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Graft related post-EVAR flow diversities

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Background

- Endovascular devices are designed by trial and error, involving animal testing and human clinical trials

- The performance of endografts can be evaluated adopting computational methods as routinely used by the aircraft and automobile industry

Background

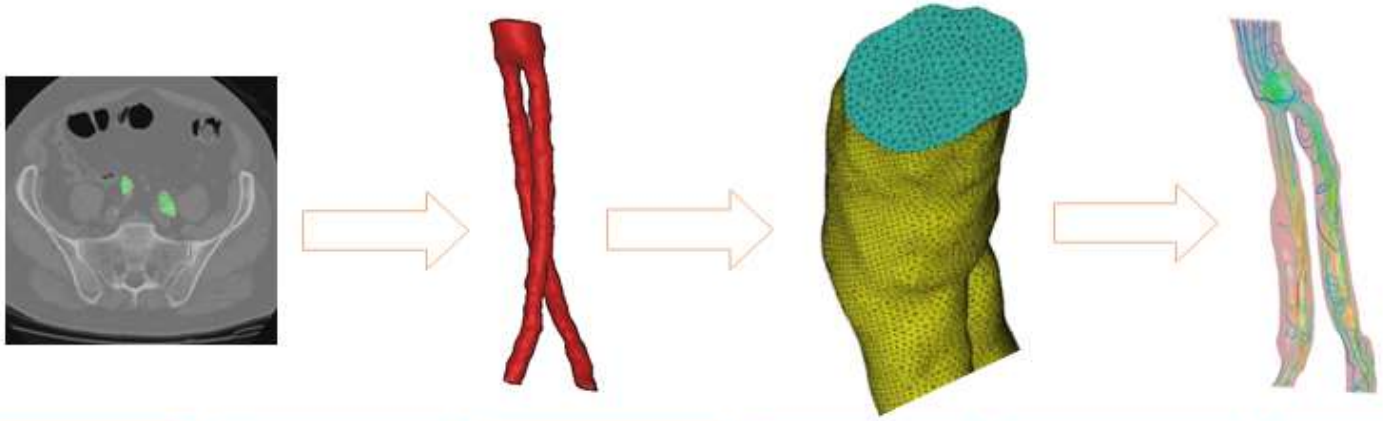
- Advances in medical imaging combined with computational modeling allow for the development of patient-specific 3D vascular models providing a viable framework
- Computational modeling has not been yet introduced in clinical routine (under research)

→ Validation
→ Larger clinical datasets
→ Better coordinated collaboration between engineers and clinicians

AIM

- Assess whether different aortic stent-graft configuration may lead to different hemodynamic properties
- The current study deals with the postoperative hemodynamic variability between 4 stent-graft systems with different structure, material and type of fixation

Workflow



32 patients: • 8 AFX • 8 Endurant • 8 Excluder • 8 Nellix	Image reconstruction	Grid Generation	CFD	Post Processing	Statistics
• 3Mensio • MATLAB	• Mimics • VMTK	ANSYS ICEM	ANSYS FLUENT	ANSYS CFD post	MATLAB

Endografts

	Graft	Stents	Fixation
AFX	Strata™ graft technology	Cobalt chromium	Suprarenal / aortic bifurcation
Endurant	Polyester fabric	Nitinol	Proximal anchoring pins
Excluder	ePTFE and fluorinated ethylene polypropylene	Nitinol	Proximal nitinol barbs
Nellix	PTFE	Cobalt chromium	Endobags filled with polyethylene glycol




