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Characterization of Flow Structure and Wall Shear Stress in Patient-Specific AAA Phantom using PIV

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Motivation and Objective:

Abdominal aortic aneurysms (AAA) involve abnormal dilation of the aorta, with ruptures posing serious risks to life. Hemodynamic factors, particularly flow dynamics and wall shear stress (WSS), play a crucial role in aneurysm growth and rupture. Variations in WSS are associated with turbulent flow and the degradation of the extracellular matrix, which can weaken the vessel wall and lead to thrombus formation. Techniques like particle image velocimetry (PIV) and computational fluid dynamics (CFD) help study AAA hemodynamics, but accurately predicting WSS near the aneurysm wall and validating models is still difficult. New parameters, including time-averaged WSS (TAWSS), oscillatory shear index (OSI), endothelial cell activation potential (ECAP), and relative residence time (RRT), are being developed to better describe shear environments related to AAA progression.

This study characterizes flow dynamics and wall shear stress (WSS) in a patient-specific abdominal aortic aneurysm (AAA) phantom using particle image velocimetry (PIV). We analyzed flow fields across 12 cardiac cycle phases and three PIV planes to derive WSS and shear stress indices such as TAWSS, OSI, ECAP, and RRT. These insights will enhance our understanding of the factors contributing to AAA growth and rupture, leading to better diagnostic tools, risk assessments, and treatment strategies for patients.

Methodology:

The experiments were performed using the *METU Cardio Simulator*, a closed-loop flow circulatory system in the Experimental Fluid Mechanics Laboratory at Middle East Technical University. Figure 1 presents the flow and pressure waveforms in aneurysm inlet and Figure 2 shows the schematic of the setup, detailing the flow of the circulatory system. The system features a computer-controlled servomotor-gear pump that simulates various physiological flow patterns and pressure distributions while circulating a blood-mimicking fluid (BMF) through a patient-specific aneurysm phantom.

