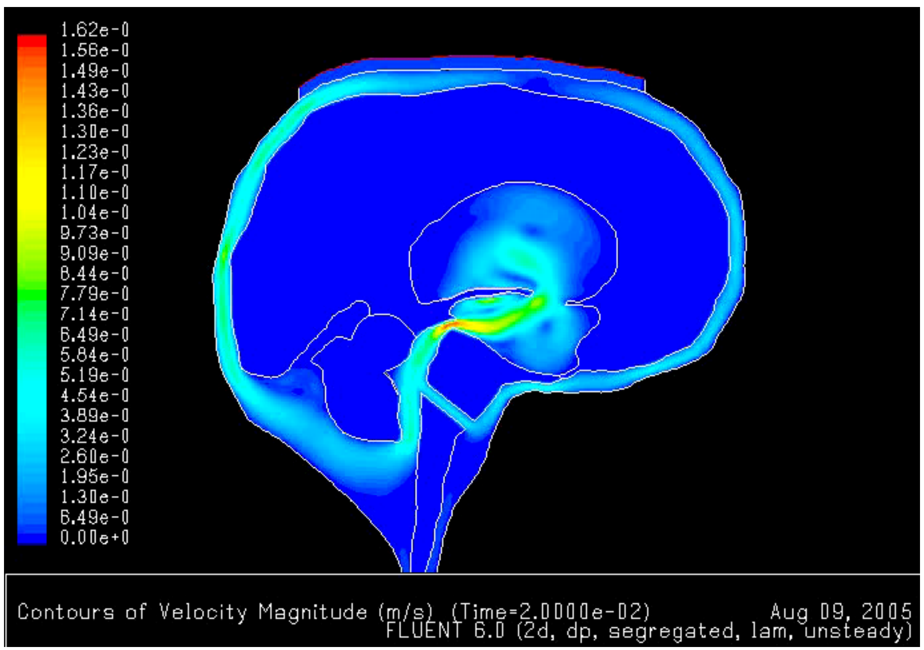
Cerebrospinal Fluid-Tissue Interactions in the Human Brain

REU Summer Program, Thursday, June 5, 2006
LPPD, UIC, Chicago, IL 60607



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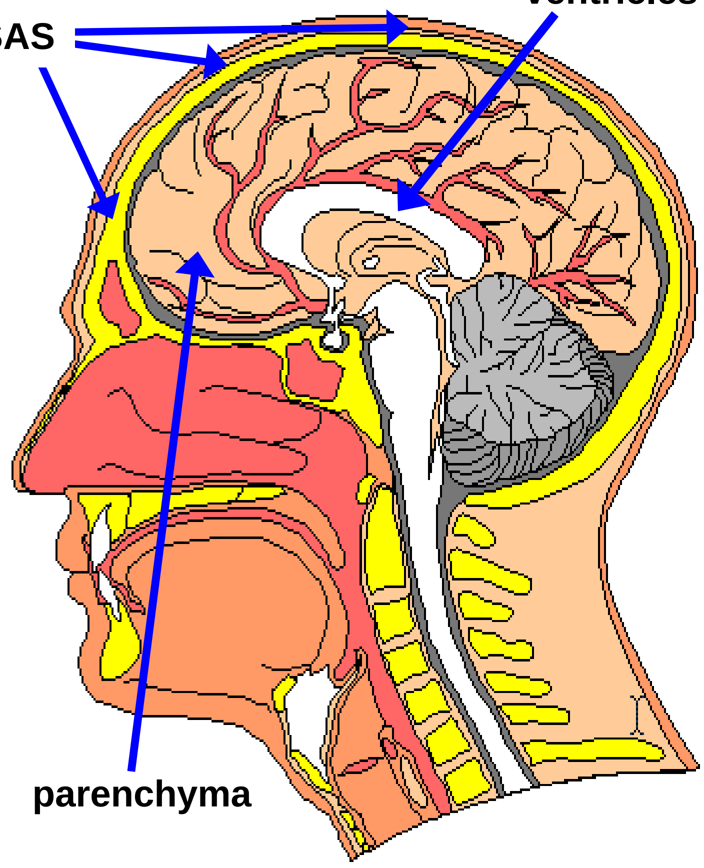
What is Intracranial Dynamics?

