

The role of simulations for LAA closure procedure: from planning to post-procedural analysis

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Introduction

The left atrial appendage (LAA) is a finger-like extension originating from the main body of the left atrium (Fig. 1) and responsible for 90% of thrombus formation in patients with non-valvular atrial fibrillation.

In the presence of this pathology and contraindications to anticoagulation therapy, the percutaneous LAA occlusion (LAAo) is a treatment strategy [1] to reduce the cardioembolic risk (Fig. 2). This procedure is particularly difficult because of LAA anatomical and flow dynamics complexity.

Aim – This study purpose is to simulate the LAA closure with Watchman device in order to assess the effect of device introduction and to investigate the left atrium fluid dynamics pre and post intervention.



Figure 1

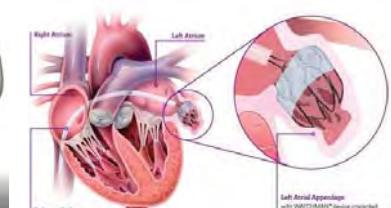
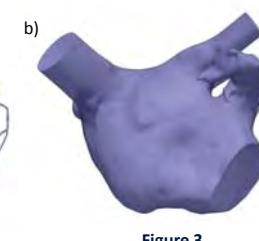


Figure 2

Image processing and models reconstruction

Anatomical model

CT datasets were segmented to obtain a left atrium and LAA 3D models for each phase of cardiac cycle (Fig. 3a). A custom plug-in software was developed to measure the LAA volume variations during cardiac cycle directly from the 3D models. The blood pressure data for the LAA were also collected from our clinical database. The 3D model corresponding to the systolic phase including LAA, pulmonary veins (PVs) and mitral valve (MV) was used for the CFD simulations (Fig. 3b).



Device model

Watchman model (Fig. 4) was reconstructed from images projections on the cartesian planes of a Watchman device.

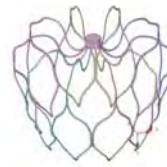


Figure 4

Figure 3

CFD simulations – Analyze the left atrium and LAA flow dynamics during the entire cardiac cycle.

CFD simulations were performed before the LAA closure procedure (PRE) and after the Watchman device introduction (POST) in order to evaluate the different flow fields for the two conformations.

- The ANSYS Fluent solver was used for the CFD simulations and a transient flow analysis was applied.
- The blood was modelled as an incompressible and Newtonian fluid with a density of $1.06 \times 10^3 \text{ kg/m}^3$ and a dynamic viscosity of $3.5 \times 10^{-3} \text{ Pa*s}$.
- The same boundary conditions were used for the two cases: a time-dependent velocity profile was imposed to the mitral valve and a constant pressure of 7 mmHg was assigned to the four PVs.
- A mesh of tetrahedral elements of 0.8 mm with a 5 inflation layers was implemented.

PRE-LAAo

The CFD simulation of left atrium before the intervention was performed on the segmented model (Fig. 3). The flow velocity at valve open configuration in the entire left atrium is reported in Figure 8. The velocity streamlines at closed valve configuration are depicted in Figure 9. The wall shear stress (WSS) maps at diastolic and systolic times are shown in Figure 10 and Figure 11, respectively.

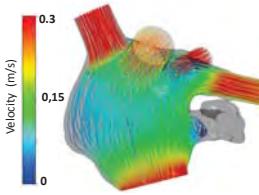


Figure 8

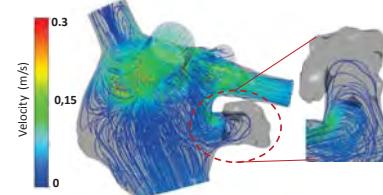


Figure 9

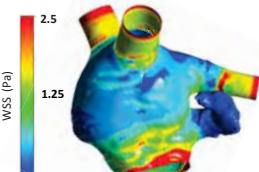


Figure 10

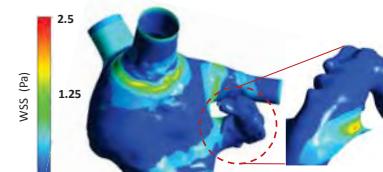


Figure 11

POST-LAAo

The CFD simulation was performed on the geometry model resulted from the described FE simulation after Watchman expansion (Fig. 12). The velocity flow fields at diastolic and at systolic phases are reported in Figure 13 and in Figure 14 respectively. The WSS distributions at diastolic and systolic times are depicted in Figure 15 and in Figure 16, respectively.

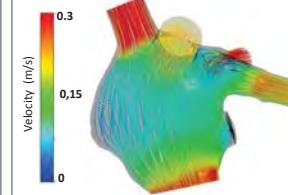


Figure 13

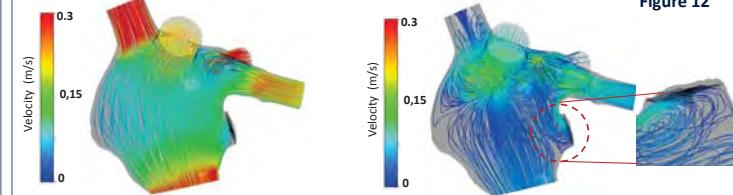


Figure 14

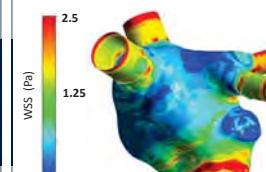


Figure 15

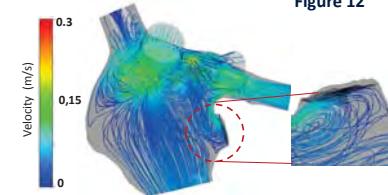


Figure 16

Conclusions – The LAA closure procedure with Watchman device is feasible by using the ANSYS Fluent solver and it has been possible to perform a CFD simulation on the resulted deformed shape to evaluate the flow field in the left atrium conformation after the LAA occlusion. No significant differences were found between the CFD-PRE and CFD-POST simulations in terms of WSS distribution and therefore we could assume that probably the Watchman device insertion will not generate inflammatory phenomena.

[1] Berti S. et al, Left atrial appendage occlusion in high-risk patients with nonvalvular atrial fibrillation, Heart 2016; 102:1969-1973.