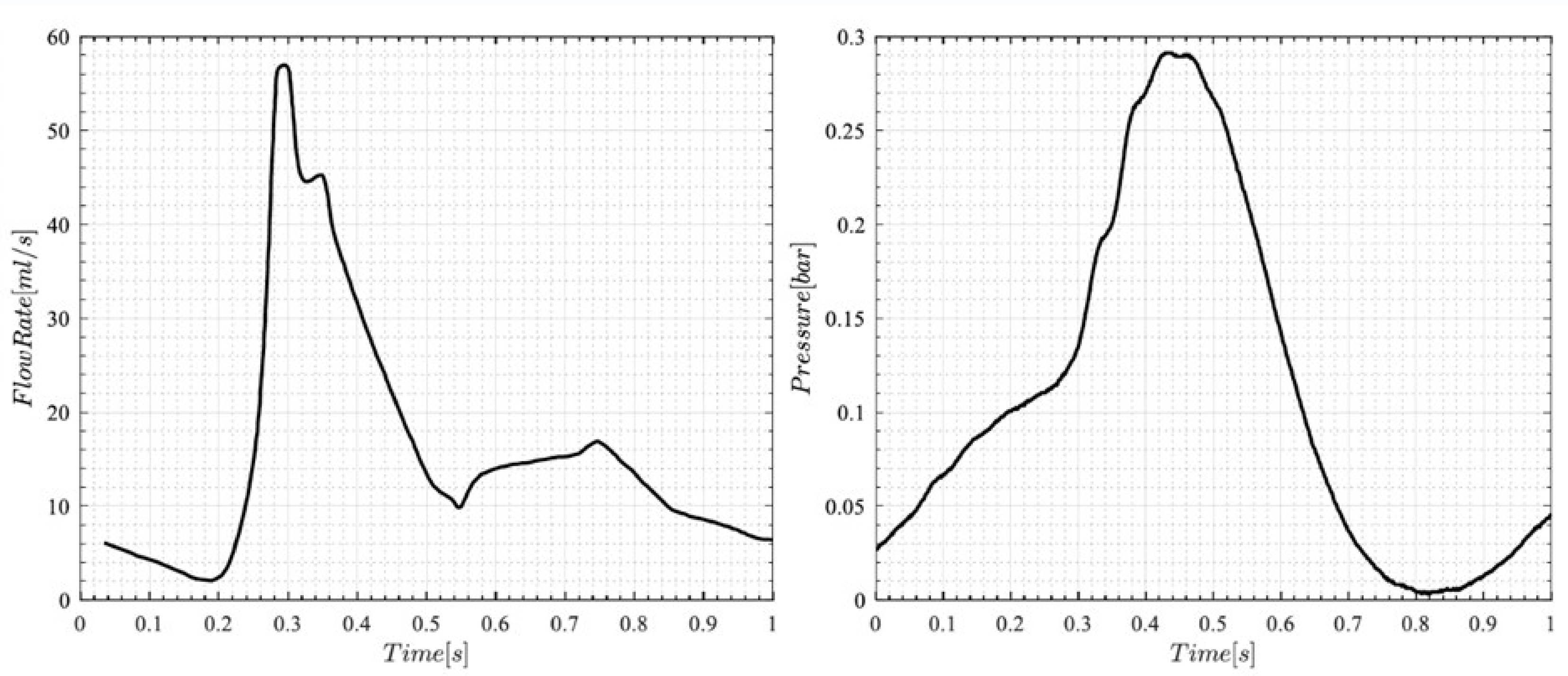


Figure 1 Flow rate (left) and pressure waveforms (right) measured