Geometric aortic root modeling and biomechanical simulation

Author: Marcos Loureiro Garcia

Coordinators: César Veiga , Generosa Fernández, Francisco Calvo

Cardioloxía – IIS Galicia Sur – Hospital Álvaro Cunqueiro

Aortic valve (AoV) stenosis is one of the most common valvular diseases. Assessing the aortic valve function could provide crucial information towards a better understanding of the disease, where numerical simulation will have an important role to play. The main scope is to find an aortic root (AR) patient specific geometric model, which could be used for simulation purposes.

METHODS

Several models [1-2] were followed to obtain an AR (aortic root) geometry using open source tools. Necessary parameters were obtained from 2D echo images.

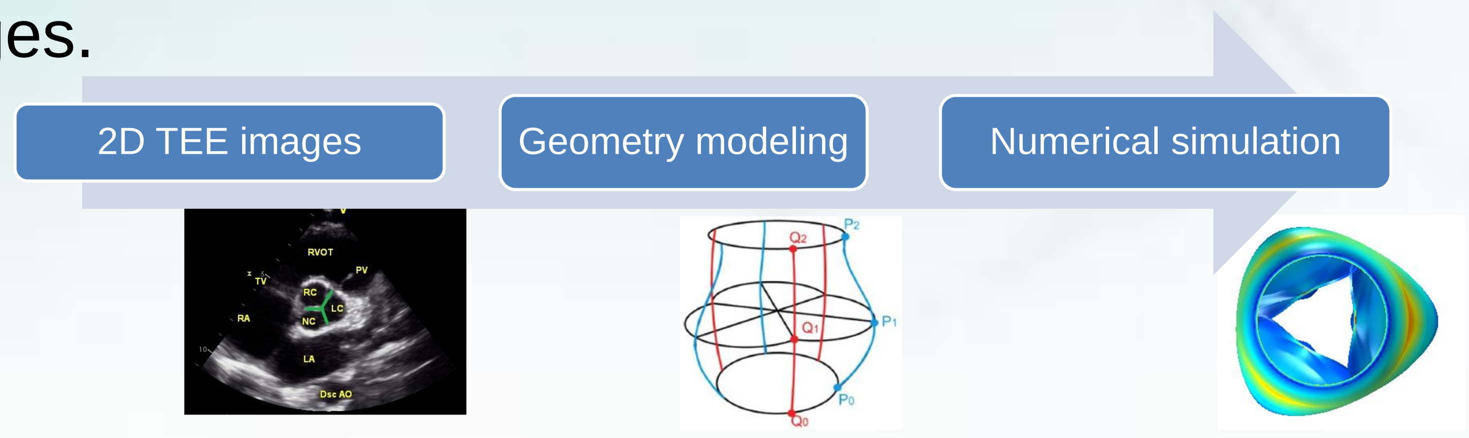

Figure 1: Methodology. Parameters are obtained from 2D transesophageal echocardiographic images in order to create a valid geometry for numerical simulation.

In order to test the approached natural AR geometry, a finite element study was performed solving fixed mesh fluid structure interaction (FSI) model. Obtained results for the 1-way FSI study are compared with the published ones for structural and 2-way FSI studies.

$div(\mathbf{v}) = \mathbf{0}$ $\rho \frac{\partial \mathbf{v}}{\partial t} + \rho(\mathbf{v} \cdot \nabla)\mathbf{v} - \nabla \mathbf{T} = \mathbf{0}$	$\left.\begin{array}{c} div\,\sigma = \mathbf{0} \\ \sigma = \lambda tr(E(\mathbf{u}))\mathbf{I} + 2\mu E(\mathbf{u}) \end{array}\right\}$ $\mathbf{E} = \frac{1}{2}(\nabla \mathbf{u}^T + \nabla \mathbf{u} + \nabla \mathbf{u}^T \nabla \mathbf{u})$	$\sigma_{solid} \cdot \mathbf{n} = \sigma_{fluid} \cdot \mathbf{n}$
FLUID - laminar	SOLID- Green St Venant	FSI – fixed mesh

