Qualitative Comparison of Harmonic and Transient Excitations in a Finite Element Brain Model for Magnetic Resonance Elastography

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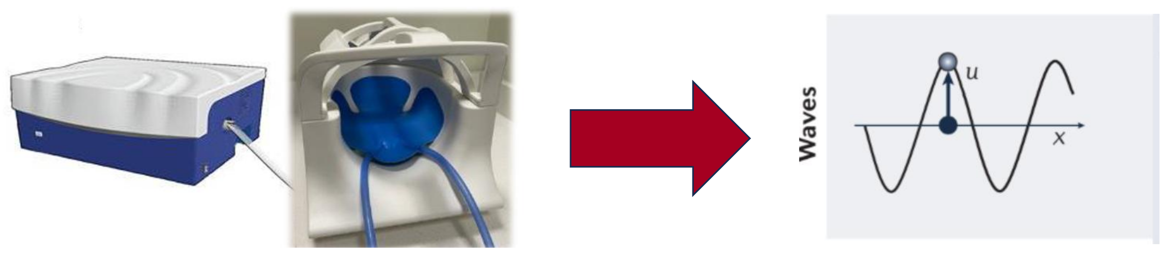
Introduction

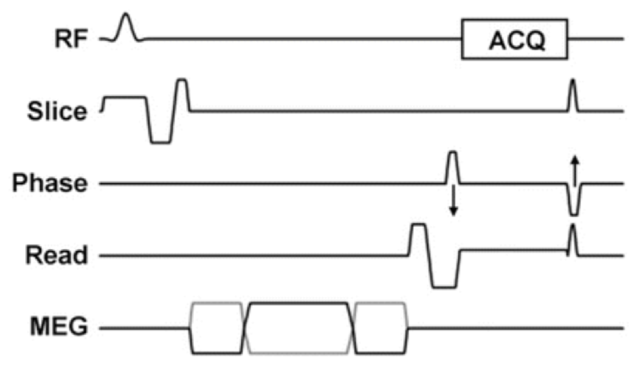
Magnetic Resonance Elastography (MRE) is a non-invasive imaging technique that quantifies tissue mechanical properties by analysing wave propagation and is crucial for diagnosing neurological disorders [1].

MRE integrates three key steps:

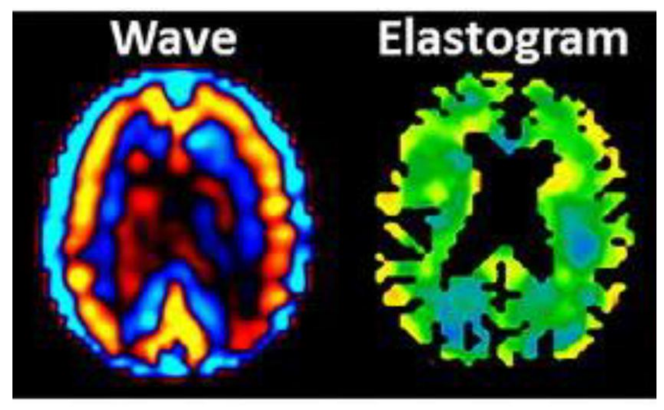
1. Mechanical excitation



2. Motion-sensitive phase-contrast imaging



3. Inversion to reconstruct stiffness maps



Excitation methods:

- Harmonic MRE: applies continuous vibrations, sampling wave motion across repeated cycles with phase offsets.
- Transient MRE: applies brief excitation, capturing propagating wave fronts.

