Developing a Model of Intracranial Pressure Dynamics: a Two – Compartment Viscoelastic Approach

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Motivation

Intracranial pressure (ICP) regulation is critical for maintaining brain function and preventing damage in conditions such as traumatic brain injury (TBI), hydrocephalus, and stroke. Many models treat the brain as a single pressure compartment, recent research suggests that more accurate physiological behavior can be captured by modeling the brain as multiple interacting compartments with viscoelastic properties.

Objectives and Hypothesis

Model ICP dynamics using a simplified two-compartment system representing the brain and body.

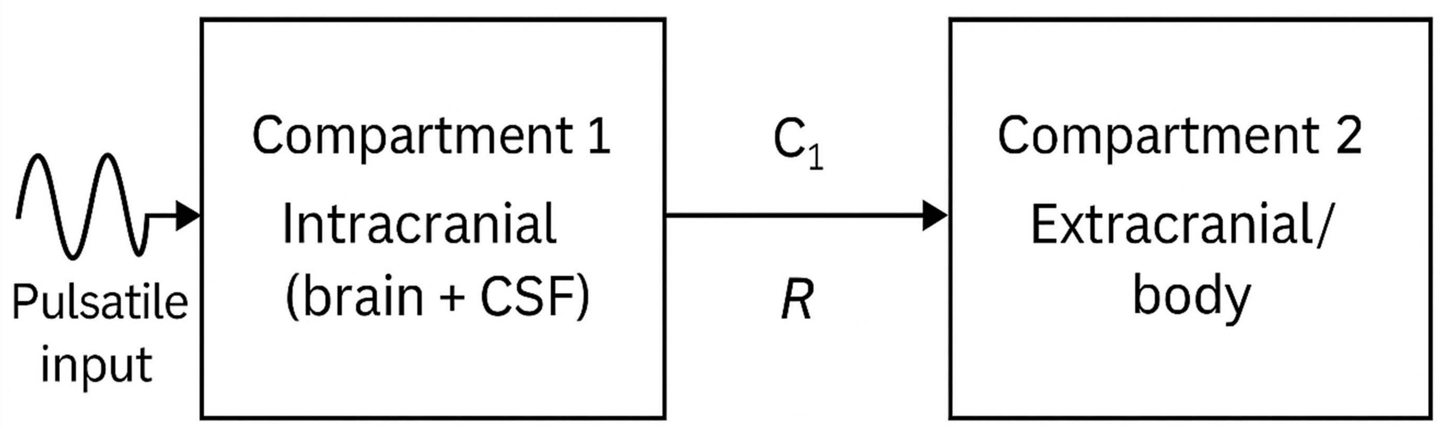
Changes in compliance and resistance will alter pressure waveforms:

↓ Compliance → higher pressure spikes

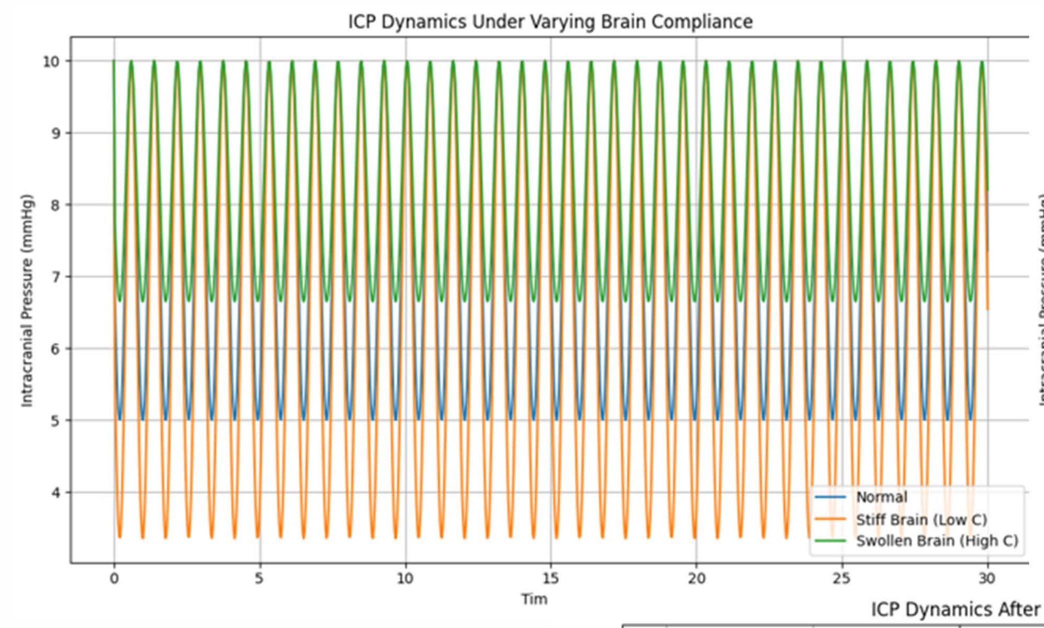
↑ Resistance → dampened flow and waveform distortion