Figure 2: Fluid structure interaction model

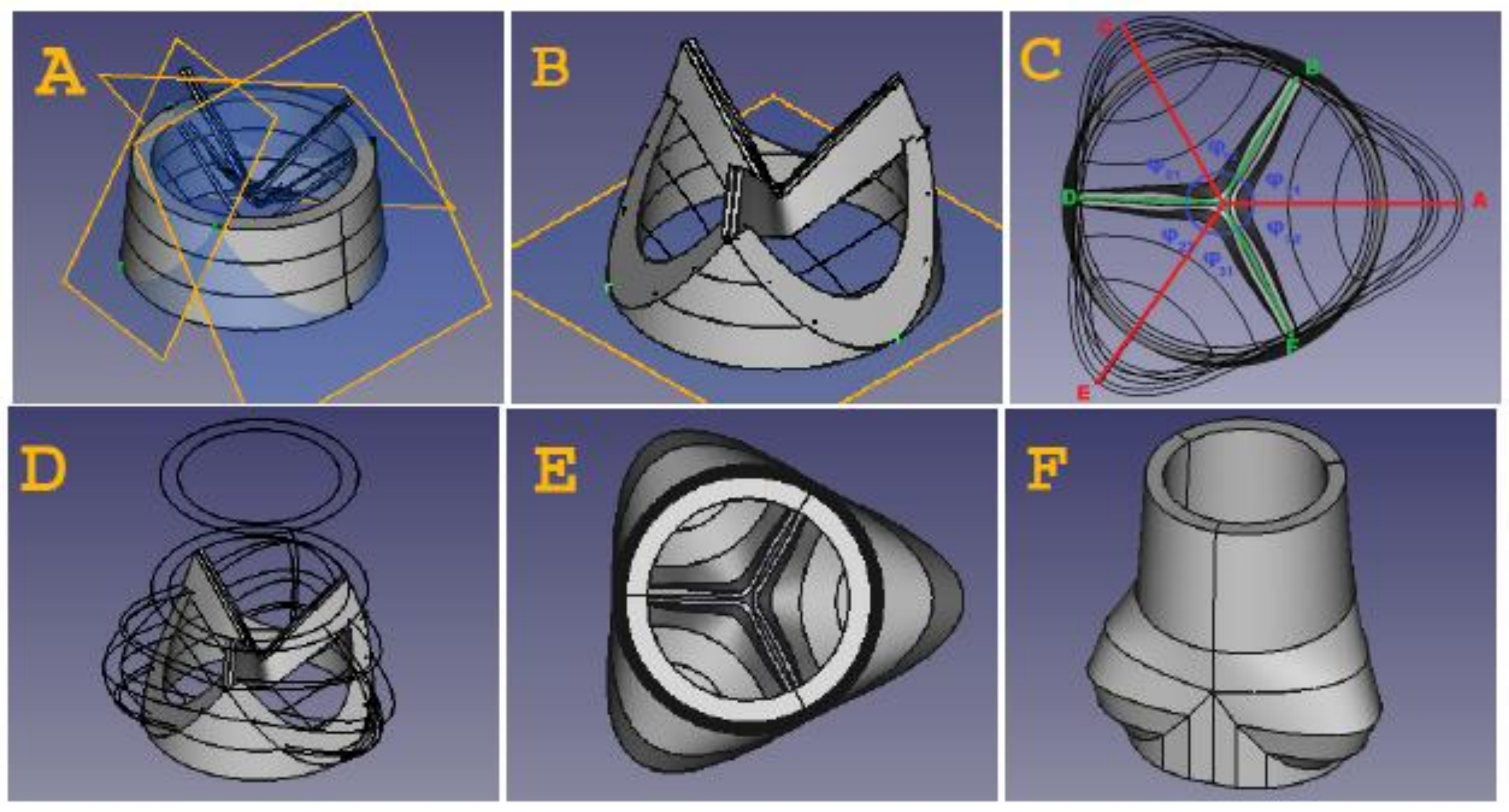

Figure 3: A succesful AR geometry reconstruction was approached using open free software FreeCAD. Four scripts were developed implementing the equations and commands in order to obtain a geometrical model of the aortic root.