Patients selections

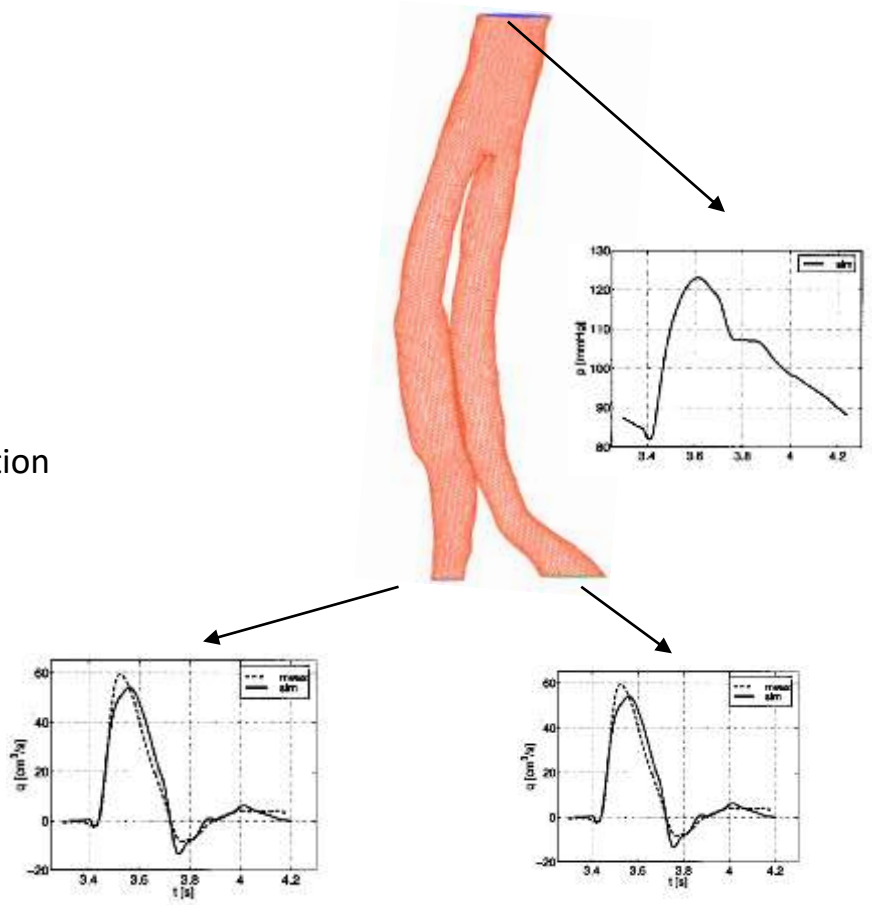
Patient	Main body diameter (mm)	Right limb diameter (mm)	Left limb diameter (mm)
EN1	25	16	16
EN2	25	16	16
EN3	28	16	16
EN4	25	20	16
EN5	28	20	16
EN6	32	20	20
EN7	25	20	20
EN8	25	20	16
EX1	23	16	16
EX2	28	16	16
EX3	23	14	14
EX4	28	14	14
EX5	28	14	16
EX6	23	20	16
EX7	23	16	16
EX8	26	14	16
AFX1	25	16	16
AFX2	28	16	16
AFX3	28	16	16
AFX4	28	16	20
AFX5	28	16	16
AFX6	25	16	16
AFX7	25	16	16
AFX8	28	16	16

Anatomical characteristics

	AFX	Endurant	Excluder	Nellix	*p*-value
Neck length (mm)	27.6±9.6	20.0±6.0	26.6±8.2	27.8±11.7	0.2
Neck diameter (mm)	23.2±1.9	24.8±3.1	22.6±2.1	23.3±2.6	0.3
Infrarenal angle (degrees)	29.3±12.5	21.4±9.0	20.5±13.6	25.7±16.7	0.5
Suprarenal angle (degrees)	20.4±13.6	19.5±10.0	16.9±8.4	26.0±13.8	0.4
Aorta length (mm)	112.7±16.6	105.9±16.1	117.3±9.3	115.6±16.5	0.4
Right iliac length (mm)	58.6±9.6	65.9±8.4	67.7±16.9	65.6±11.5	0.4
Right iliac diameter (mm)	13.3±1.7	15.5±2.0	13.7±2.0	13.8±2.2	0.1
Neck to right iliac diameter	1.8±0.3	1.6±0.3	1.7±0.2	1.7±0.3	0.7
Left iliac length (mm)	62.6±7.3	70.2±9.0	70.7±14.7	62.2±18.1	0.3
Left iliac diameter (mm)	14.1±2.0	14.4±2.2	14±2.7	13.2±2.6	0.8
Neck to left iliac diameter	1.7±0.3	1.7±0.2	1.6±0.2	1.8±0.4	0.6

