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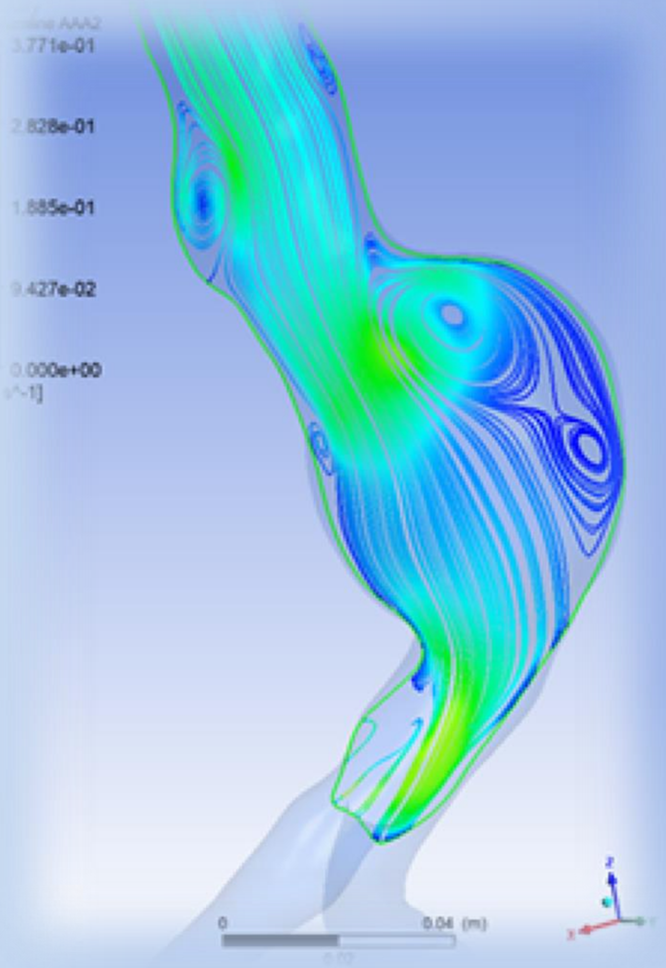

On the role of hemodynamics in predicting rupture of the abdominal aortic aneurysm

Key words:
Hemodynamics, Computational Fluid Dynamics, Wall Shear Stress (WSS), Vortex Dynamics, Abdominal Aortic Aneurysm, Patient-specific Modelling

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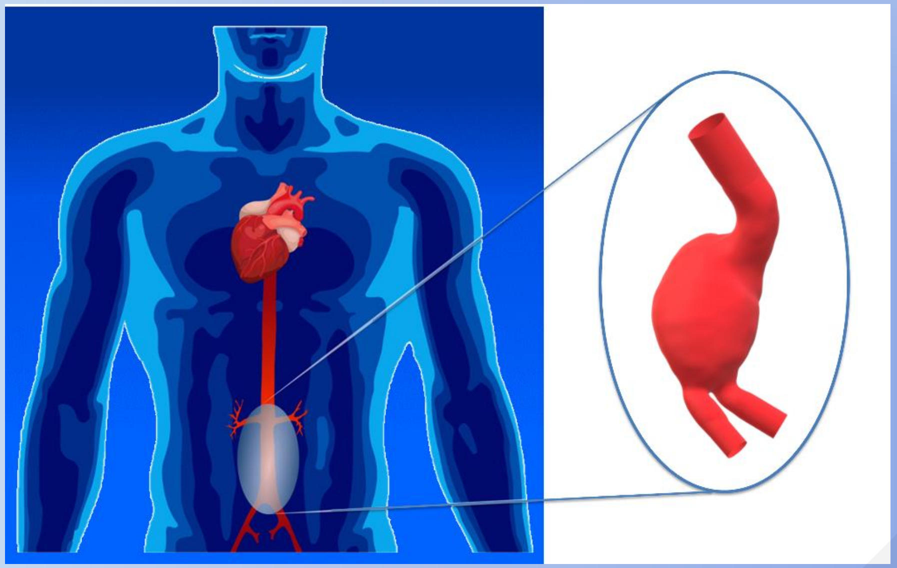
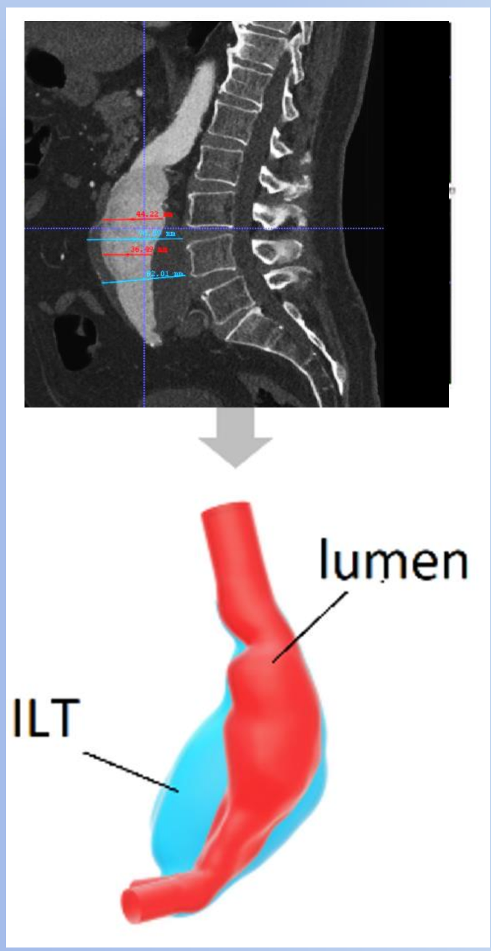
Aspects of the ISSUE



