GENERATION OF ARTERIOVENOUS FISTULA SOUNDS THROUGH FLUID-STRUCTURE INTERACTION SIMULATIONS

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Introduction

The arteriovenous fistula (AVF) is the preferred vascular access for hemodialysis, but it is still associated with a high failure rate due to unfavorable vascular remodeling [1]. Recent findings revealed that the presence of transitional flow within the AVF vein, and its interaction with the vessel wall, leads to high-frequency vascular wall vibrations [2]. Moreover, in routine clinical practice, the functionality of AVFs is evaluated through the auscultation of AVF sounds, but this approach is still qualitative and based on clinician experience [3]. Indeed, the relationship between sounds and hemodynamic conditions still needs to be elucidated. Thus, the purpose of this study was to develop a pipeline to sonify fluid pressure and wall vibration obtained from fluid-structure interaction (FSI) simulations.

Methods

Six patients with radio-cephalic AVF were involved in the study. At the time of AVF functional maturation (3-8 weeks after surgery), MRI was acquired and patient-specific 3D models were generated. High-fidelity patient-specific FSI were performed using a fully coupled 2nd order accurate space/time centred scheme [4] and the results were used for post-processing and sound generation. Specifically, the point on the venous segment associated with the maximum vibration amplitude was selected as the most representative of vibration behavior. Data were high pass filtered at 25 Hz and the corresponding sound was generated and evaluated for 4 cardiac cycles to allow comparison against clinical measurements, assuming the magnitude of vibration amplitude as the sound intensity and the same sampling frequency of the simulation. Similarly, the point in the vein with the maximum pressure fluctuations was selected and sonified. Spectrograms were obtained from generated sounds.

Results

For all AVFs, vibration and pressure sounds were successfully generated in the points of interest. Within the same patient the sonification of pressure and displacement produces different tones with higher frequencies detected in the pressure sounds. The six participants had different AVF geometries, distinct hemodynamics, and wall vibrations outcomes, resulting in unique sound profiles. As shown for two representative cases in Figure 1, AVFs with reduced vibration amplitudes generate sounds with both lower frequencies and intensity. Conversely, elevated peak pressure results in sounds spectrograms characterized by higher frequencies, visible up to 1000 Hz.
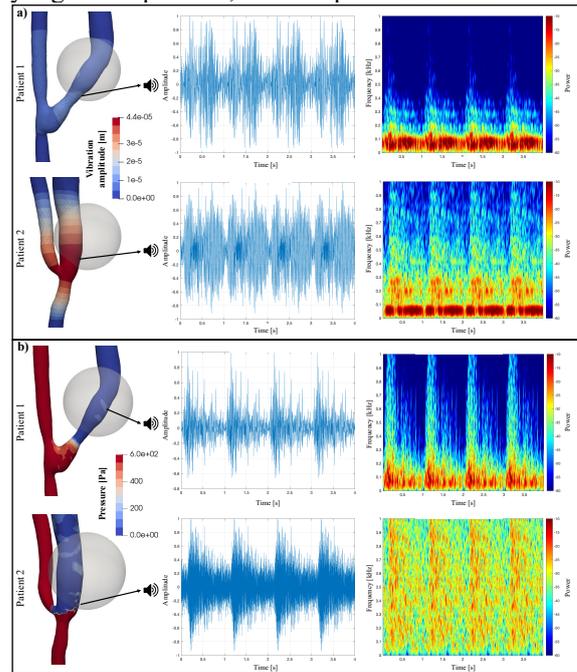

Figure 1: Surface maps of a) time-averaged vibration amplitude and b) systolic peak pressure with associated time analysis and spectrograms of point-wise generated sounds for two representative patients.

Discussion

Preliminary results indicate the potential to generate sounds through FSI simulations, revealing differences that can be related to geometry, hemodynamic and stress conditions. All generated sounds were considered plausible when compared with those typically observed in clinical practice [5]. Implementing the sonification of points with well-characterized hemodynamic patterns could elucidate the source and causes of specific sound features detected in clinical settings, relating frequency bands and AVF clinical conditions. This approach can also pave the way to the validation and exploitation of sound analysis as a monitoring technique for the AVF.

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.