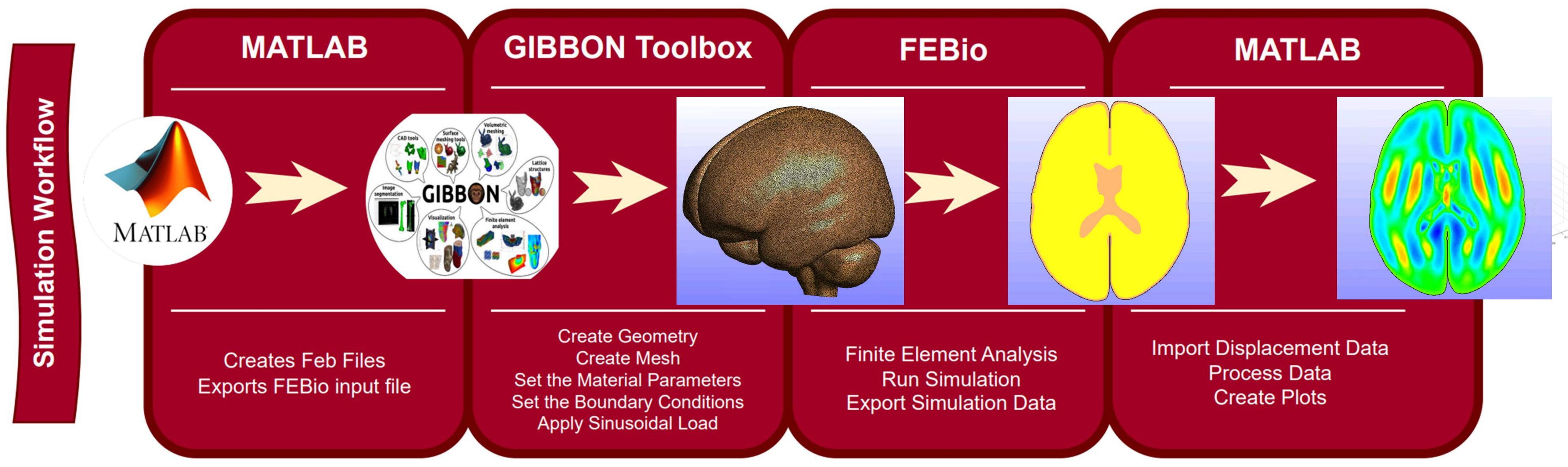
Excitation type influences:

- Wave propagation patterns
- Spatial distribution of waves [2]

Aim of this study: This study aims to qualitatively compare harmonic and transient excitations in brain MRE and to investigate their influence on wave propagation characteristics. Wave propagation was simulated using the open-source FEBio software [3] in a 3D simplified finite element model of the brain.

Method

- 3D brain geometry exported from a published FE model [4] and imported into MATLAB using GIBBON toolbox [5] to generate FEBio input files.
- Mesh: tetrahedral (tet4) elements; 580k elements for brain, 400k elements for CSF by using TetGen.



- Material properties taken from literature (Table 1); CSF modelled as a very soft solid for mechanical contrast.

	Material Model	Parameters	Value	Unit
CSF	neo-Hookean	Young's Modulus	100	Pa
		Poisson's ratio	0.495	-
		Density	1005	kg/m^3
Brain	neo-Hookean	Young's Modulus	3000	Pa
		Poisson's ratio	0.49	-
		Density	1040	kg/m^3

Table 1. Material properties of CSF and Brain used in FE simulation.

✓ Two loading types simulated:

➢ **Harmonic excitation**: Continues sinusoidal excitation at 60.1 Hz

➢ **Transient excitation**: Single sinusoidal excitation at 60.1 Hz

✓ To mimic experimental MRE: Y-direction displacement of 150 µm (Fig.1) applied to outer CSF surface; X and Z directions fixed to simulate skull constraints.

✓ The 400 ms FEBio simulation (2 ms time steps) was completed in ~100 mins, demonstrating efficient performance on a 12-core compute node with 192 GB RAM.

✓ Post-processed Y-displacement data in MATLAB for qualitative comparison of wave propagation.

