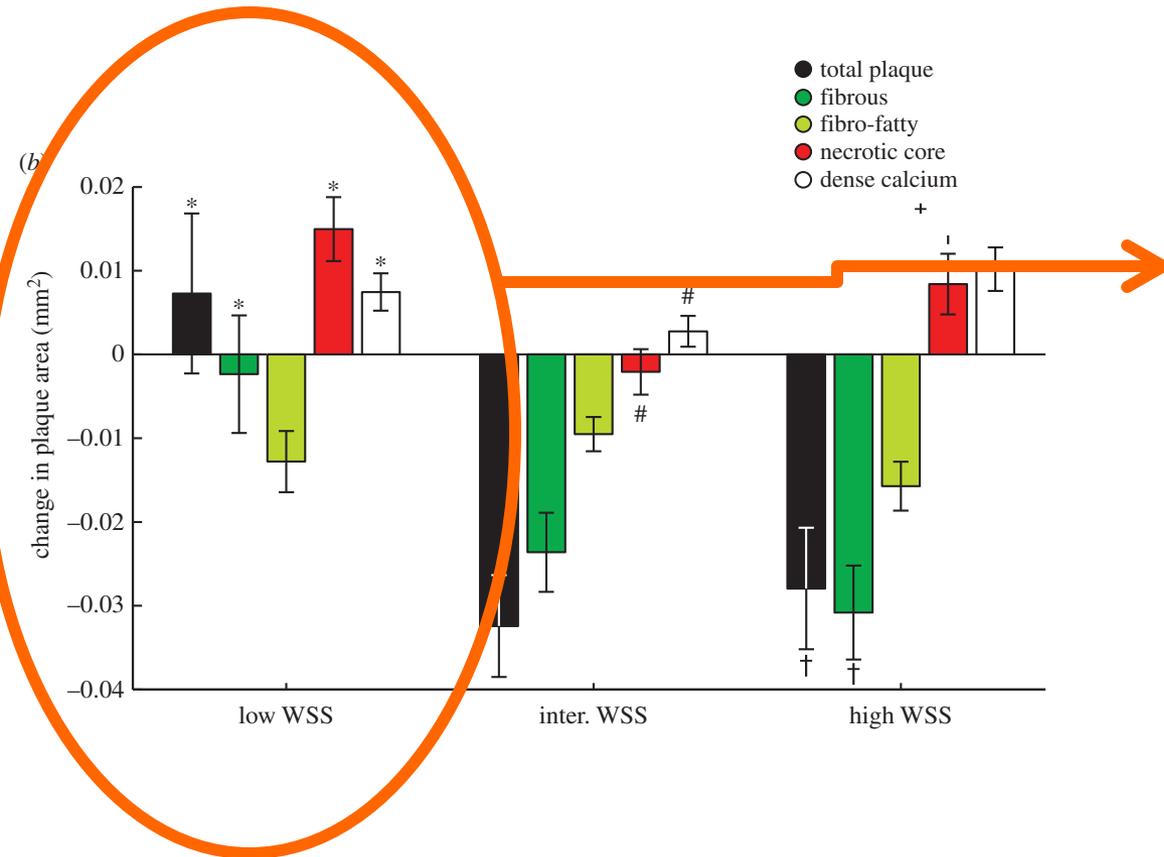
**N=20 pts with NOCAD
6 months f/u
High Dose Statin Tx**



Low and Oscillatory WSS associated with Plaque vulnerability



Low and Oscillatory WSS associated with Plaque vulnerability



Potential Effect of BRS Design on Fluid Dynamics, Solid mechanics, and Stent Healing

- Vessel Level
- Strut Level

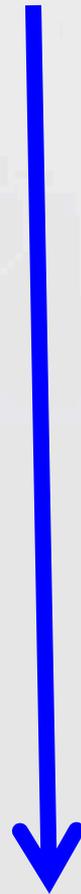
Post Implantation

1 Year

2 Years

3 Years

Beyond

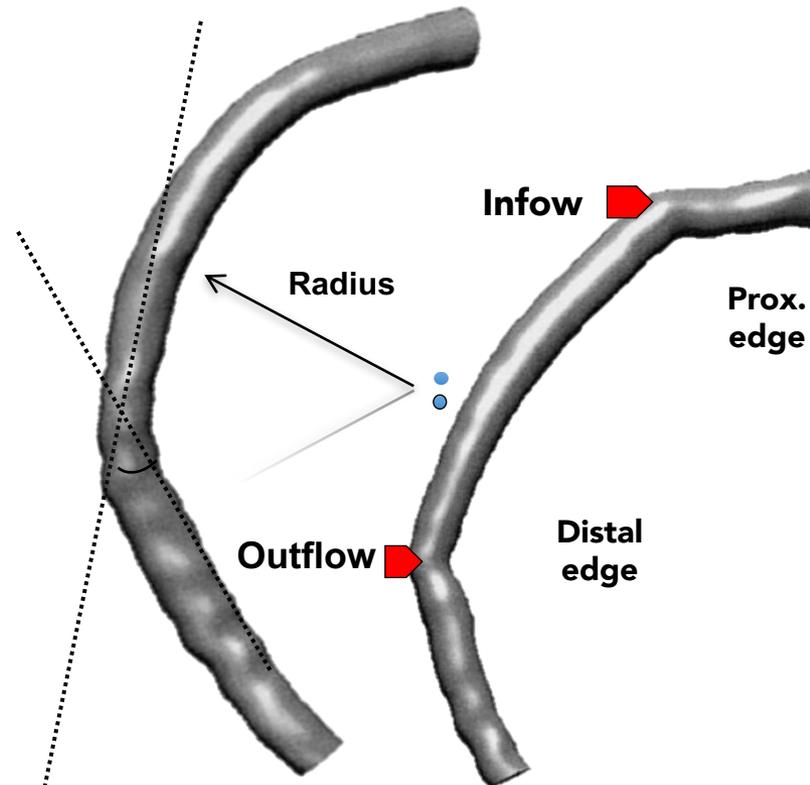


Potential Effect of BRS Design on Fluid Dynamics, Solid mechanics, and Stent Healing

Post Implantation

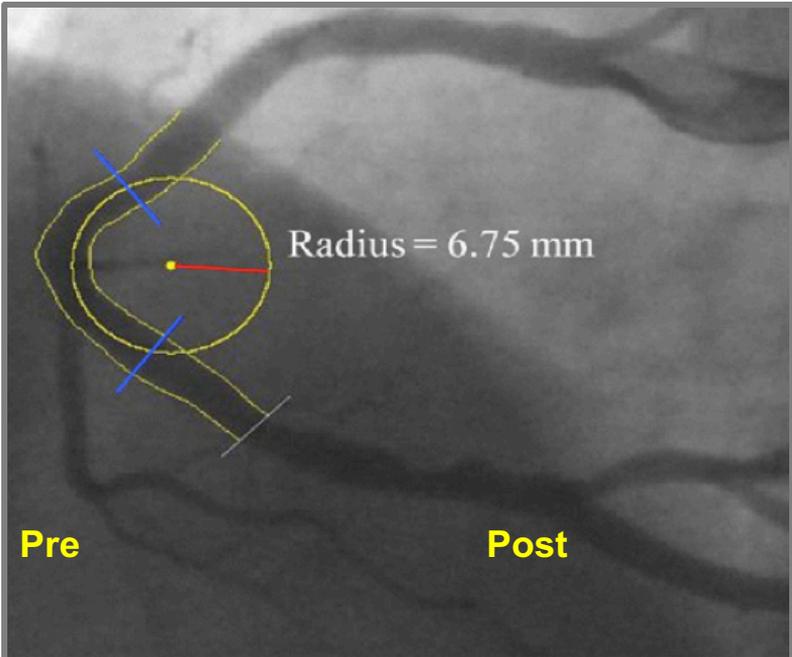
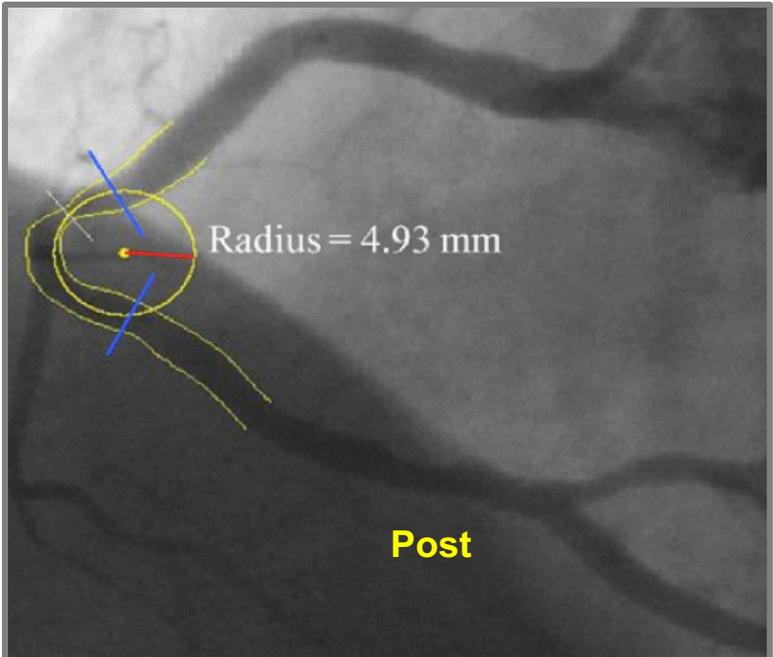
- Vessel Level

Stent implantation changed 3-D vessel geometry in healthy porcine coronary arteries following Wallstent deployment. Regions with decreased and increased WSS occur close to the stent edges



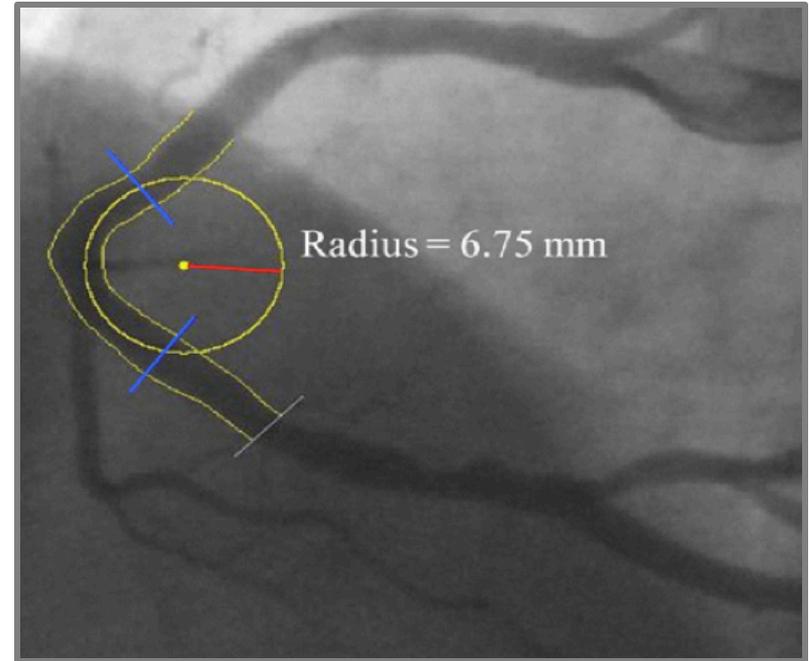
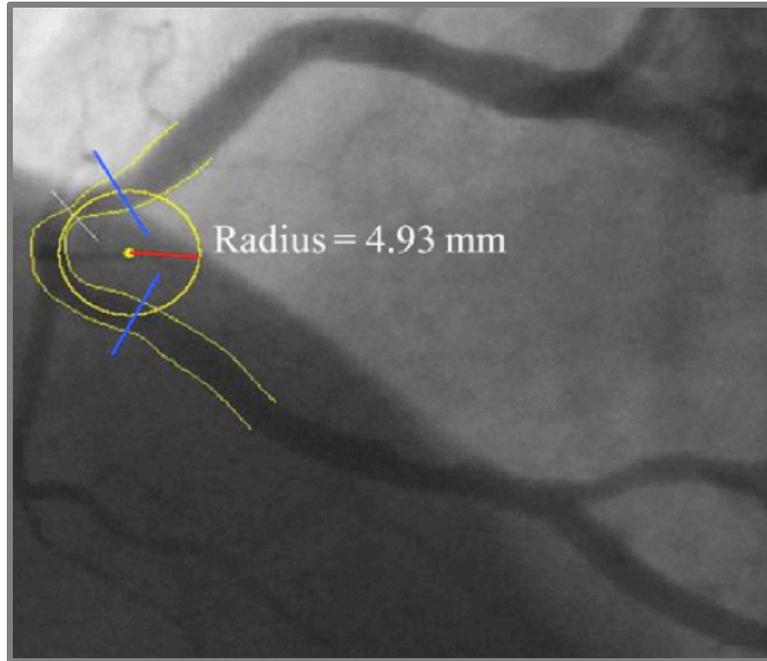
Curvature = 1/radius
Angulation = Tangents of centerlines