in aneurysm inlet.

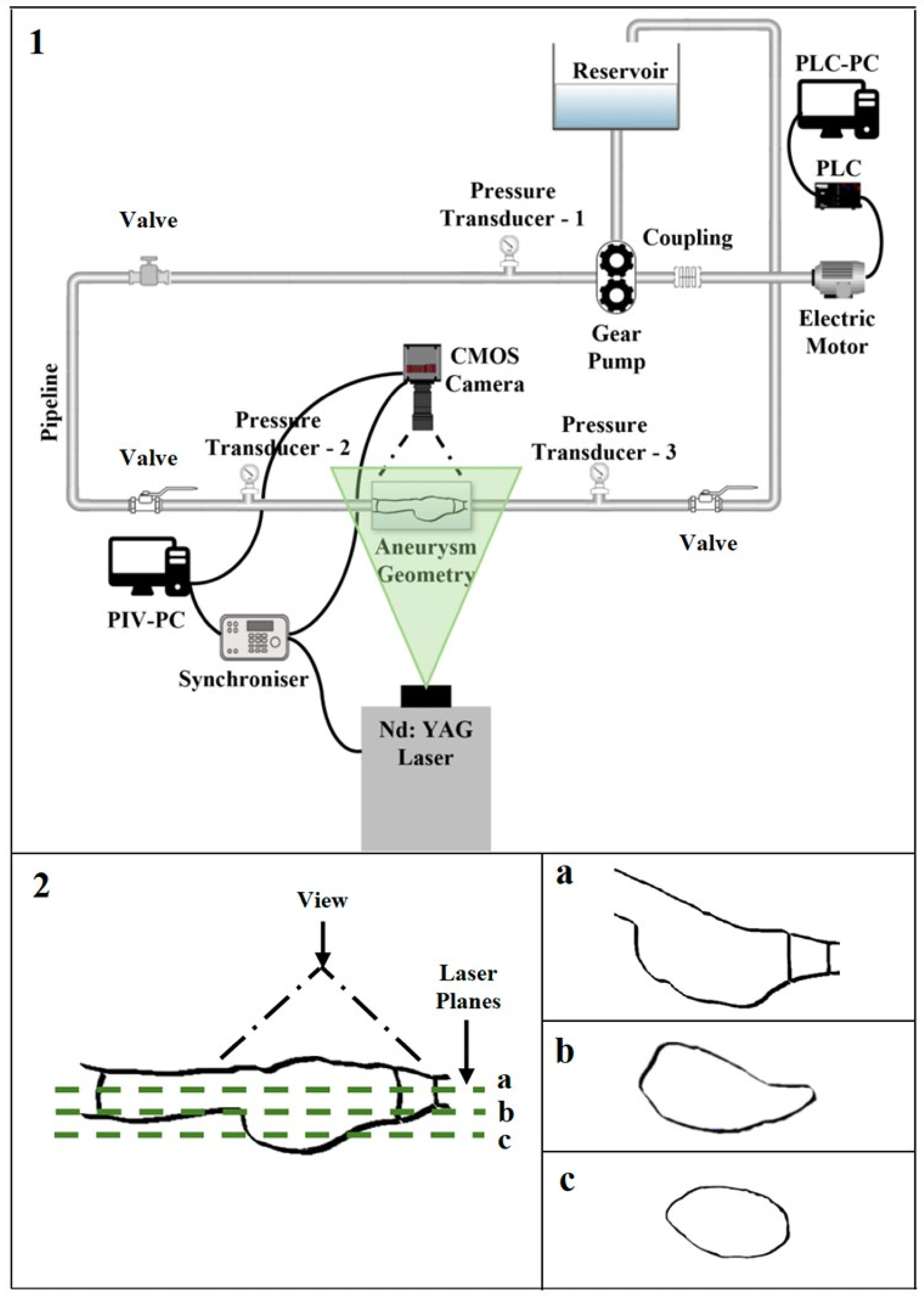
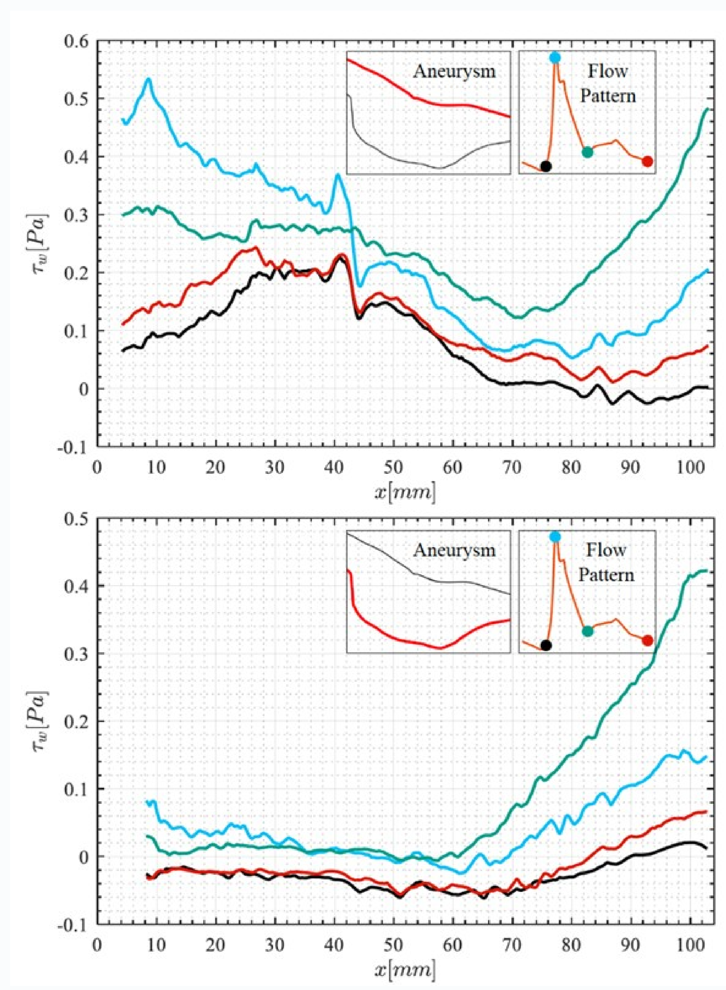


