The Effects of Leg Flexion on the Hemodynamic Behaviors of the Femoro-popliteal Arterial Tract

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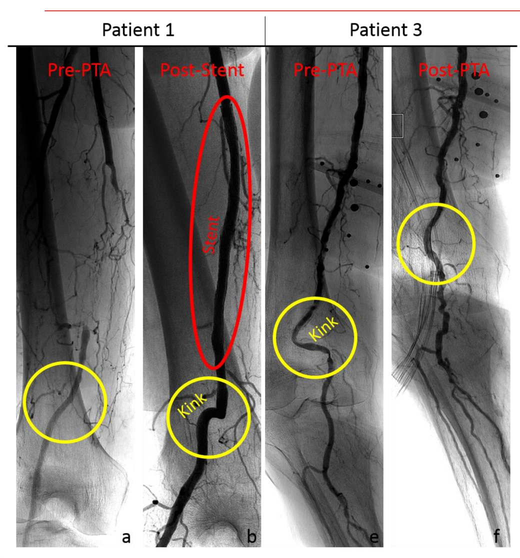
Introduction



Despite the continuous advancements in devices to treat Peripheral Arterial Disease (PAD), the loss of primary patency and high rates of target lesion revascularization (TLR) continue to be an underlying problem in the Femoropopliteal (FP) arterial tract. The hypothesis is that the poor clinical outcomes are linked to repeated mechanical deformations of the FP arteries, which are caused by leg movements.There is a very limited number of clinical investigations, and even a lower number of numerical studies, on the post-treatment arterial deformations[1]. As such, the changes in the hemodynamics of FP arteries due to leg flexion, as well as the role of adverse hemodynamic effects on the high rates of restenosis, are not known. This study aims at characterizing personalized hemodynamic parameters at the time of intervention based on a description of the arterial tract obtained by radiographic imaging. The goal is to determine the changes in the patient-specific flow due to leg flexion, as well as due to the choice of treatment method (PTA or Nitinol stent implantation), and investigate a possible correlation with clinically observed restenosis.

Datasets, Image Acquisition & 3D Reconstruction

> **20 patients[2]**

Treatment Method
- Nitinol stent implantation 10
- PTA (non-coated balloons) 10

Region of Interest
- Distal SFA/Popliteal Artery

Kinking due to leg flexion
- Post-stent 7
- Post-PTA 0

Restenosis at 6 months
- Stent 5
- PTA 2

> A calibration phantom was attached to the patients' thighs using a strap

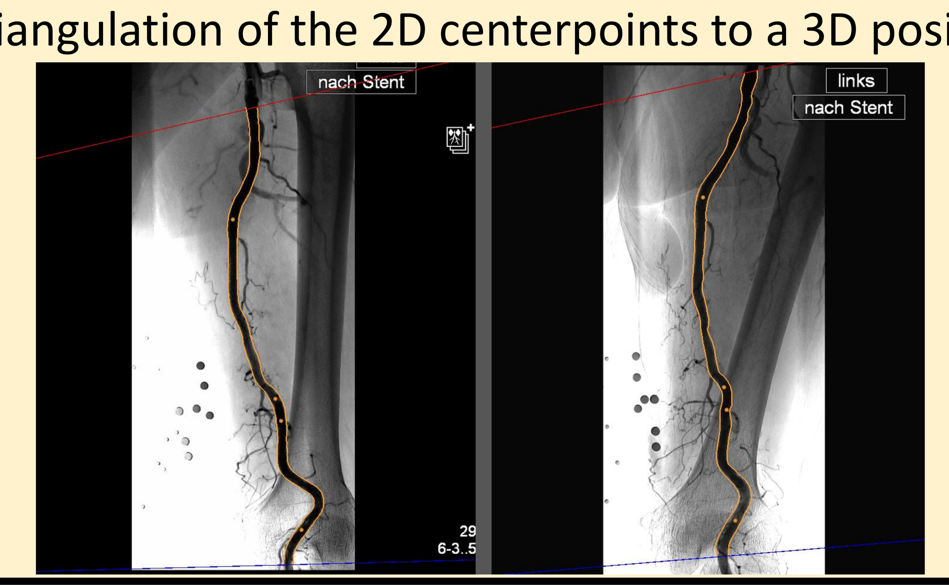
> A set of two angiographic images was acquired