RESULTS

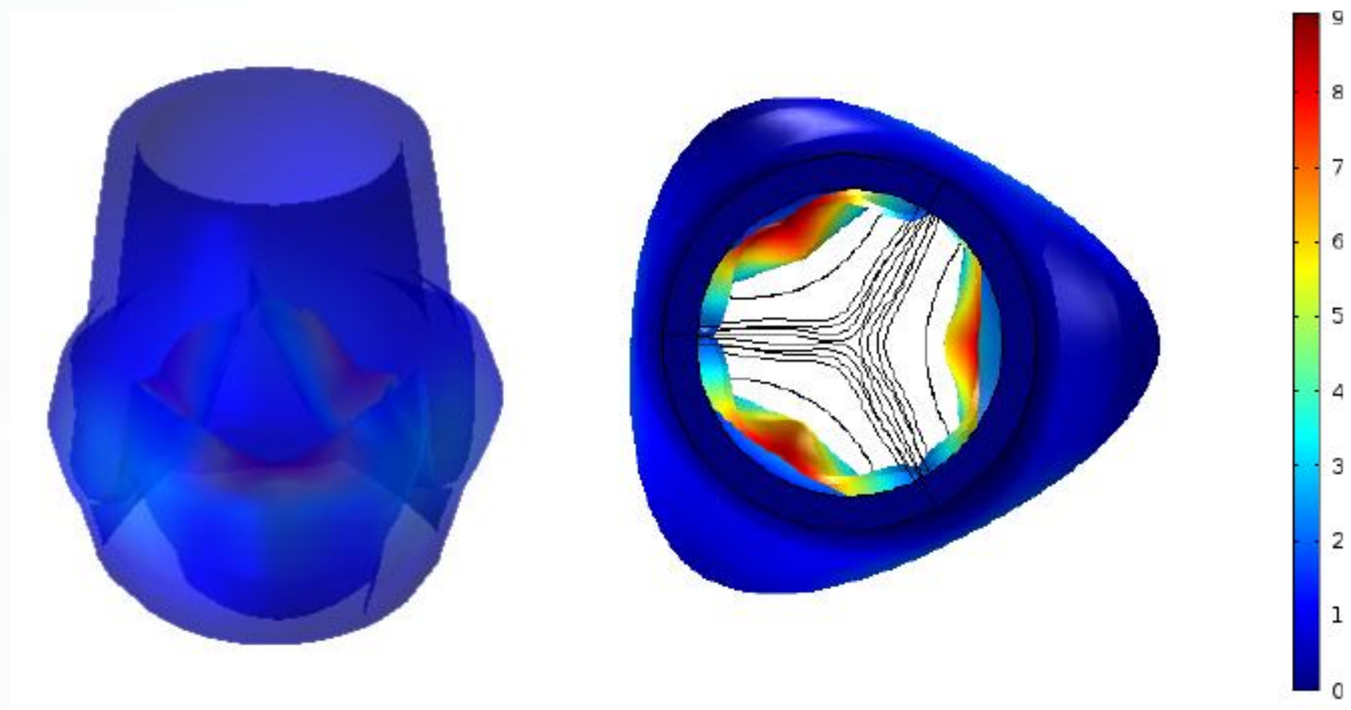

Figure 4: Aortic root displacement [mm] with a maximum of 9 mm in the nodule of Arantius. A proper opening of the aortic leaflets is also visible.