Mesh and boundary conditions

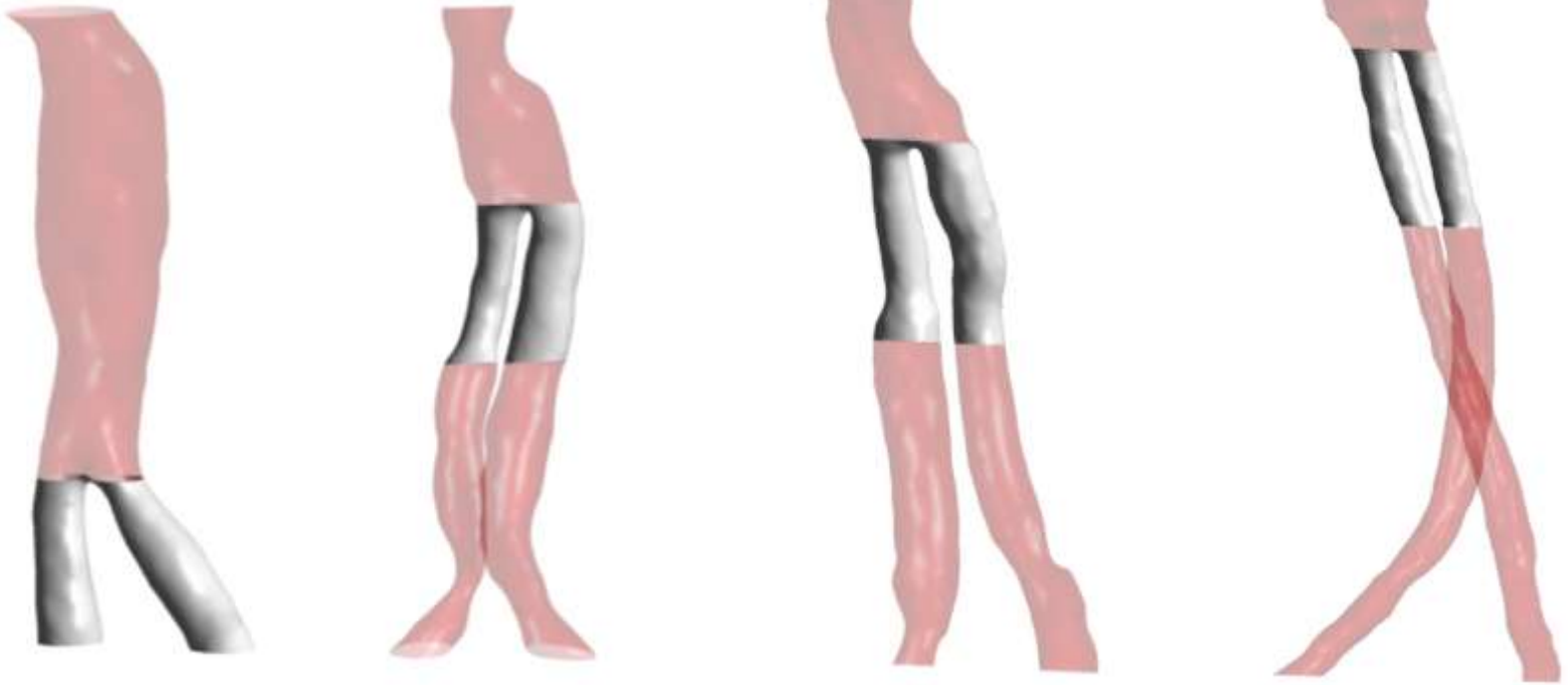
- 500.000 to 1.300.00 tetrahedral elements
- No patient-based boundary conditions (limitation)
- Physiologic pulse pressure at the inlet
- No-slip boundary condition at the surface. Rigid wall assumption
- Time-dependent velocity waveforms at the outlets
- Simulations performed in a powerful Dell™ Precision™ T7500 workstation owned by Laboratory for Vascular Simulations



Ref: Olufsen MS, Peskin CS, Kim WY, Pedersen EM, Nadim A, Larsen J. Numerical simulation and experimental validation of blood flow in arteries with structured-tree outflow conditions. Ann Biomed Eng 2000; 28:1281-1299.