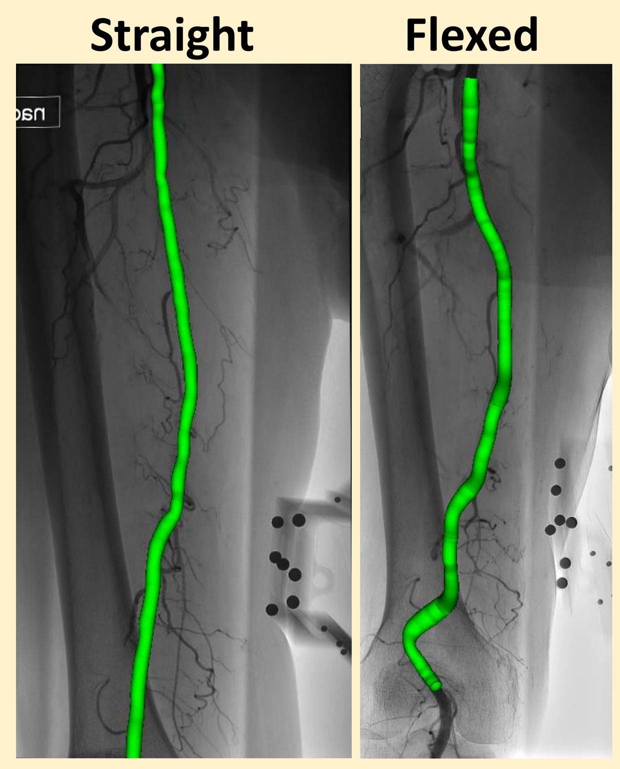
- With the leg **straight** & knee/hip **flexion** of 70°/20°

> Acquisitions performed **post-treatment** (after Nitinol stent implantation or PTA)

> **3D reconstruction of the arteries[3]**

- Calibration of the two images via the the phantom
- Segmentation of the artery by 2D contour extraction
- Triangulation of the 2D centerpoints to a 3D position

