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

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Director, Cardiac Catheterization Laboratory Emory University Hospital

EMORY UNIVERSITY SCHOOL OF MEDICINE

EPIC-SEC

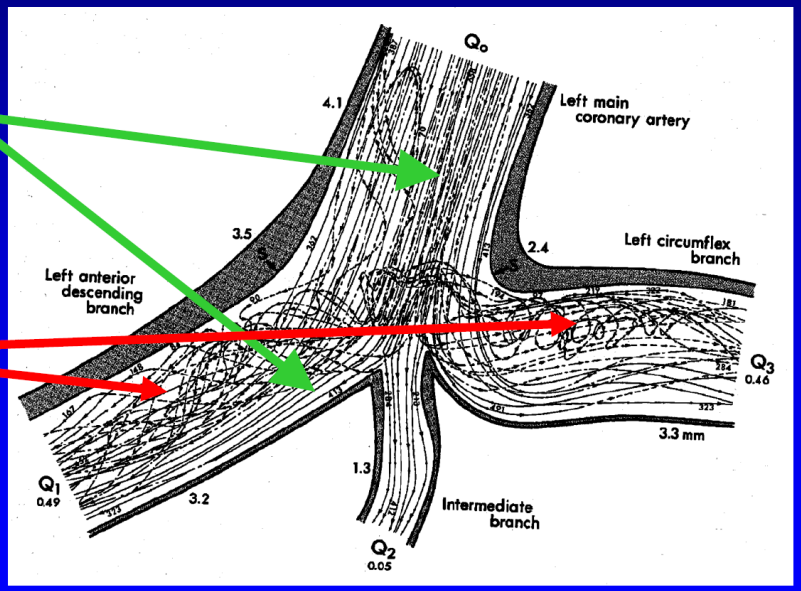
Disclosures

- **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

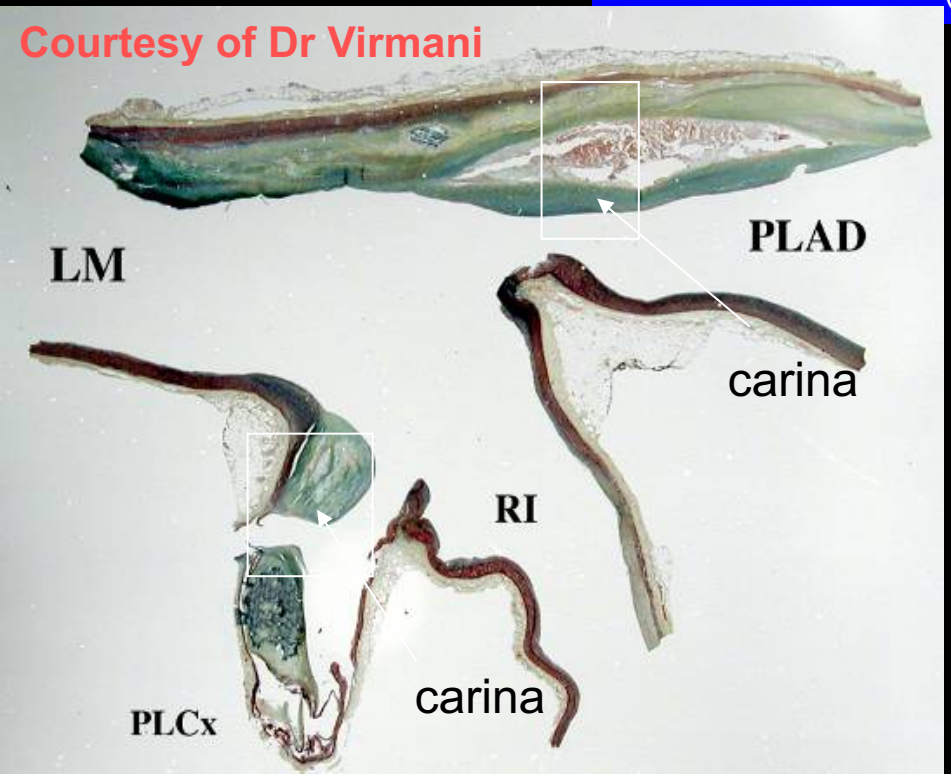
Coronary Bifurcations

Undisturbed laminar flow (vasculoprotective)

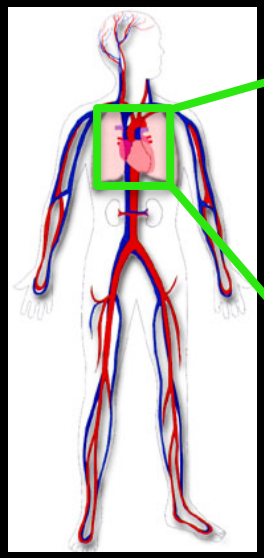
Low and oscillatory disturbed laminar flow (pro-inflammatory and atherogenic)

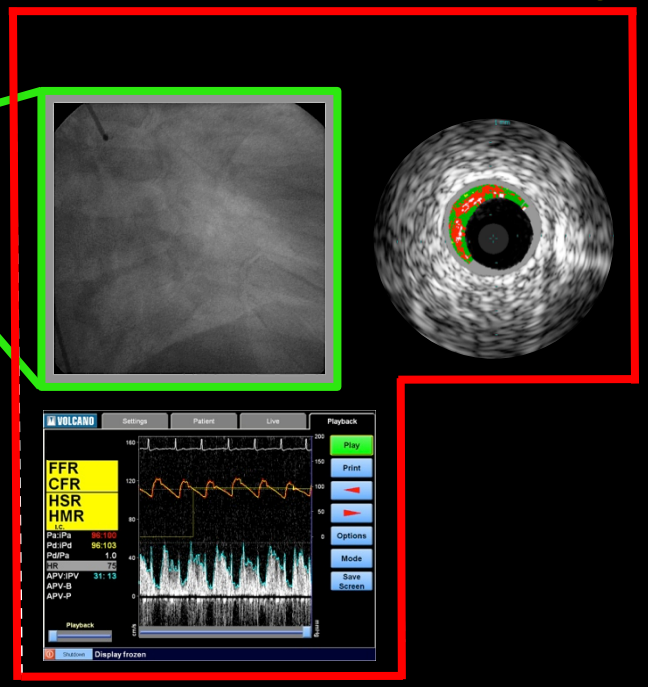


(Asakura and Karino. Circ Res 1990;66:1045)