Measurement zones

- Two zones: 1) before and 2) after bifurcation
- Blood flow is expected to be disturbed in these zones
- Nellix doesn't involve an artificial bifurcation but divides blood flow

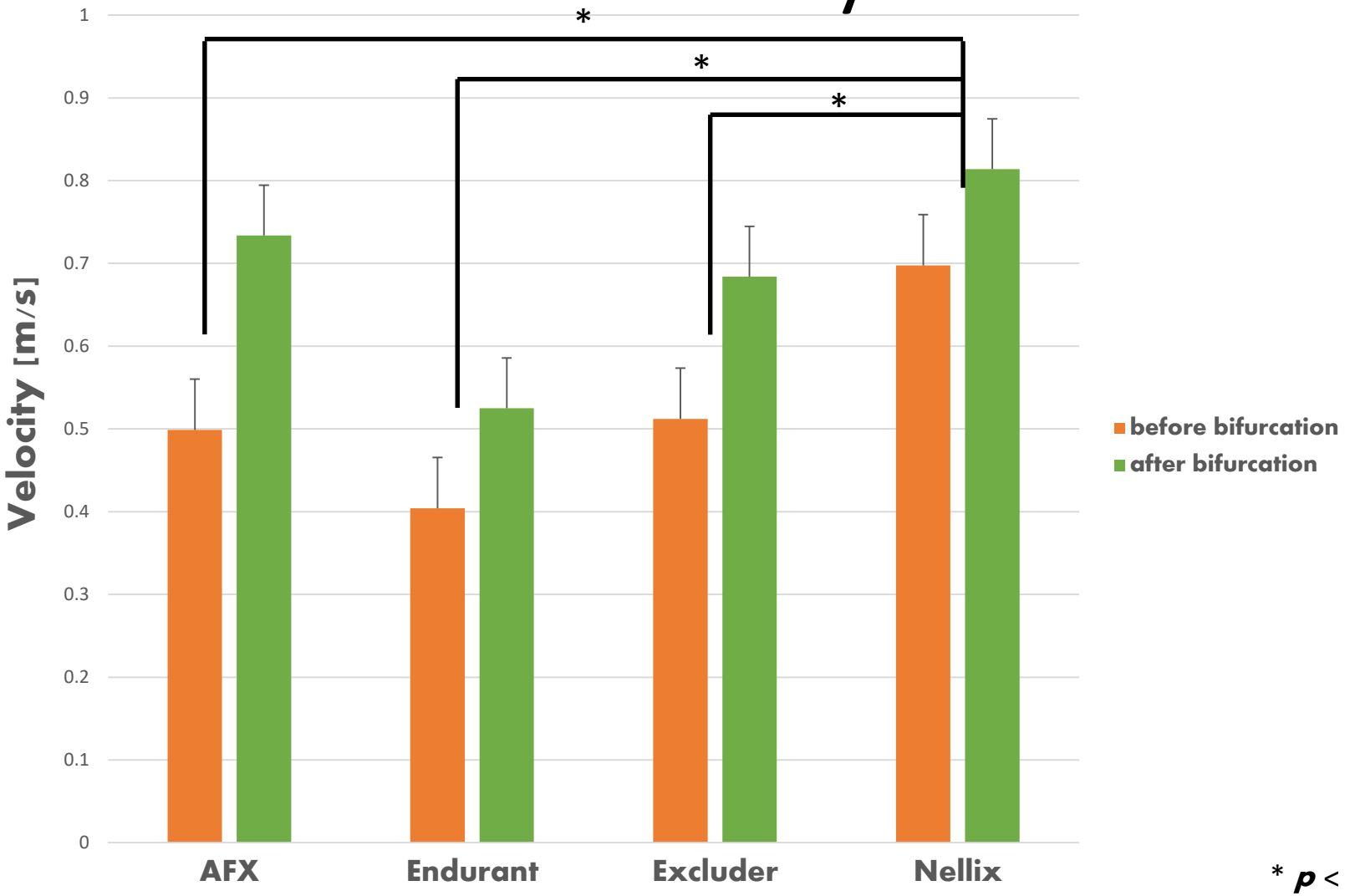


AFX Endurant Excluder Nelli

Hemodynamic properties

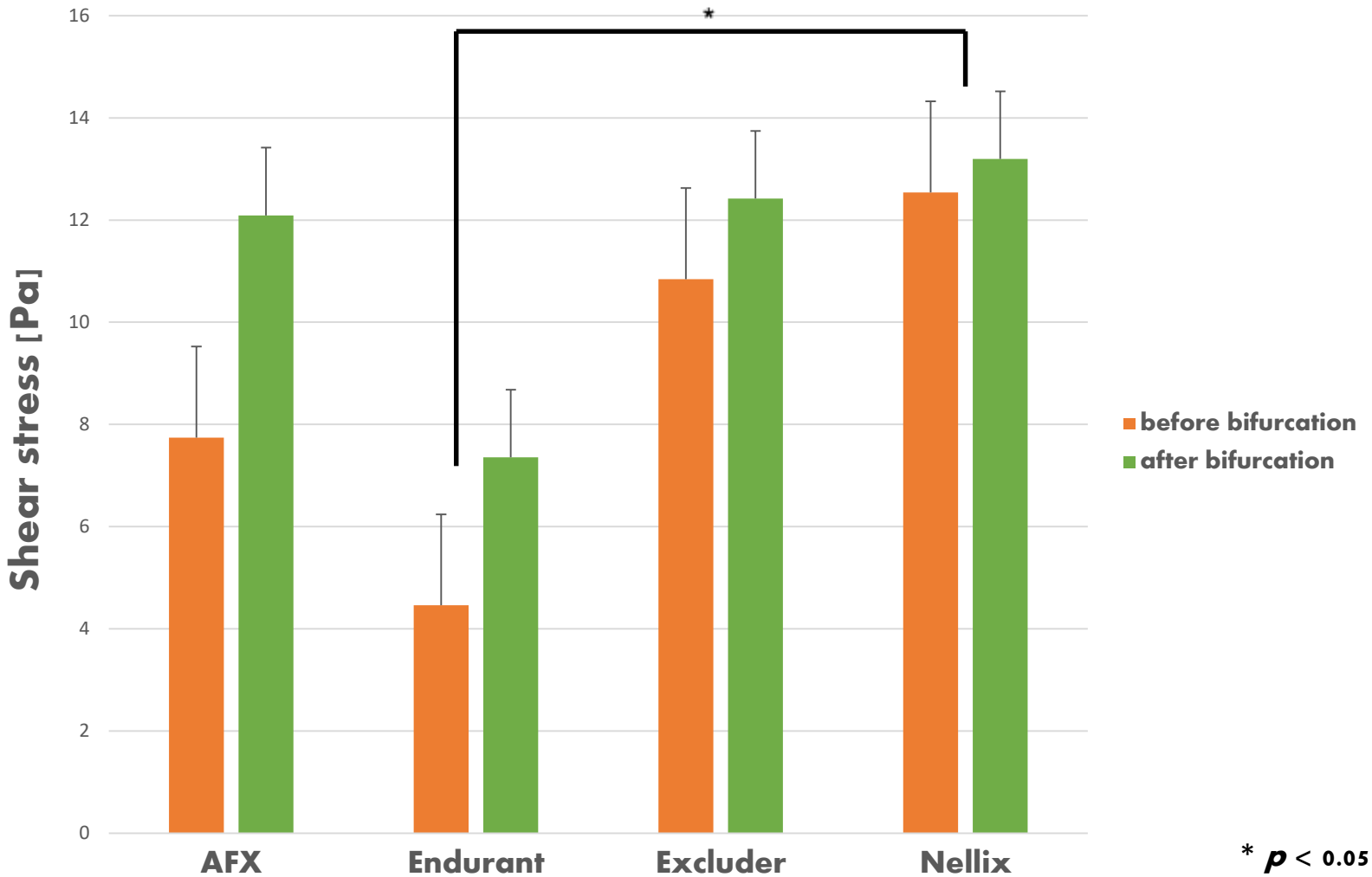
Index	Time instance	Clinical background
Max velocity	Peak systole	• No special instructions required
Max WSS	Peak systole	• Physiological profile impedes atherogenesis, thrombosis, adhesion of leukocytes, smooth muscle proliferation and endothelial apoptosis
Mean helicity	Mid-diastole	• facilitates blood flow transport • suppresses disturbed blood flow • prevents accumulation of atherogenic low-density lipoproteins on the luminal surfaces of arteries • enhances oxygen transport from the blood to the arterial wall • reduces the adhesion of blood cells on the arterial surface

