Design, Development and Test of Different Cardiac Contraction Models in Atrial Fibrillation

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Computational fluid dynamics represents a valuable non-invasive approach to assess physically meaningful parameters in a complex fluid dynamics system represented by AF. The aim of this study was the design, development and test of different LA motion fields in AF to clarify the influence of contraction models on LA hemodynamics.

A patient-specific 3D anatomical model of the LA was obtained from CT data. Non-rigid registration of the dynamic acquisitions allowed us to derive the 3D LA motion field in sinus rhythm (SR). Since LA motion field during AF is not available from clinical data, three displacement models were designed to simulate the irregular, disorganized, very rapid and strongly reduced LA contraction:

- a random model: $\boldsymbol{d}_f = M \cdot \boldsymbol{r} sin(2\pi f t)$ with f=4Hz, M=0.1 and $\boldsymbol{r}$ random spatial and temporal distribution;
- a discrete random model:
  $$Newnode(i,j) = Node\ (i,j) \pm \frac{0.5+0.5\cdot rand(1,1)}{d} \cdot \vec{l}$$
  where l is the displacement direction and d an attenuation term;
- a continuous sinusoidal model: $\boldsymbol{d}(\boldsymbol{\theta}) = \boldsymbol{r}(\boldsymbol{\theta}) \cdot \sin(\frac{2\pi\boldsymbol{\theta}}{L}) \cdot d \cdot \sin(wt)$ where $\boldsymbol{\theta}$ is the angular direction with respect to the LA barycenter and the spatial length L =7.5 mm.

Blood velocity, kinetic energy, vortex structures and blood stasis in the LA were analyzed in both SR and AF conditions.

Velocities in SR were higher than in AF, particularly during atrial systole. The three AF models resulted in different wash-out velocities both at the mitral valve and at the ostium of the LA appendage (see figure). Vortices were also differently distributed inside the LA showing a more organized flow in the sinusoidal model which was also characterized by the lowest blood stasis (8.6%) inside the LA appendage. Overall, different LA deformation models in AF affect LA hemodynamics and additional studies should be performed to develop a realistic contraction model to simulate AF episodes.

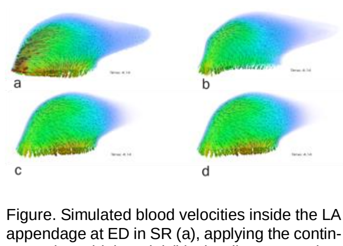

Figure. Simulated blood velocities inside the LA appendage at ED in SR (a), applying the continuous sinusoidal model (b), the discrete random model (c) and the random model (d).