



Biomechanical Evaluation of Transcranial Vibroacoustic Stimulation (tVAS) for Enhancing Cerebrospinal Fluid Circulation

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Background

Neurodegenerative diseases such as **Alzheimer's disease** are a major public health challenge. **Transcranial vibroacoustic stimulation (tVAS)** has emerged as a novel modality that utilizes low-frequency mechanical vibrations to modulate neural circuits. While previous research has evaluated the efficacy of tVAS from neurophysiological perspectives, this study examines its **mechanical impact** using a comprehensive **whole-head finite element (FE) model**. Specifically, the effects of stimulation frequency, input force magnitude, and device positioning were evaluated to determine their influence on **cerebrospinal fluid (CSF) hydrodynamics**.

Methods

Whole head modeling

Material parameters were adopted from prior literature [1–3]

Solid: **linear viscoelastic**

$$-\rho\omega^2\mathbf{u} = \nabla \cdot (\mathbf{FS})^T + \mathbf{F}_v e^{i\phi}$$

Liquid (CSF) :

linearized Navier–Stokes equation

$$\rho \frac{\partial \mathbf{u}}{\partial t} = -\nabla p + \mu \nabla^2 \mathbf{u} + \rho \mathbf{g}$$

Model validation

Washington University 50 Hz **MRE data** (n = 26) were used for model validation. Load was applied to the right temporal region, and shear strain components ($\epsilon_{xy}, \epsilon_{xz}, \epsilon_{yz}$) were extracted for calculating **similarity metrics**:

$$C_V \text{ (volumetric)} = \epsilon_V^{(p)} \cdot \epsilon_V^{(q)} \quad C_S \text{ (slice-wise)} = \epsilon_S^{(p)} \cdot \epsilon_S^{(q)} \\ (\text{p=experiment, q=simulation})$$

Using a **leave-one-out approach**, we verified that the simulated similarity scores (C_V , C_S) fell within the inter-subject variability range of the 26-subject dataset.

AriBio tVAS device

The **AriBio tVAS device** served as a source to evaluate the influence of the following parameters on **CSF hydrodynamics**

Category	Investigated Parameters
Frequency	Low (10–40 Hz) vs. High (50–100 Hz)
Force	0.5–2.0N
Placement	3 positions on the temporal lobe