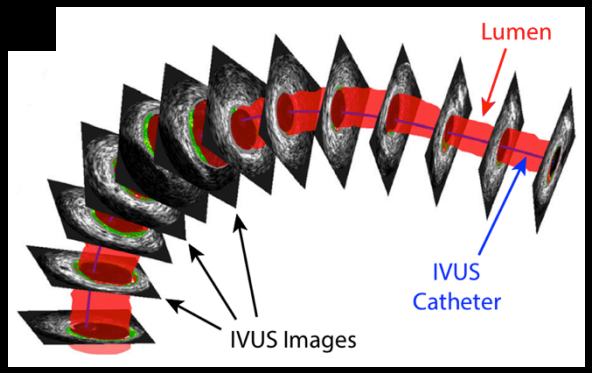


Overview of Computational Methods





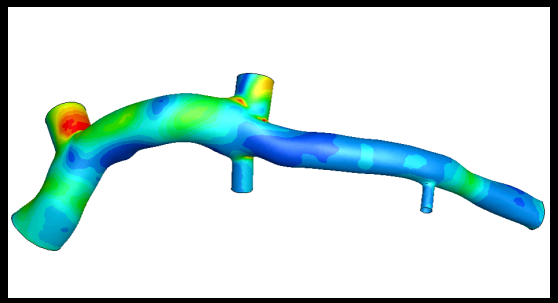
Geometry Reconstruction

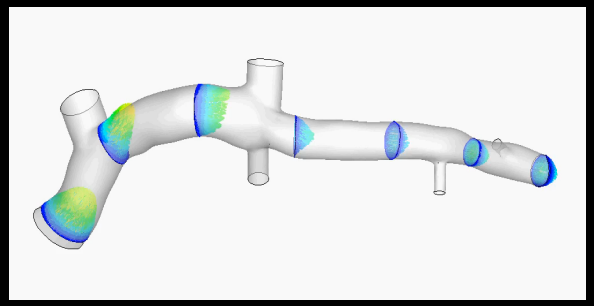


boundary conditions, numerical methods

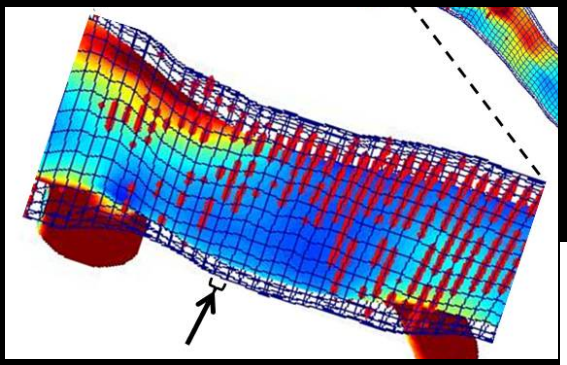
Verify calculations

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

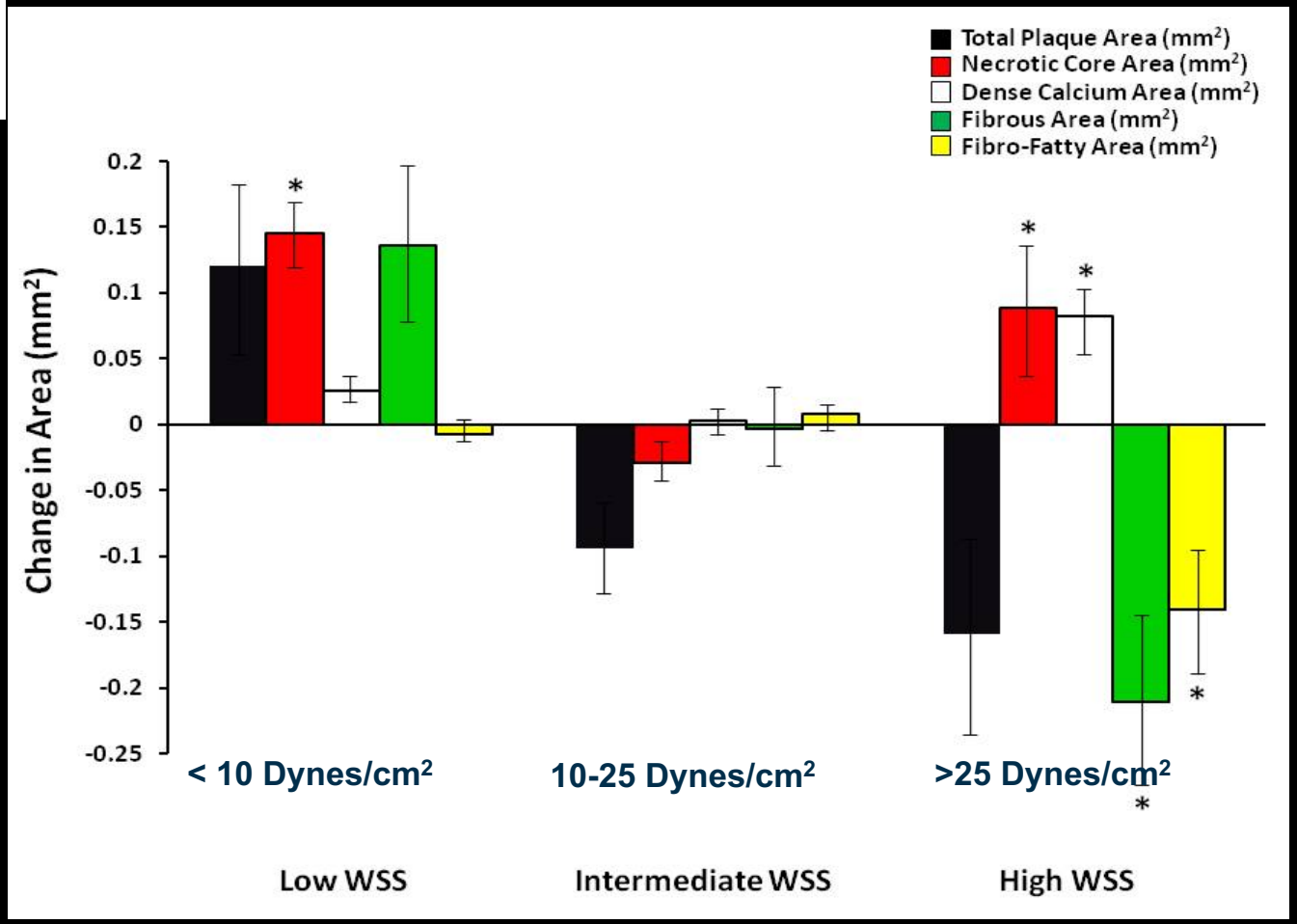




WSS and Plaque Progression

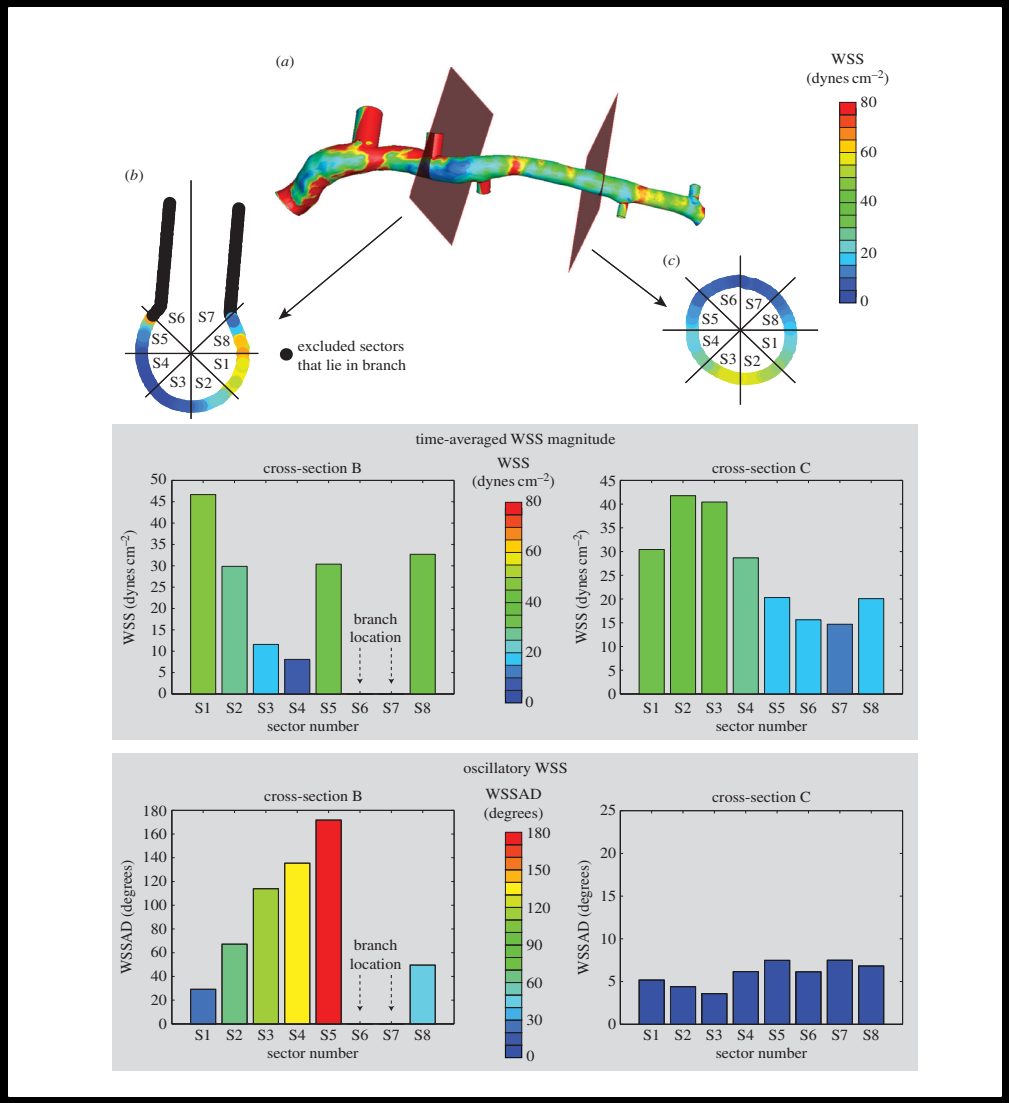


N=20 pts with NOCAD
6 months f/u
High Dose Statin Tx



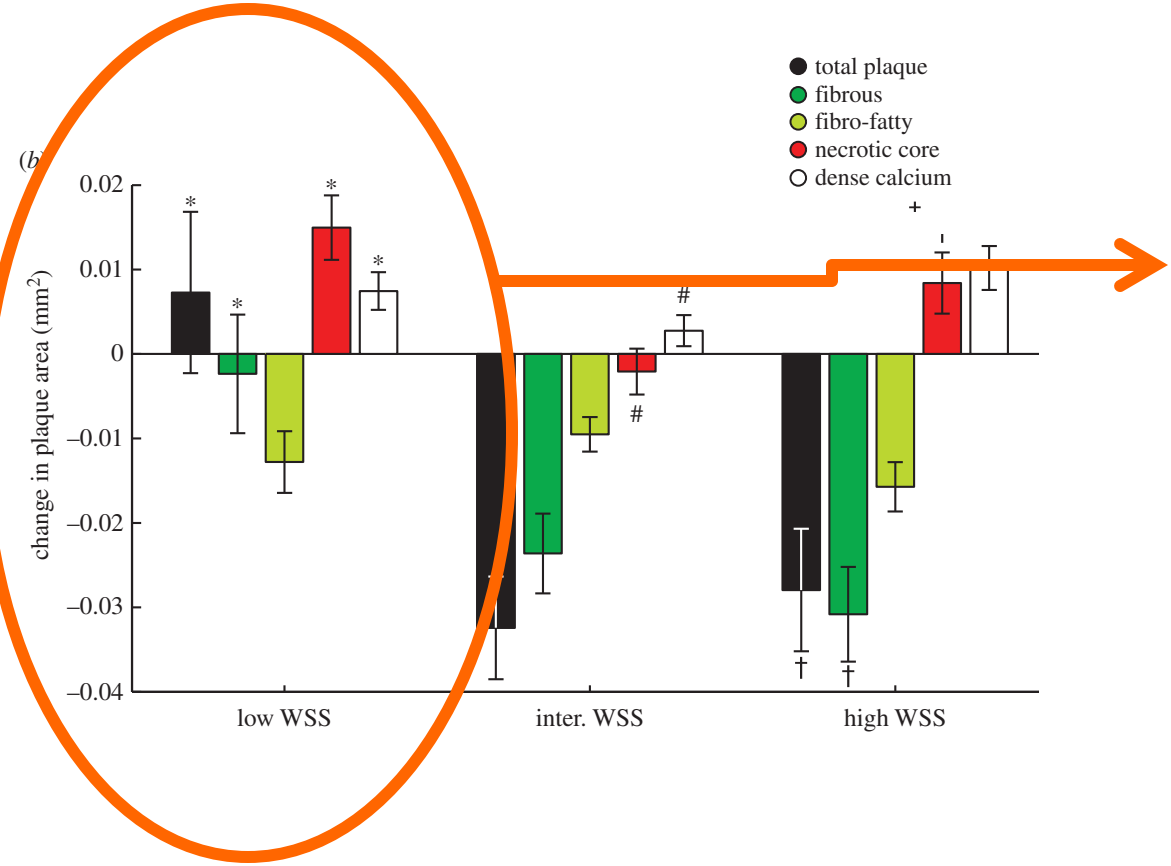
Samady et al. Circulation. 2011 Aug 16;124(7):779-88.

Low and Oscillatory WSS associated with Plaque vulnerability



Timmins et al. J. R. Soc. Interface 14: 20160972.

Low and Oscillatory WSS associated with Plaque vulnerability



Timmins et al. J. R. Soc. Interface 14: 20160972.

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

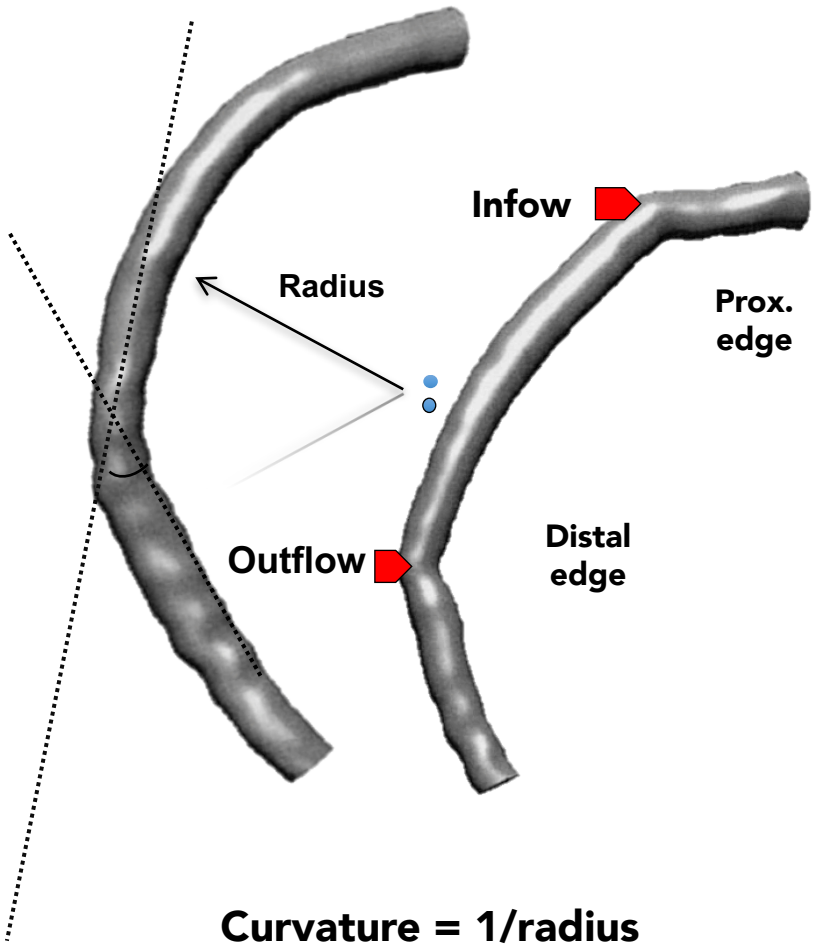
Post Implantation

- Vessel Level

Coronary stent implantation changes 3-D vessel geometry and 3-D shear stress distribution

Jolanda J. Wentzel[a,b], Deirdre M. Whelan[a,b], Willem J. van der Giessen[a], Heleen M.M. van Beusekom[a,b], Ivan Andhyiswara[a], Patrick W. Serruys[a], Cornelis J. Slager[a], Rob Krams[a,*]

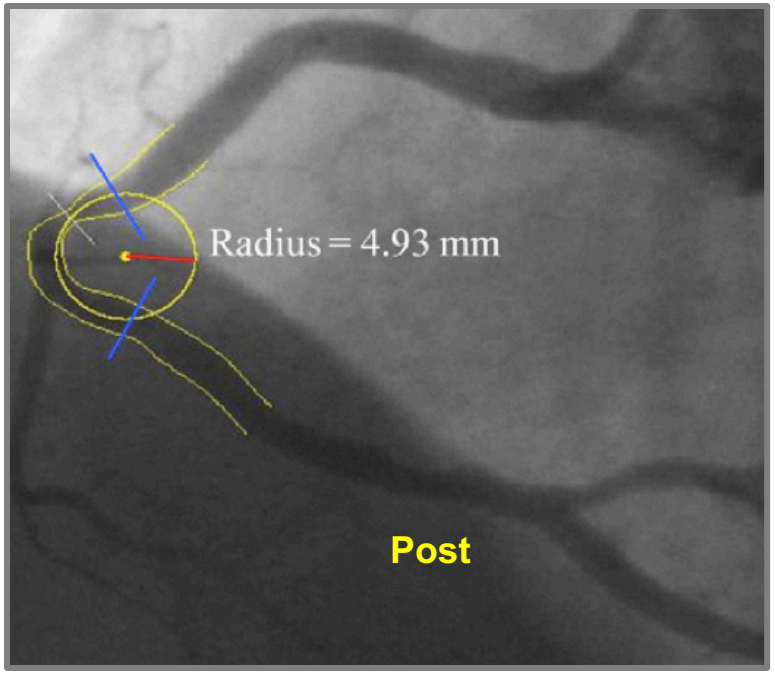
Stent implantation changed 3-D vessel geometry in healthy porcine coronary arteries following Wallstent deployment. Regions with decreased and increased WSS occur close to the stent edges