Intracranial dynamics (ICD) is defined as the interaction between the solid brain, cerebral spinal fluid (CSF), and blood flow

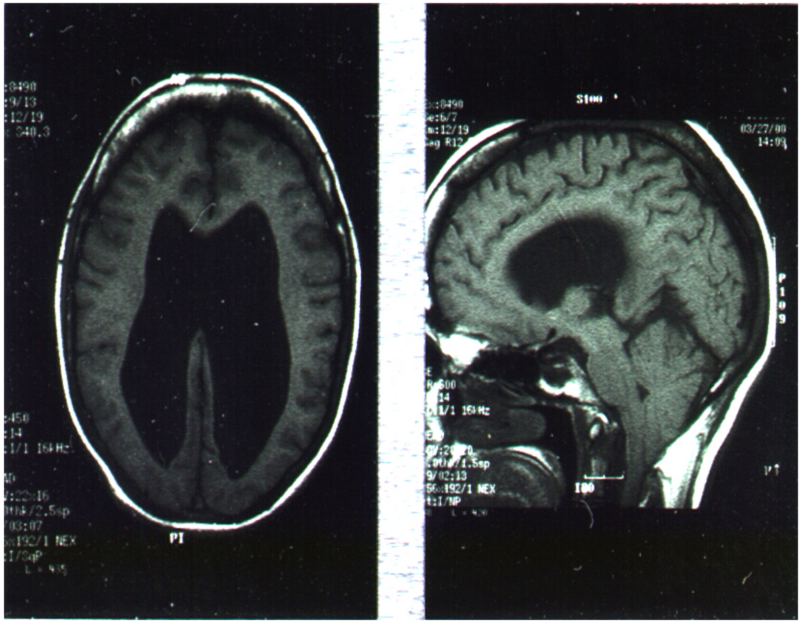


- CSF flows through ventricles and cerebral, spinal SAS, and the porous parenchyma in a pulsatile manner

- Dynamics of blood and CSF flow result in deformation of brain tissue

Goal: use physics and math to quantify what was previously only understood qualitatively

Motivation for Brain Deformation Studies



Hydrocephalus

- **Analysis quantifies clinical observations**
- **Quantification can lead to prediction**
- **Prediction allows more effective treatments or prevention**

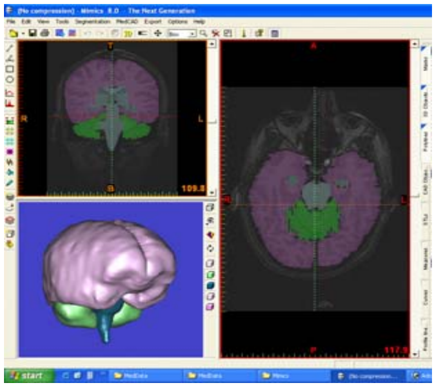
By accurately predicting fluid tissue interactions, resulting deformations lend insight into pathological conditions, in particular, hydrocephalus

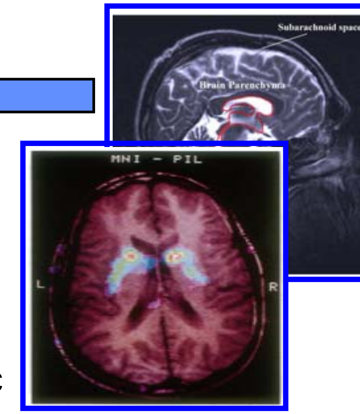
Current treatment methods very costly and dangerous - $1 billion annually,

3% mortality rate for hydrocephalus related hospital admissions

high failure rate – replacement surgeries as prevalent as primary surgeries

Computer-assisted analysis approach





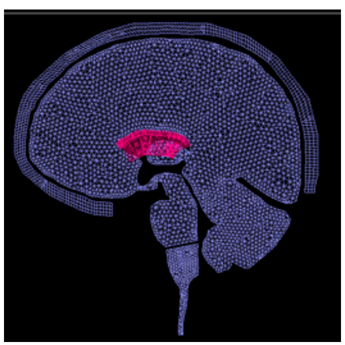
MR Imaging/Histological data
Current state-of-the-art approach

Direct experimental measurements

Reconstruction tools
ImageJ, Insight SNAP, Mimics

Grid Generation

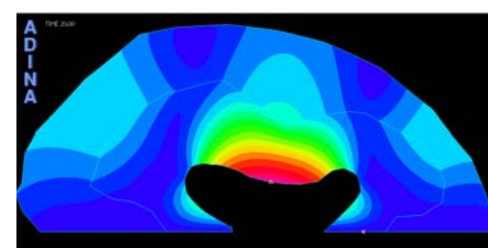
Capturing the anatomic complexity of the brain