A Comparison of the Conformability of Everolimus-Eluting Bioresorbable Vascular Scaffolds to Metal Platform Coronary Stents



Variable	Device	Relative Changes Pre vs. Post (%)	p Value*
Curvature (cm^{-1})	BVS	7.5	<0.01
	MPS	28.7	<0.01
Angulation ($^{\circ}$)	BVS	13.4	<0.01
	MPS	25.4	<0.01

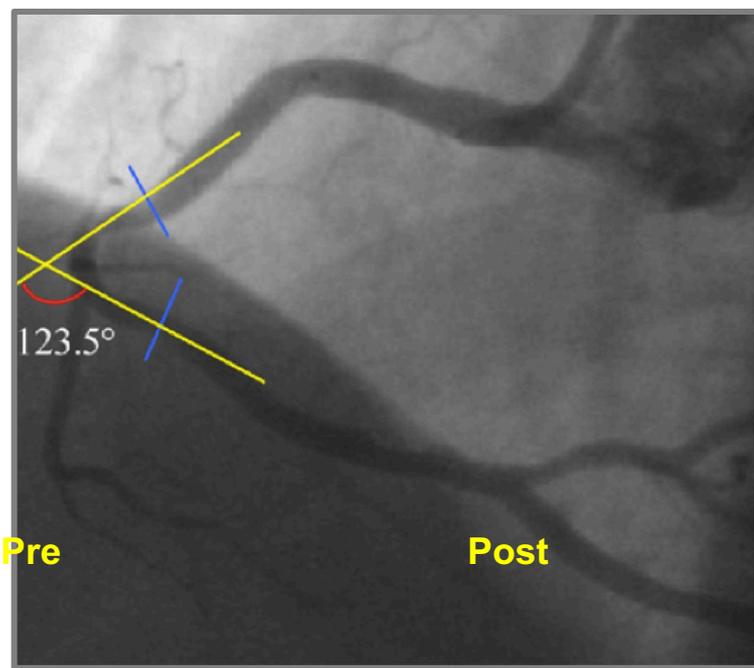
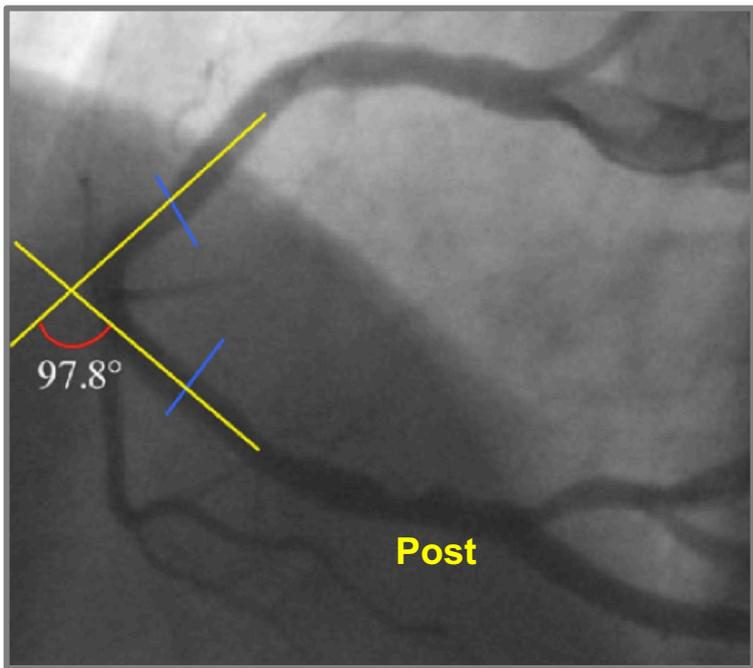
A Comparison of the Conformability of Everolimus-Eluting Bioresorbable Vascular Scaffolds to Metal Platform Coronary Stents



Pre

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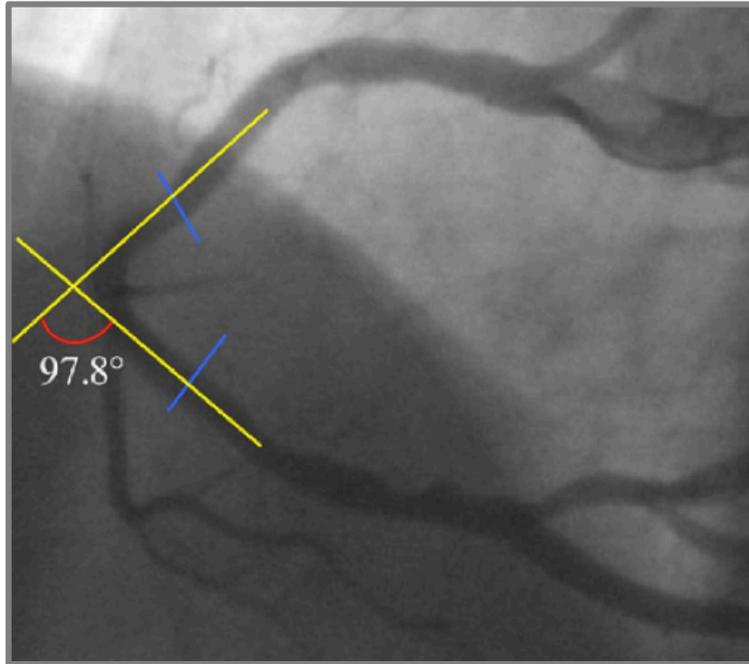
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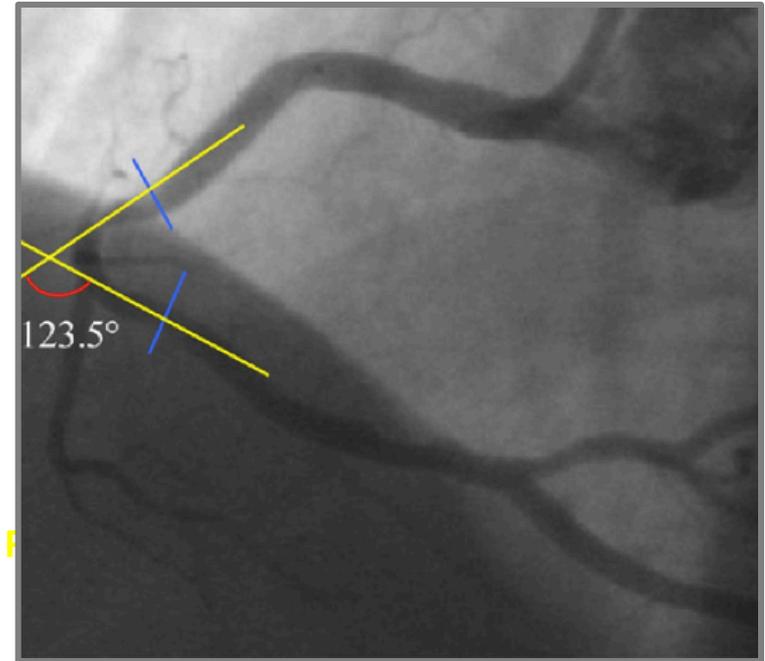
Post

Variable	Device	Relative Changes Pre vs. Post (%)	p Value*
Curvature (cm ⁻¹)	BVS	7.5	<0.01
	MPS	28.7	<0.01
Angulation (°)	BVS	13.4	<0.01
	MPS	25.4	<0.01

A Comparison of the Conformability of Everolimus-Eluting Bioresorbable Vascular Scaffolds to Metal Platform Coronary Stents



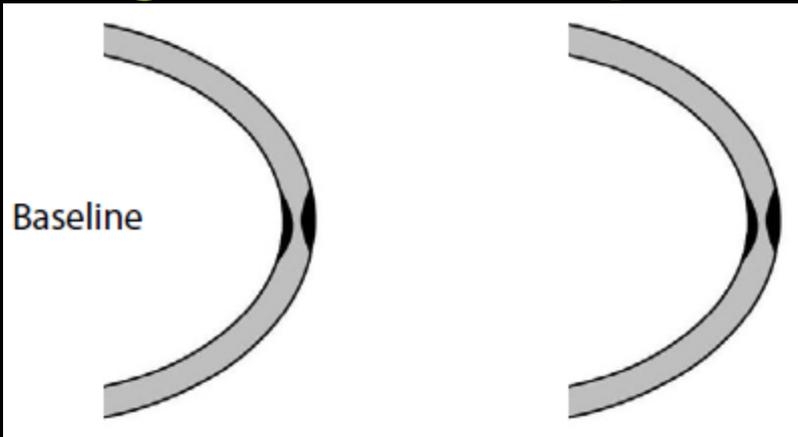
Pre



Variable	Device	Relative Changes Pre vs. Post (%)	p Value*
Curvature (cm^{-1})	BVS	7.5	<0.01
	MPS	28.7	<0.01
Angulation (°)	BVS	13.4	<0.01
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Rigid