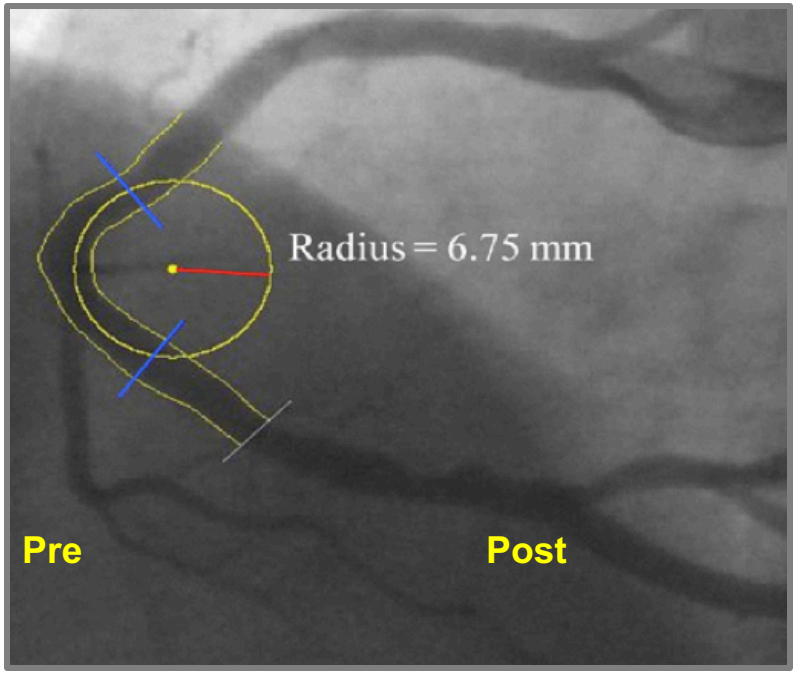


Curvature = 1/radius
Angulation= Tangents of centerlines

Wentzel JJ, Krams R et al., JBM 2000

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



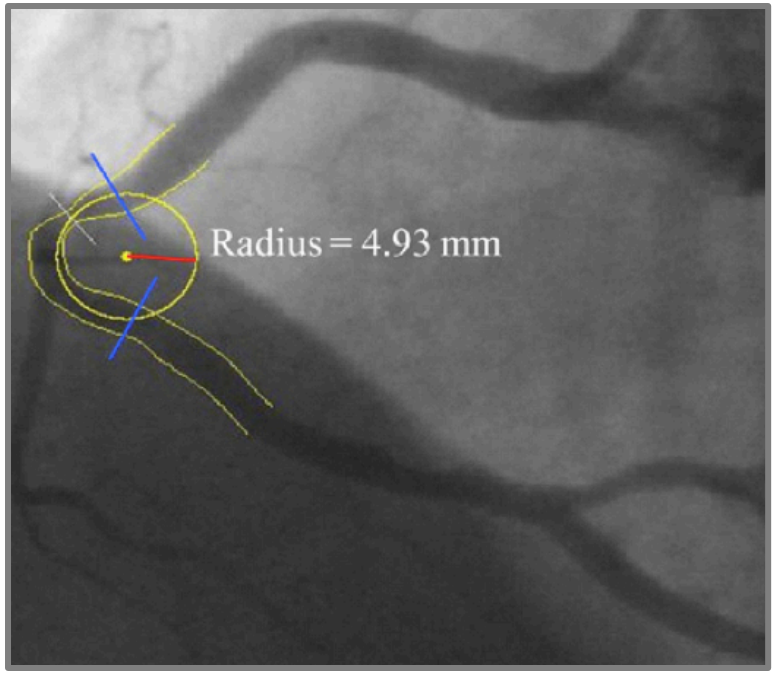


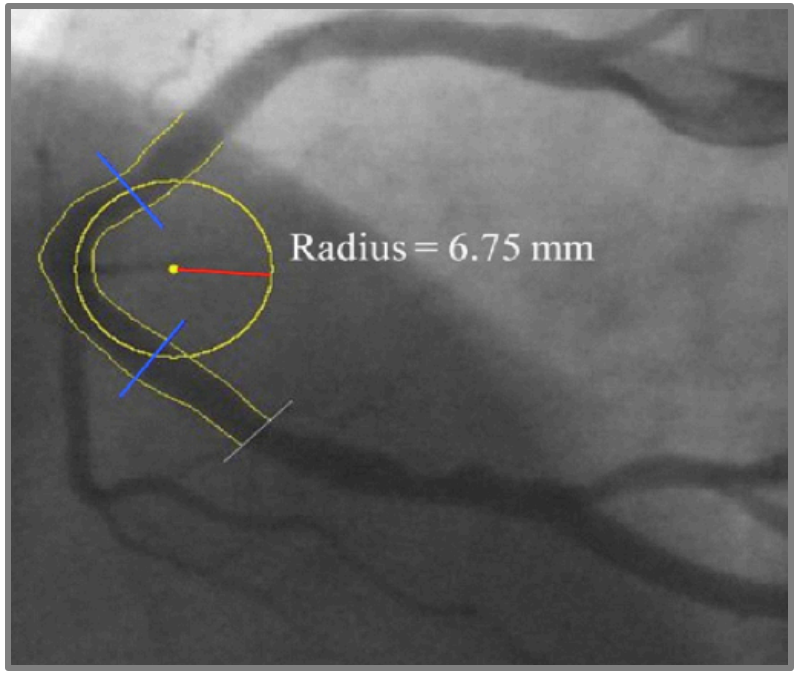
Variable	Device	Relative Changes Pre vs. Post (%)	p Value*
Curvature (cm^{-1})	BVS	7.5	<0.01
	MPS	28.7	<0.01
Angulation (°)	BVS	13.4	<0.01
	MPS	25.4	<0.01

Gomez-Lara, Serruys PW et al.

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

Pre





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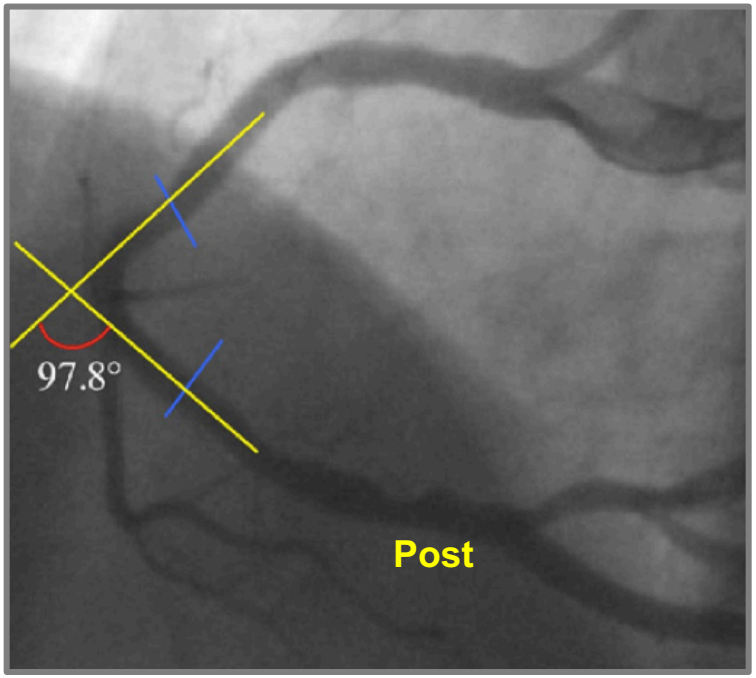

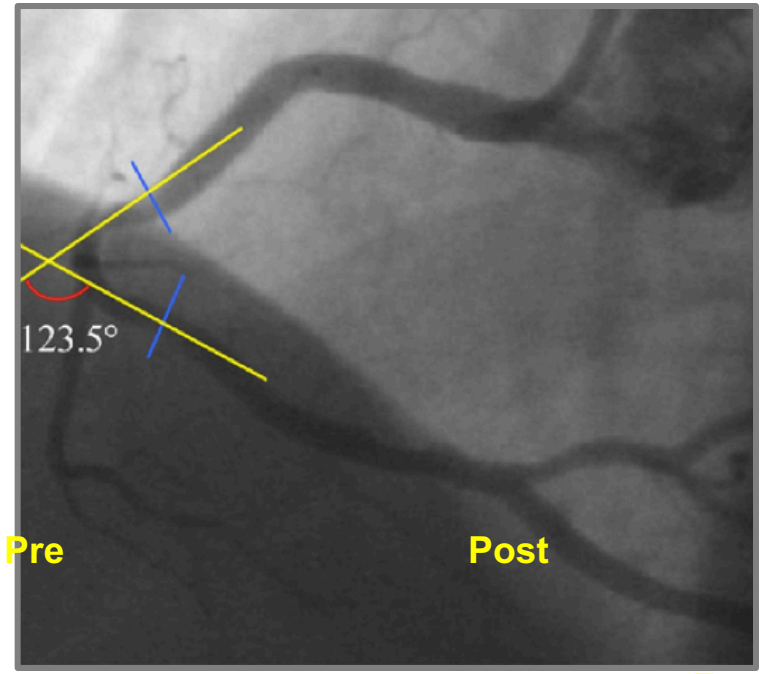

Post

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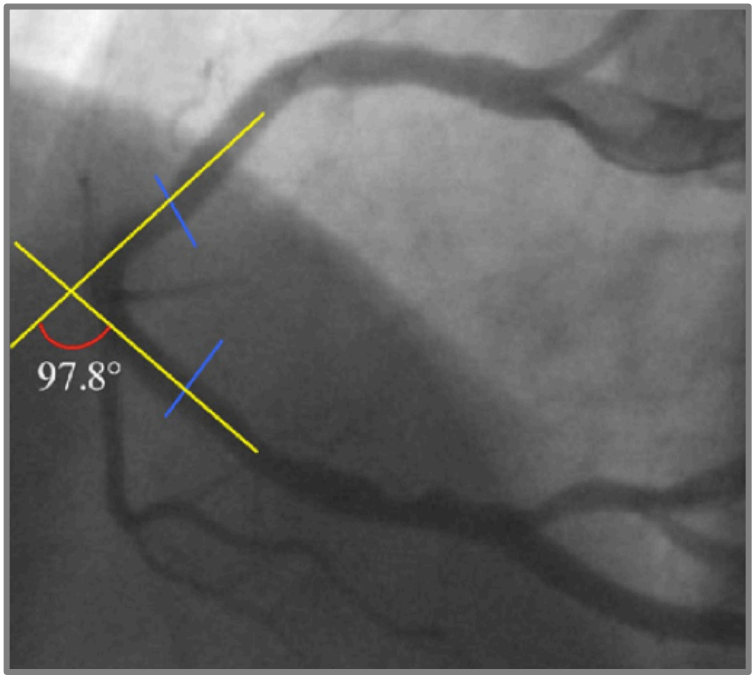
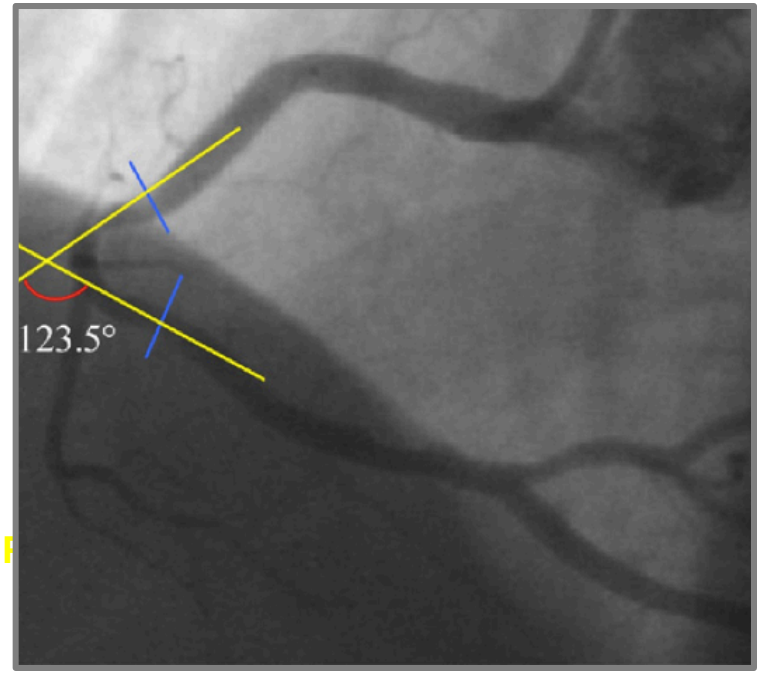
	MPS	28.7	<0.01
Angulation (°)	BVS	13.4	<0.01
	MPS	25.4	<0.01

Gomez-Lara, Serruys PW et al.

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

Pre





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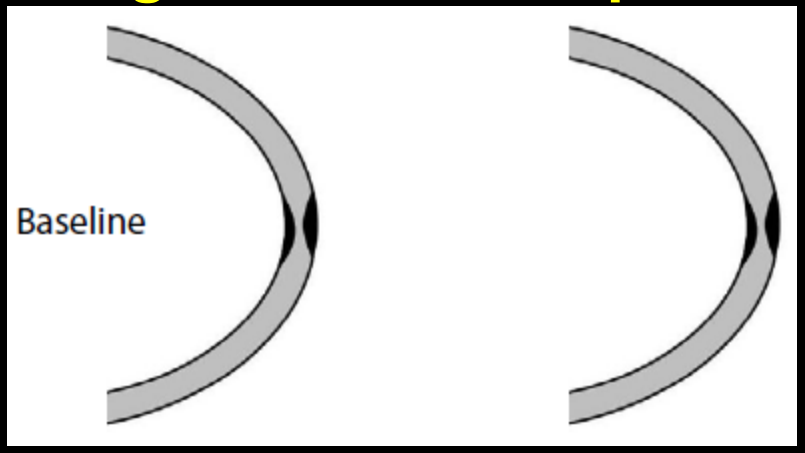
Gomez-Lara, Serruys PW et al.