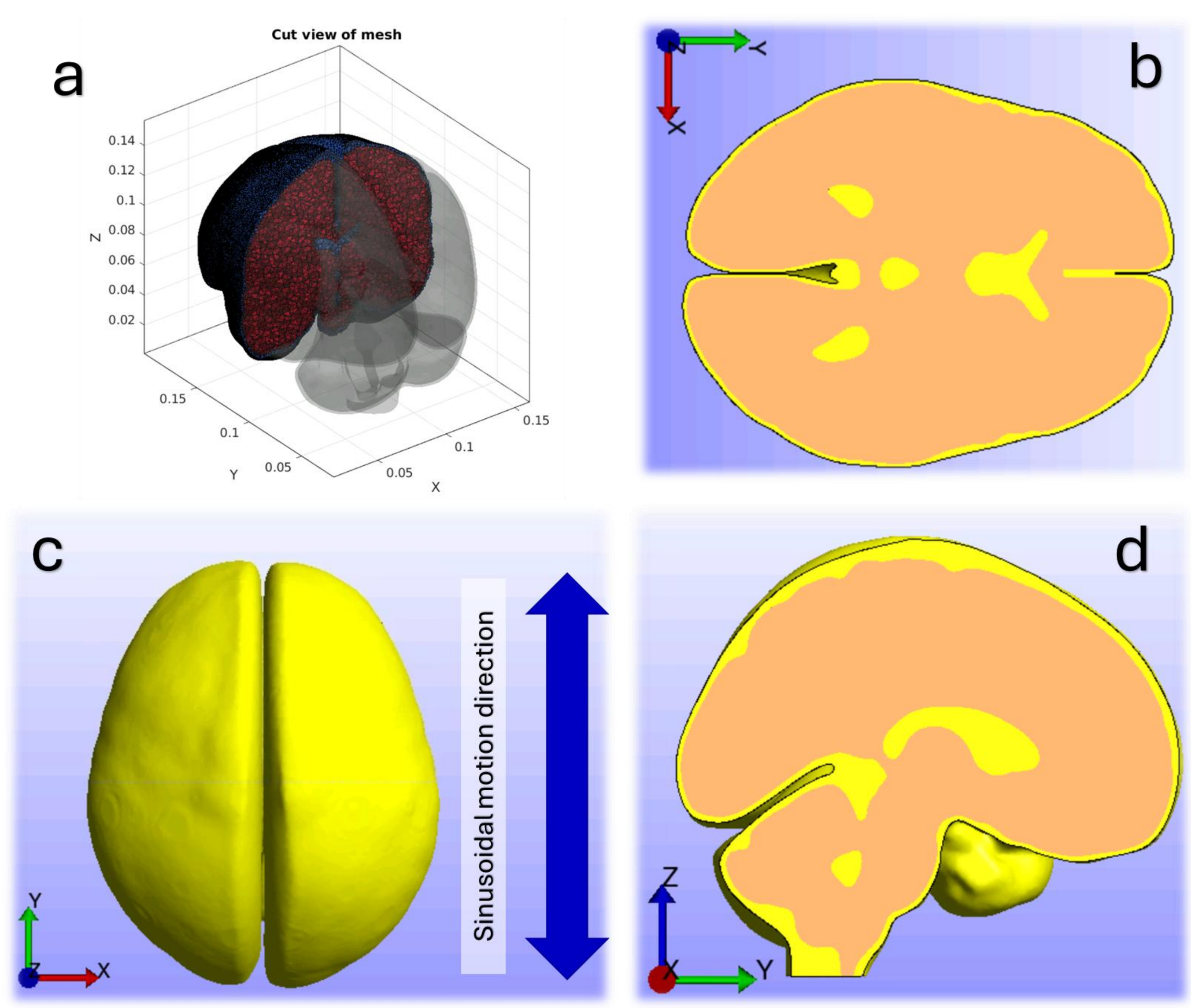


Fig. 1. Visualization of the 3D brain finite element (FE) model and anatomical structures. (a) Cut view of the meshed brain model showing tetrahedral elements representing brain tissue (red) and cerebrospinal fluid (CSF) (blue). (b) Axial cross-section of the brain model highlighting internal structures. (c) Lateral view of the brain model surface with the indicated direction of applied sinusoidal motion (Y-axis), simulating MRE excitation. (d) Midsagittal view of the brain illustrating the anatomical regions. Coordinate axes (X, Y, Z) are shown according to MR scanner coordinate system for reference in each panel.

Results and Discussion

➢ Simulations using harmonic and transient excitations were performed to qualitatively compare wave propagation in the brain model.

➢ Sagittal slices at different time-points revealed distinct wave patterns: harmonic excitation produced smooth, periodic wavefronts with consistent propagation, reflecting steady-state behaviour, whereas transient excitation generated more complex but coherent wave patterns with broader spatial variation and faster attenuation, yet still measurable for analysis.