Figure 2 The schematic representation of the experimental setup (1), Field of view and measurement planes, planes - a, b, and c (2).

Results:



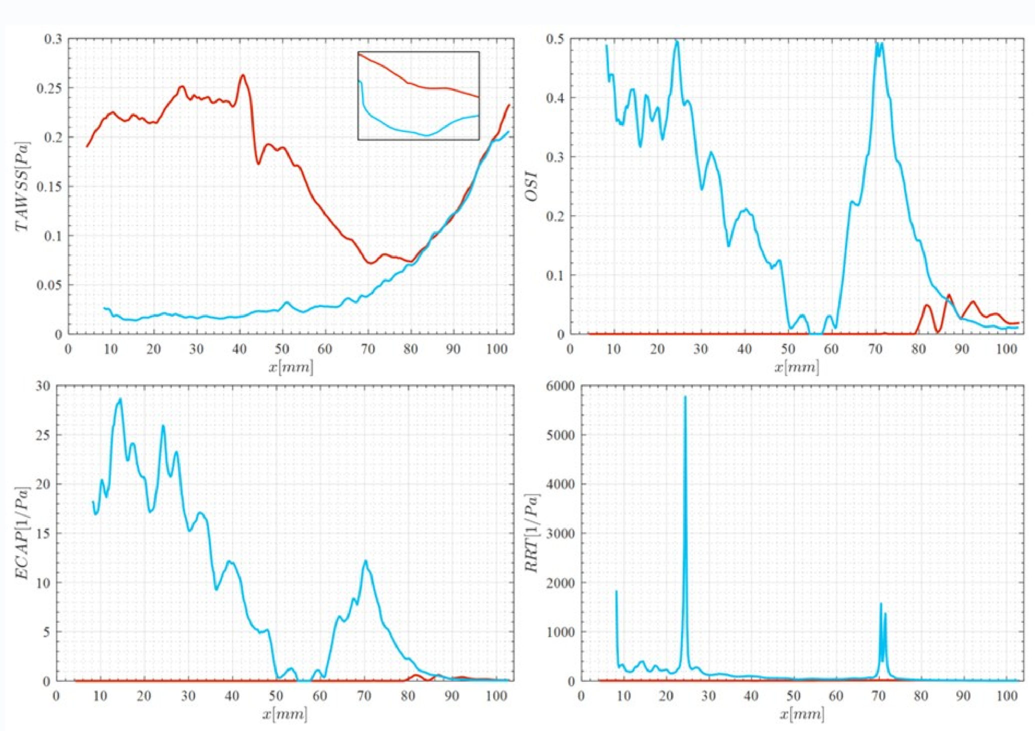


Figure 3 WSS parameters at upper and lower walls of bulge center.

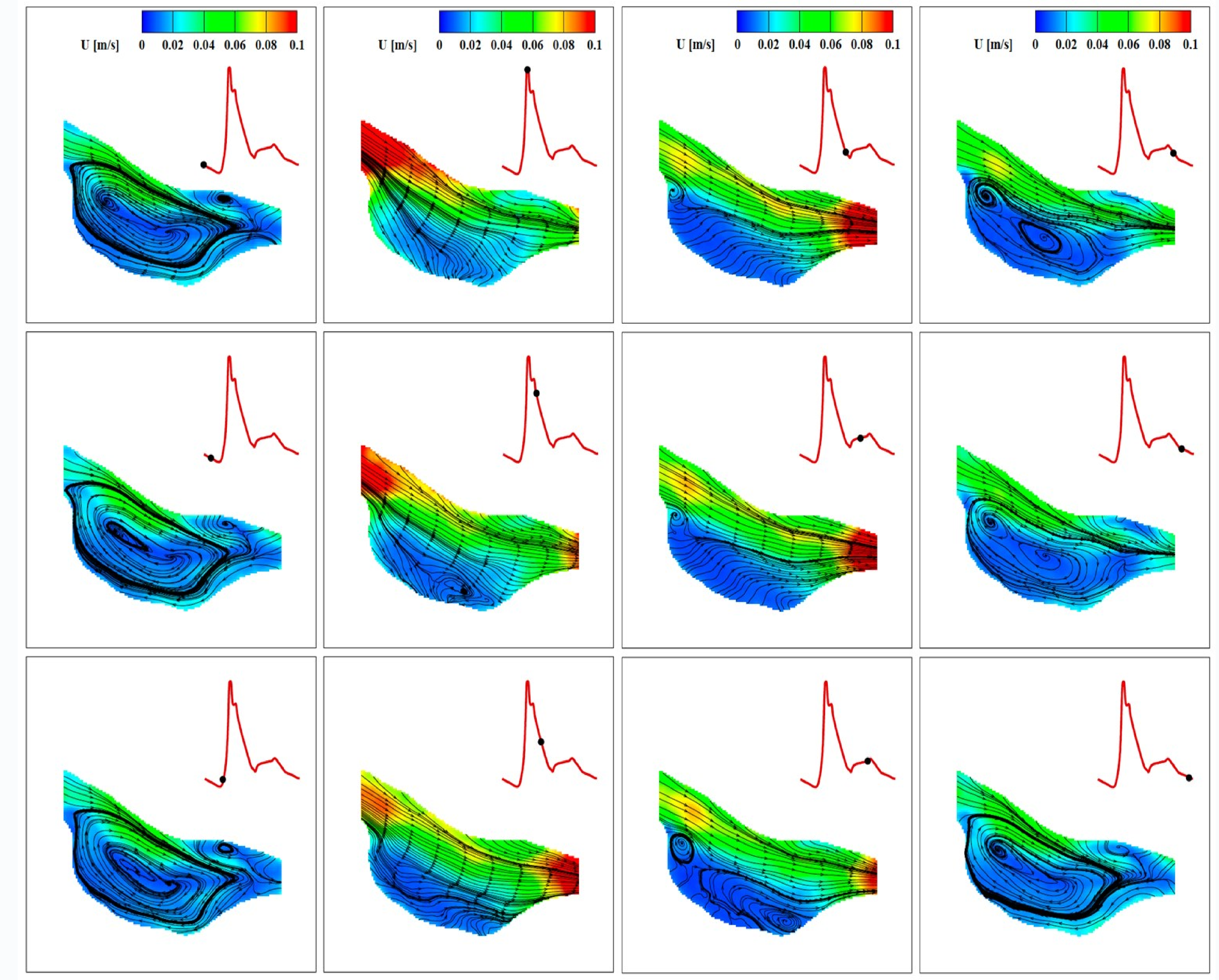


Figure 4 The phase-averaged streamline patterns and velocity magnitude contours at center plane, plane - a, of the cardiac cycle.