Hemodynamics plays a crucial role in the growth of an **A**bdominal **A**ortic **A**neurysm (**AAA**) and its possible rupture.

The presence of **I**ntraluminal **T**hrombus (**ILT**) strongly affects the evolution of the pathology. Most studies indicate an association between ILT and growth and early rupture of AAAs (Haller et al., 2018; Koole et al., 2013; Zhu et al., 2020).

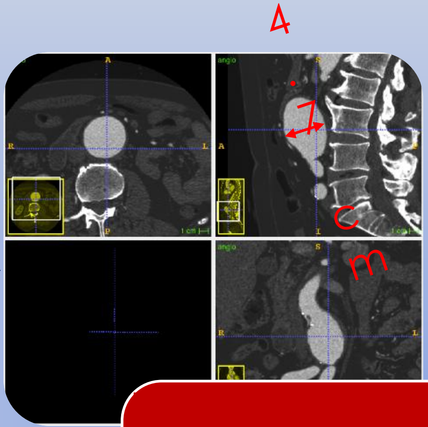
Blood fluid dynamics in AAAs is difficult to simulate accurately because the flow is pulsating, blood is a non-Newtonian fluid, and the real geometries are extremely complex.



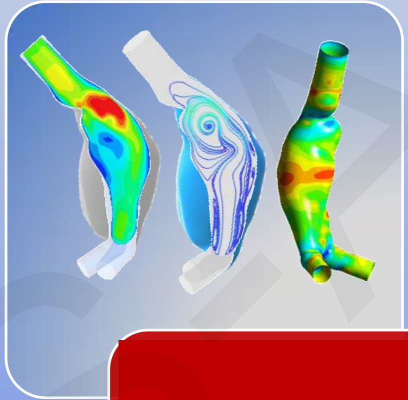
Numerical investigations of pulsatile non-Newtonian blood flow were performed in six patient-specific AAAs reconstructed from diagnostic images, of different size and shape, and characterized by the presence of thin (<5 mm) or thick (>5 mm) ILT.

Contents

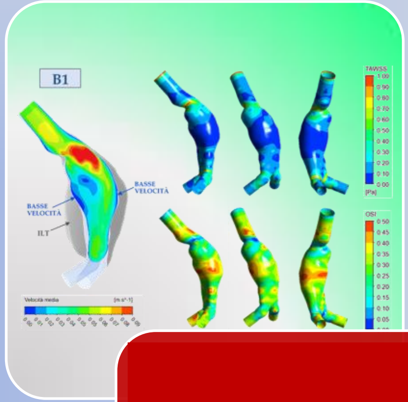
Influence of hemodynamics on the growth and possible rupture of AAAs



Patient-specific model reconstruction (6 AAAs)



Numerical Investigation



Results and conclusions

Six **patient-specific AAAs** classified into two groups, based on the thickness of the ILT

- **class A:** AAAs without ILT or very thin ILT (<5 mm)
- **class B:** AAAs with ILT thickness >5 mm