Figure 1. Anatomical layers in the FE head model

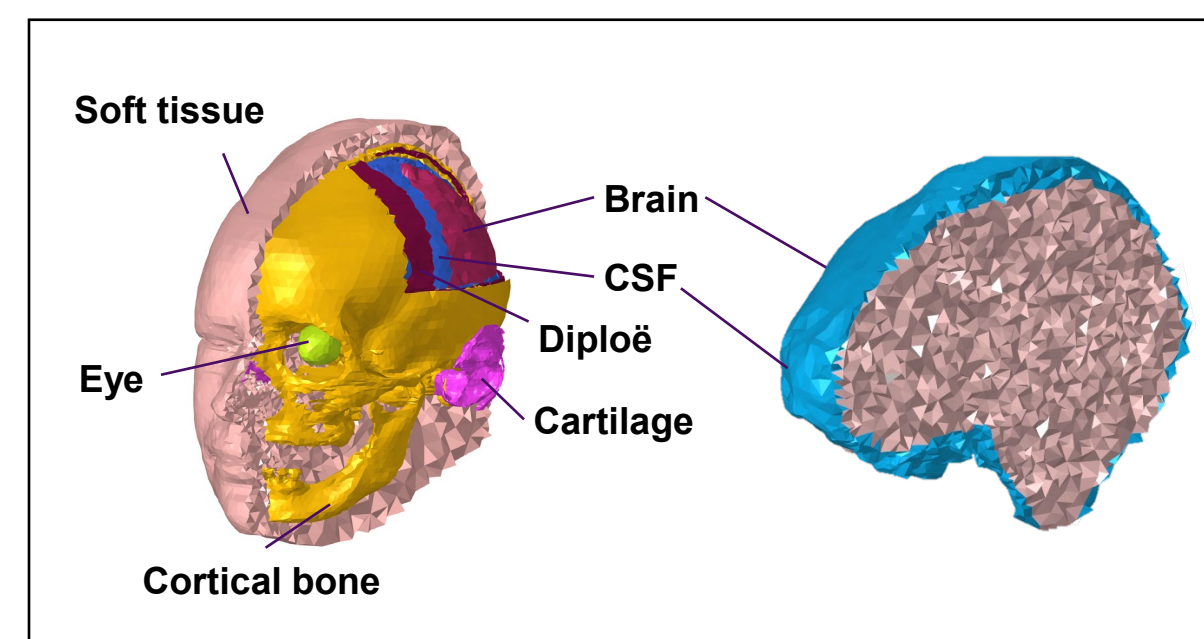