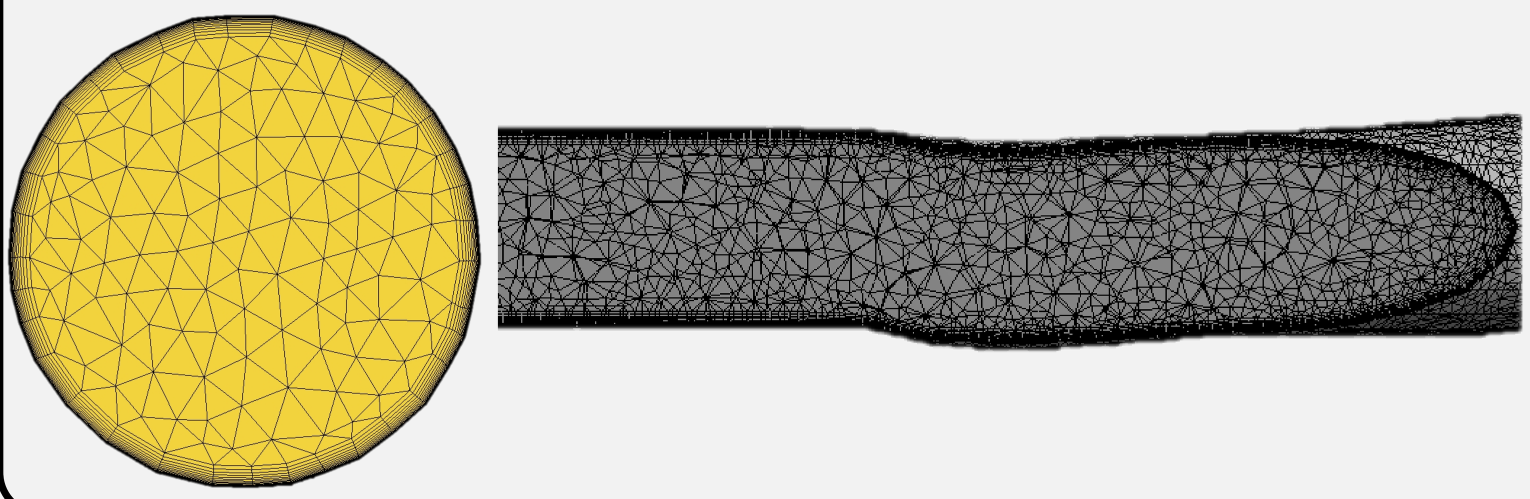




CFD Analyses: Mesh & Model Definition

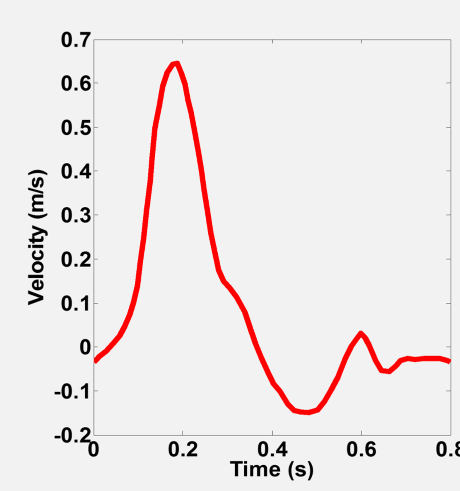
> **Mesh Generation**

- ANSYS ICEM CFD
- A mix of tetra & penta elements
- Mesh sensitivity analysis: 2 – 2.5 x 10^6 elements
- Extension of the inlet & outlet
  - Approx. 30 mm



> **CFD Analyses**

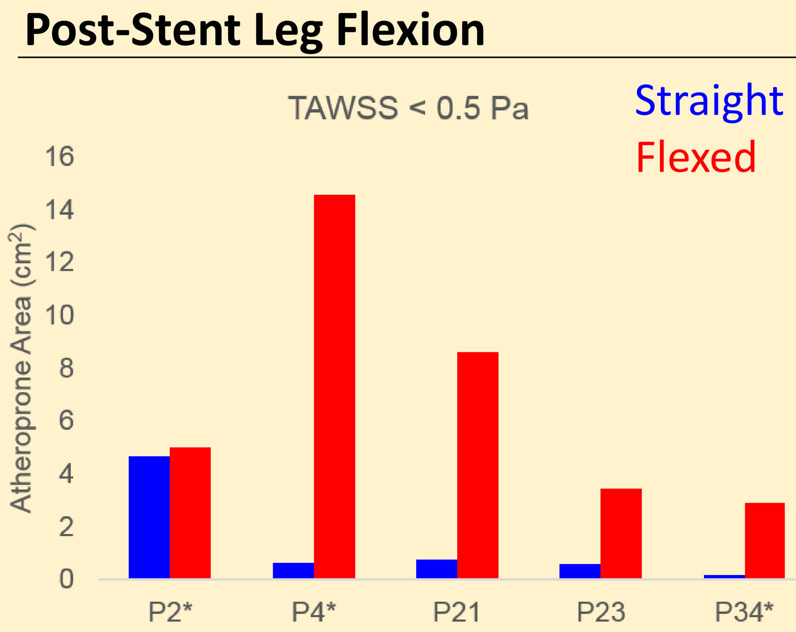
- ANSYS CFX
- Transient analyses
  - 3 cardiac cycles
- Laminar flow (Re < 2000)
- Fluid domain
  - Material: Blood
    - Density: 1050 kg/m^3
    - Viscosity: 3.5 x 10^{-3} Pa s
- Convergence control
  - RMS target: 1 x 10^{-5}
- Boundary conditions
  - MRI measured velocity[4] at the inlet
    - Tri-phasic flow
    - Modified based on inlet diameter
- Analysis parameters
  - Wall Shear Stress (WSS); Time-Averaged WSS; Oscillatory Shear Index (OSI)

