SIMULATING ARTERIOVENOUS FISTULA SOUNDS: A FLUID-STRUCTURE INTERACTION APPROACH

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Introduction

The arteriovenous fistula (AVF) remains the preferred vascular access for hemodialysis, but its effectiveness is compromised by frequent failure due to adverse vascular remodeling [1]. Recent research has unveiled that the presence of transitional flow within the vein, coupled with its interaction with the vessel wall, induces high-frequency wall vibrations [2] and sounds. The qualitative auscultation of AVF sounds is used in clinical settings for the assessment of AVF functionality [3]. However, the relationship between these sounds and hemodynamic conditions remains unclear. Hence, this study aims to establish a method to translate fluid pressure and wall vibration data derived from fluid-structure interaction (FSI) simulations into sounds.

Methods

In this study, six patients with radio-cephalic AVF were examined. Following the AVF's functional maturation (3-8 weeks post-surgery), MRI scans were conducted to create patient-specific 3D models. These models were utilized for high-fidelity FSI simulations using a fully coupled 2nd order accurate space/time centred scheme [4]. The simulation data were converted into sounds, assuming the magnitude of hemodynamic data as the sound intensity and the same sampling frequency of the simulation. The resulting sounds, filtered at 25 Hz, were repeated over four cardiac cycles to compare with clinical measurements and spectrograms were generated. Specifically, the location within the venous segment exhibiting the highest vibration amplitude was selected to represent vibration behavior and sonified. Similarly, the point within the vein experiencing the highest pressure fluctuations was selected for sound generation.

Results

Vibration and pressure sounds were successfully generated at specific points of interest for all AVFs. Within the same patient the sonification of pressure and displacement produces different tones with higher frequencies detected in the pressure sounds. The six participants presented varying AVF geometries, hemodynamics, and outcomes in wall vibrations, leading to individualized sound profiles. Illustrated in Figure 1 are two representative cases. AVFs with decreased vibration amplitudes (as for Patient 1) produced sounds characterized by lower frequencies and intensity. Conversely, heightened peak pressure (Patient 2) led to spectrograms displaying higher frequencies.

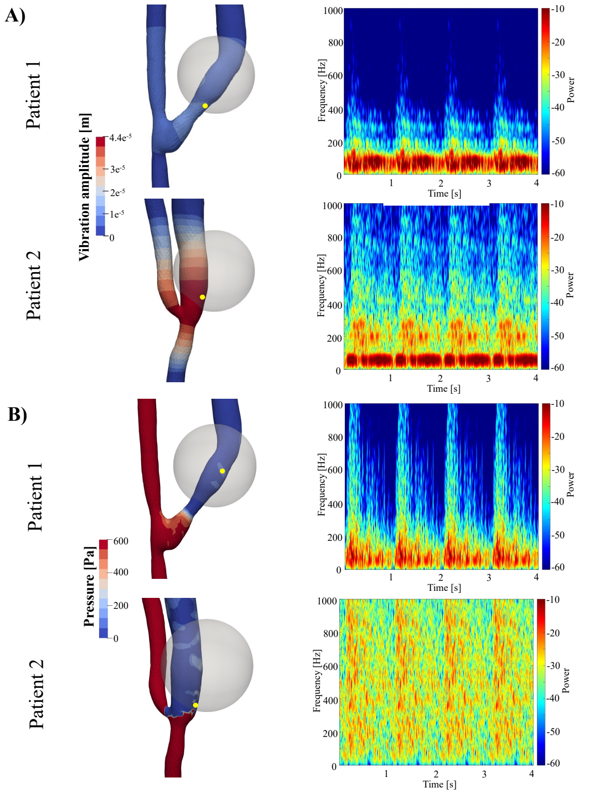

Figure 1: Surface maps with associated spectrograms of point-wise generated sounds of A) time-averaged vibration amplitude and B) systolic peak pressure for two representative patients.

Discussion

All sounds generated from FSI results were considered similar to those recorded in clinical practice [5]. Preliminary findings revealed differences in generated sounds potentially related to AVFs geometry and hemodynamics. Understanding the relation between computationally generated sounds and related hemodynamic phenotypes could clarify the origin and the specific determinants of certain sound features detected in clinical settings, connecting frequency bands with AVF clinical conditions. This approach could further facilitate the validation of AVF sound analysis as a monitoring technique.

References

1. Bozzetto M et al, JVA, 24.5: 1061-1068, 2023.
2. Bozzetto M et al, Phys Eng Sci Med, 1-11, 2023.
3. Lok CE et al, Am J Kidney Dis, 75.4: 1-164, 2020.
4. Bergersen A W et al, JOSS, 5.50: 2089, 2020.
5. Tsuboi M et al, JVA, 23.3: 390-397, 2022.