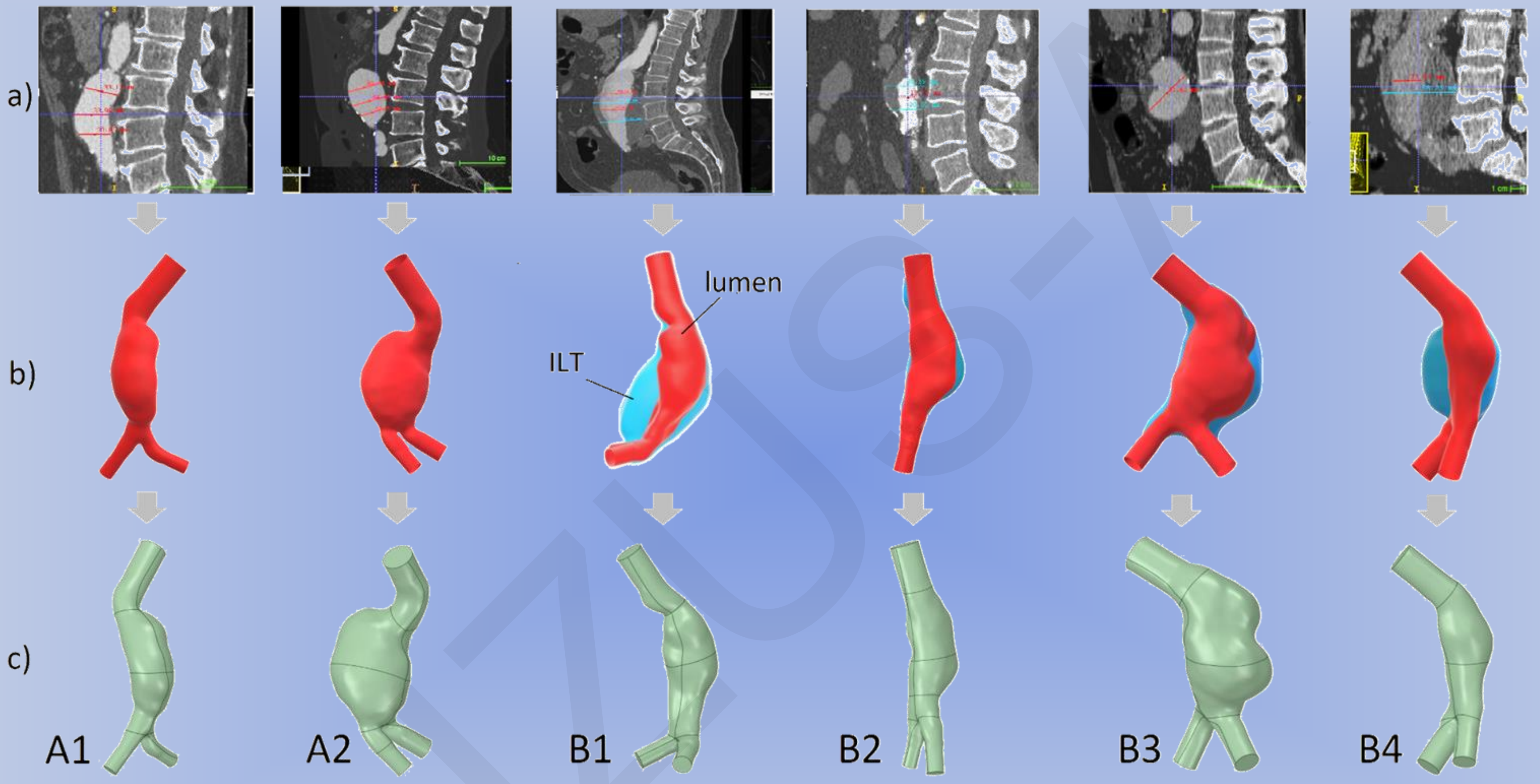
Pulsatile blood flow

Non-Newtonian fluid

the unsteady nature of blood flow in the diseased arteries was described in space and time:

- 2D, 3D streamlines and WSS contours
- computed hemodynamic indicators

Patient-specific model reconstruction



- A coarse 3D model was obtained from the 2D slices of CT (ITK-SNAP software)
- Some arterial branches were eliminated, the corresponding areas closed (Meshmixer software)
- The 3D model was smoothed and *extensions* were added (VMTK software)
- Aneurysm surface was extracted from the 3D model (SpaceClaim software)