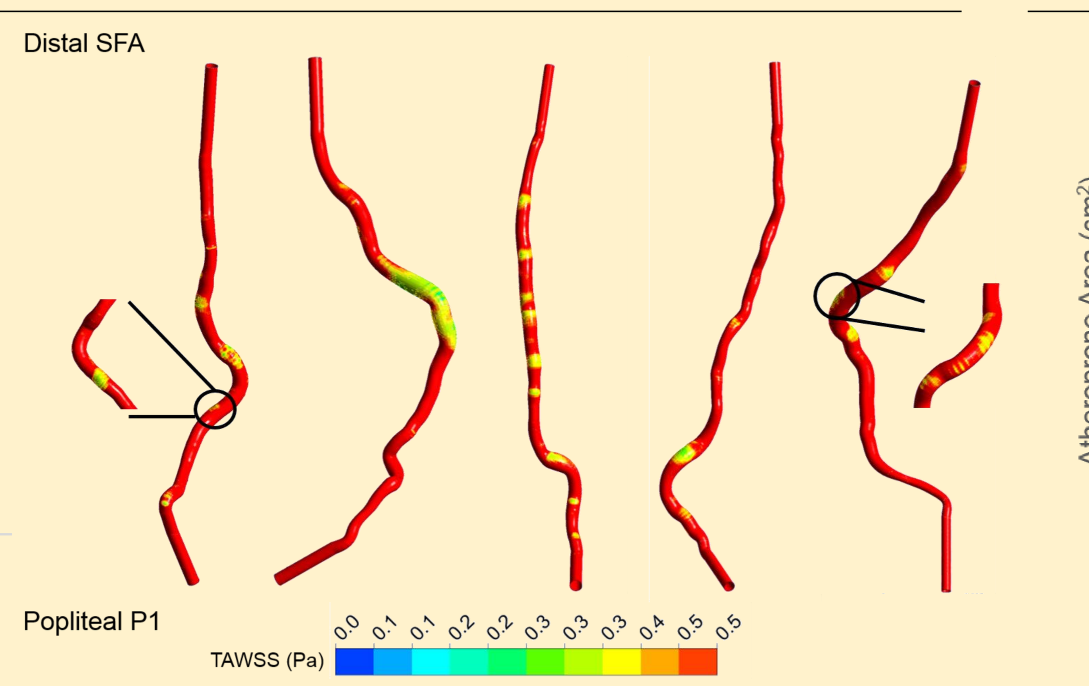


Results

*Restenosis within 6 months

Post-Stent Leg Flexion

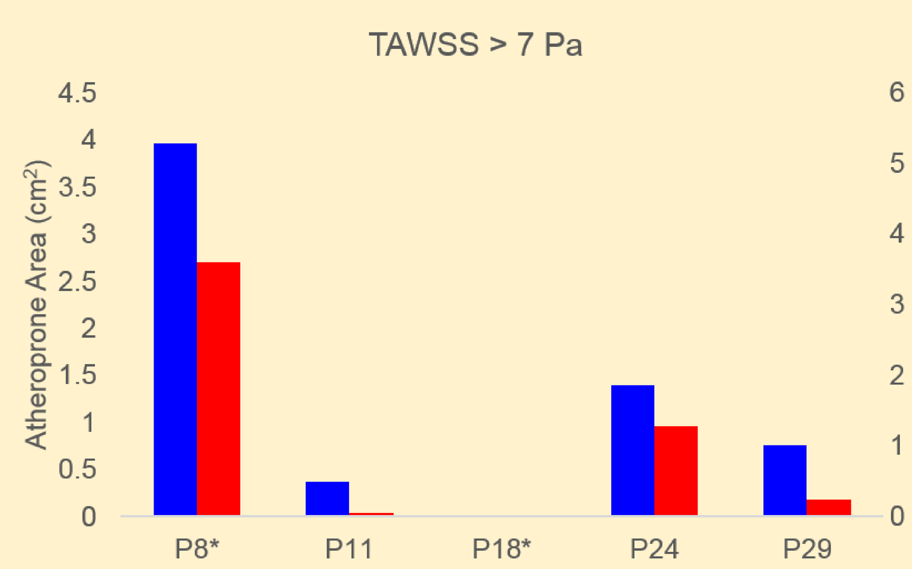


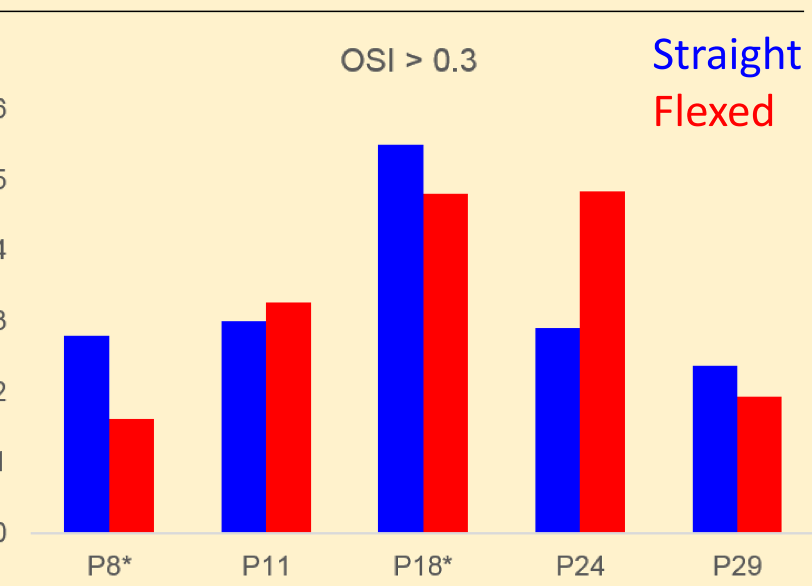


> Leg flexion caused an increase in the area that was affected by **low WSS** in stented arteries