Figure 2. MRE validation results

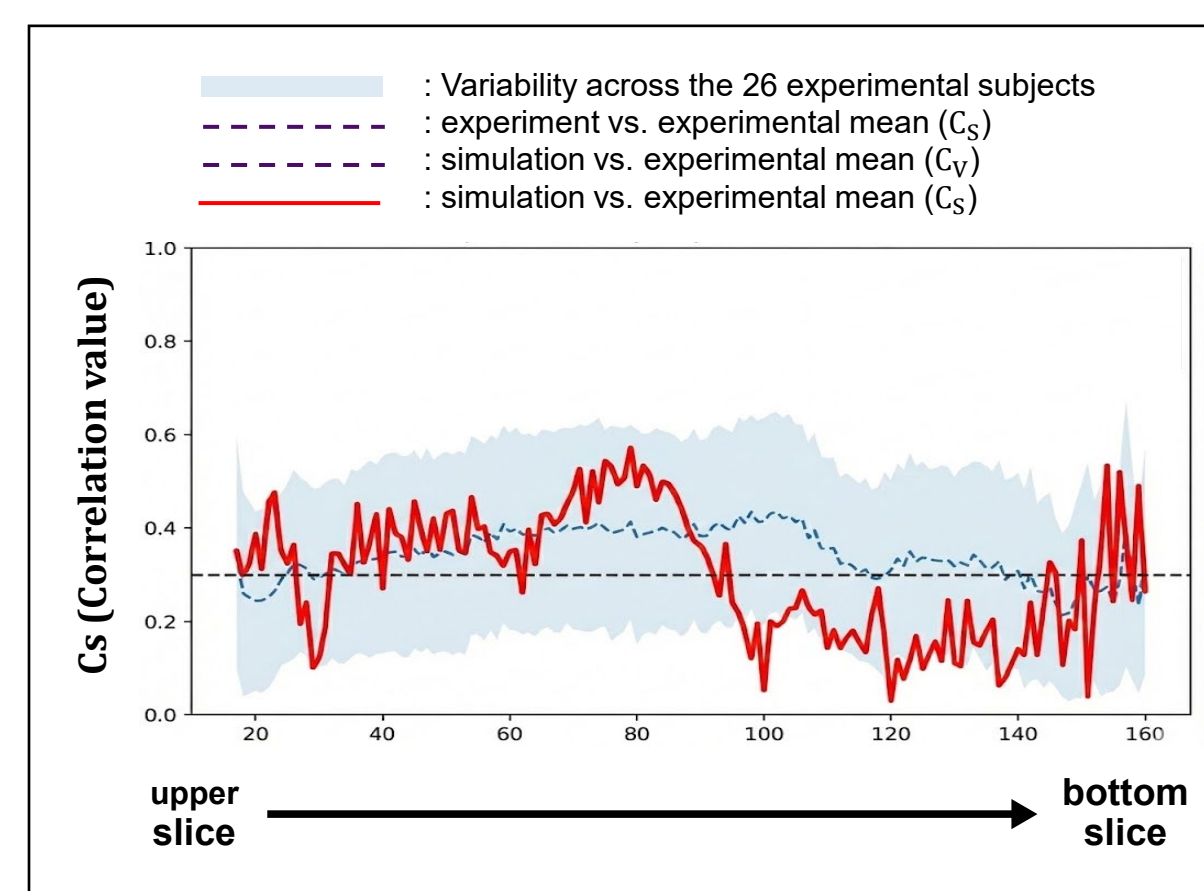
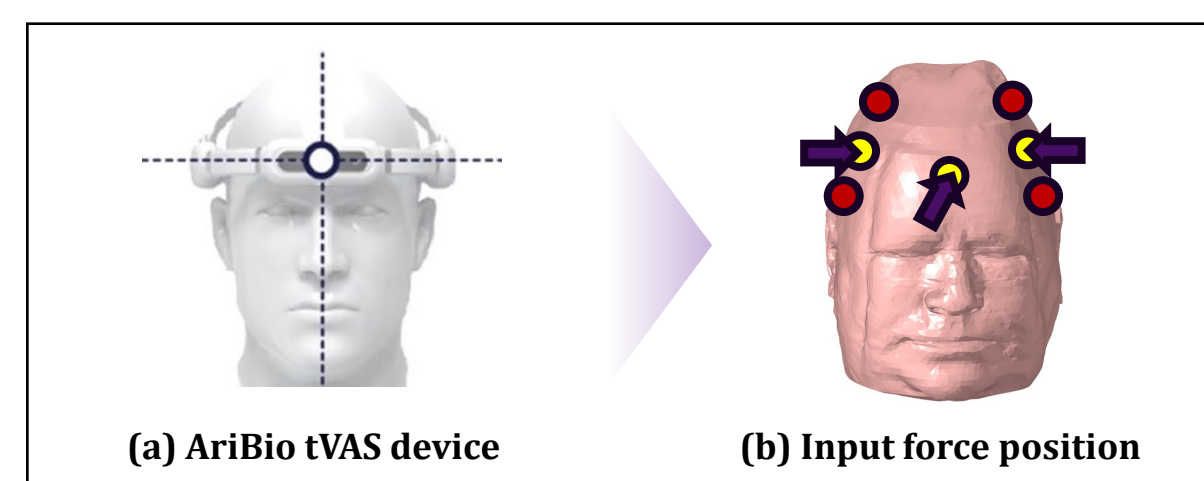