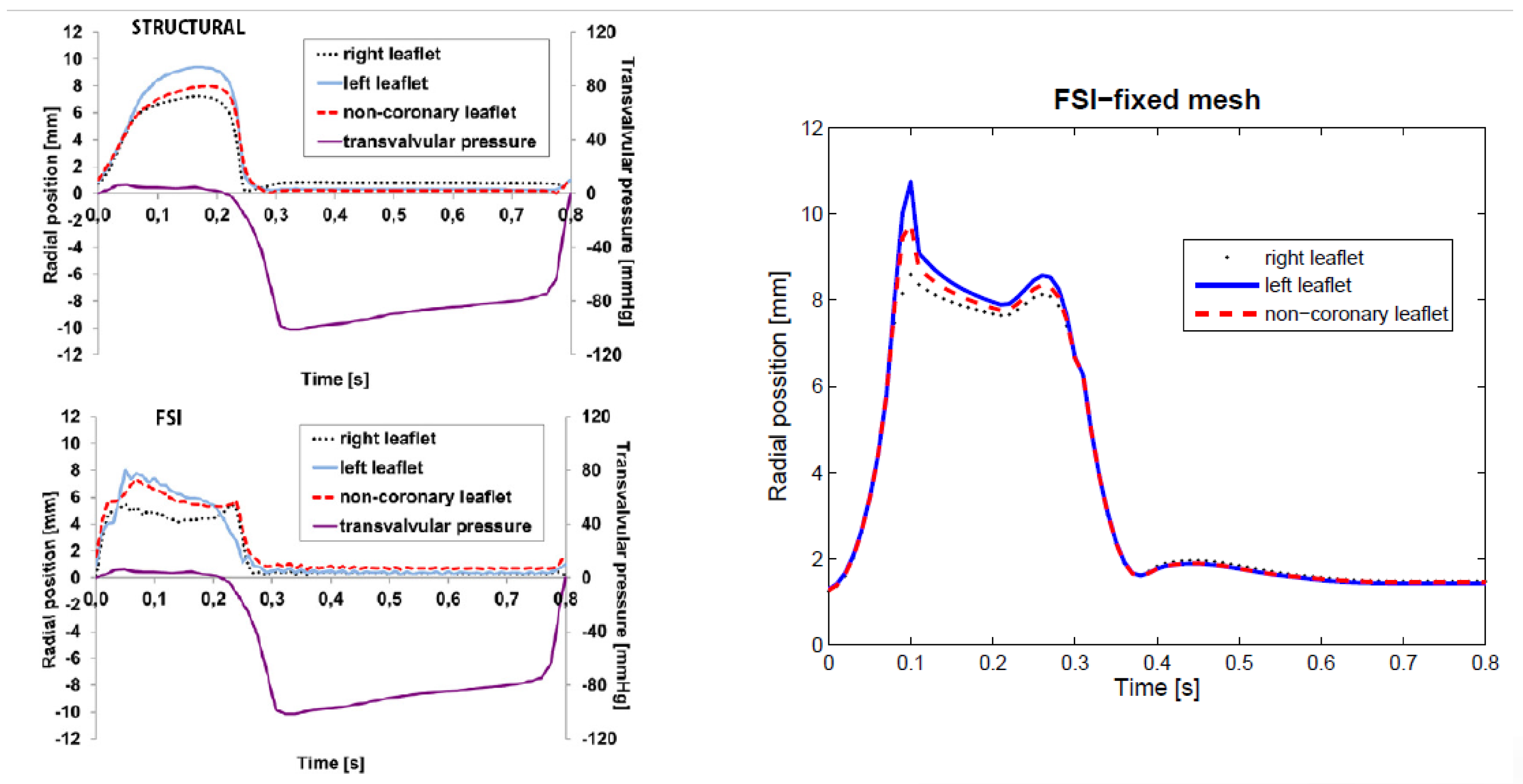

Figure 5: Time-dependent radial position of the nodulus of Arantius. On the left hand side, Sturla's results for structural and moving mesh FSI analysis [3]. On the right hand side, approached results in this work with a fixed mesh FSI.

CONCLUSIONS

- The presented parametric model for AR geometric reconstruction from clinic data (including leaflets, inter-leaflet triangles and sinus of Valsalva) is suitable for numerical simulation.
- It is possible to develop a FSI fixed mesh model of the AR using the presented AR geometry.
- FSI simulations based on the presented model provide similar results as presented in the literature.
- The obtained results prove that the use of numerical simulation could be a valid and powerful tool that could be used in the future in clinic applications.

REFERENCES:

[1] Labrosse, M., Beller, C., Robicsek F., Thubrikar M.: Geometric modeling of functional trileaflet aortic valves: Development and clinical applications. J Biomec 39 , 2006

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[3] Sturla, F., Votta, E., Stevanella, M., Conti, C., Redaelli, A.: Impact of modeling fluid-structure iteraction in the computational analysis of aortic root biomechanics, MedEng&Phys 35, 2013