Computational Fluid-Structure Dynamics and Deformations
Commercial solvers (ADINA)

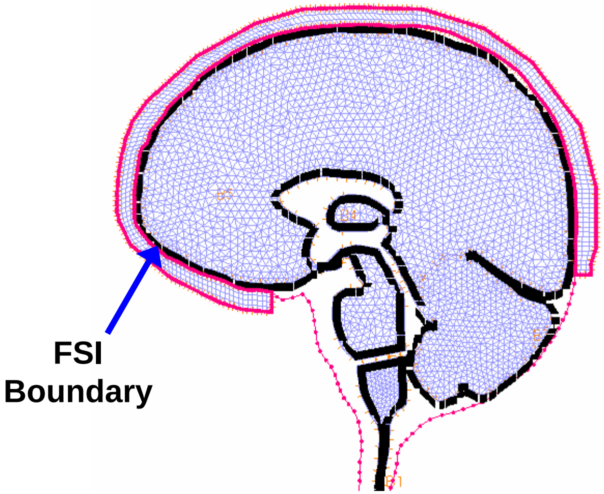
Mathematical modeling of normal and pathological intracranial conditions based on first principles

Quantitative analysis of normal and pathological intracranial conditions
- **Understanding of intracranial dynamics**
- **Predict causes of pathological conditions**
- **Design of therapeutic/preventative measures**



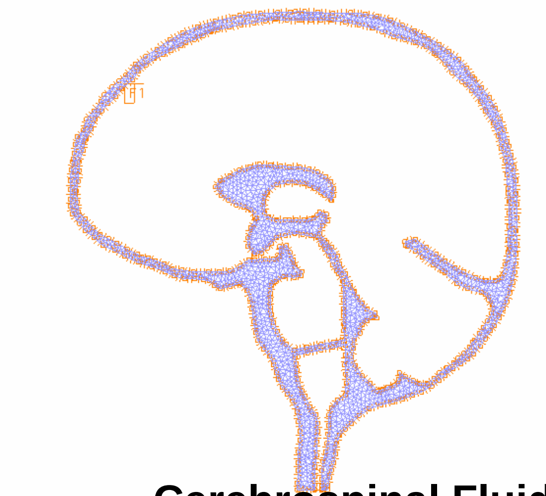
Fluid Structure Interactions (FSI) in Biological Tissues

- **Elements described by assigned empirical parameters:**
  - Material properties (solids)
    - » Young's Modulus
    - » Poisson's Ratio
    - » Density
    - » In some cases; Porosity, Permeability
  - Flow properties (fluids)
    - » Viscosity
    - » Density
- **Solve differential equations over these elements**



Solid Parenchyma

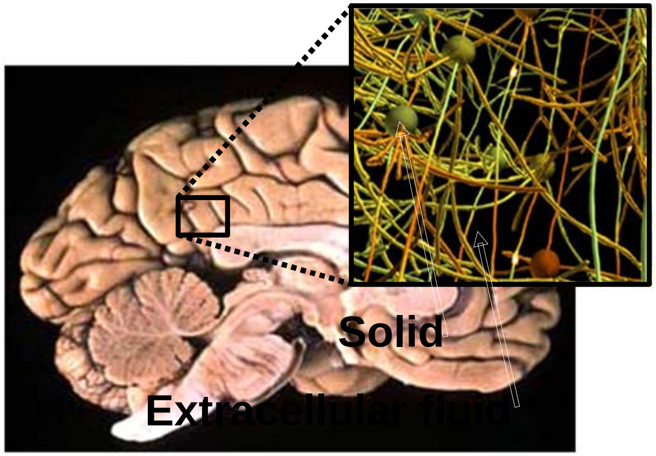
Using only Newton's Laws and material properties, physiological phenomena are effectively described