Compliant

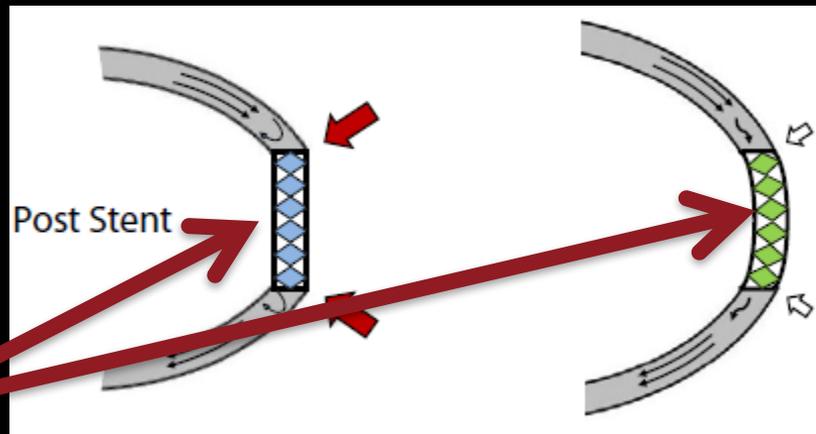


EDITORIAL COMMENT

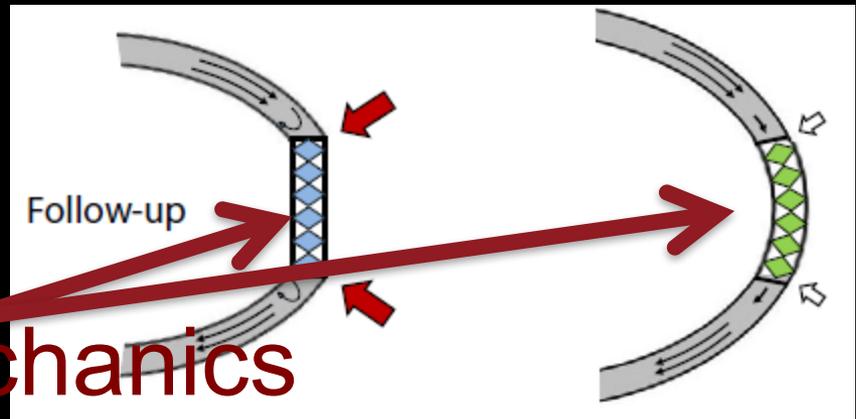
The Shear Stress of Straightening the Curves

Biomechanics of Bioabsorbable Stents*

Michael C. McDaniel, MD, Habib Samady, MD



Fluid Dynamics



Solid Mechanics

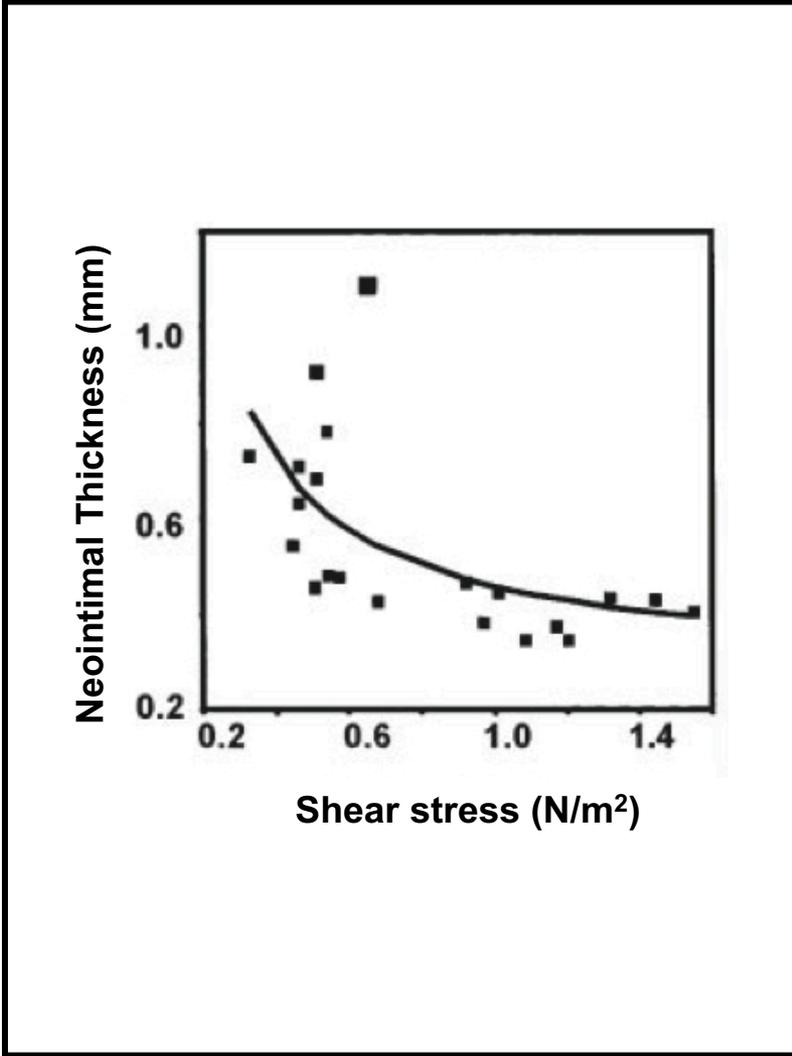
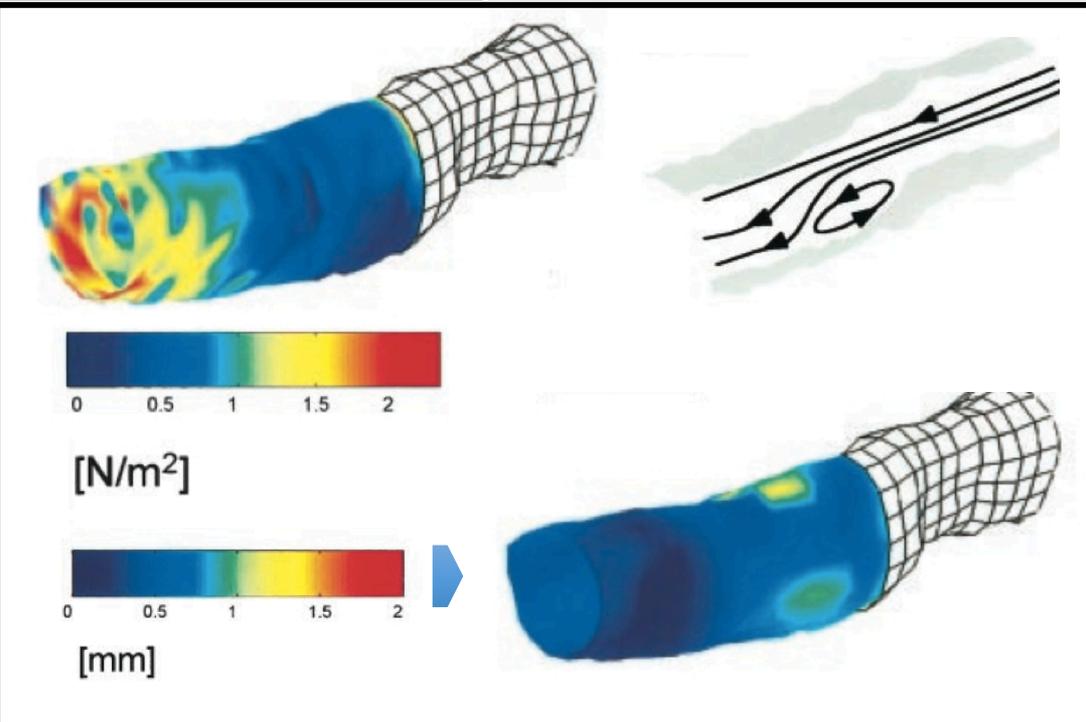
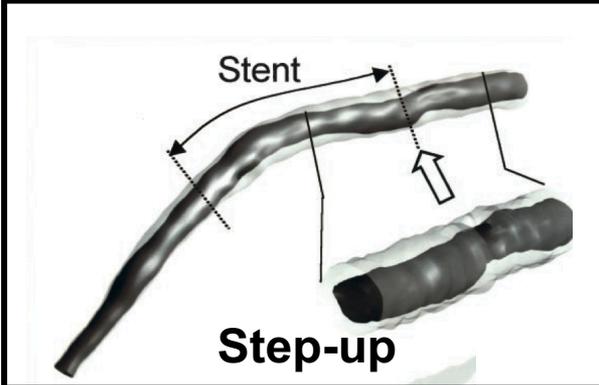


Focal In-Stent Restenosis Near Step-Up

Roles of Low and Oscillating Shear Stress?

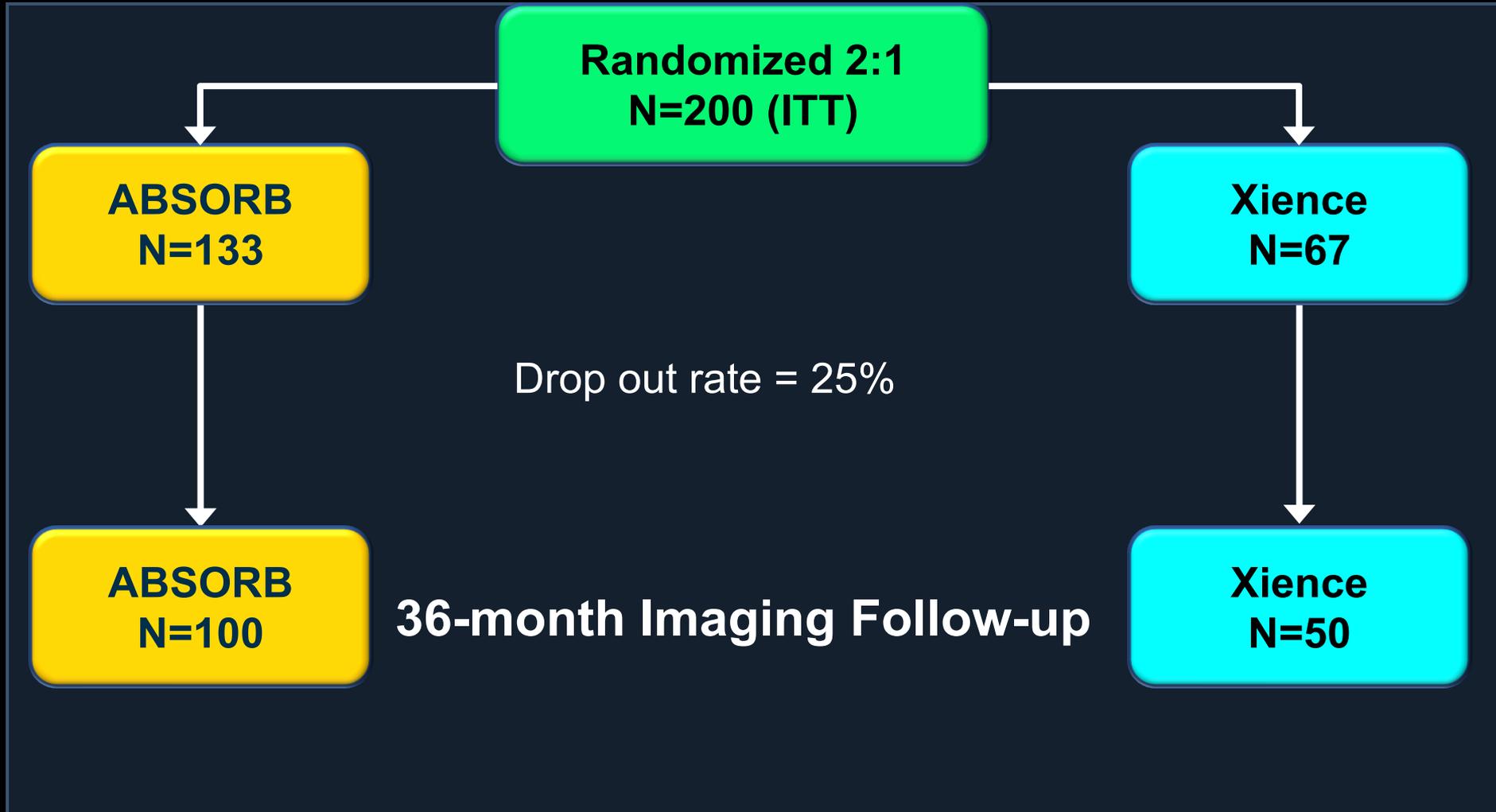
Attila Thury, MD; Jolanda J. Wentzel, PhD; Ruud V.H. Vinke, MSc; Frank J.H. Gijsen, Johan C.H. Schuurbiens, BSc; Rob Krams, MD, PhD; Pim J. de Feyter, MD, PhD; Patrick W. Serruys, MD, PhD; Cornelis J. Slager, PhD