> The location of these atheroprone areas were mainly in the vicinity of the kinks or high curvature areas

Post-PTA Leg Flexion





> The arteries that were only treated with PTA were affected by **high WSS** within or distal to the treated regions

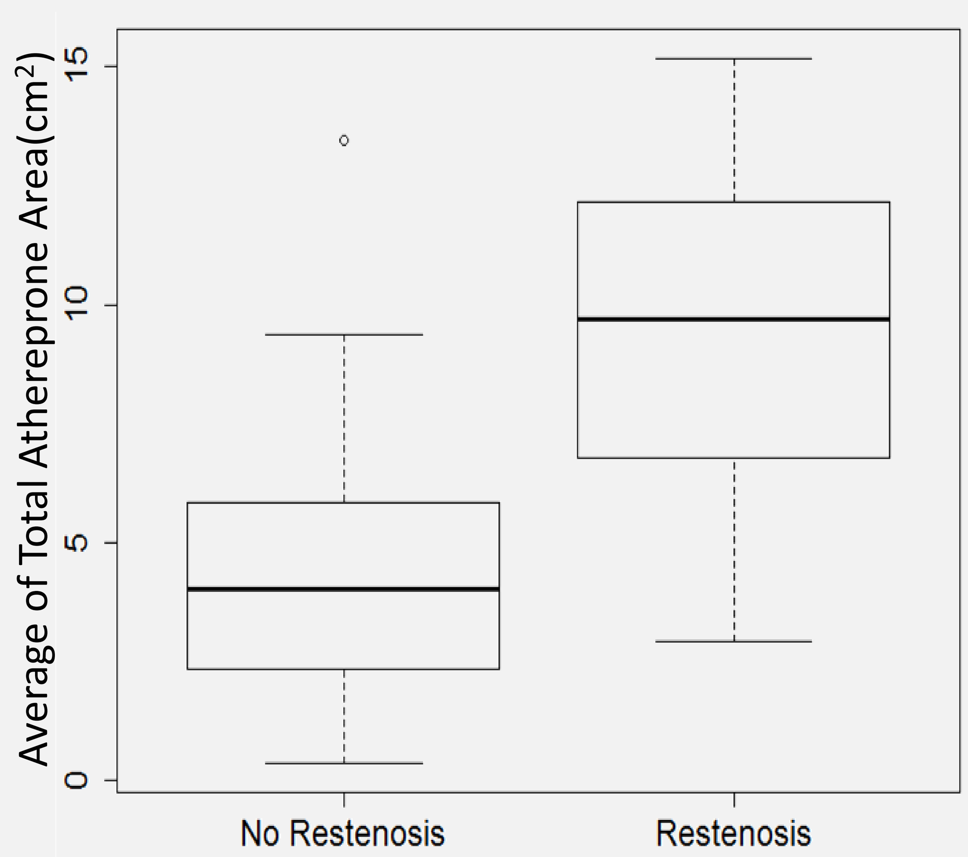
> Leg flexion did not have a significant effect on the areas that were affected by high OSI.

Discussion & Conclusion

> Hemodynamical behaviors showed differences between different treatment methods
  - **Post-Stent:** Flexion pushes the stent to over-dilate the artery or cause localized diameter changes in the lumen.
  - **Post-PTA:** Sub-optimum revascularization or diameter mismatch between the treated and healthy segments.

> OSI affected by treatment method; but not affected by leg flexion
  - Compared to the arteries that underwent only PTA, the atheroprone areas for stented arteries were larger.

> **Correlation with restenosis**
  - Average of the total atheroprone areas affected by both low and high WSS in straight and flexed positions



> Statistically significant difference (**$p = 0.04$**) between the atheroprone areas of arteries with and without restenosis

> Limitations
  - Limited follow-up time
  - No stent model or dissections
  - Boundary conditions not patient-specific

Acknowledgments

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References

[1] Conti et al. 2016. *Meccanica.*
[2] Gokgol et al. 2016. *J. Endovasc. Ther.*
[3] Schumman et al. 2016. *J. Vasc. Intv. Rad.*
[4] Mohajer et al. 2006, *J. Magn. Reson. Imaging.*