Cerebrospinal Fluid

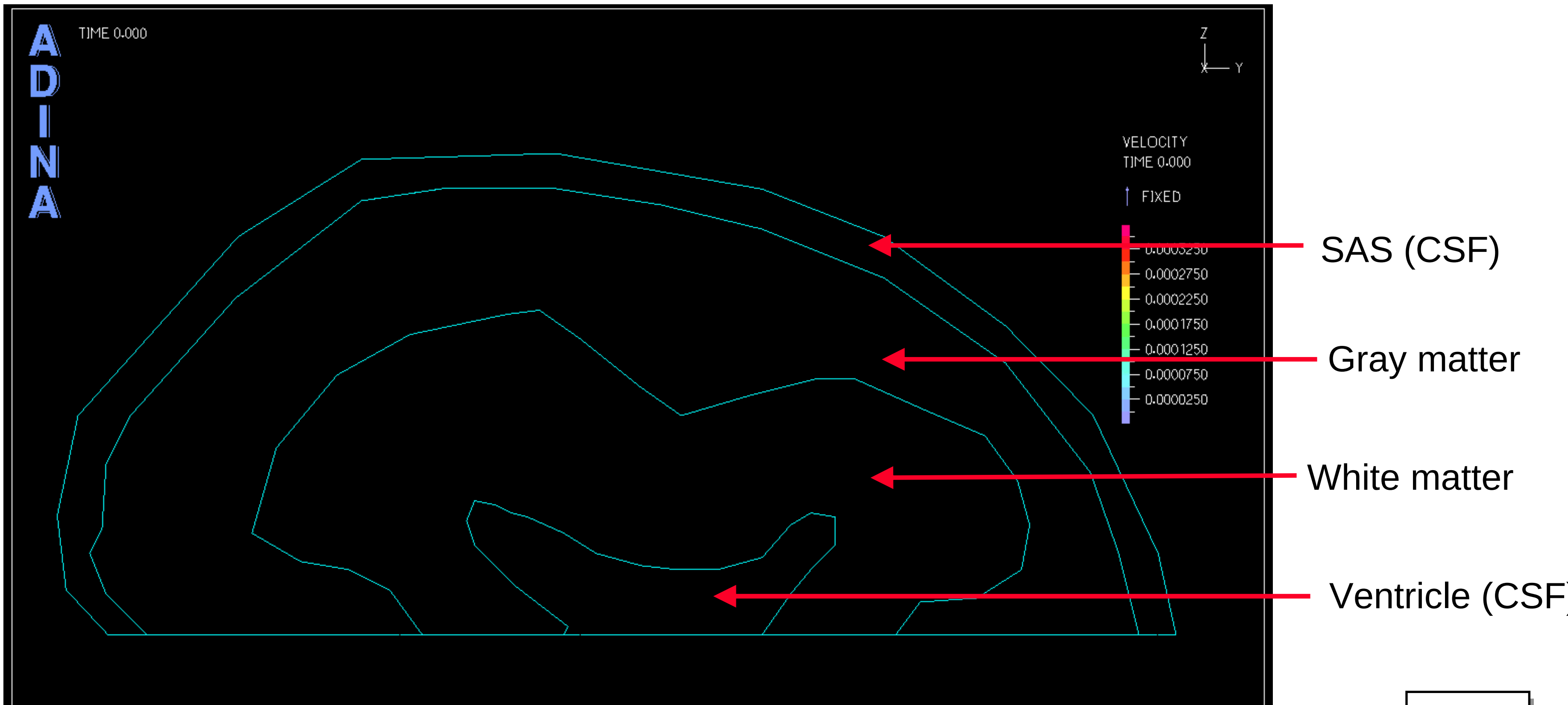
I Poroelasticity of the Brain

- **Parenchyma is neither solid nor fluid**
  - Solid brain matter
  - CSF filled pores
- **Brain is a porous, elastic, deformable medium through which fluid flow is permissable**
  - Deformation is a function of flow and pore pressure
- **Neither solid nor fluid description appropriate so consolidation theory is used to unite the different descriptions of motion**



Simulated Hydrocephalus

- **Pressure applied to SAS and ventricles (slightly higher ~ 100Pa) – observed distension validated previous results**
- **Explicity applied pressure implicitly defines velocity in CSF and deformation of the solid – demonstrates effective coupling of porous solid and fluid models**



CSF Dynamics

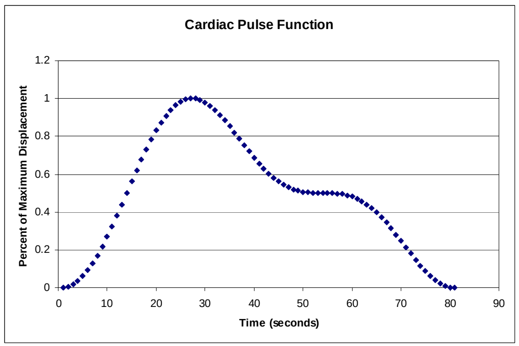
- **CSF flow patterns determined not only by brain geometry and CSF production/reabsorption rates, but also by the dynamic interaction of intracranial fluids and tissues**