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Restoration Biomechanical Study

Emory Cardiovascular Biomechanical Core Laboratory (ECBC)



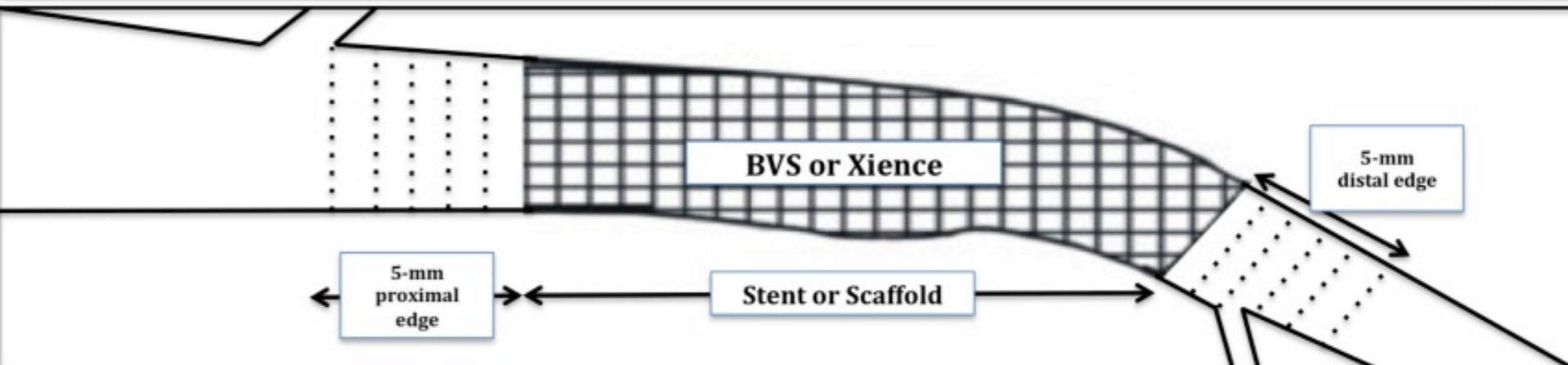
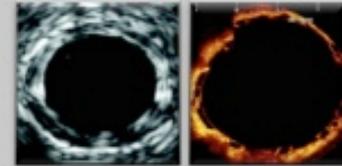
Biomechanical Comparison of Xience vs BVS

ABSORB III Imaging Sub-Study: RESTORATION

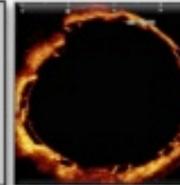
Strut and Vessel Level IVUS Analysis

1. Comparison of **vascular straightening** between BVS and Xience assessed by 3-D reconstruction in:

- 50 Angio/ OCT patients &
 - 130 Angio/ IVUS patients
- defined as change of angulation pre- to post-device implantation.

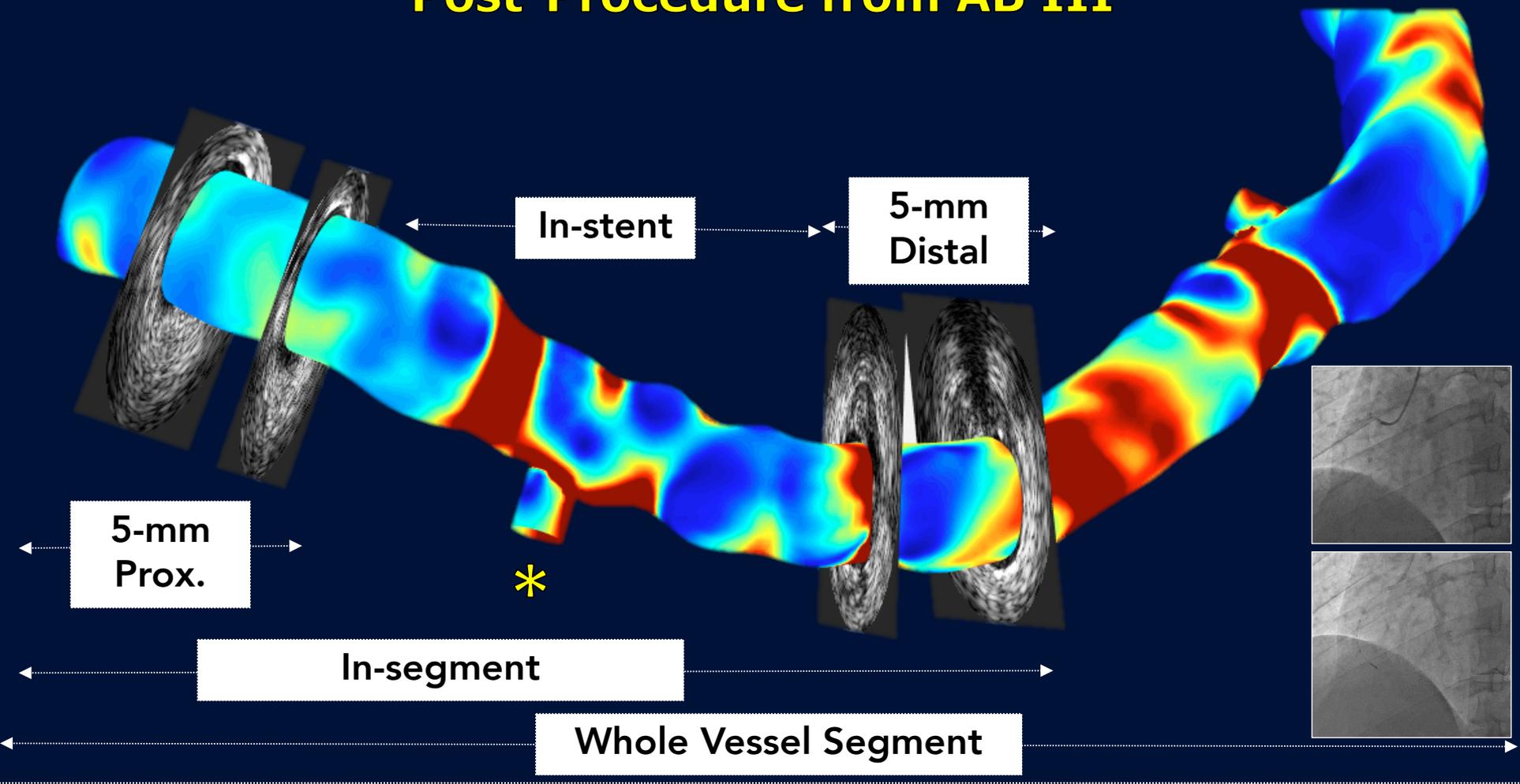


2. Comparison of **OCT derived area of micro low-WSS** (defined as area vessel with $WSS < 10$ dynes/ cm^2) between BVS and Xience within the index area divided by total area of vessel with the implanted device and 5-mm proximal and distal edges.



3. Comparison of **IVUS derived area of macro-low WSS** (defined as area vessel with $WSS < 10$ dynes/ cm^2) within the index area divided by total area of vessel with device and within 5-mm proximal and distal edges.

In Vivo IVUS-derived Computational Fluid Dynamics Post-Procedure from AB III



*

**IVUS
L-view**

Potential Effect of BRS Design on Fluid Dynamics, Solid mechanics, and Stent Healing

Post Implantation

- Vessel Level
- Strut Level

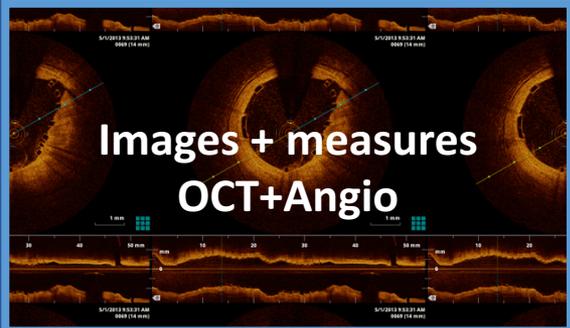
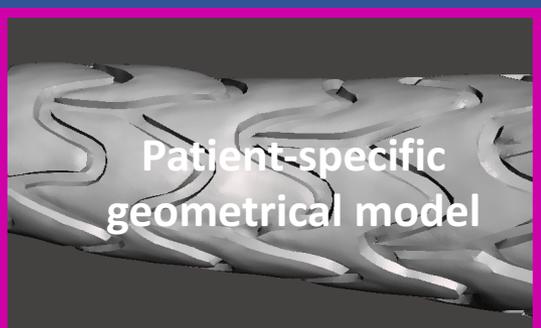
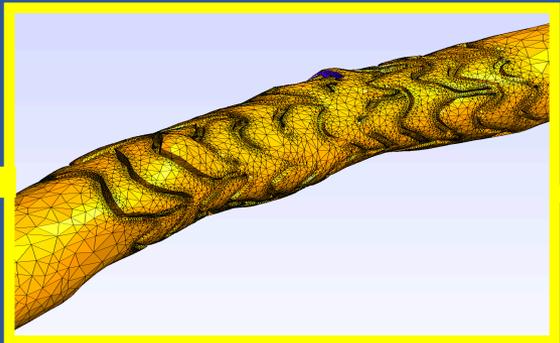


Image and Geometrical Processing
Strut detection, Interpolation, Classification, Angiography Registration, Volumetric Reconstruction, Stented Lumen Computation



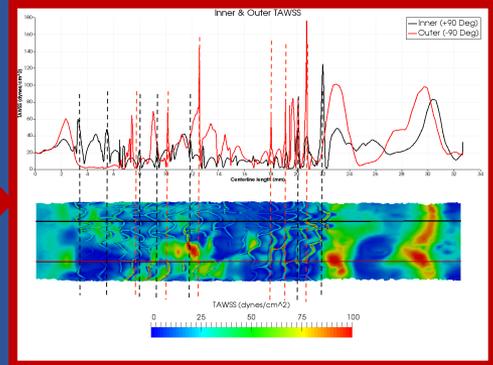
Computational Fluid Dynamics
Finite Element Analysis on High Performance Supercomputers



