ARTERIOVENOUS FISTULA MATURATION – A FLUID-STRUCTURE INTERACTION FOLLOW-UP STUDY.

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Introduction

Arteriovenous fistula (AVF) is a widely accepted vascular access in haemodialyzed patients. AVF is formed by suturing the patient's artery and vein. Creating such an artificial connection (anastomosis) is followed by a maturation process (MP) associated with significant hemodynamic changes. MP is crucial, however, 20-60% of newly created AVFs fail to mature which is associated with the mutual interaction of non-physiological blood flow and AFV vasculature [1]. This bidirectional fluid-structure interaction (FSI) study addresses blood flow through the maturing AVF. This extends the findings obtained in a preliminary study based on rigid wall simulations [2].

Methods

A single AVF was followed up for 15 weeks and examined 1.5 years after surgery. Geometric and flow data were collected using the safe ultrasonic methodology described in [2]. Velocity curves were used as inlet boundary conditions. Blood pressure pulsations were modelled. The stiffness of the artery, suture, and vein was varied and the stiffening of the venous wall was modelled over time. The mechanical response and attenuation of the loose connective tissue surrounding the AVF were taken into account (Fig. 1).

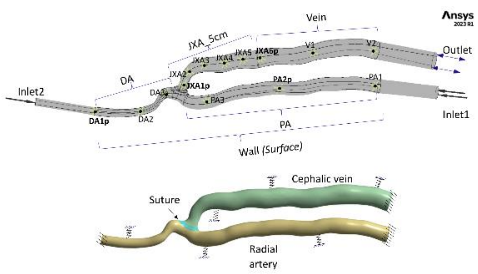

Figure 1: Fluid and wall of the fully matured AVF.

While obtaining geometric data, the patient's vascular system is subjected to initial stress. To compensate for unwanted deformations caused by pressure, external pressure was applied. Blood was treated as a non-Newtonian fluid. The SST turbulence model was used.

Results

The FSI methodology allowed us to take into account the interaction of blood flow and blood vessel walls. In the third cardiac cycle, temporal hemodynamics, wall deformation, and von Mises stress were analyzed. Changes in time-weighted parameters were monitored within the maturation and later. The two combining arterial blood streams generated two opposing rotating vortices at the anastomosis, increasing the local blood velocity and lowering the blood pressure throughout the MP process. Blood flow disturbances were visualized with coherent structures. Large fluctuations in blood vorticity, shear strain, and TKE were found in the JXA region (Fig. 1) where peak values of these parameters were determined. Extreme WSS>20 Pa was present near the anastomosis over the entire cardiac cycle at every stage of the MP. The absence of stagnation, associated with sufficient washout, was confirmed by small zones occupied by low WSS (<0.6 Pa) covering 10% of the entire vasculature for a short time (Fig. 2). Changes in time-averaged WSS were monitored in all parts of the AVF.

Figure 2: Low-WSS zones (max outflow).

The largest wall deformation (0.277 mm) was found in the JXA in 1st week due to the highest compliance of the venous wall. After 4 weeks of venous stiffening, the maximal extension zone moved to the artery (Fig. 3).

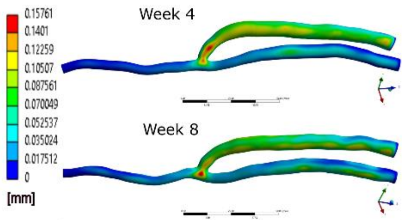

Figure 3: Migration of maximal deformation zone.

Discussion

Blood flow disturbances occurred at all stages of MP. Extreme WSS increases the risk of internal remodelling, but stenosis has not developed within 1.5 years. The studied AVF, due to continuous washout, was a well-functioning fistula without thrombosis. The deformation of the wall depends on the MP stage.

References

1. Bozzetto et al., Cardiovasc. Phys. Eng. Sci. Med. 47(1):187-197, 2024.
2. Colley et al., Biomech. Model. Mechanobiol., 21:1217–1232, 2022.

Acknowledgments

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