Rigid Compliant

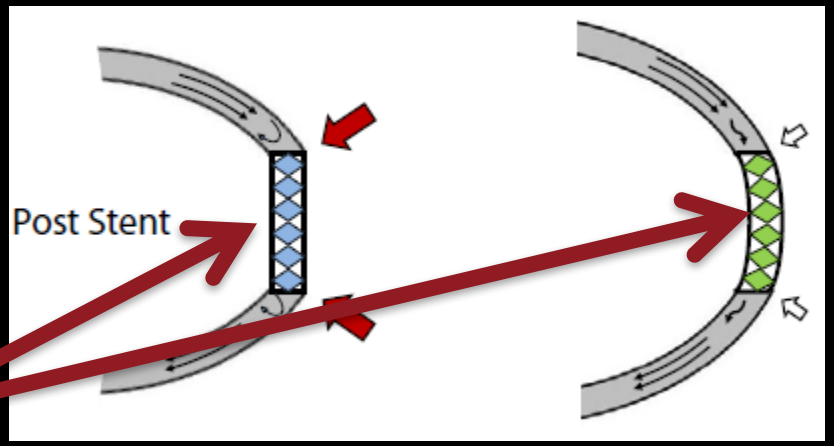


EDITORIAL COMMENT

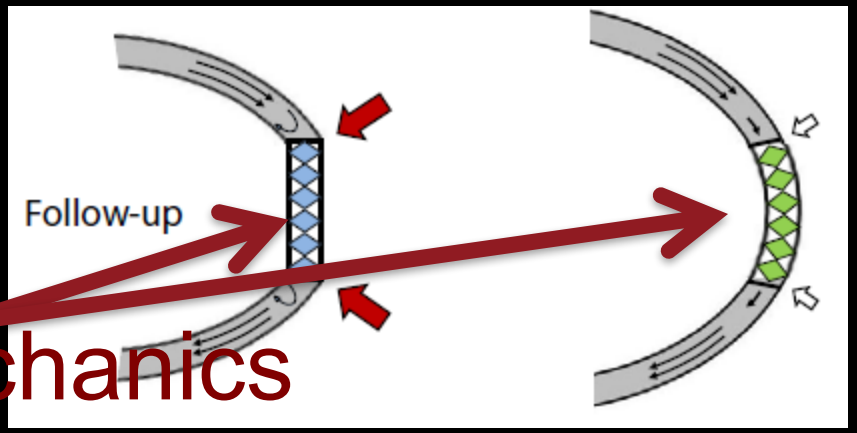
The Sheer Stress of Straightening the Curves

Biomechanics of Bioabsorbable Stents*

Michael C. McDaniel, MD, Habib Samady, MD



Fluid Dynamics



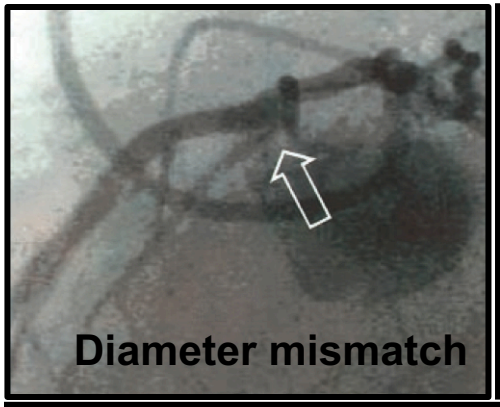
Solid Mechanics

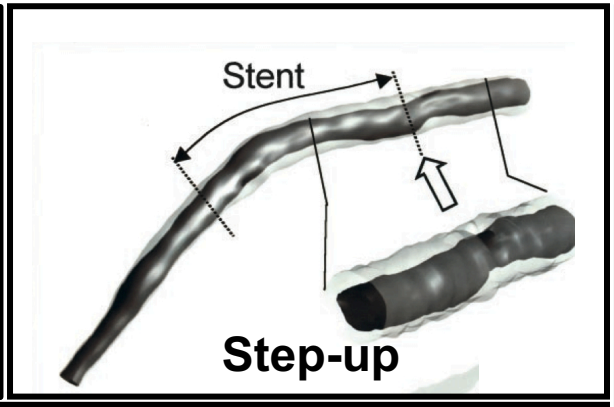
JACC CV Interventions 2011

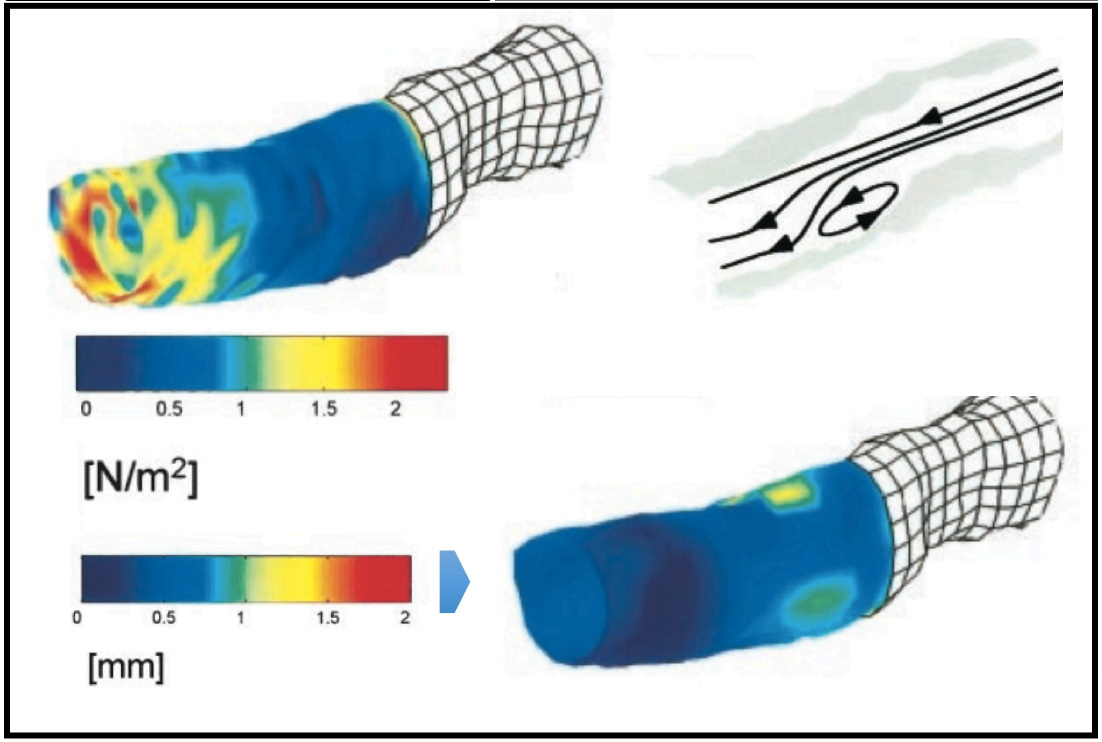
Focal In-Stent Restenosis Near Step-Up

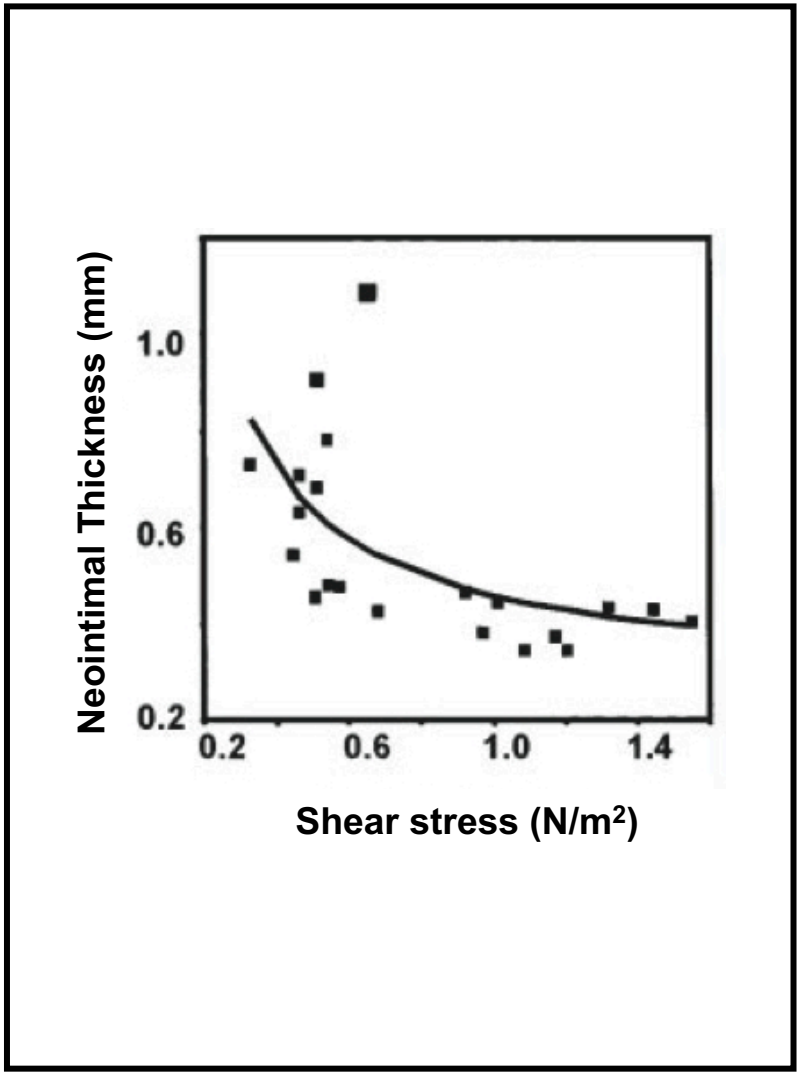
Roles of Low and Oscillating Shear Stress?

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





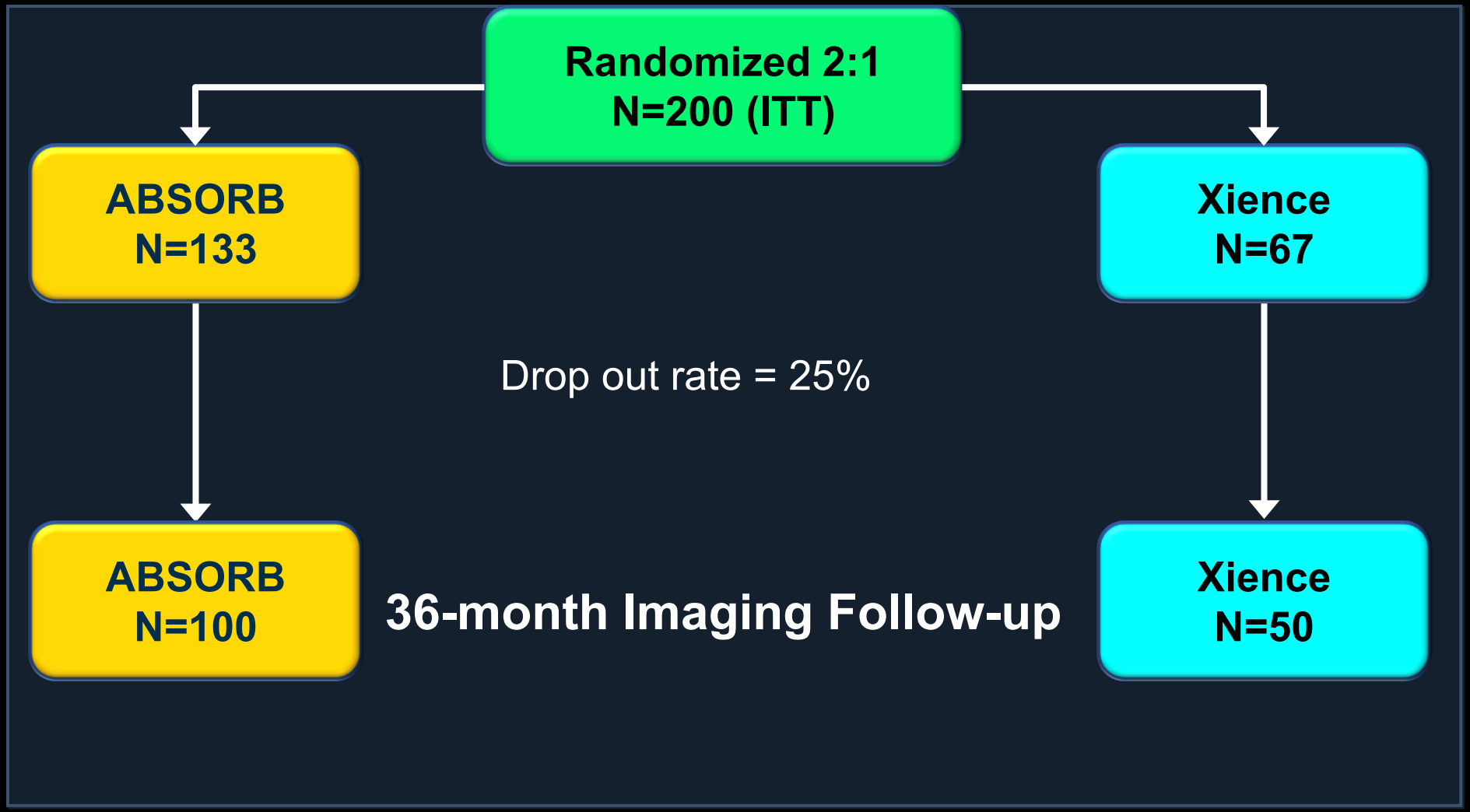




Circulation. 2002;105:e185-e187

Restoration Biomechanical Study

Emory Cardiovascular Biomechanical Core Laboratory (ECBC)