ANSYS Fluent

Numerical Investigation

Pulsatile *non-Newtonian* blood flow

Blood: incompressibile fluid

Carreau rheological model

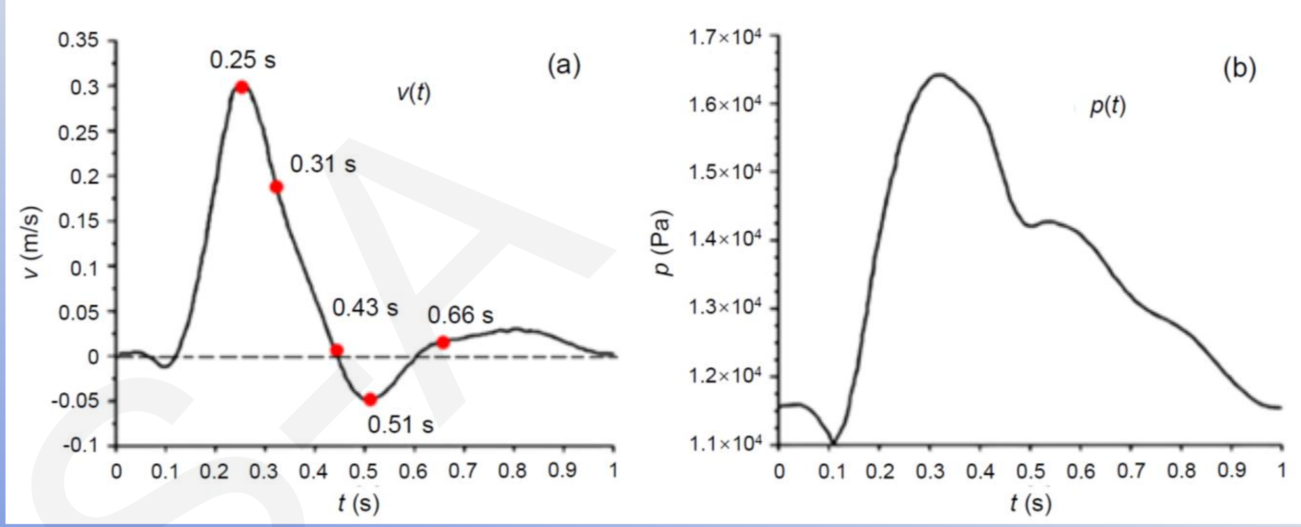
$$\mu(\dot{\gamma}) = \mu_\infty + (\mu_0 - \mu_\infty)(1 + (\lambda\dot{\gamma})^2)^{\frac{n-1}{2}}$$

Boundary conditions

- Inlet: *v(t)*
- Outlet: *p(t)*
- Wall: *no slip boundary condition*

Mesh independency analysis

Final mesh ≈ 3 million elements for each model

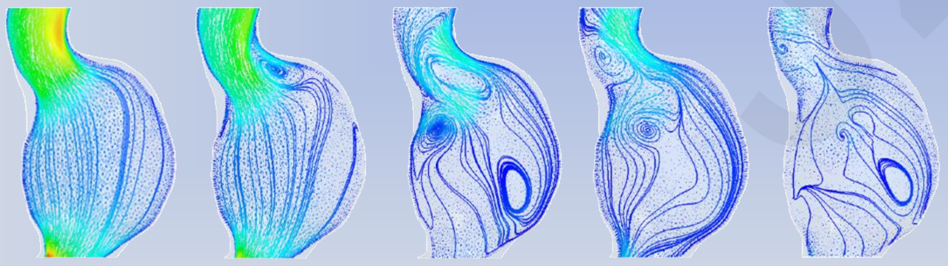


Pulsatile waveforms prescribed at the inlet and the outlet derived from Xenos et al. (2010)

Hemodynamic indicators

$$\boldsymbol{TAWSS} = \frac{1}{T}\int_0^T \left|\overrightarrow{WSS(s,t)}\right| dt$$

$$\boldsymbol{OSI} = \frac{1}{2}\left(1 - \frac{\left|\int_0^T \overrightarrow{WSS(s,t)}\, dt\right|}{\int_0^T \left|\overrightarrow{WSS(s,t)}\right| dt}\right)$$