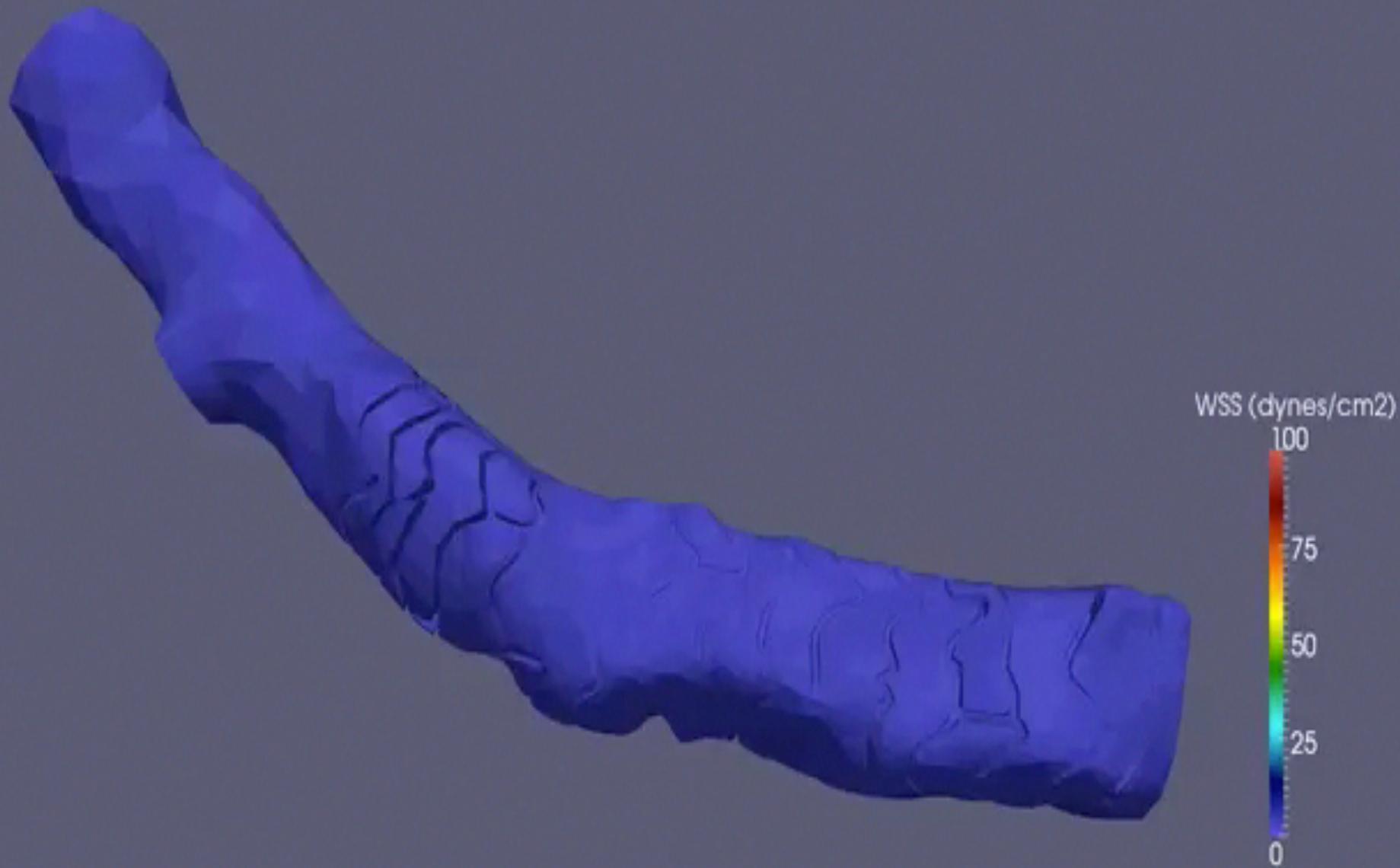
Meshing Computation
Smoothing, Error Fixing, Boundary Layers

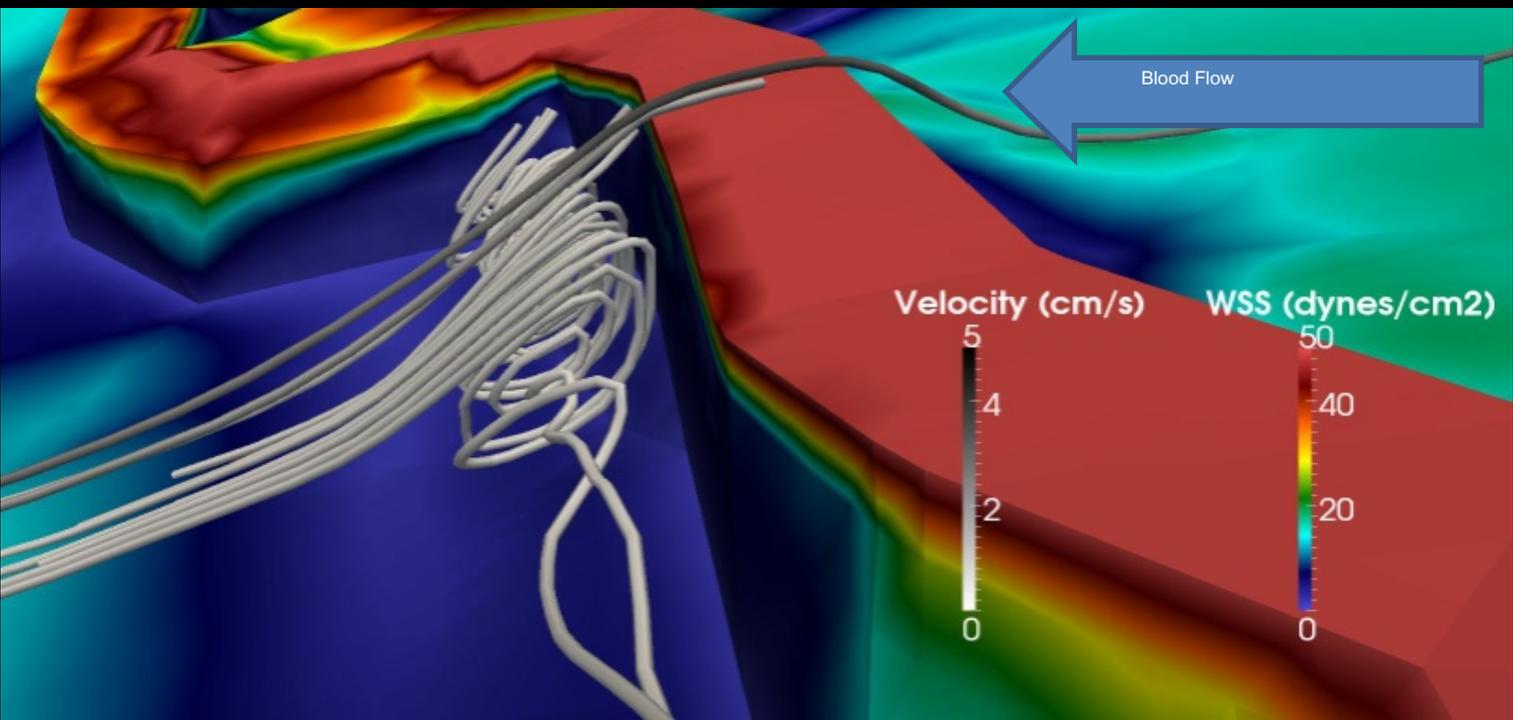
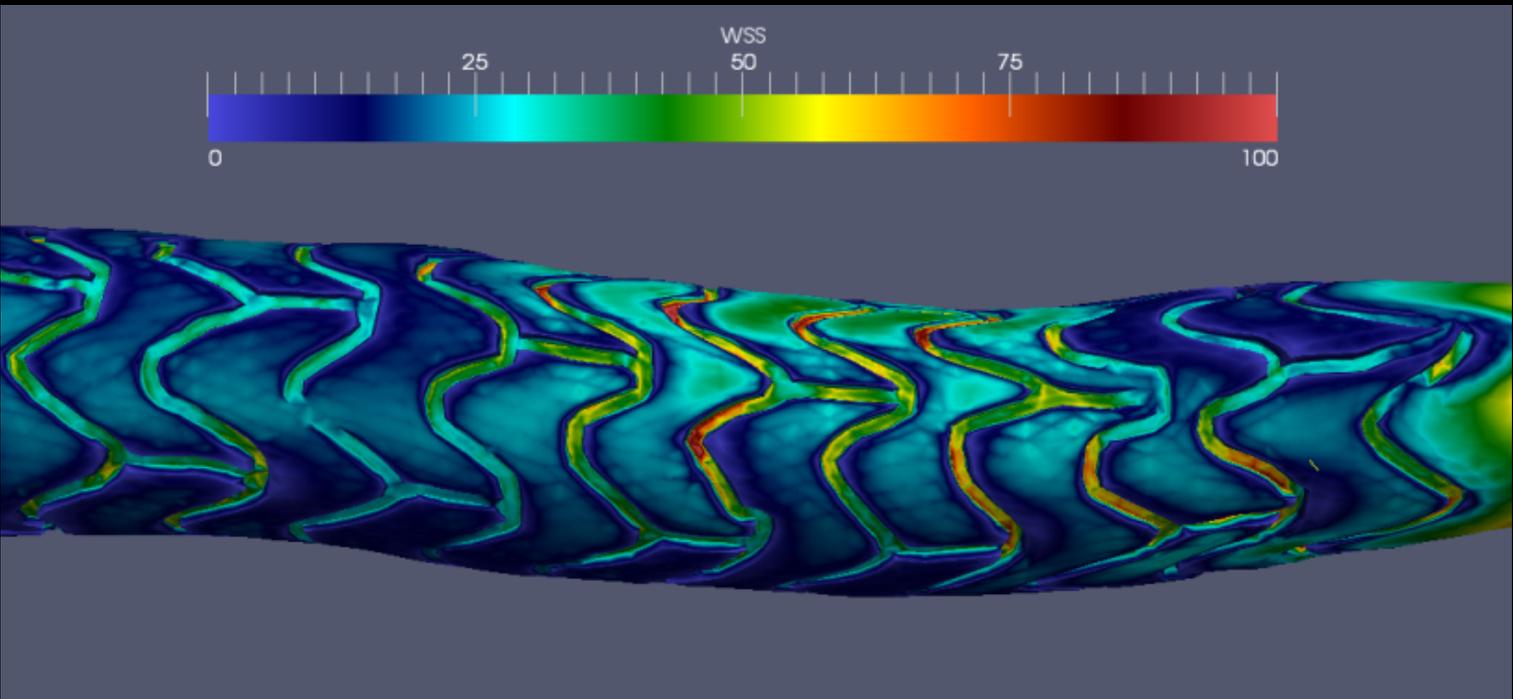