Figure 3. AriBio tVAS device and input force positions on whole head model



Results

Effect of frequency on CSF hydrodynamics

A comparison of the shear field and energy intensity between low-frequency (20 Hz, 40 Hz) and high-frequency (80 Hz) device inputs shows that low-frequency input produces both higher shear fields and greater energy intensity.

Figure 4. CSF shear field comparison in (a) (b) Low-frequency and (c) high-frequency

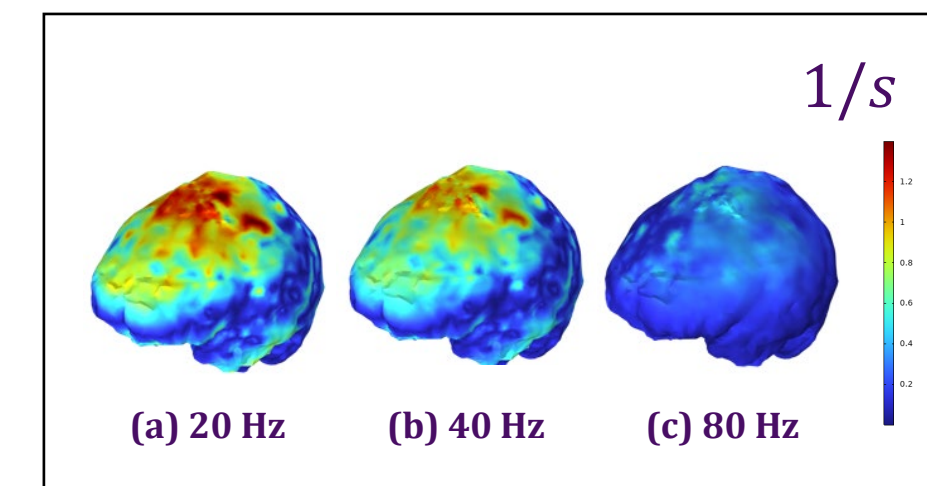
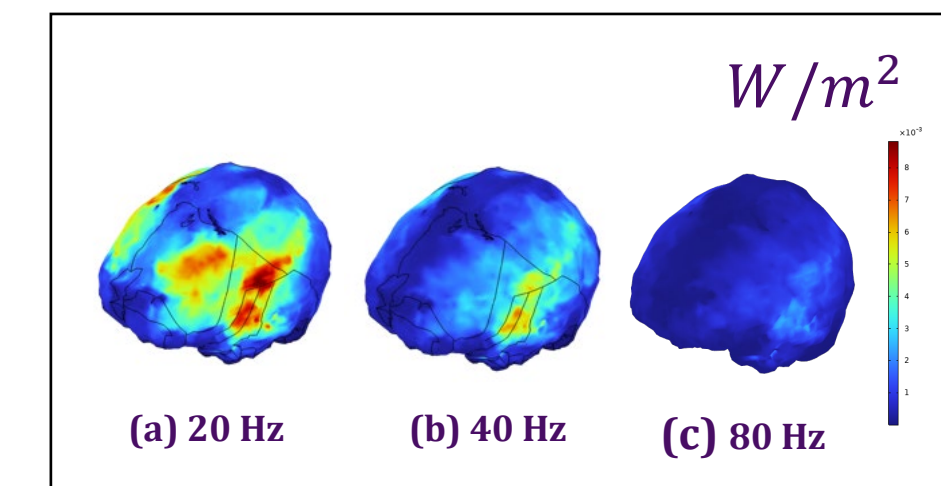


Figure 5. CSF shear field comparison in (a) (b) Low-frequency (c) high-frequency



The maximum energy intensity and shear field show a clear decreasing trend as the excitation frequency increases, with the highest values observed at low-frequency inputs.