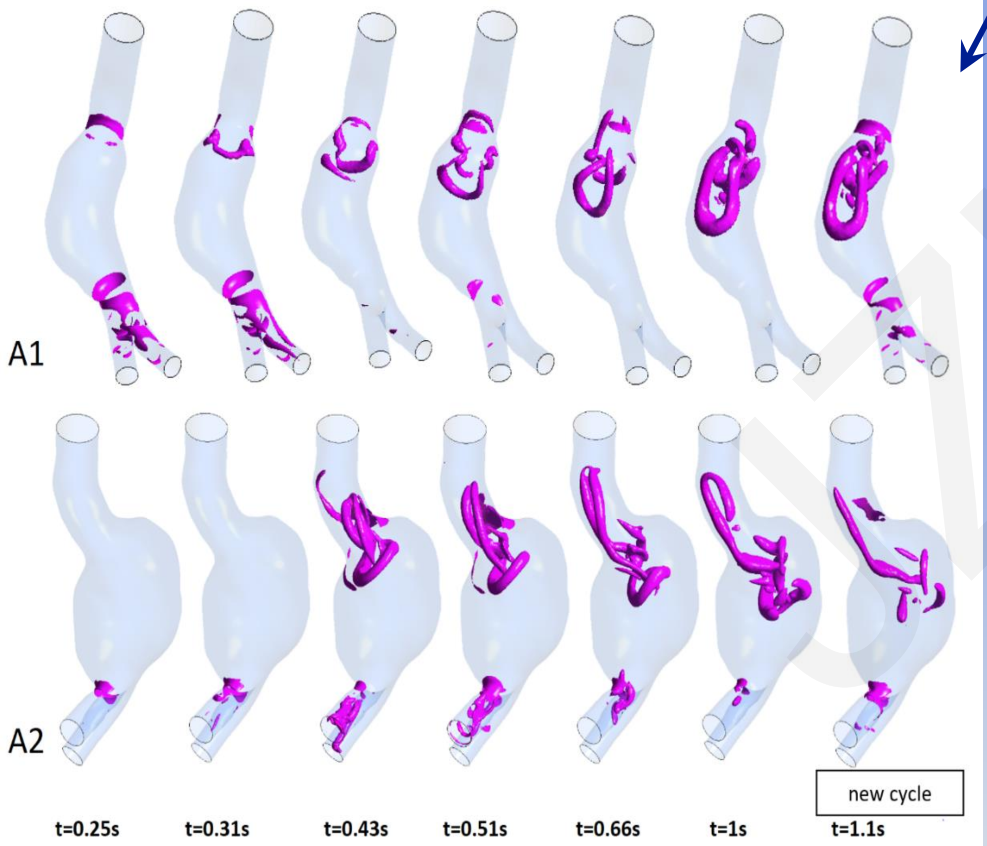


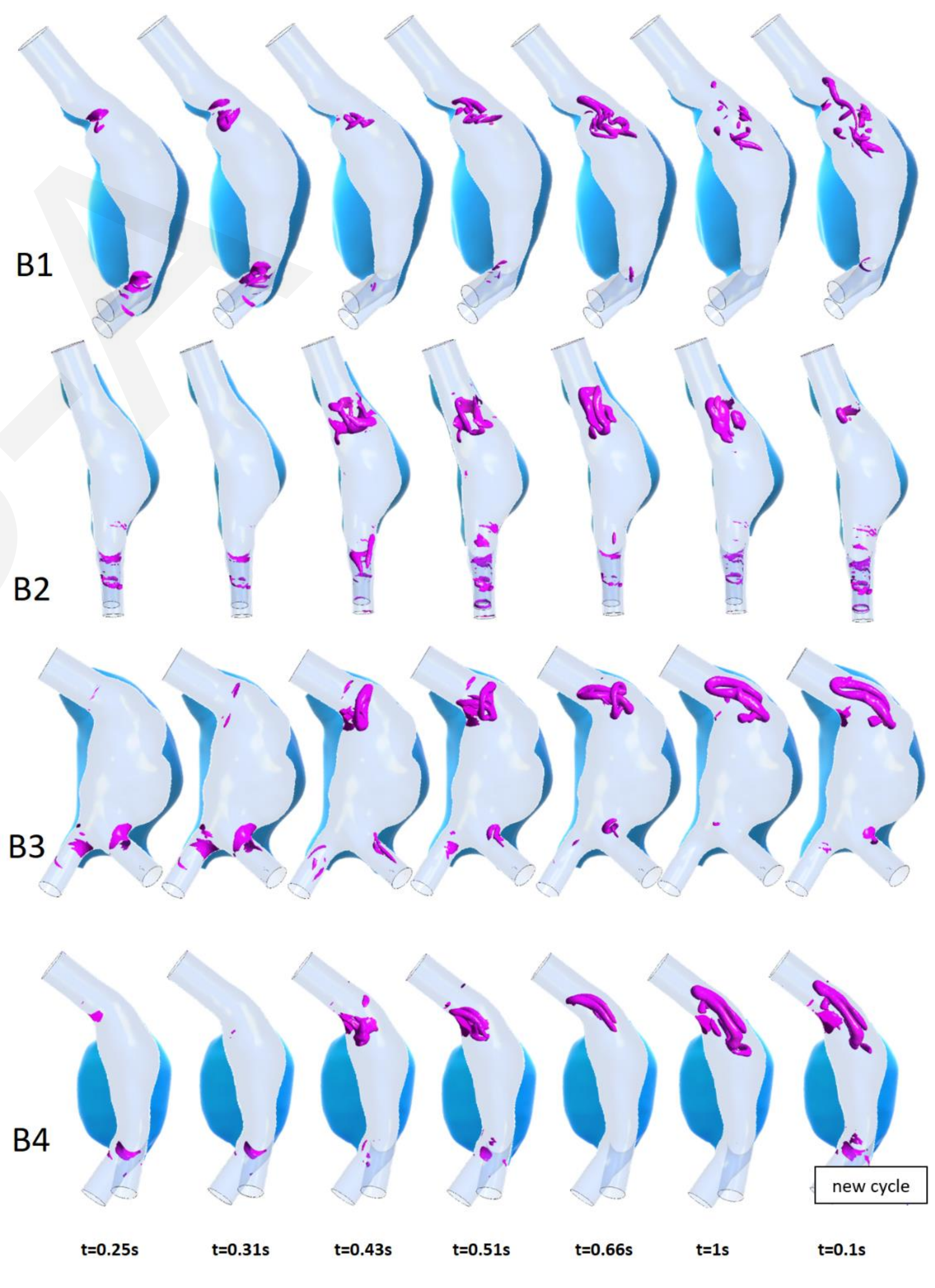
To describe the unsteady nature of blood flow in the diseased arteries 2D and 3D streamline evolutions were analyzed, as well as the instantaneous WSS contours. Moreover, hemodynamic indicators, including TAWSS and OSI, were calculated.

R e s u l t s

Information on the **vortex dynamics** was obtained by analyzing the temporal evolution of the vortex core isosurfaces, detected by the Q-criterion method.

Vortex core isosurfaces for AAAs belonging to class A and class B.