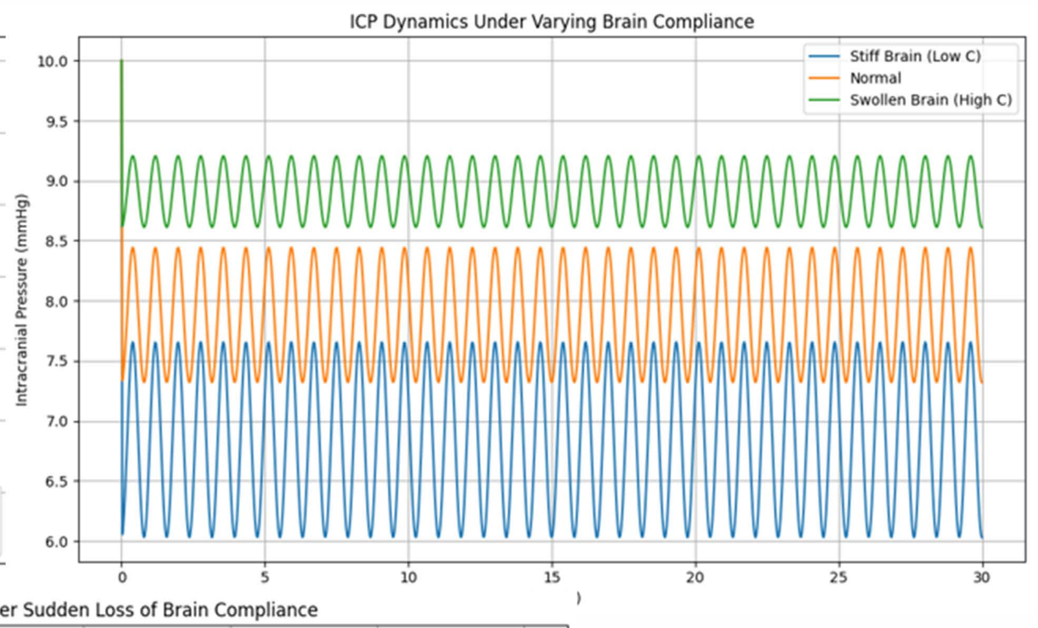
Viscoelastic properties will affect response to pulsatile inputs