Figure 6. CSF max shear field comparison 10–100Hz

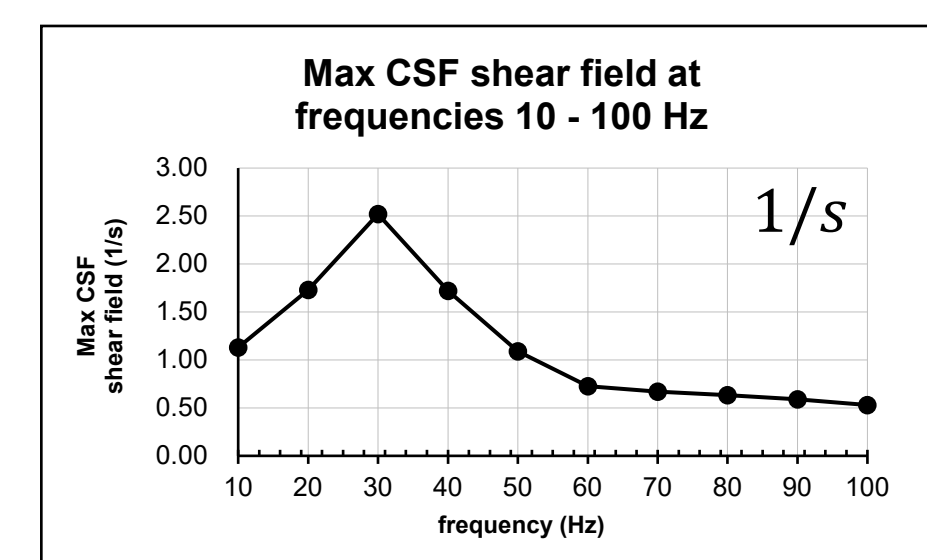
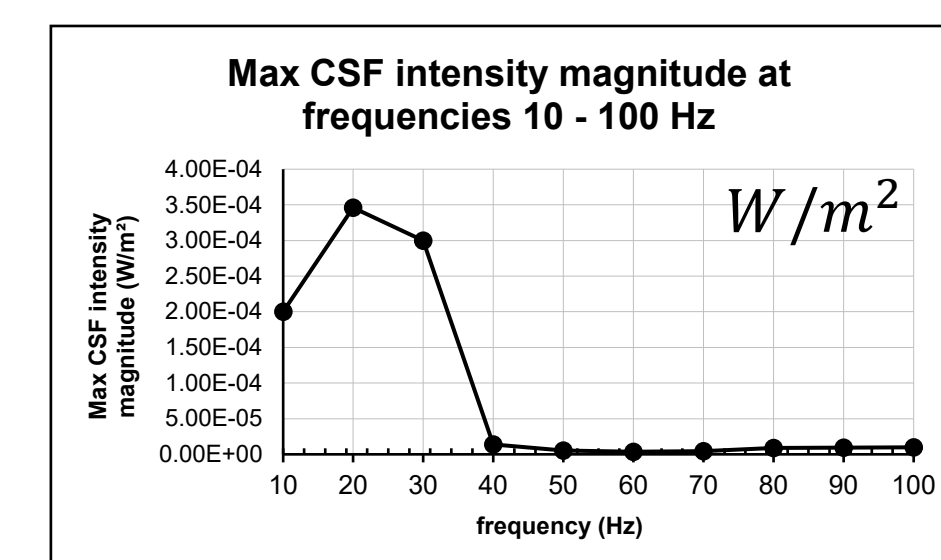


Figure 7. CSF max energy intensity comparison 10–100Hz



Effect of vibration input force on CSF hydrodynamics

The results showed that both the maximum CSF shear field and energy intensity increased with device level, from level 1 to 15 (vibration load: 0.5–2 N).