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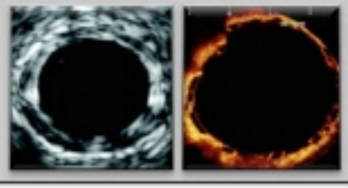
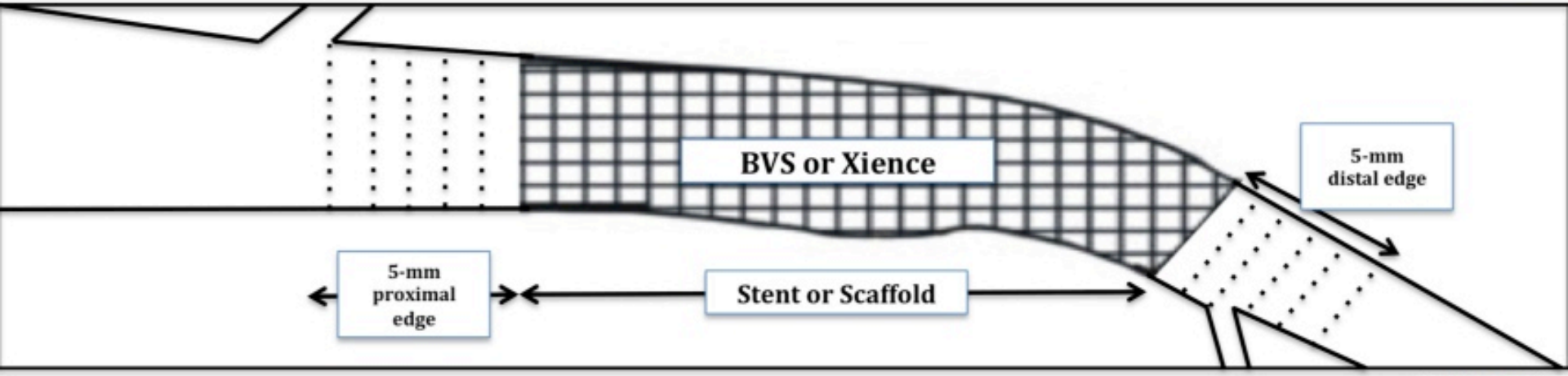
ABSORB III

Biomechanical Comparison of Xience vs BVS ABSORB III Imaging Sub-Study: RESTORATION Strut and Vessel Level IVUS Analysis

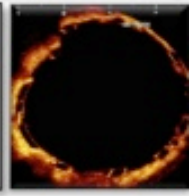
1. Comparison of **vascular straightening** between BVS and Xience assessed by 3-D reconstruction in:
   - 50 Angio/ OCT patients &
   - 130 Angio/ IVUS patients

   defined as change of angulation pre- to post-device implantation.



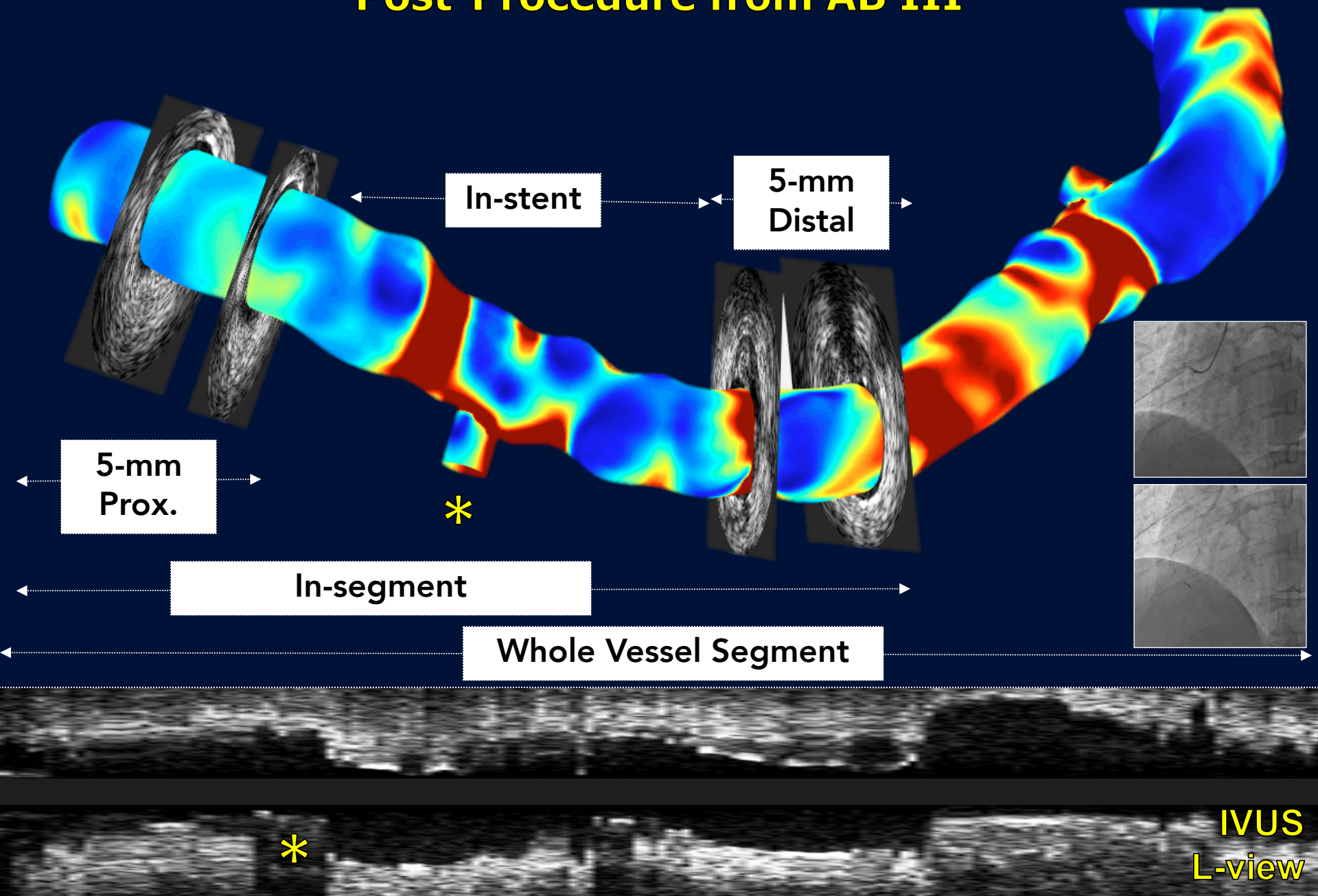


2. Comparison of **OCT derived area of micro low-WSS** (defined as area vessel with WSS< 10 dynes/ cm^2) between BVS and Xience within the index area divided by total area of vessel with the implanted device and 5-mm proximal and distal edges.



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



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

Post Implantation

- Vessel Level
- Strut Level

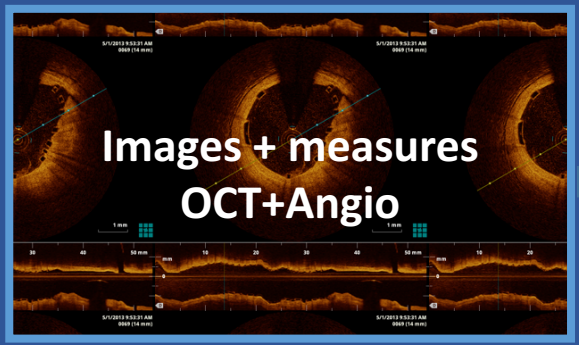
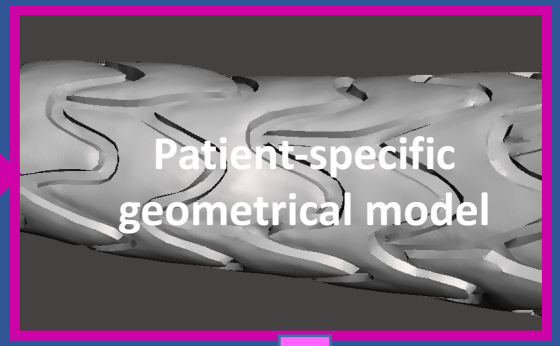


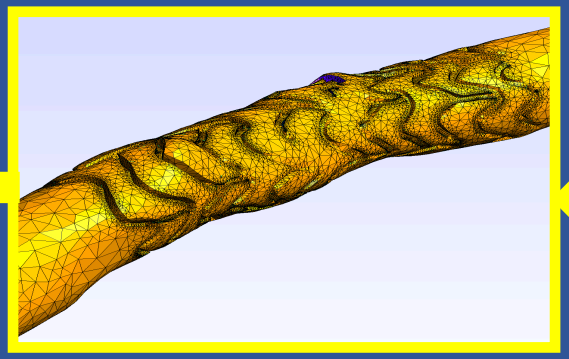
Image and Geometrical Processing

Strut detection, Interpolation,
Classification, Angiography Registration,
Volumetric Reconstruction,
Stented Lumen Computation



Meshing Computation

Smoothening, Error Fixing,
Boundary Layers

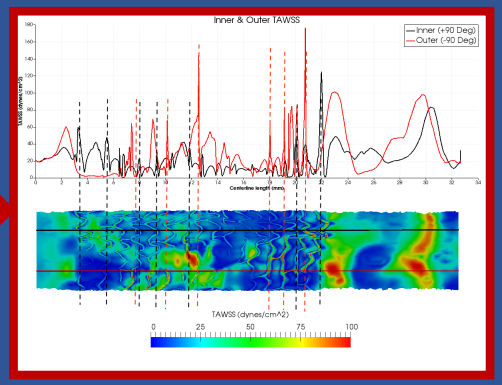


Computational Fluid Dynamics

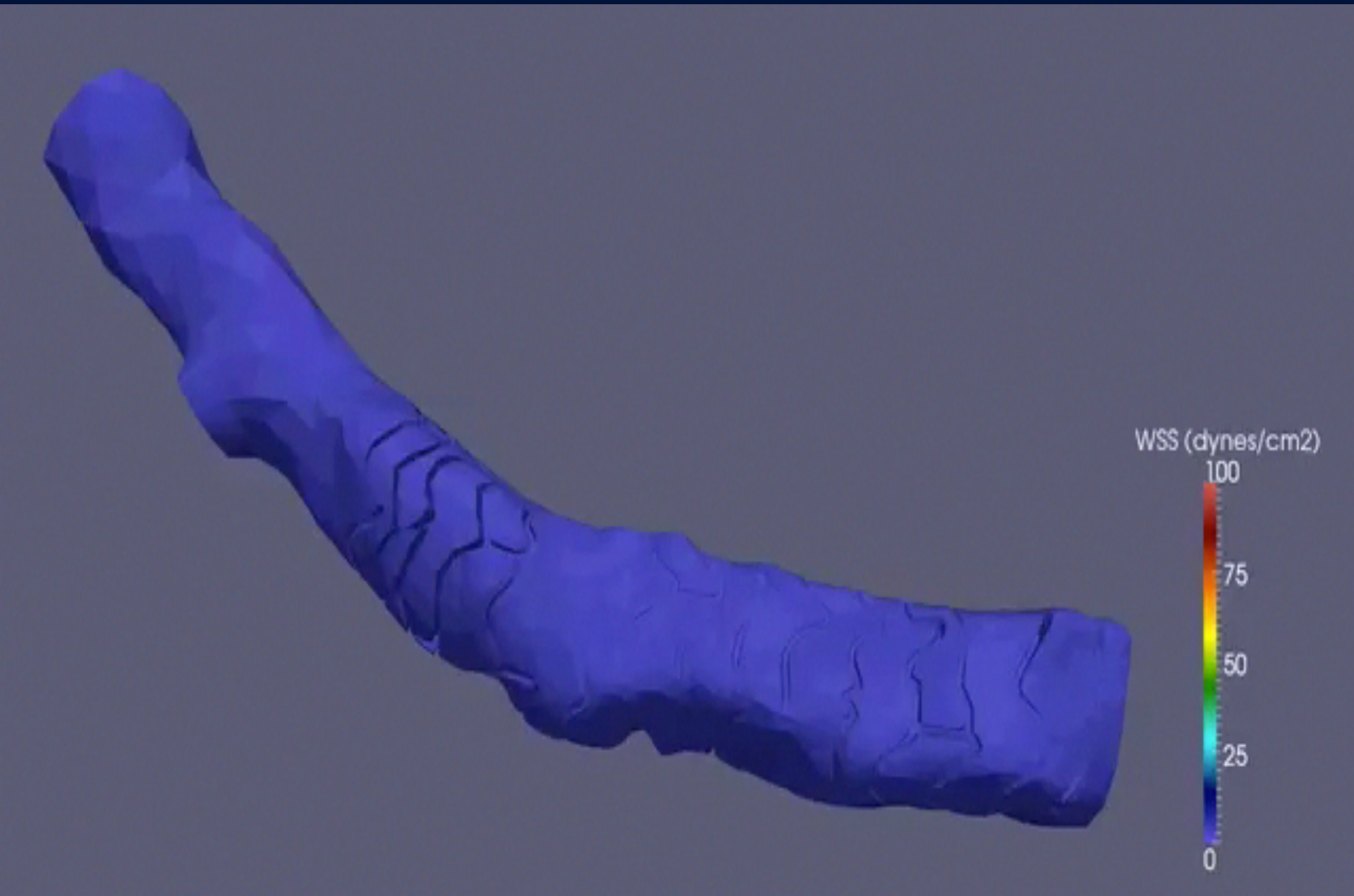
Finite Element Analysis on High
Performance Supercomputers