Postprocessing
VIRTUAL IN SILICO HISTOLOGY

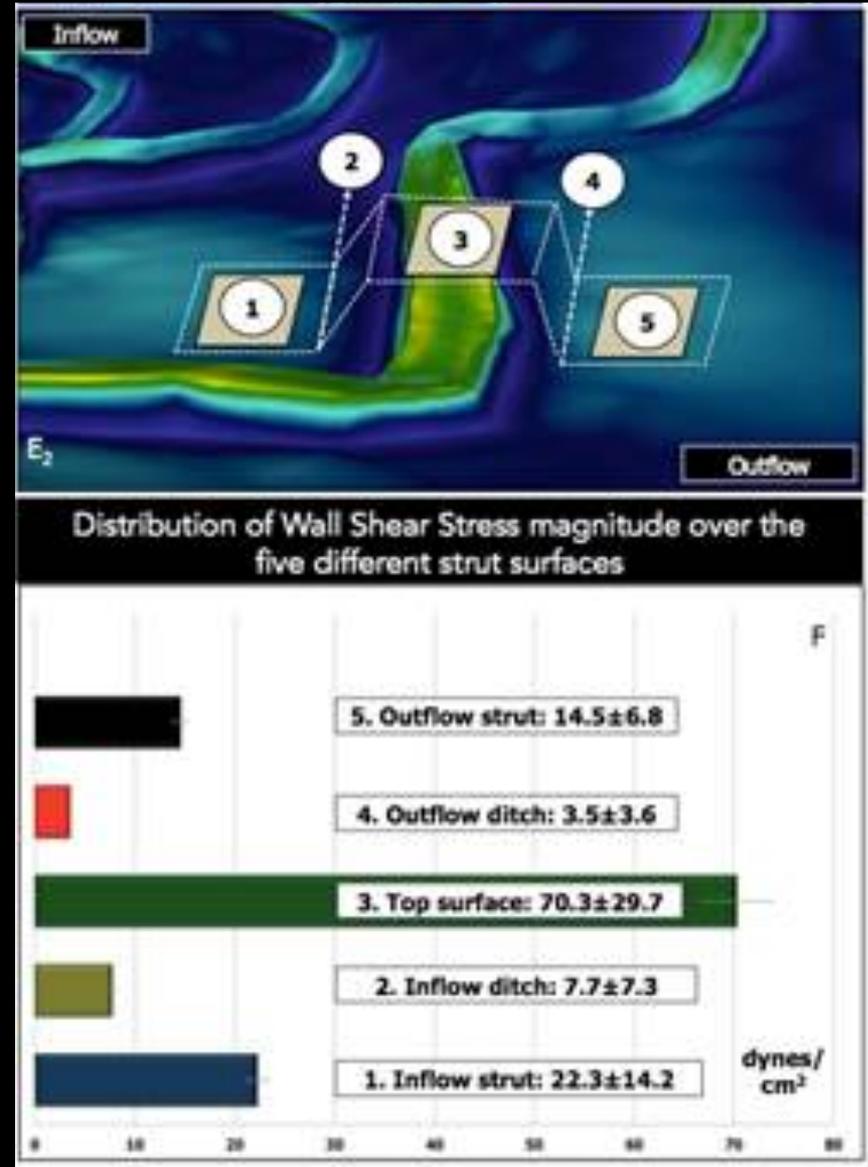
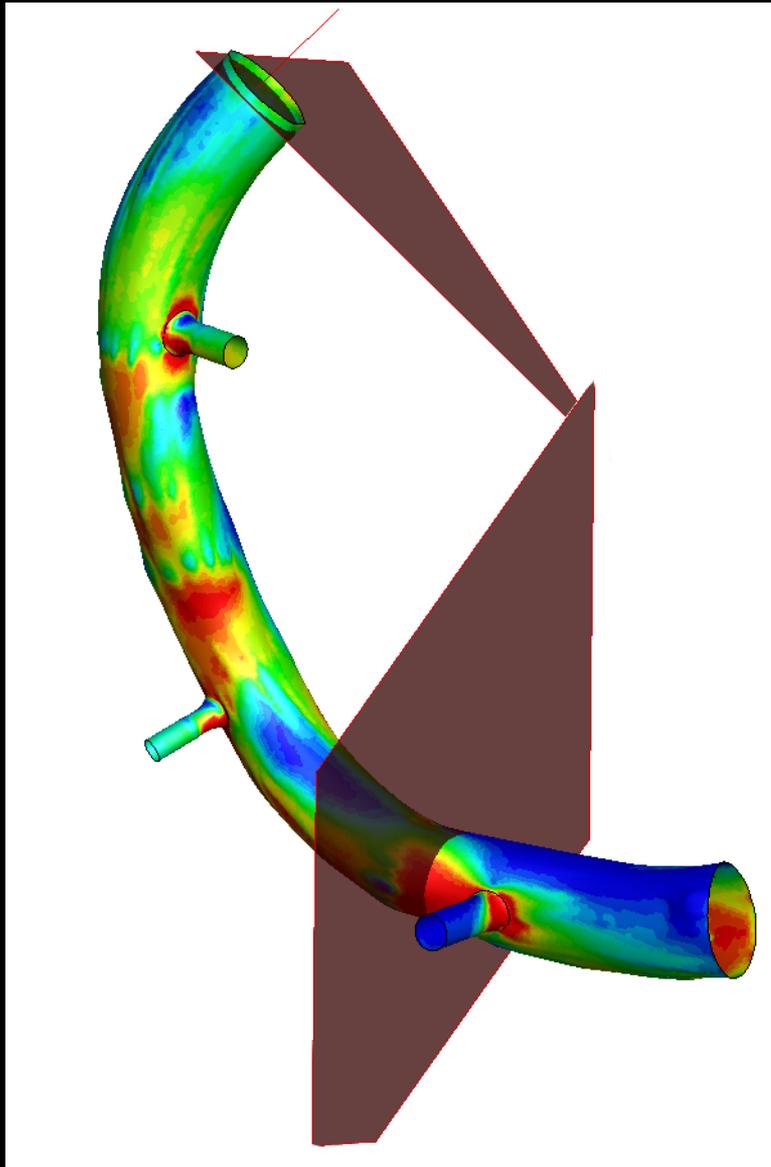


In vivo OCT-derived Computational Fluid Dynamics Post-Procedure from AB III

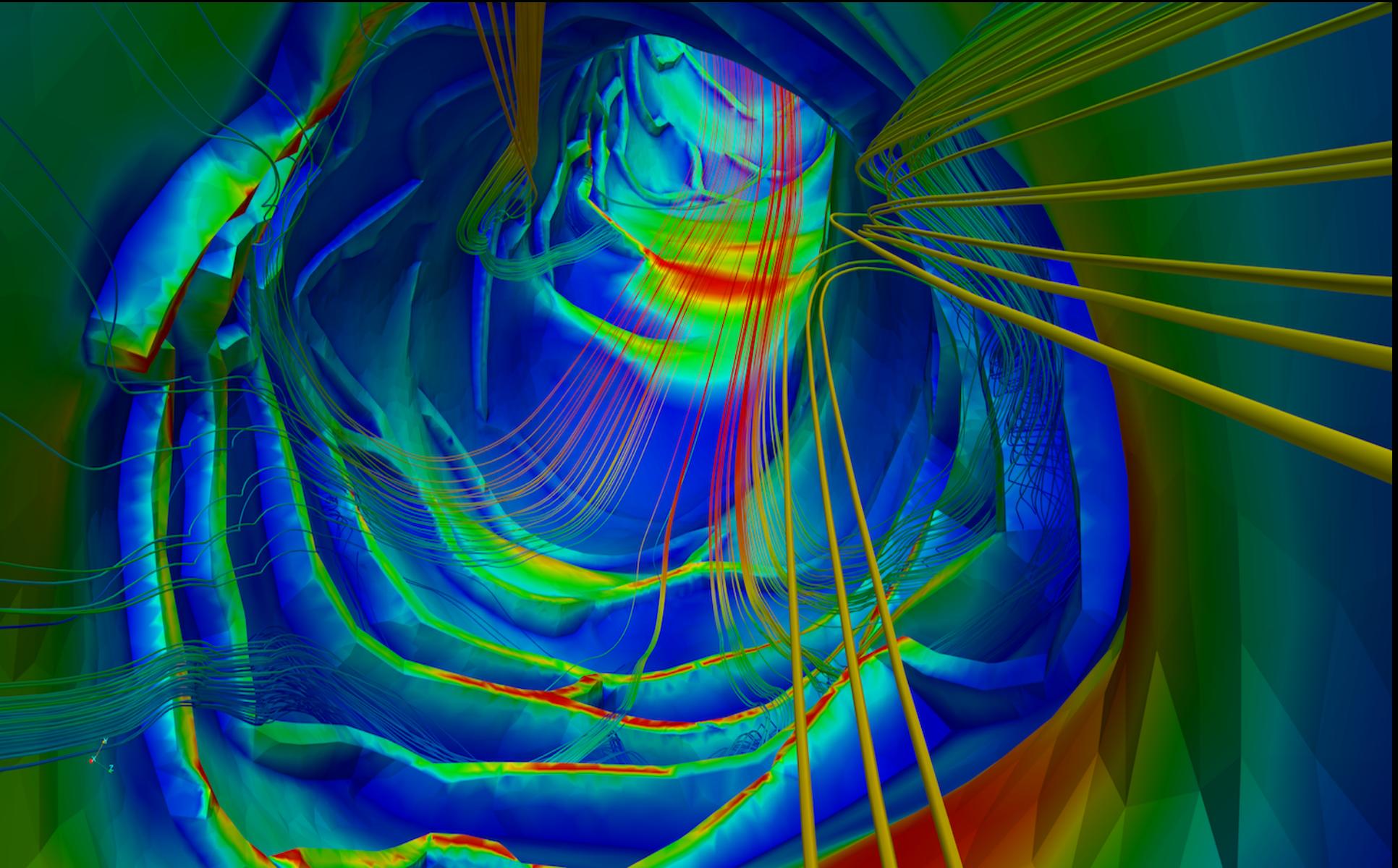




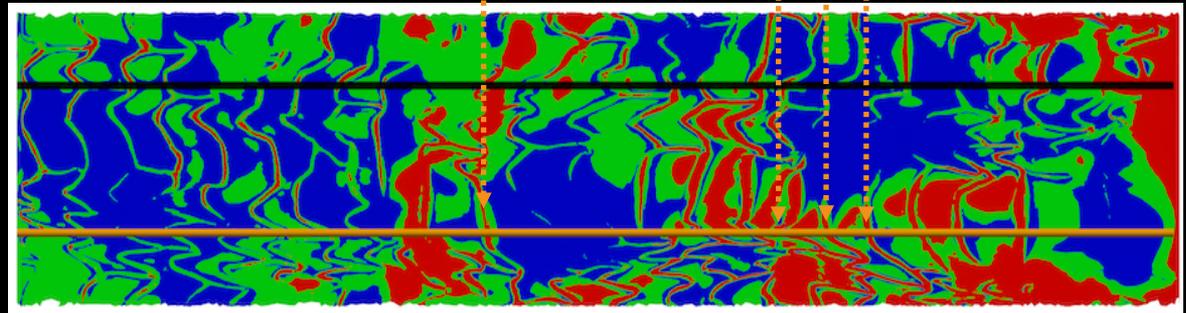
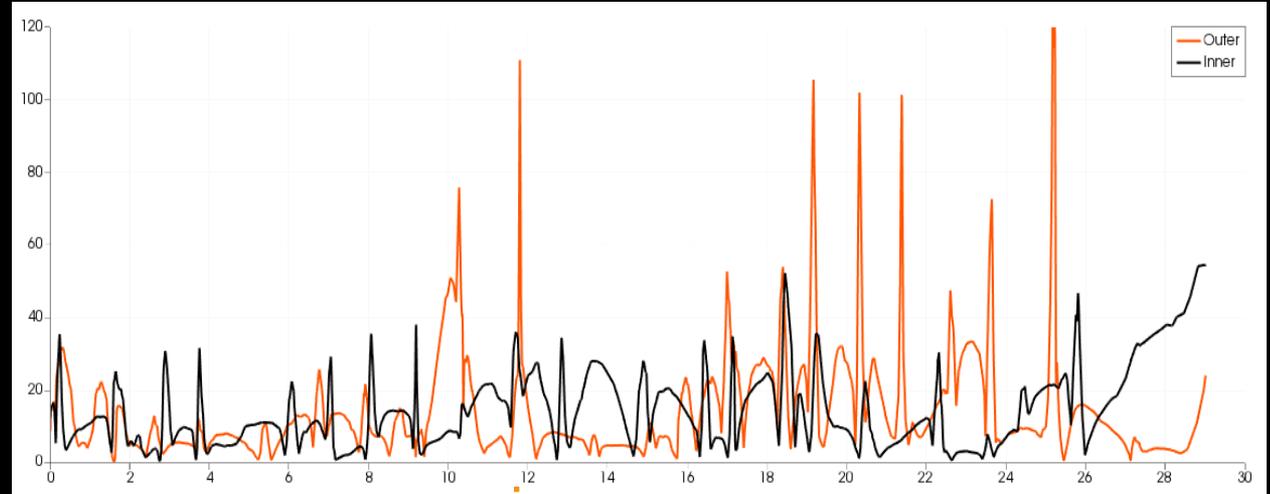
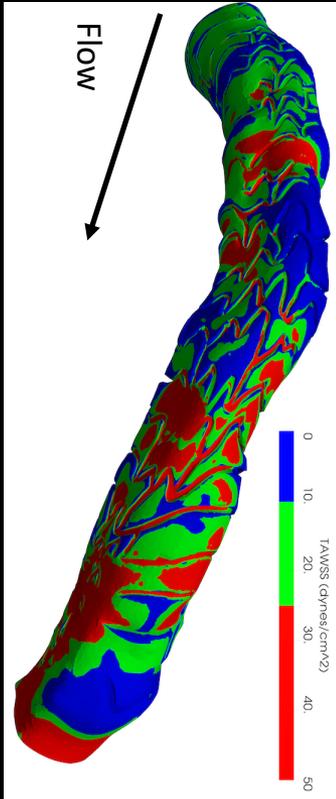
Vessel and Strut Level Wall Shear Stress