Figure 8. CSF max shear field comparison at increasing vibration load

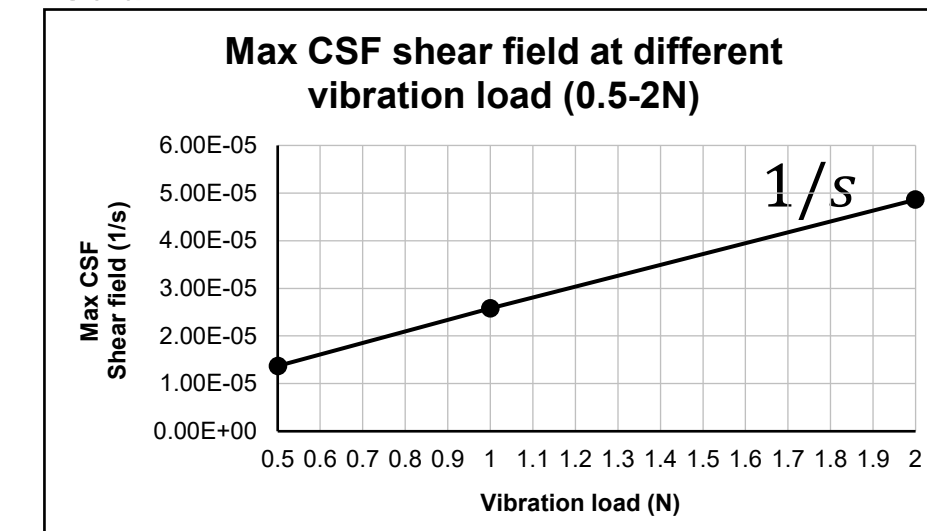
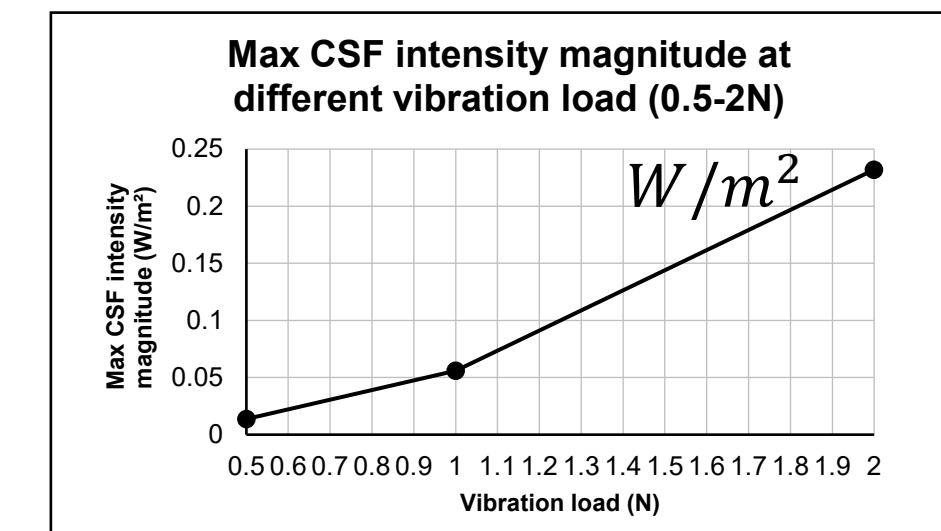


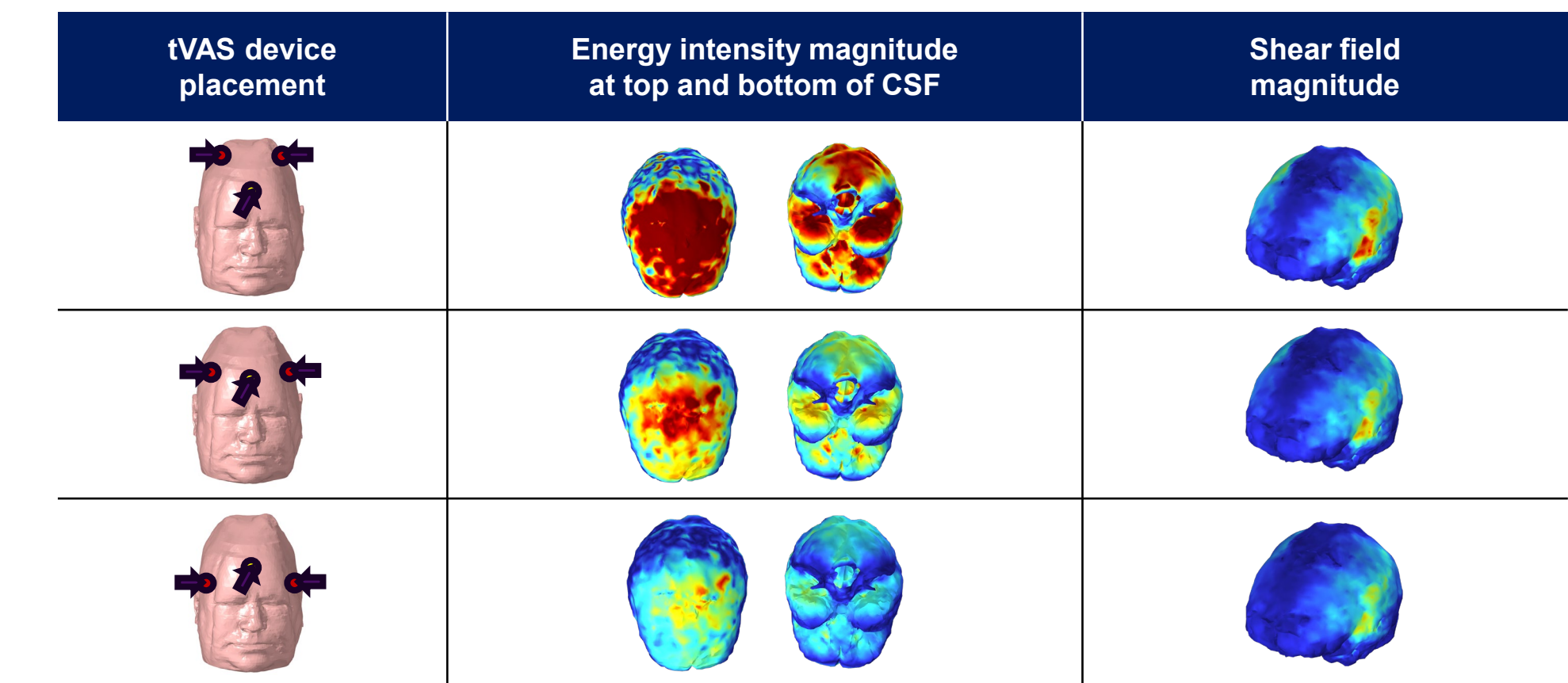
Figure 9. CSF energy intensity at increasing vibration load