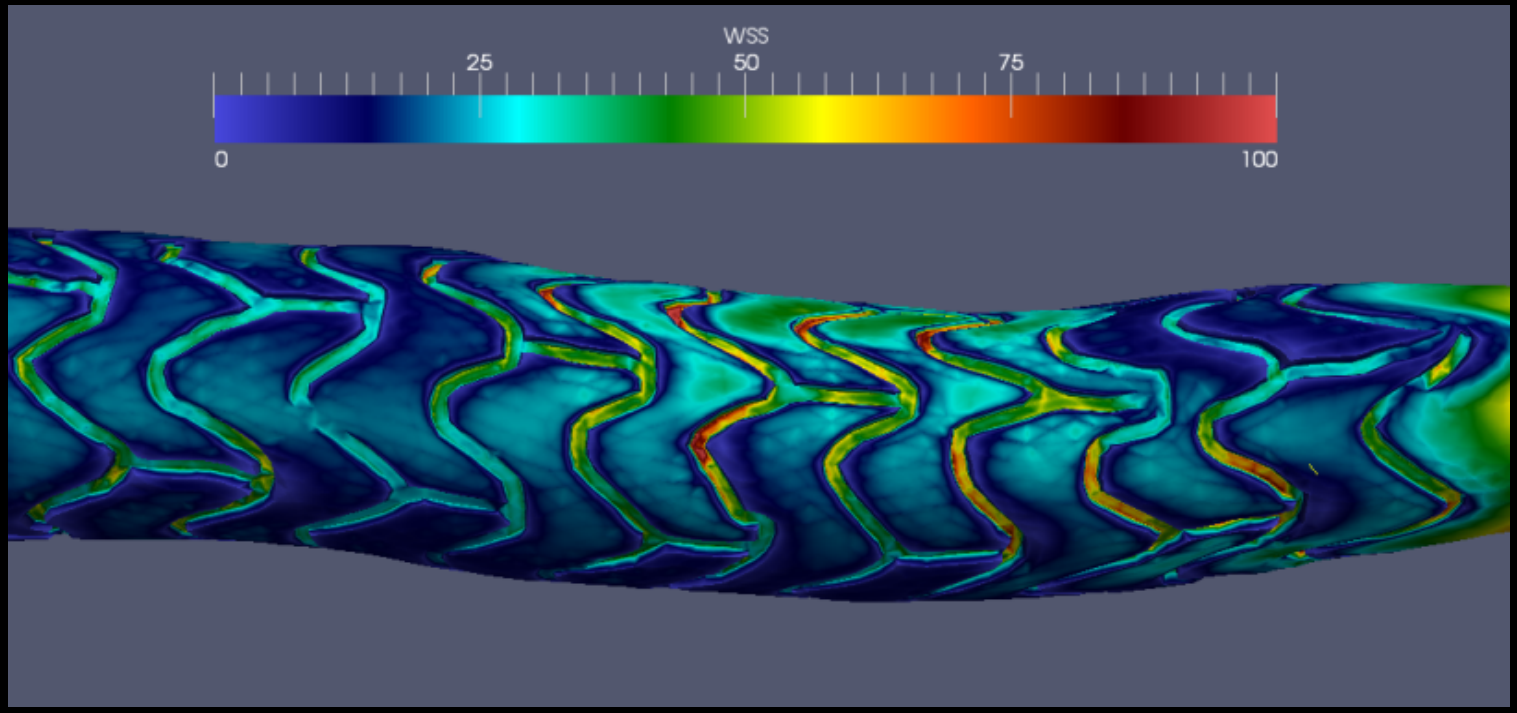
Postprocessing

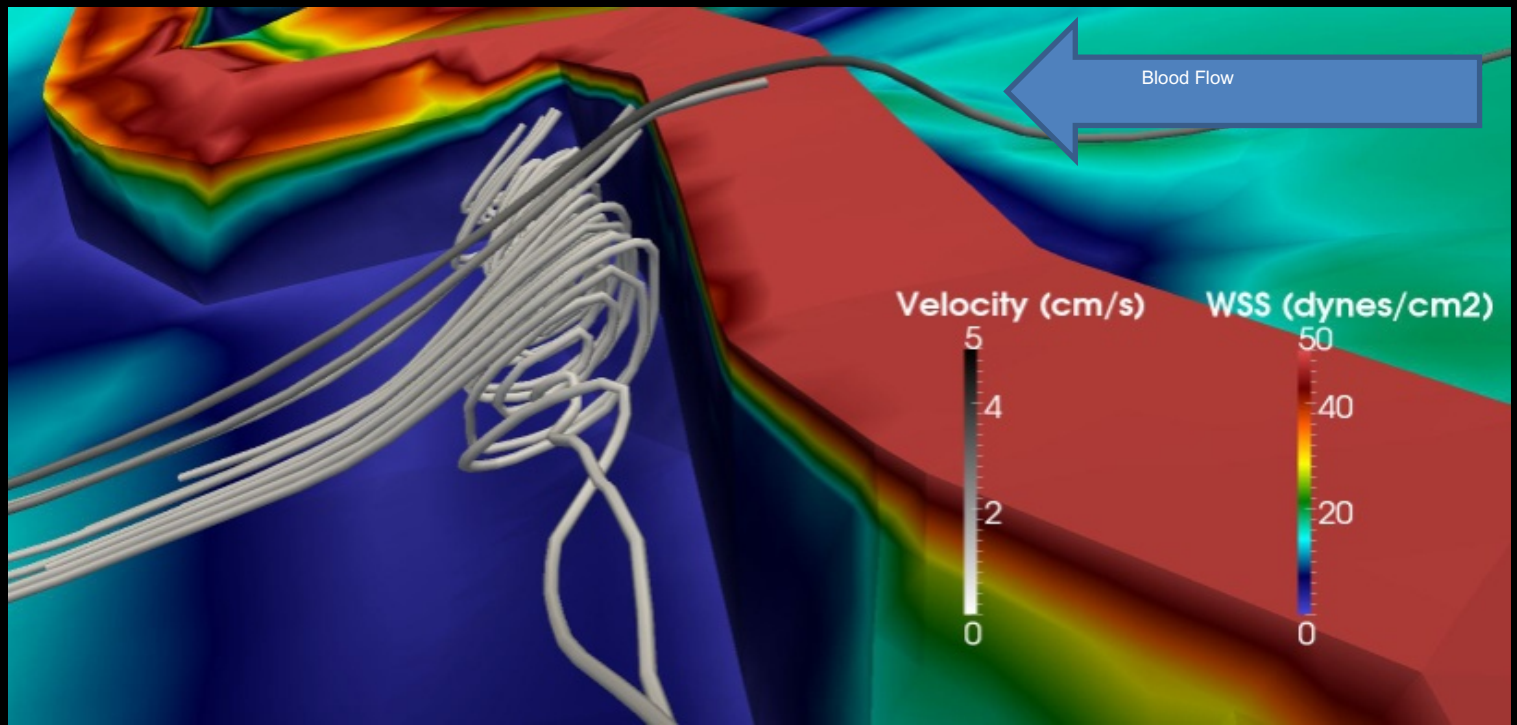
VIRTUAL IN SILICO HISTOLOGY



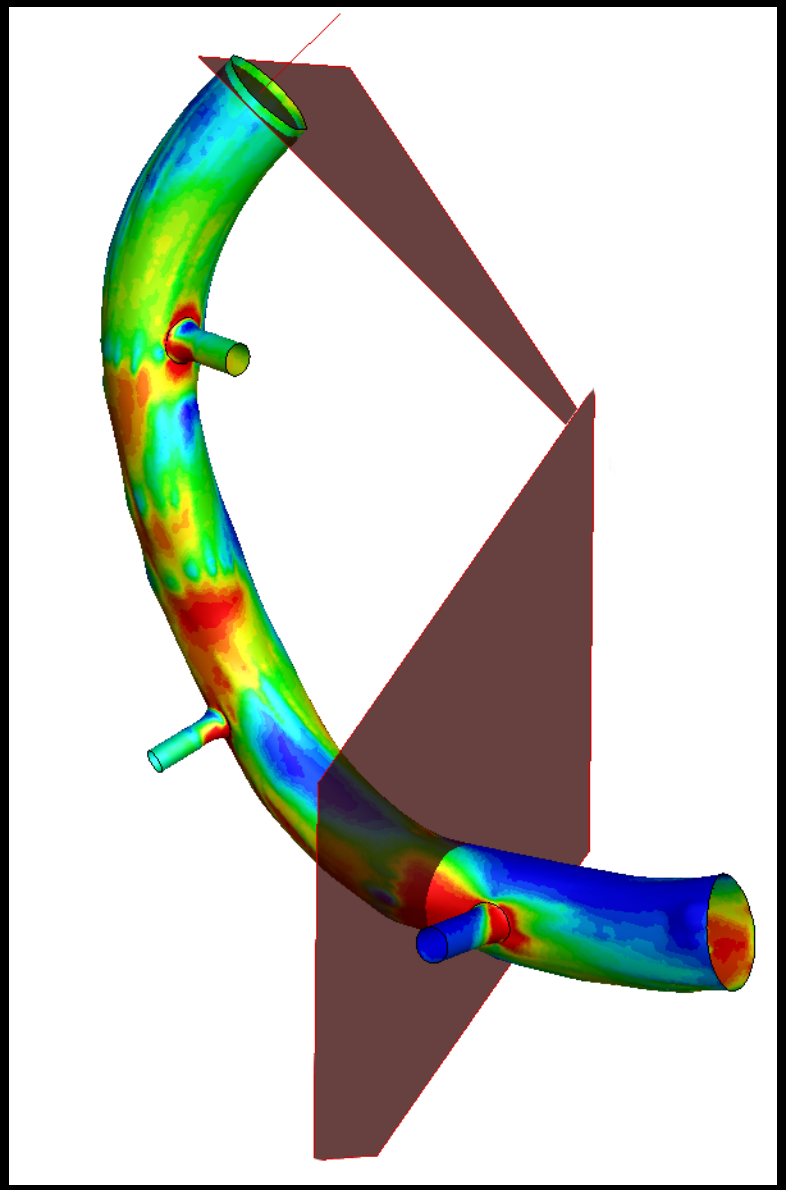
In vivo OCT-derived Computational Fluid Dynamics Post-Procedure from AB III