➢ Both excitation types produced usable wave patterns, despite differences in complexity and propagation characteristics. Although a simplified, homogeneous brain and CSF model was used, these results demonstrate how the choice of excitation qualitatively influences wave behaviour.

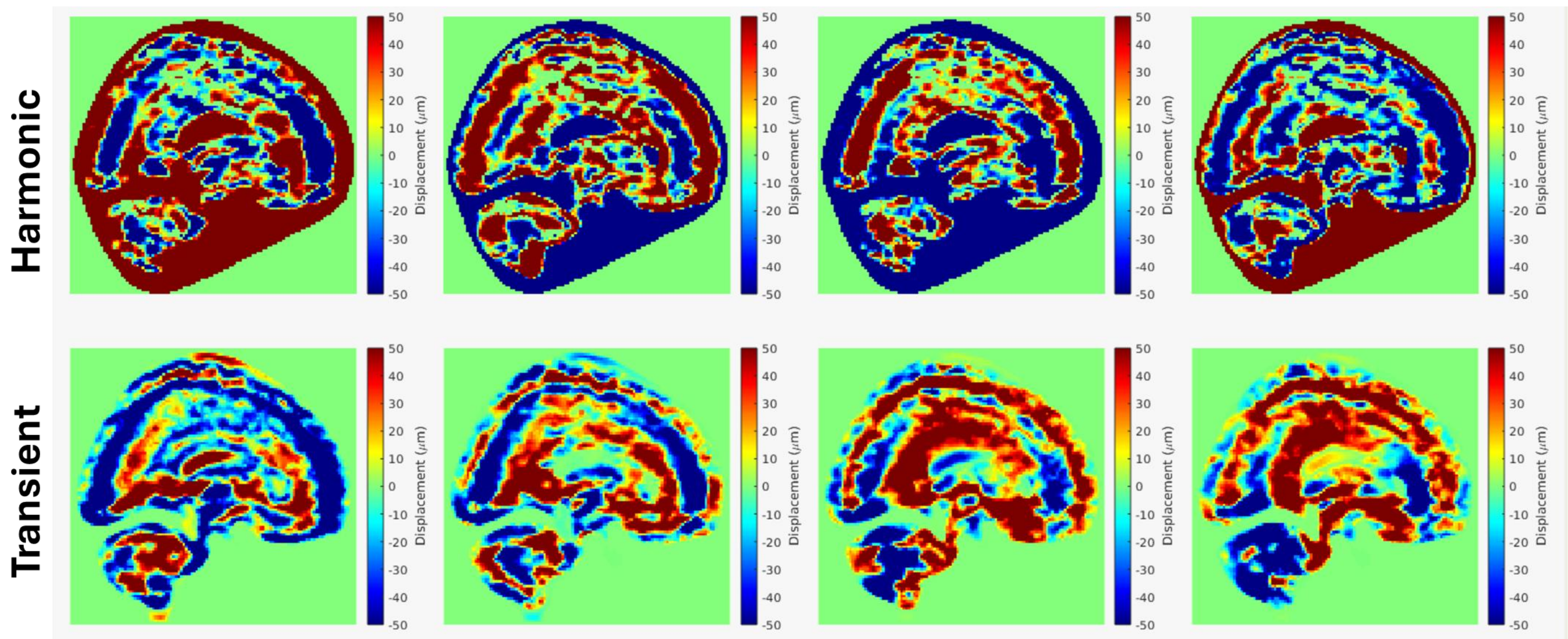


Fig. 2. Displacement fields (µm) in the sagittal plane of the 3D brain model under harmonic and transient excitation at 60.1 Hz.

Conclusion

This study used a simplified finite element brain model to qualitatively examine the effects of harmonic and transient excitations on wave behaviour. The simulation results revealed distinct spatio-temporal wave characteristics associated with each excitation type. The model effectively captured these differences, demonstrating its suitability for exploring excitation-dependent dynamics in MRE. Future work will focus on incorporating viscoelastic and anatomically detailed properties to enhance physiological accuracy and broaden clinical relevance.

References & Acknowledgement

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References

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