Max Velocity



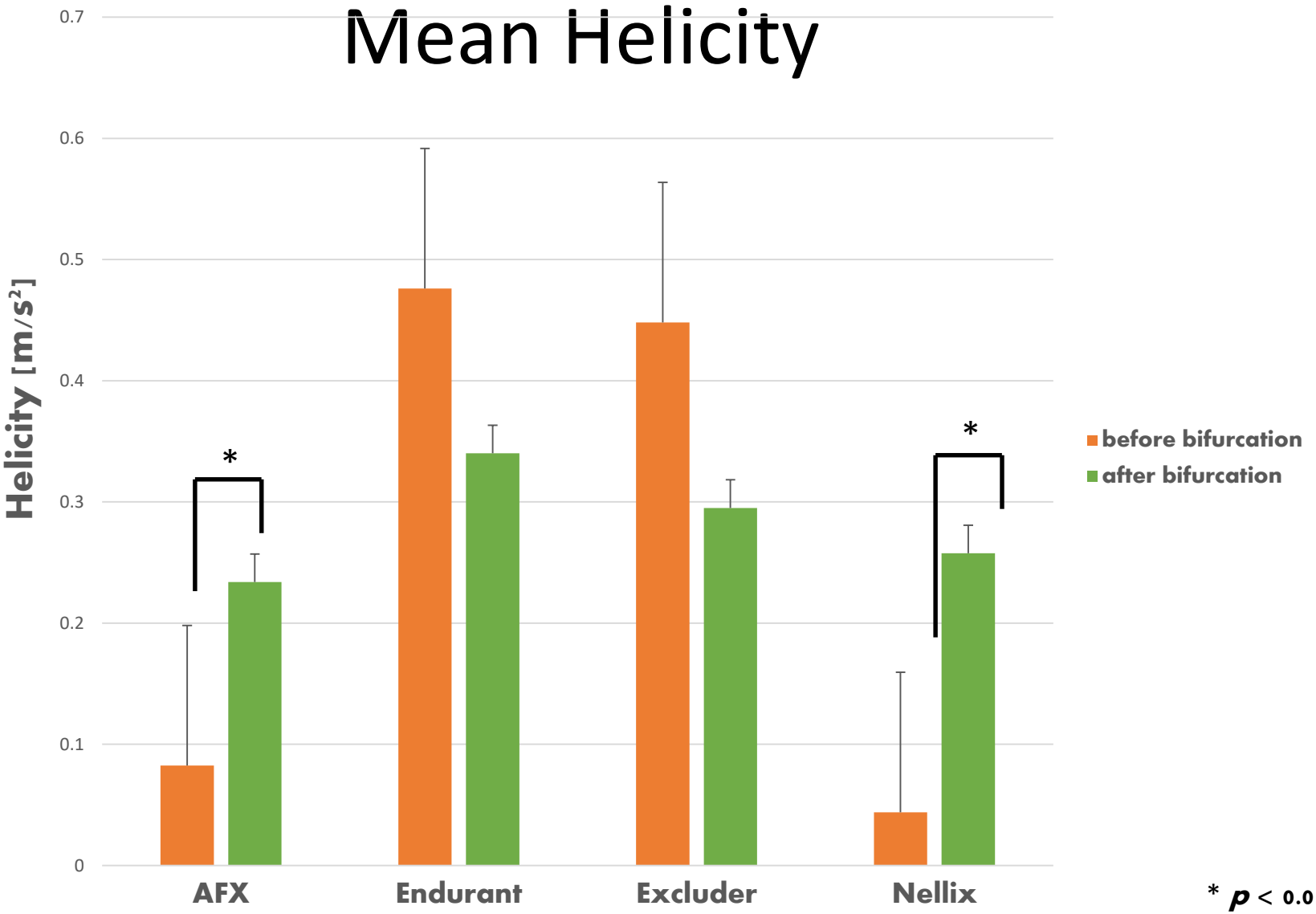
* $p < 0.05$

Max Wall Shear Stress



* $p < 0.05$

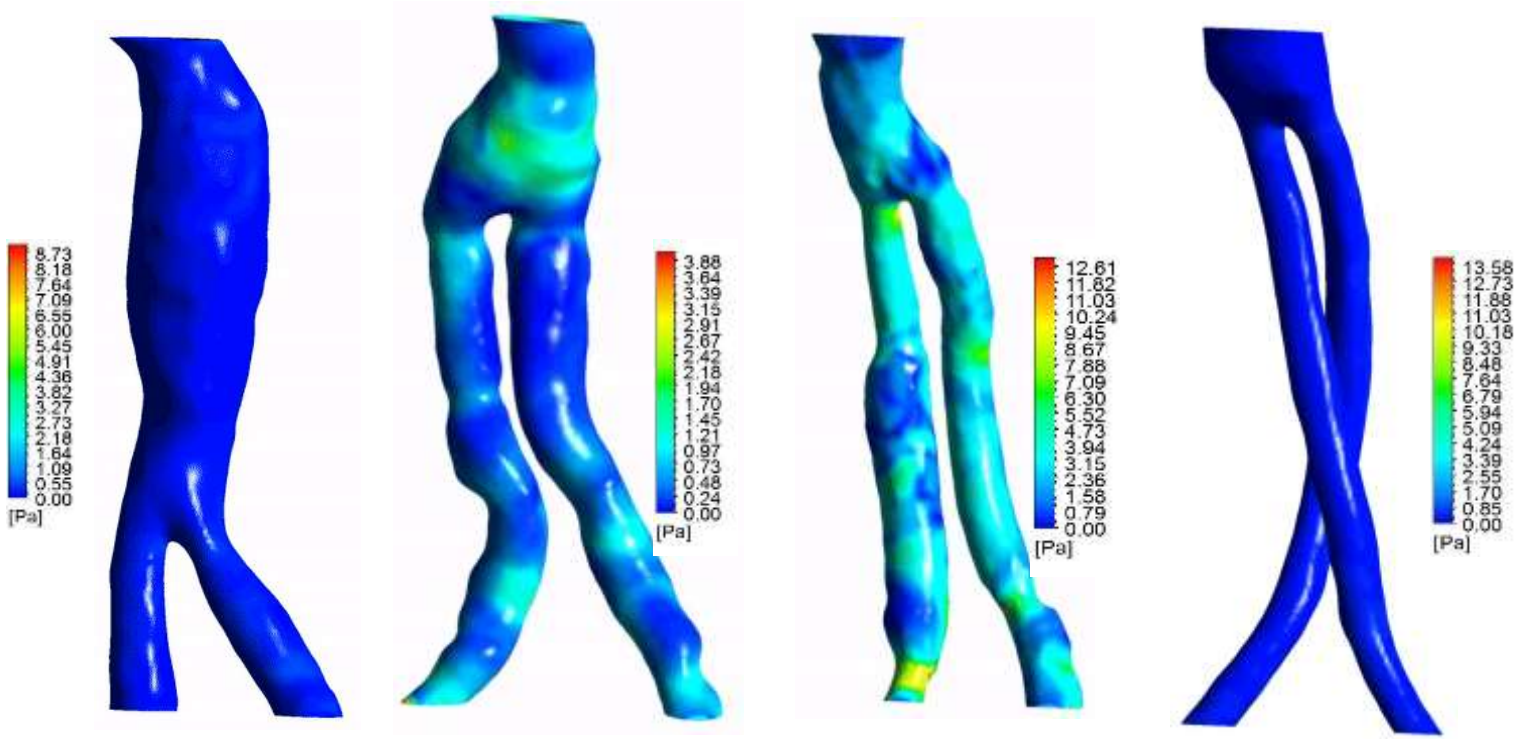
Mean Helicity



* $p < 0.05$

WSS

- WSS is typically a gradient of velocity. Increased WSS means higher blood velocity changes
- Smoother WSS profile for AFX and Nellix compared to Endurant and Excluder



AFX Enduran Excluder Nellix

Helical Structures

- Vortical structures develop and dissipate mainly during diastole
- Helical structures are limited before the flow division in AFX and Nellix cases while more dense vortical zones are observed before the bifurcation of Endurant and Excluder cases.

AFX Enduran Excluder Nellix

Conclusion

- Endografts with **different anatomic characteristics** demonstrate different hemodynamic parameters

  - near the flow divider depending on the endograft type,
  - different flow conditions of several different limb configurations

- **Future studies** are needed to examine whether these differences in hemodynamic characteristics may have a clinical impact in the long-term follow-up of the patients

- The study suggests that computational assessment of the **quality of post-EVAR blood flow** should be extended in all devices represented by bigger patient cohorts

Thank you