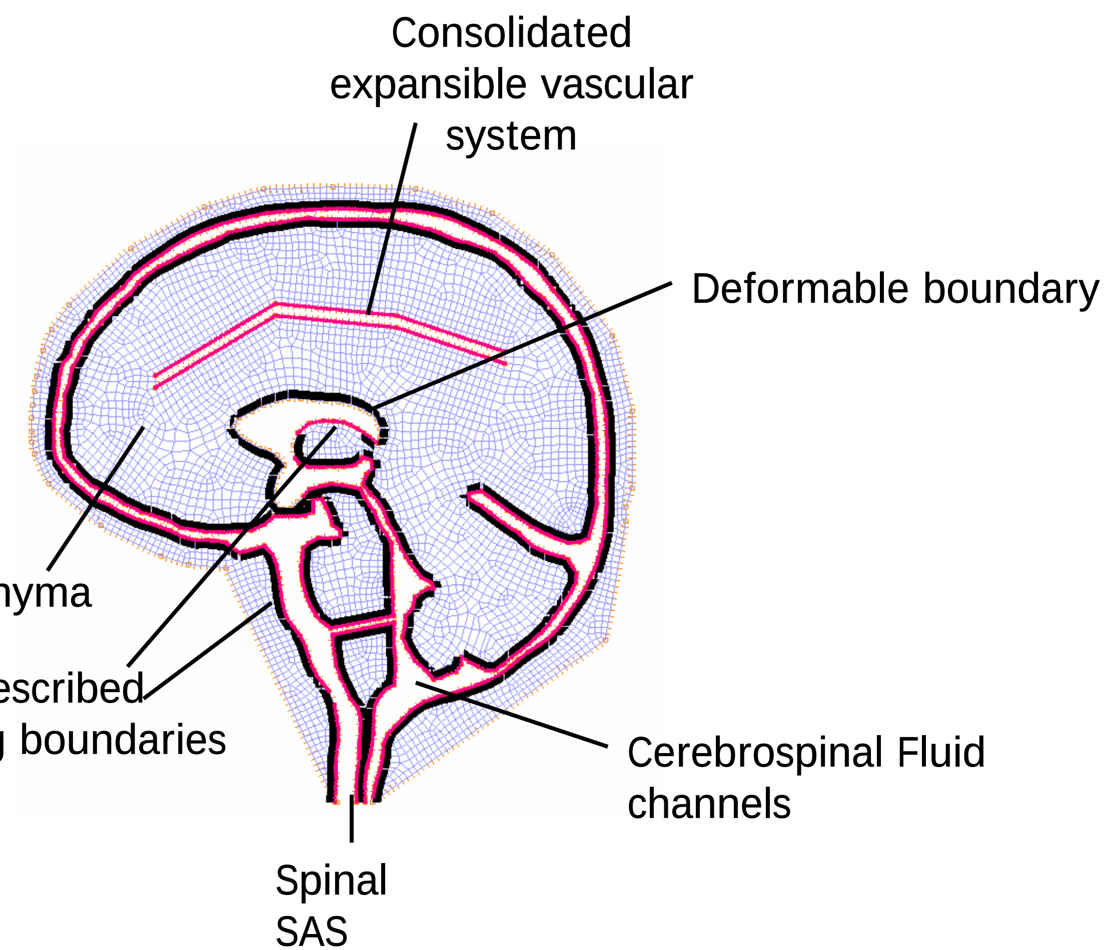
- **Brain motion hypothesis –cerebral blood flow causes motion of the solid brain which in turn drives CSF flow**

- **Expansion of the vascular bed causes subsequent changes in the volume of CSF pathways**
  - Transient pressure gradients
  - Pulsatile pressure-driven reversals of flow