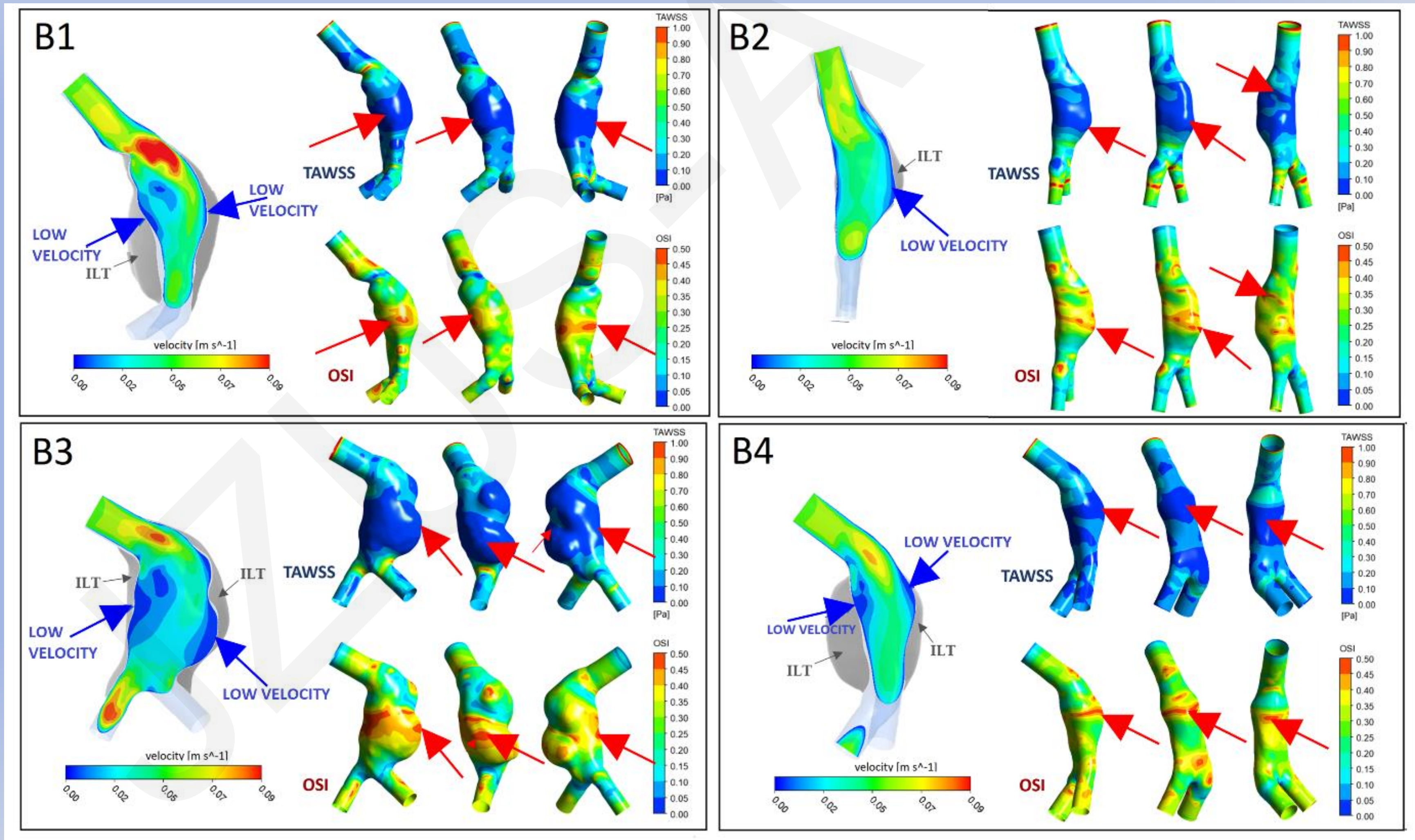




Results

Low values of mean velocities correlated with low TAWSS and high OSI.

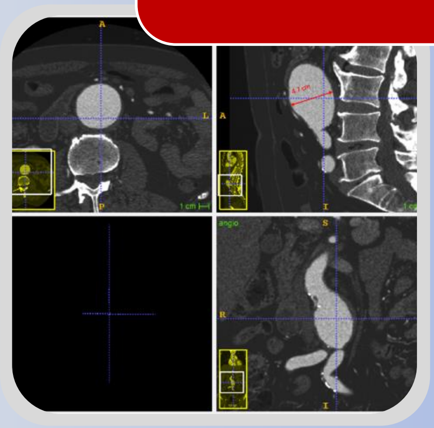
ILT deposition was observed just in these areas.



Time-averaged velocity contours on a suitable longitudinal cross-section, TAWSS and OSI on the luminal surfaces for AAAs belonging to class B

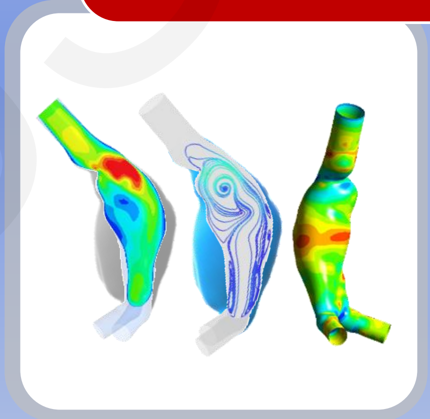
Conclusions

Larger maximum diameters, including ILT, were found to be associated with thicker ILT



High WSS values were found in the proximal neck area of the bulge

Vessel curvature contributed to the generation of vortices, with consequent possible ILT accumulation



Further accumulation of ILT in the regions of low averaged velocities, low TAWSS and high OSI can be hypothesized

Possible AAA rupture

This work highlights the importance of hemodynamics in assessing the vulnerability of the aortic wall and underlines the crucial role of patient-specific investigations in predicting the rupture of individual aneurysms.