In vitro comparison of the flow in the left atrium in simulated normal and pathological conditions

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Introduction
In the context of atrial fibrillation, the occurrence of thrombo-embolic events is increased, among other, by the absence of atrial contraction. As the latter represents an important lack of activity in atrium dynamics, it is therefore important to identify and evaluate the hemodynamic factors determining the incidence of pathological events. The aim of this study is to explore the hemodynamics in a model of left atrium using Particle Image Velocimetry (PIV) technique in simulated normal and pathological conditions.

Methods
To perform this study we use a Dual Activation Simulator (DAS). The DAS (Mouret et al., 2000) is mainly composed of silicone-made, anatomically shaped models of the left heart cavities. Two pumps activate independently the atrial and ventricular models in order to reproduce physiological normal or pathological flow conditions in the left heart. For these experiments, flow conditions are the following: (1) The heart rate is 70 beats per minute (systole duration is 350ms). (2) The mean flow rate is 5 litres per minute. In accordance with clinical observations, the mitral flow is simulated as follows: for the normal conditions, the early filling magnitude is about twice the late filling magnitude and for the atrial fibrillation, there is no late filling and the atrium is slightly dilated. The ventricle is in sinus rhythm to allow instruments synchronisation and averaging.

PIV systems measure velocity by determining particle displacement in a plane of the flow over a known time. Eight planes are highlighted successively by the laser sheet. The planes are perpendicular to the mitral valve annulus and parallel to the plane made by the pulmonary veins (see figure 1). The cardiac cycle is studied on 17 instants. The velocity fields are averaged on 50 successive cycles.

Figure 1: PIV planes in the left atrium
Results & Discussion

In vitro atrial flow pattern has not been described yet. We encounter a complex flow dynamics in the left atrial cavity as suggested by in vivo MRI measurements (Kilner et al., 2000).

The atrial flow in normal conditions can be summarized as follows:
- In early diastole, the flow is aspired by the ventricular relaxation from the pulmonary veins to the mitral valve,
- The atrial contraction provides also a not insignificant emptying of the cavity,
- During the whole cardiac cycle, the filling by the pulmonary veins is symmetrical,
- We can observe the setting of four contra-rotative vortices when atrial pressure increases and filling and emptying flow decrease,
- A 3D structure develops in the external part of the atrium.

Figure 2: (left: plane +3, middle: plane 0, right: plane -3) In early diastole, a strong flow in the whole cavity. The pulmonary venous flow is symmetrical.

Figure 3: (left: plane 0, middle: plane -1, right: plane -2) In mid-diastole, four contra-rotative vortices develop due to low emptying.

The atrial flow in fibrillation can be summarized as follows:
- In early diastole, flow is strongly aspired by the ventricle,
- The cavity is strongly compressed during diastole,
- The pulmonary venous flow presents only one filling wave instead of two in normal conditions,
- Swirling structures, which are created in diastole, persist in systole thanks to the absence of atrial contraction,
- A helical vortex, located in the inferior part of the atrium, lasts during the whole systole.
A major difference in hemodynamics is observed when comparing normal condition and atrial fibrillation. As in *in vivo* measurements, the pulmonary venous flow is different in both conditions. Atrial fibrillation modify the filling pattern of the cavity, due to the absence of relaxation of the cavity after its contraction. This leads to an increase in residence time of the blood in the cavity and could help to favour thrombo-embolic events. Lack of atrial contraction is characterized by the presence of a helical motion which reminds of spontaneous echo contrast, often observed by echocardiography in case of atrial fibrillation. This study could be a first step towards the explanation of thrombo-embolic events incidence.

References