CFD with a Very Fine Mesh

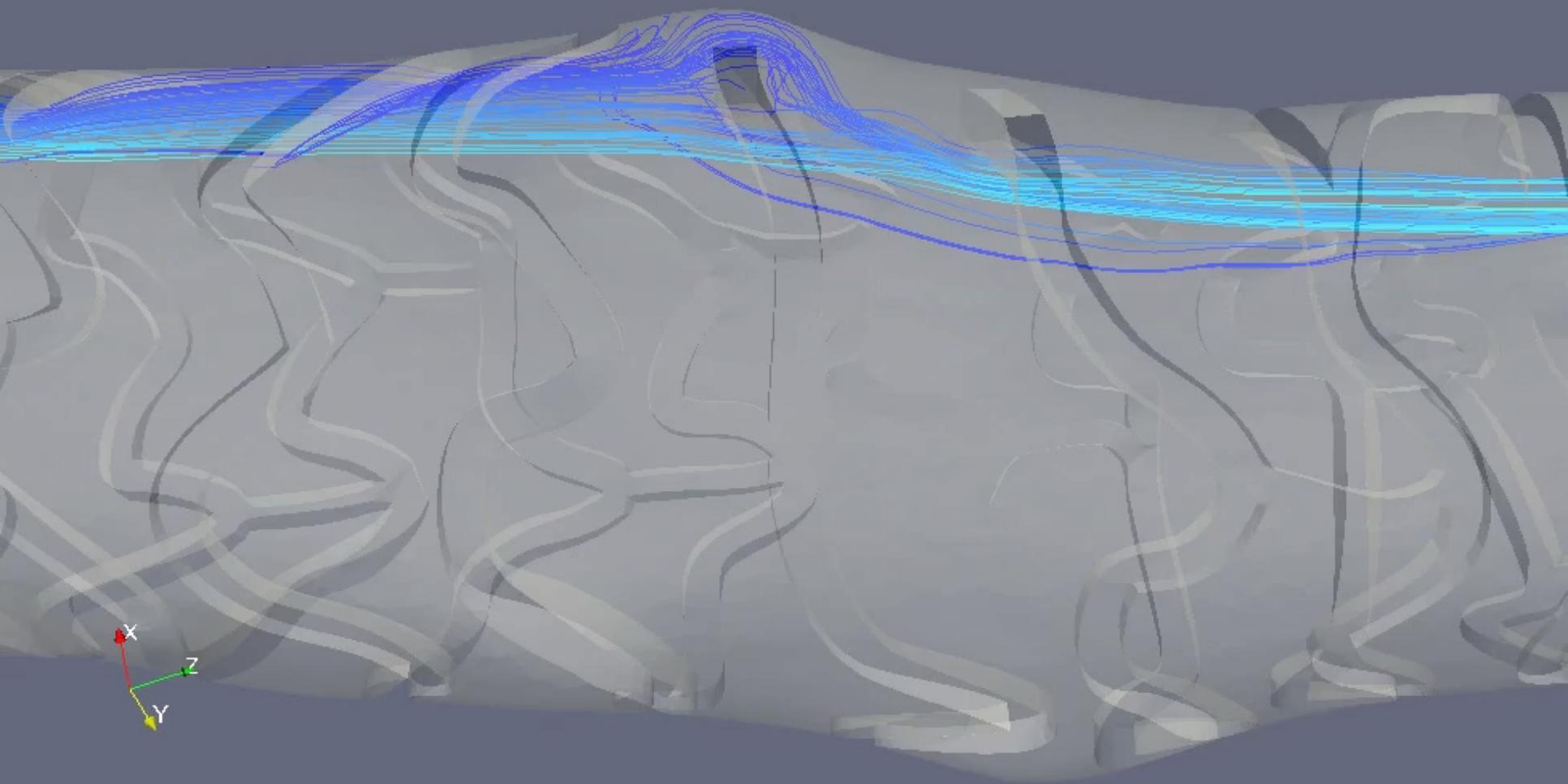


Impact of Vessel Curvature on WSS

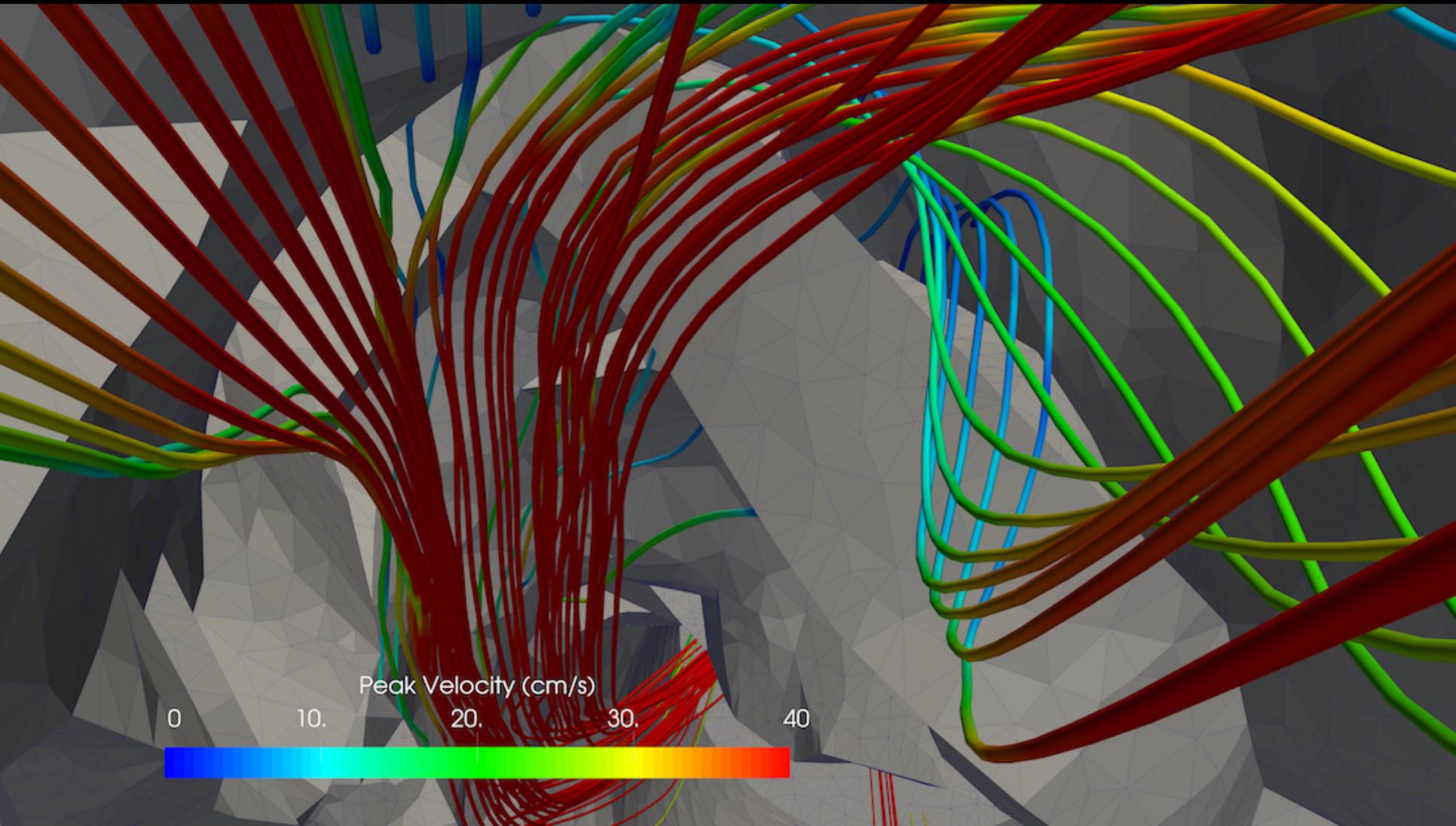


velocity Magnitude

0.000e+00 23.2 46.3 69.5 9.260e+01



Velocity Profiles Around Malapposed Struts



Potential Effect of BRS Design on Fluid Dynamics, Solid mechanics, and Stent Healing