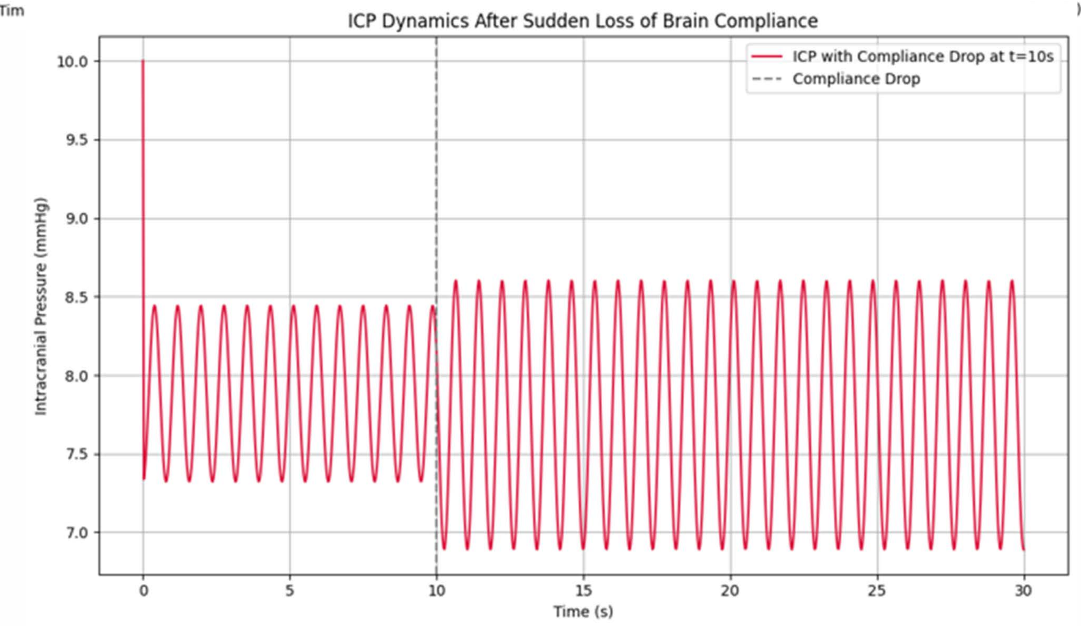
Two-Compartment Model



Results







Discussions and Future Work

Vascular resistance and brain tissue compliance significantly affect intracranial pressure dynamics. Higher resistance led to amplified pressure fluctuations, while reduced compliance resulted in sharper, more dangerous ICP waveforms. These results support clinical understanding of ICP regulation and highlight the importance of monitoring tissue-level changes in pathological conditions.

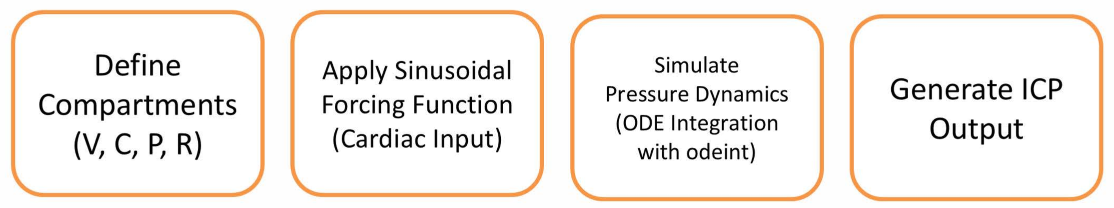
Future work will expand the model to include cerebrospinal fluid outflow, respiratory influence, and nonlinear autoregulation mechanisms. The phantom model can serve as a testing ground for new sensor placement strategies and therapeutic interventions.

Methods

A two-compartment lumped-parameter model was developed to simulate intracranial pressure (ICP) dynamics using Python. The compartments represent the intracranial space and the rest of the body, connected by a pressure-dependent resistance and governed by nonlinear compliance.

Cardiac pulsations were modeled as a sinusoidal forcing function to mimic arterial input. Compliance was modeled as inversely related to pressure, reflecting the viscoelastic properties of brain tissue. Resistance was also pressure-dependent to simulate vascular constriction and dilation.

Simulations were run using the odeint function from SciPy to solve the system of differential equations over time. Parameters such as compliance and resistance were systematically varied to simulate physiological and pathological conditions. Plots of ICP response under different conditions were generated using matplotlib.



Acknowledgements

Special thanks to Dr. Jit Muthuswamy
Tools: Python, SciPy, NumPy, matplotlib
Code & Simulation : Developed entirely in Google Colab

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