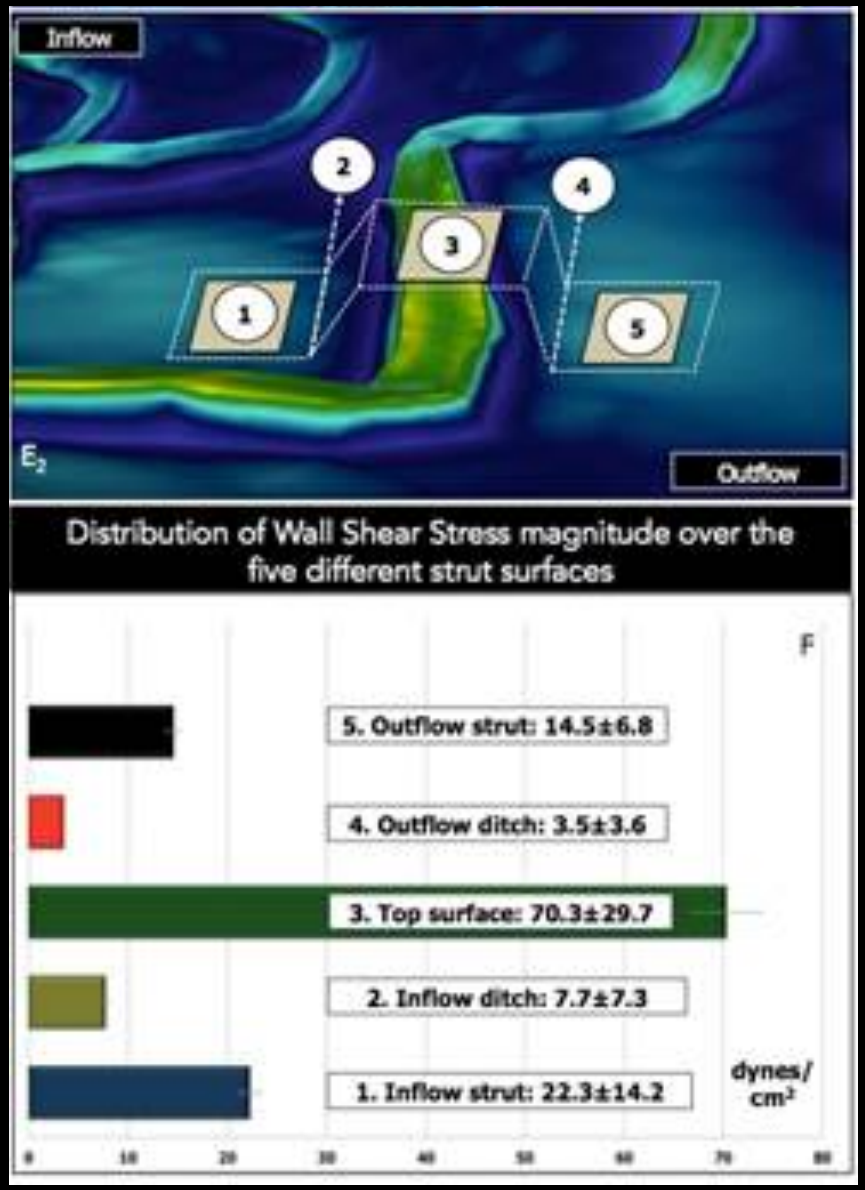



WSS
25
50
75
0
100


Blood Flow
Velocity (cm/s)
5
4
2
0
WSS (dynes/cm2)
50
40
20
0

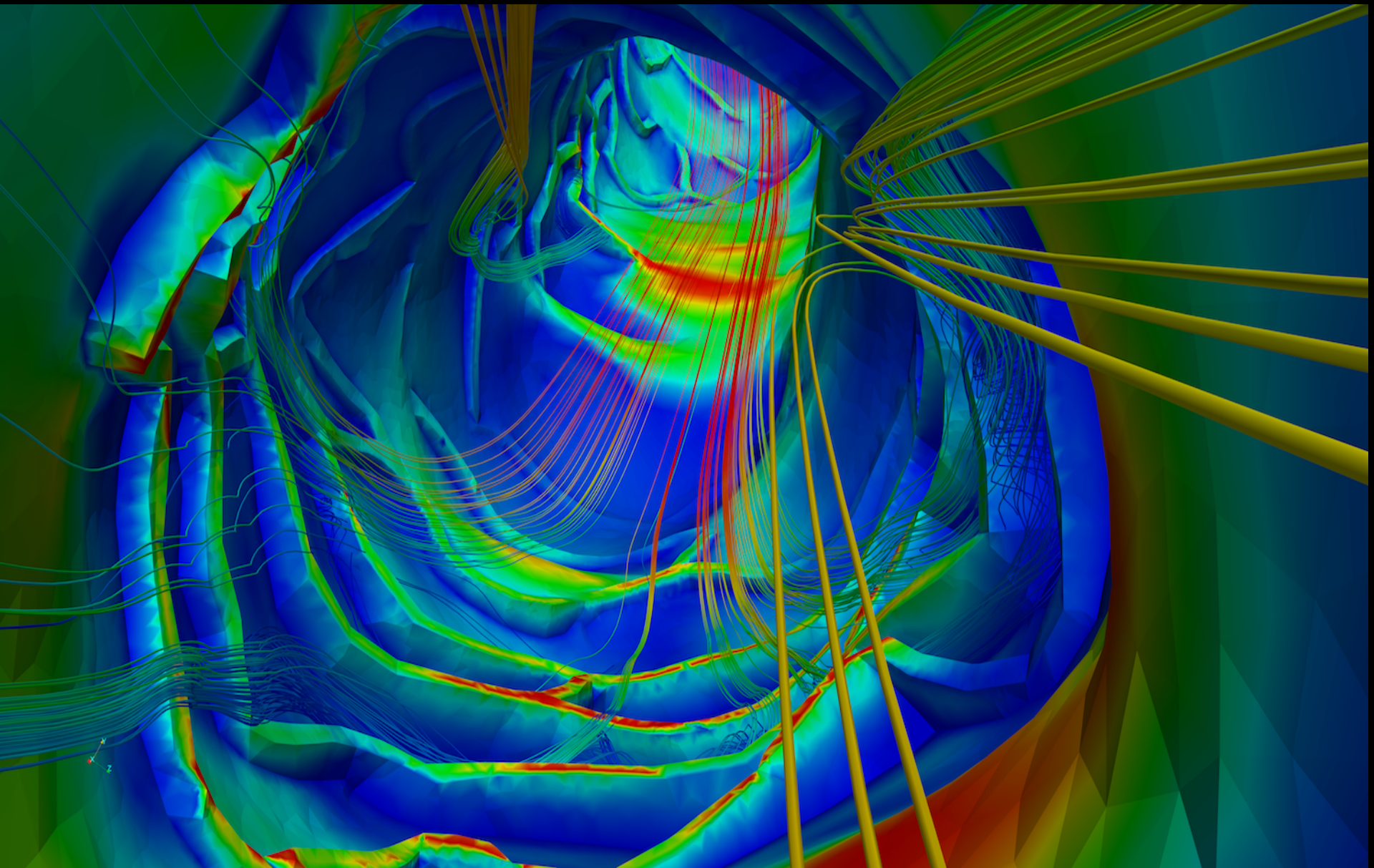
Vessel and Strut Level Wall Shear Stress



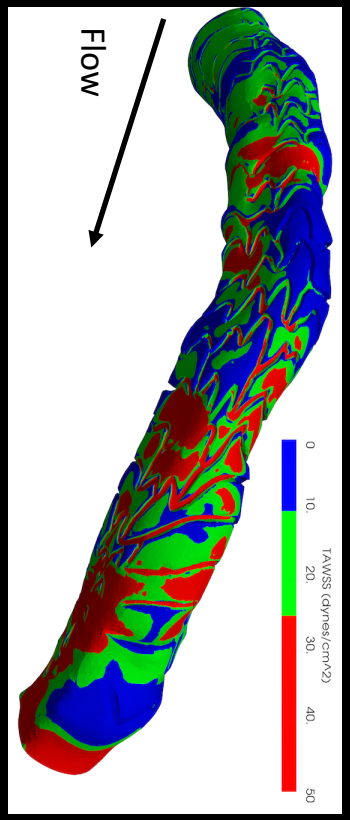


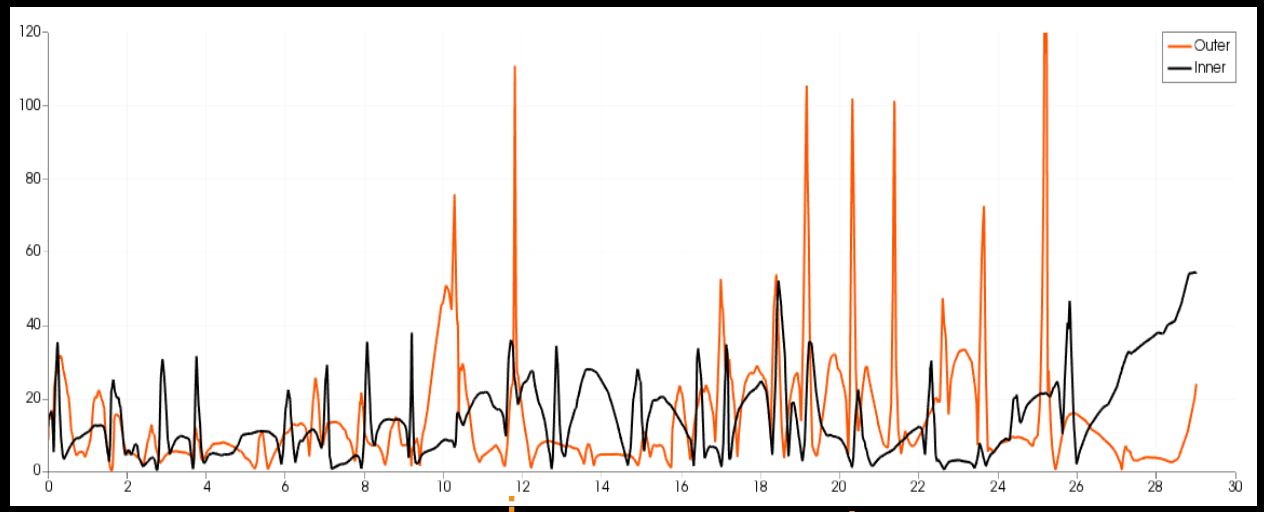
Gogas BD, Yang, B, Picinelli M, Giddens GP, Veneziani AV, Samady H. JACC CV Interventions 2016