Effect of vibration tVAS device placement on CSF hydrodynamics

As the device was placed at more superior (cranial) positions, both the CSF shear field and the energy intensity increased.

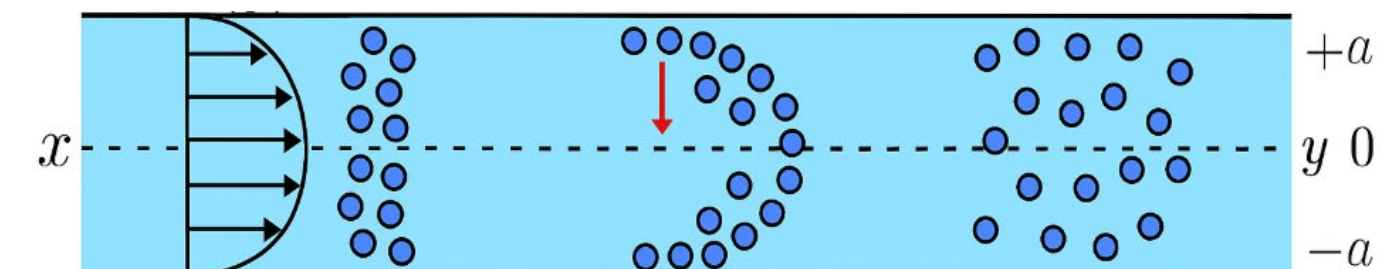
Figure 10. CSF energy intensity and shear field at different tVAS device placements



Conclusions

Based on Taylor dispersion theory, elevated CSF shear field magnitudes are associated with enhanced CSF circulation. Given the observed correlation between CSF shear field magnitude and energy intensity, increased vibration energy is expected to strengthen shear fields, thereby facilitating CSF circulation and waste clearance.

Figure 11. Taylor Dispersion theory: solute dispersion and mixing induced by shear field



Accordingly, this study demonstrates that lower vibration frequencies, higher vibration magnitudes, and device placement over the temporal lobe increase both CSF shear fields and energy intensity within the CSF, suggesting their potential to enhance waste clearance.

Keywords

transcranial vibroacoustic stimulation, CSF circulation, waste clearance

Key Takeaway Message

This study provides a mechanical analysis of vibroacoustic stimulation and its effects on CSF hydrodynamics, offering insights for optimizing and personalizing tVAS devices in terms of vibration frequency, load, and placement.

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