- Vessel Level
- Strut Level

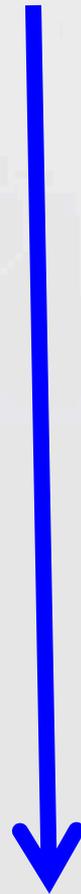
Post Implantation

1 Year

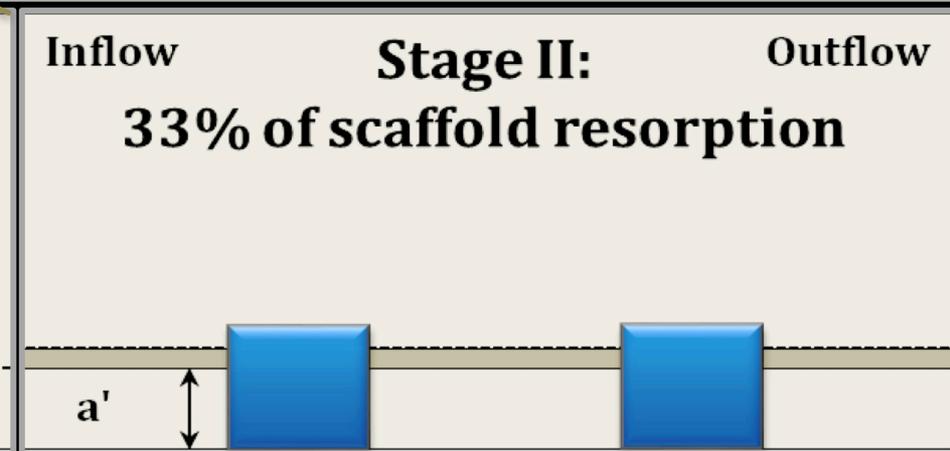
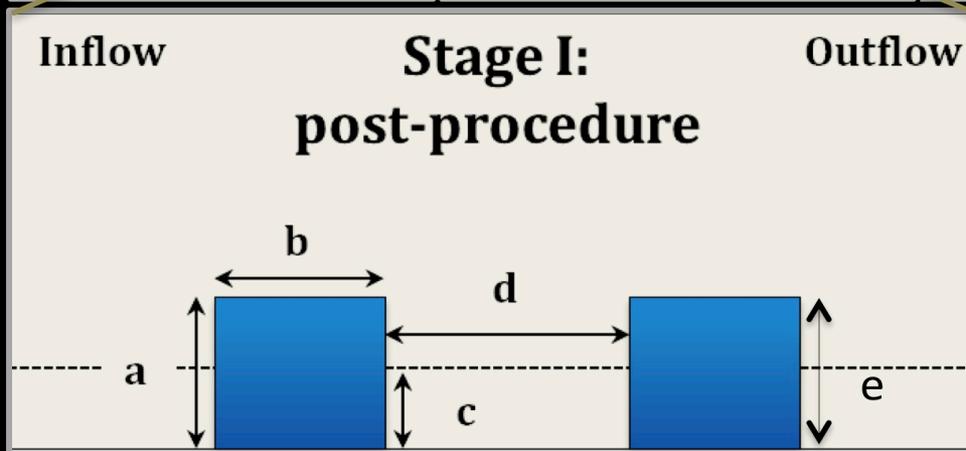
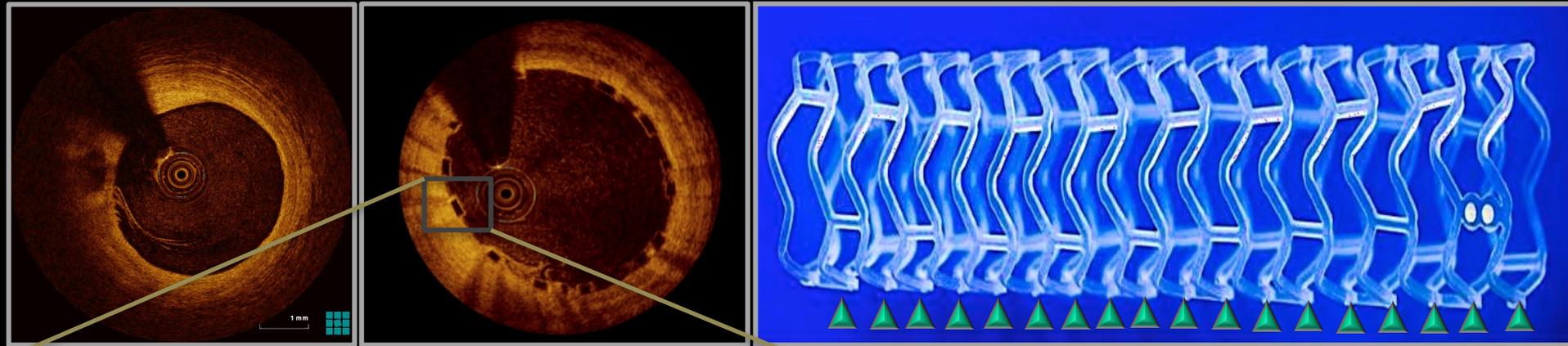
2 Years

3 Years

Beyond

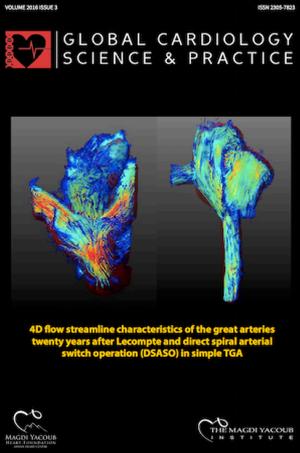


Scaffold Geometry Upon which Computational Fluid Dynamics were Applied



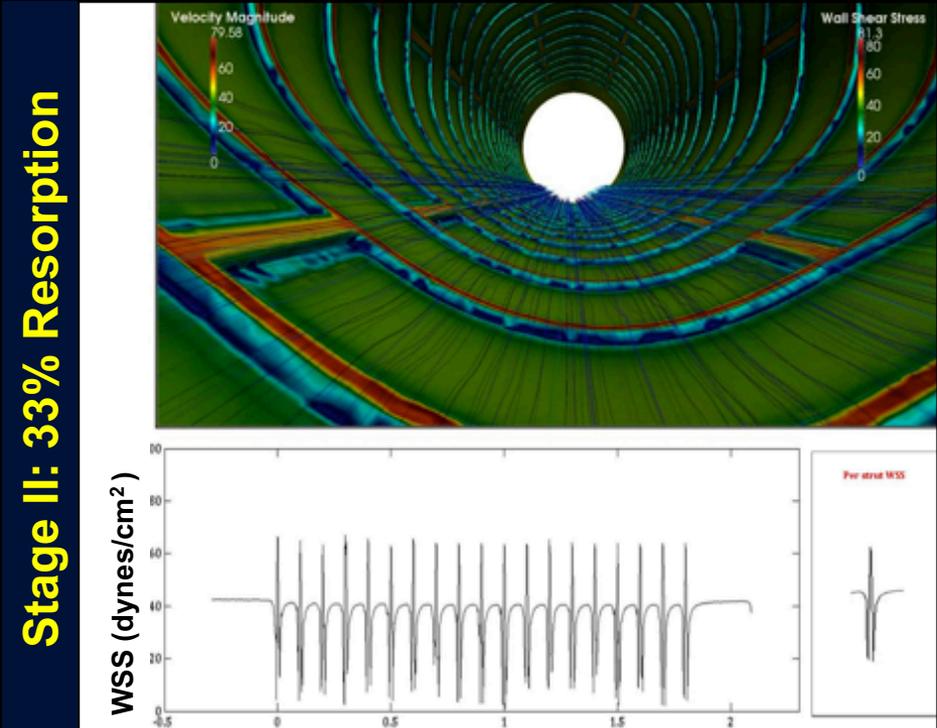
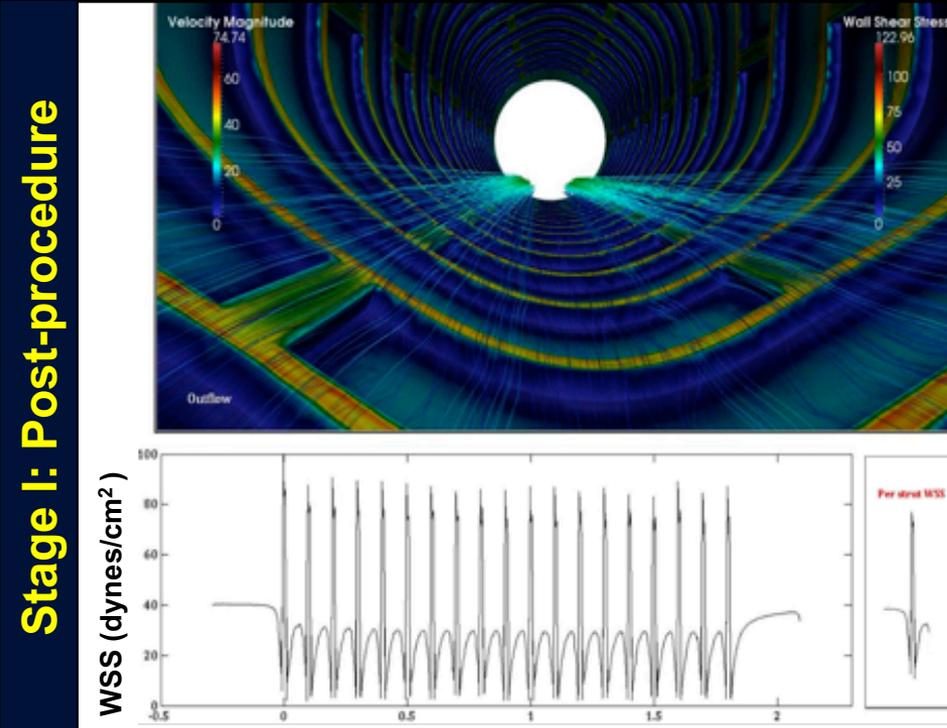
Computational fluid dynamics applied to virtually deployed drug-eluting coronary bioresorbable scaffolds: Clinical translations derived from a proof-of-concept

Glob Cardiol Sci Pract.
2014 Dec 31;2014(4):428-36



Bill D. Gogas^{1,6,†}, Boyi Yang^{2,6,†}, Tiziano Passerini², Alessandro Veneziani^{2,6}, Marina Piccinelli^{3,6}, Gaetano Esposito^{2,6}, Emad Rasoul-Arzrumly^{1,6}, Mosaab Awad¹, Girum Mekonnen^{1,6}, Olivia Y. Hung^{1,6}, Beth Holloway^{1,6}, Michael McDaniel^{1,6}, Don Giddens^{4,6}, Spencer B. King III^{1,5,6}, Habib Samady^{1,6,*}

CFD simulations following virtual scaffold deployment were calculated at the inflow, endoluminal surface (top surface of the strut), and outflow of each strut surface post-procedure (stage I) and at a time point when 33% of scaffold resorption has occurred (stage II) [6-9-month]



Shear Stress Analysis / 3 Dimensional Vessel and Scaffold: Take Home Messages

- Vessel and Strut level hemodynamics may influence post scaffold and long term vascular healing
- The methodology deployed should be tailored to the clinical questions asked
- Macro or vessel level hemodynamics may not require 3 D vessel scaffold reconstruction which is extremely complex and time consuming
- Micro or strut level hemodynamics require complex, meticulous and time consuming techniques but have the potential of evaluating the interaction of plaque prolapse, strut morphology and perhaps scaffold thrombosis
- Prospective studies are underway to investigate the prognostic value of both macro and micro level hemodynamics as they relate to vascular healing of scaffolded vessels

Emory/Ga Tech Research Team

Samady Lab/Emory

- Bill Gogas, MD PhD
- Parham Eshtehardi, MD
- Olivia Hung, MD PhD
- Sung Ahn, MD
- Jon Suh, MD
- Brian Yoo, MD
- Vishnu Koganti, PhD
- Michel Corban, MD
- Michael McDaniel, MD
- Yasir Bouchi, BS
- Udit Joshi, MD
- Faten Sebali, MS
- Wenjie Zeng, MD, MPH
- Emily Davis, BS
- Beth Thompson, BS
- Heesu Lee, BS
- Roanok Ghandhi, MD
- Nikita Chand, MD
- Christina Chanoud, BS
- Hossein Hoseini, MD
- Rani Rabah, MD
- Isha Singal
- Mansi Maini

Giddens Lab/Ga Tech

- Don Giddens, PhD
- Luke Timmins, PhD
- David Maloney, PhD
- Sung Ho Kim, PhD
- Jin Suo, PhD

Veneziani Lab/Emory

- Alessandro Veneziani, PhD
- Boyi Yang, PhD
- Adrien Lefieux, PhD
- Alex Viguerie

Oshinski Lab/Emory/Tech

- Spencer King Emory
- Ernest Garcia, PhD
- Marina Piccinelli, PhD

- Jolanda Wentzel, PhD
- Annette Kok

Shear Stress Analysis / 3 Dimensional Vessel and Scaffold: Reconstruction Methodology



European Bifurcation Club 2017
Porto, Portugal

BRS for bifurcation stenting: After thrombosis crisis

October 13th, 2017

Habib Samady MD

Professor of Medicine

Director, Interventional Cardiology, Emory University

Director, Cardiac Catheterization Laboratory Emory University Hospital