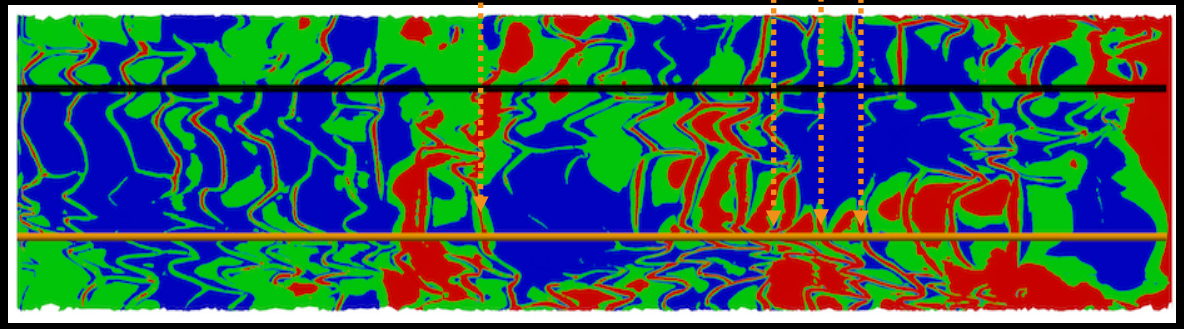
CFD with a Very Fine Mesh

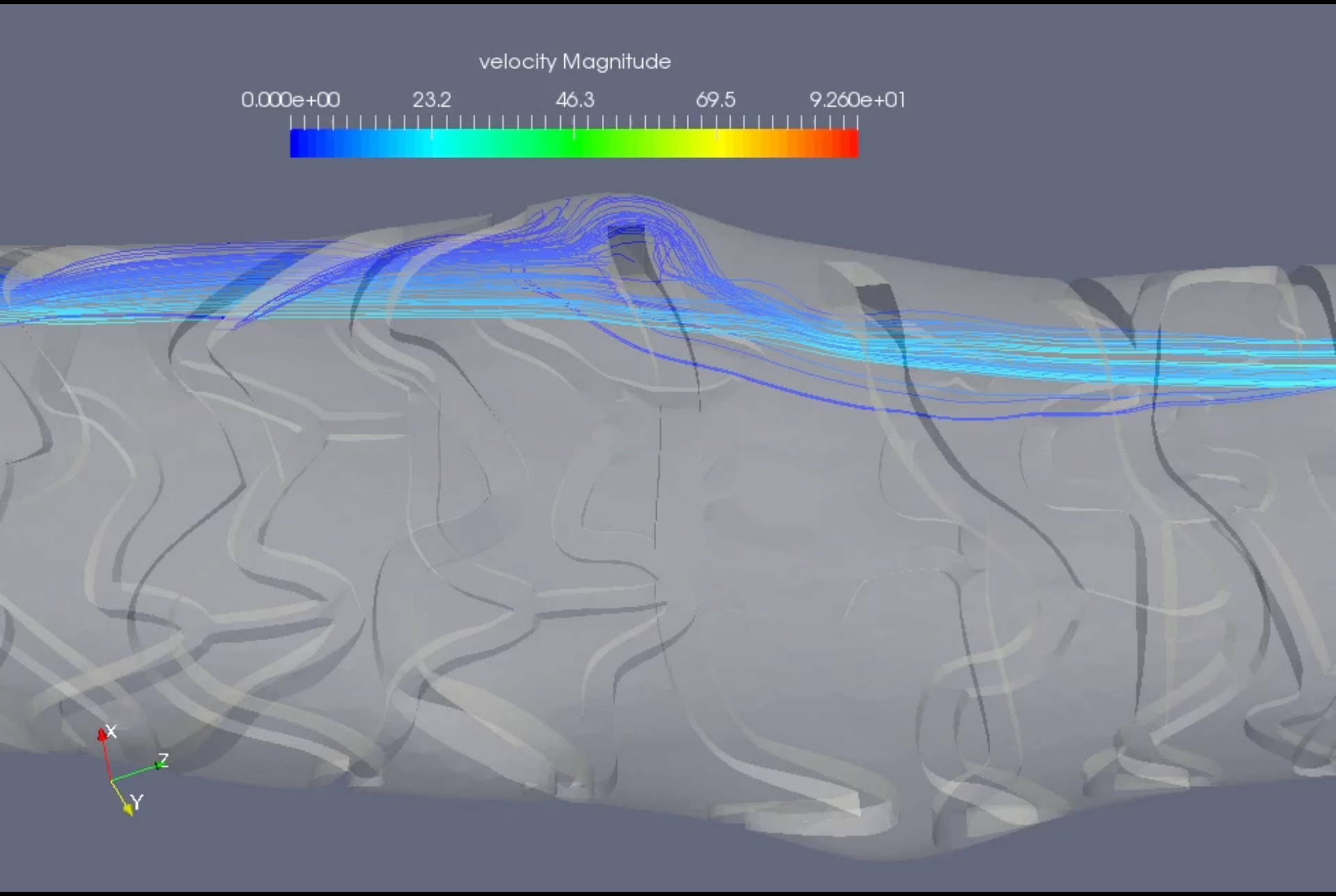


Impact of Vessel Curvature on WSS

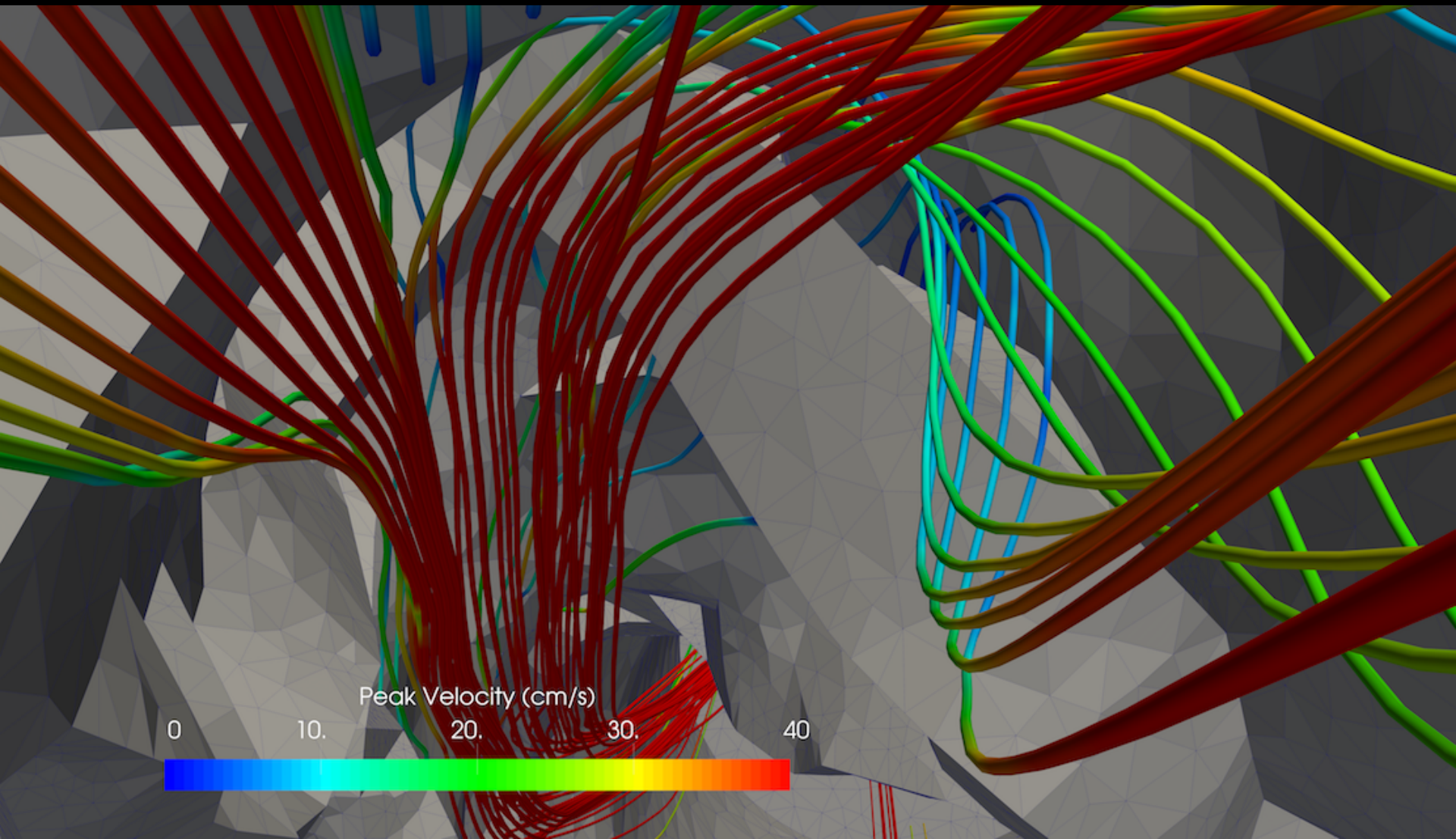







velocity Magnitude
0.000e+00
23.2
46.3
69.5
9.260e+01
X
Z
Y

Velocity Profiles Around Malapposed Struts



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

- Vessel Level
- Strut Level

Post Implantation

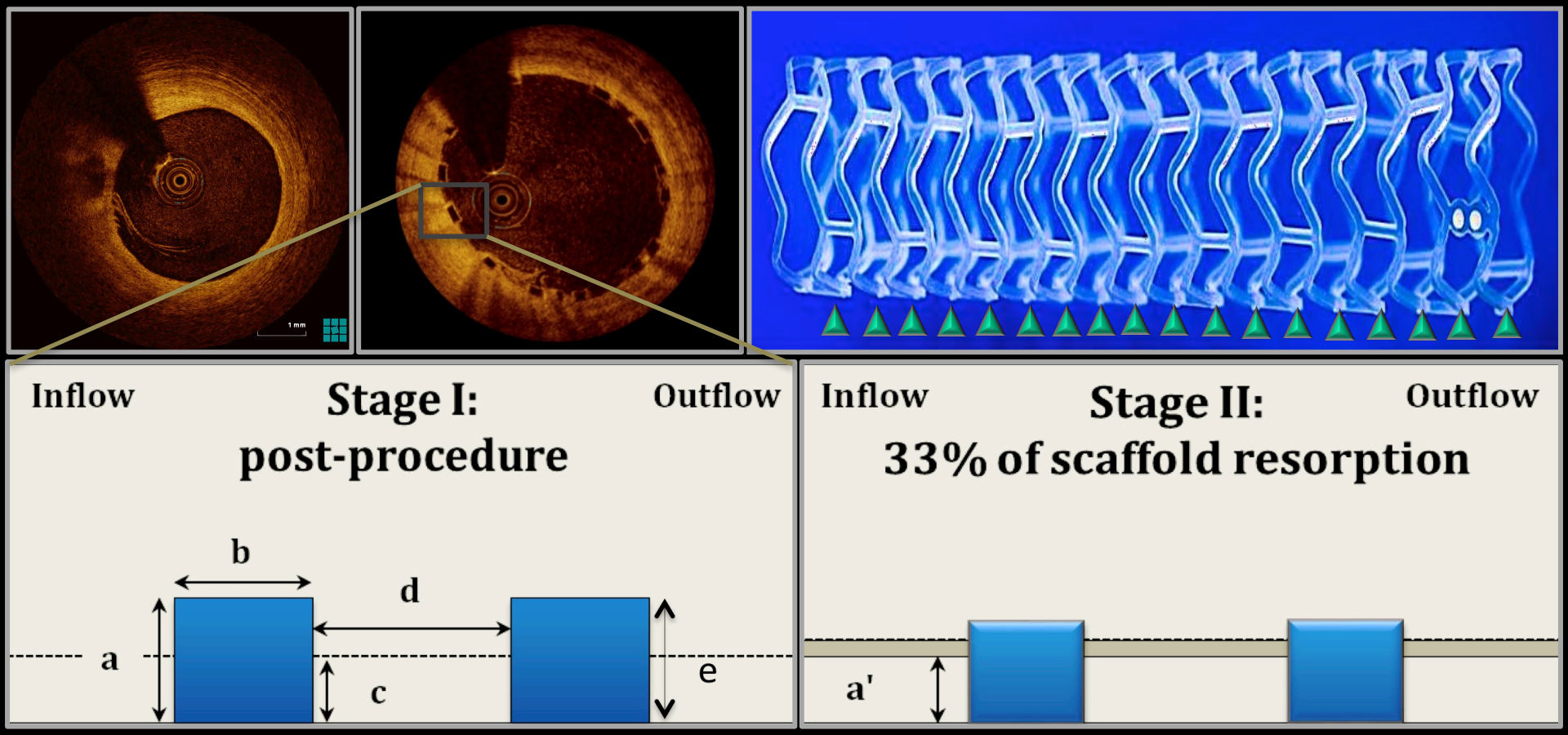
1 Year

2 Years

3 Years

Beyond

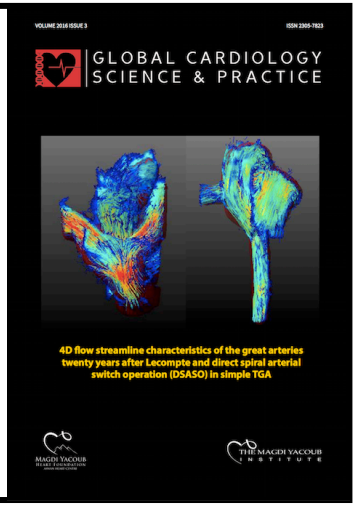
Scaffold Geometry Upon which Computational Fluid Dynamics were Applied



Gogas BD, Samady H et al.: Global Cardiology Science and Practice 2015

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



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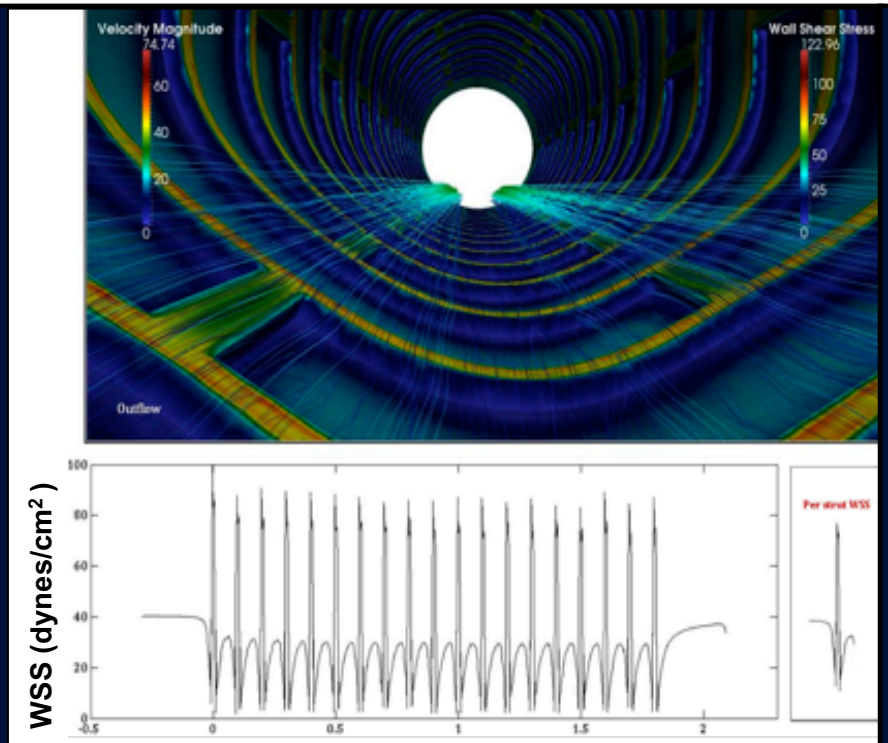
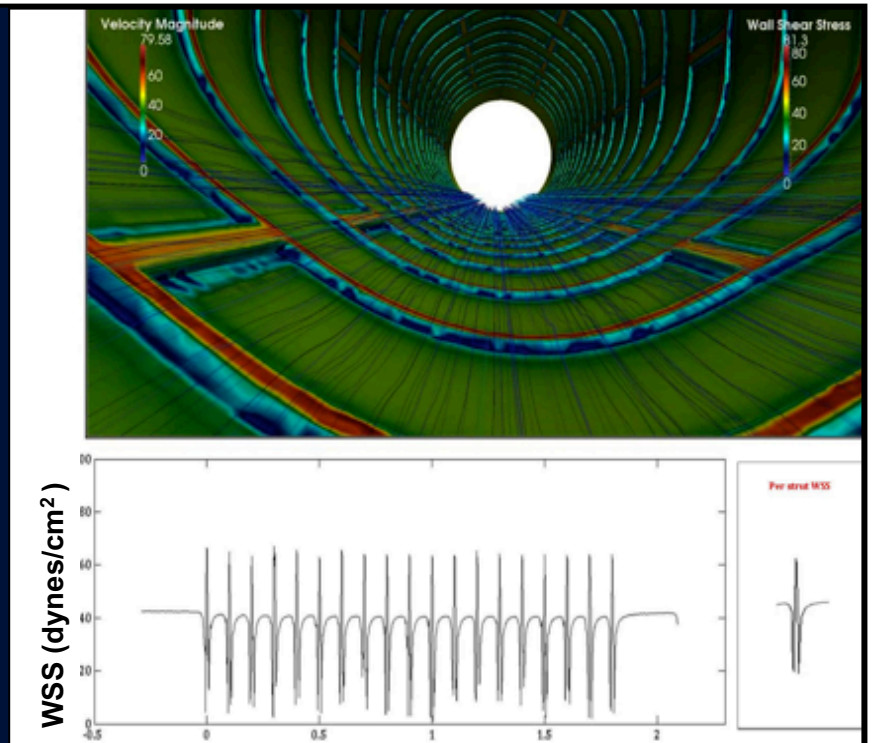
CFD simulations following virtual scaffold deployment were calculated at the inflow, endoluminal surface (top surface of the strut), and outflow of each strut surface post-procedure (stage I) and at a time point when 33% of scaffold resorption has occurred (stage II) [6-9-month]

Stage I: Post-procedure



Stage II: 33% Resorption



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

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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

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