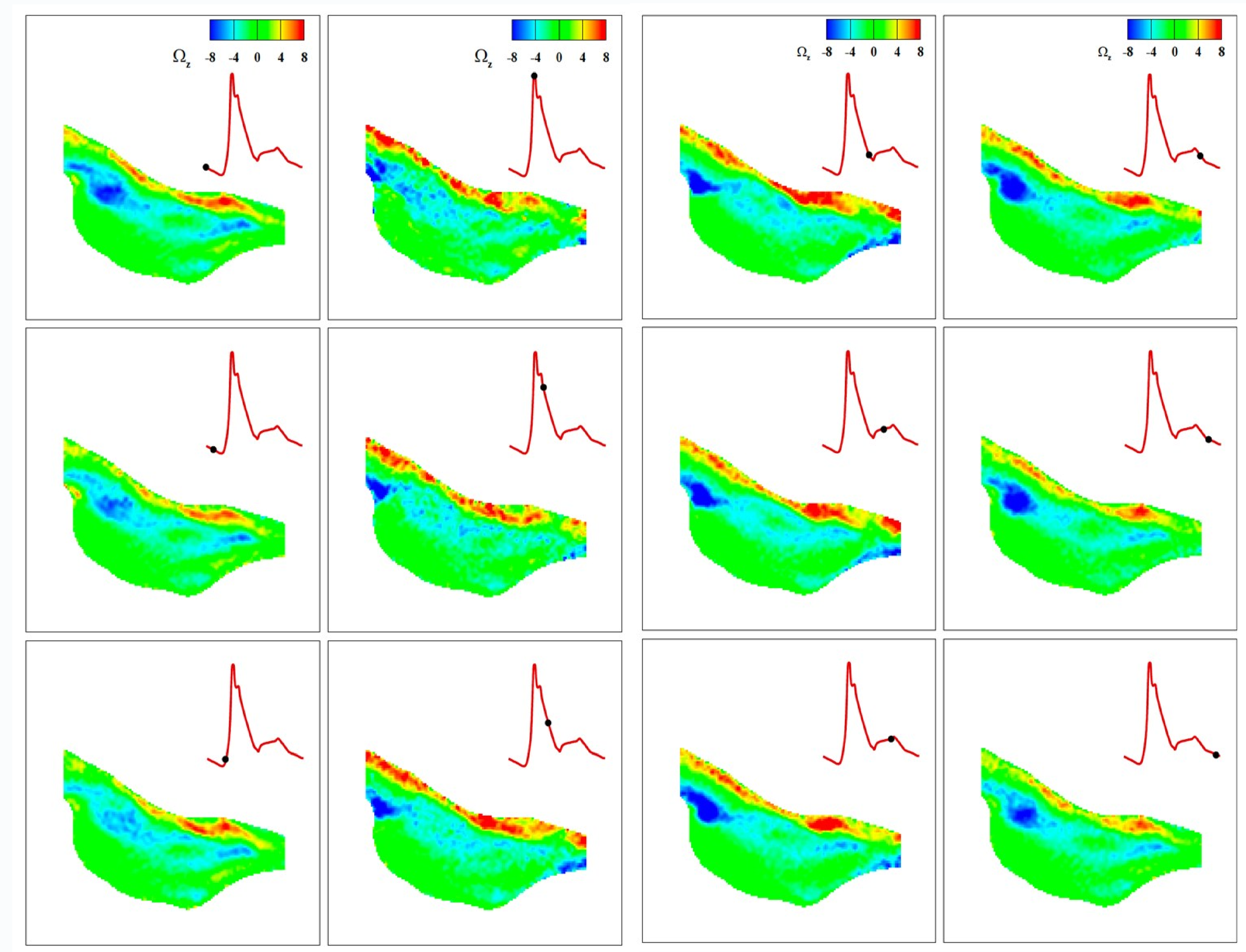


Figure 5 The phase-averaged vorticity contours at center plane, plane - a, of the cardiac cycle.

Conclusions:

- Flow separates from the bulge's lower surface near the inlet and reattaches at the end, creating a large swirl pattern in the sac. There is also flow separation from the upper surface near the outlet due to a change in curvature.
- Separation regions and the reattachment zone are linked to strong swirling concentrations, creating vortical patterns, corresponding with high OSI, ECAP, and RRT values.