EXPLORING ARTERIOVENOUS FISTULA WALL VIBRATIONS: A FLUID-STRUCTURE INTERACTION LONGITUDINAL STUDY

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Introduction

Native arteriovenous fistula (AVF) is the preferred vascular access for hemodialysis, yet its high failure rate [1], mainly due to stenosis formation, remains a challenge. We have recently demonstrated that transitional flow induces high frequency vibrations in the AVF wall, and hypothesised that the associated dynamic mechanical stresses resulting from these vibrations can be an overlooked mechanobiological stimulus [2]. This fluid-structure interaction (FSI) longitudinal study aims to investigate the unexplored relation between high-frequency vascular wall vibrations and potential adverse vessel remodeling.

Methods

Contrast-free magnetic resonance imaging (MRI) scans were acquired at multiple timepoints (up to 1 year) in six patients referred for radio-cephalic AVF. Two patients exhibited proper maturation and long-term patency, while the remaining four developed complications, that were either stenosis development or excessive dilatation. Three-dimensional AVF geometries were reconstructed and fully coupled 2nd order accurate space/time centred high-fidelity FSI simulations were performed using turtleFSI [3]. Meshes consisting of 200,000 tetrahedral elements were used, along with a time discretization set at 0.1 ms. Patient-specific inflow and pressure were incorporated, and a 3-term Mooney-Rivlin model was fitted using experimental data for both artery and vein. The viscoelastic effect of perivascular tissue was modeled with Robin boundary conditions. A cutoff threshold of 25 Hz was used for high-pass filtering to isolate vibrations from the displacement caused by heart rate pulsation. The time-average of the 99th percentile spatial value was considered for vibrations amplitude [4]. Spectrograms were generated to illustrate the evolution of high-frequency content in displacement signals over the cardiac cycle [4].

Results

Patients who experienced AVF complications exhibit notably elevated vibration amplitudes ([1.4 - 63.7 μm]) and a visible spectral content up to 500 Hz, characterized by a prominent narrowband around 60 Hz. In contrast, patients with successful maturation show negligible high-frequency vibrations ([0.5 - 11.0 μm]) and a markedly lower spectral content. *Figure 1* illustrates the results for two representative patients, P1 with venous stenosis and P2 with successful long-term patency.

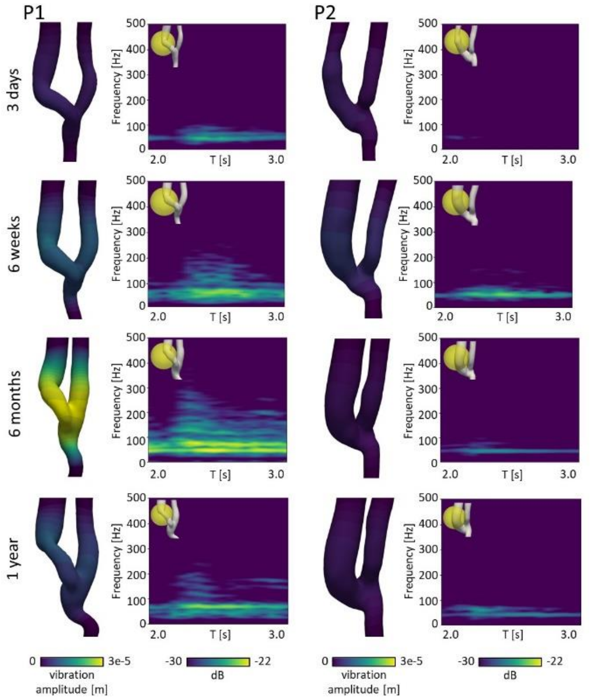

Figure 1: Surface maps of time-averaged vibration amplitude and displacement spectrograms extracted in the juxta-anastomotic vein for two representative patients at four timepoints.

Discussion

Results reveal high frequency vibrations in the patients who developed complications, whereas the fistulas that underwent proper maturation and showed long-term patency exhibited very low high-frequency content. Our preliminary findings indicate distinct vibration responses corresponding to different AVF outcomes, suggesting a potential association between high-frequency mechanical stresses within the vascular wall and adverse remodeling. If the relation between vibrations and AVF complications will be confirmed in a lager cohort, this finding could have implications for clinical practice. The possibility of detecting AVFs at risk of closure, based on monitoring their vibrations, could enable surgeons to timely intervene, improving AVF clinical outcomes.

References

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