Simulation Parameters

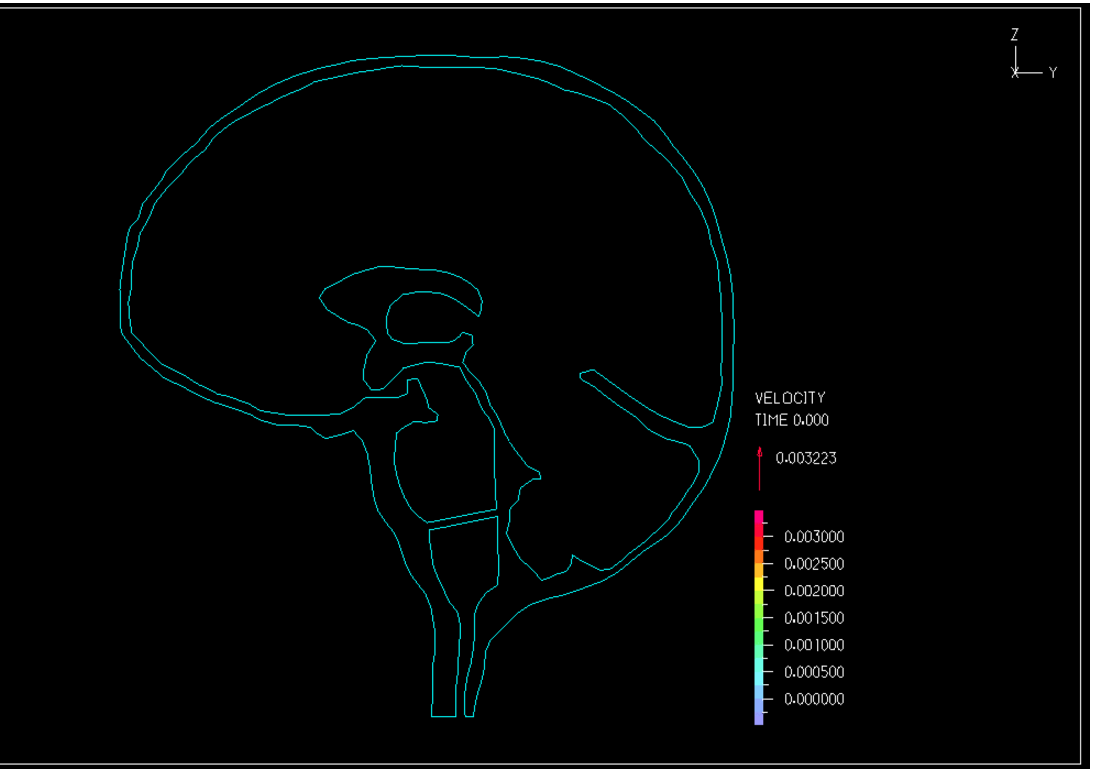
Pulsatile expansion of vasculature described by cardiac function:



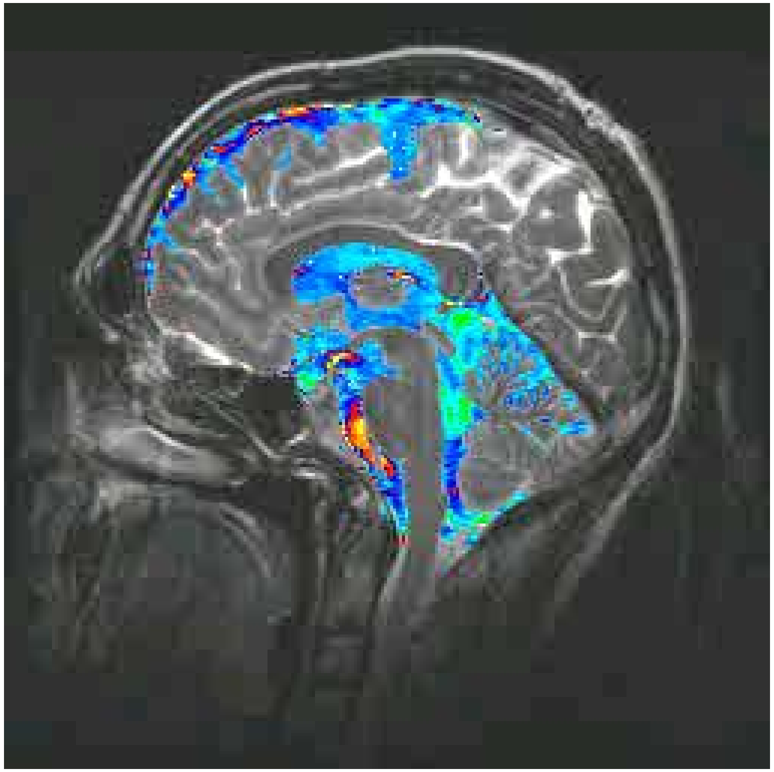


LPPD

Dynamics of CSF Flow Throughout the Cardiac Cycle



Simulate Flow Field (m/s)



Live Patient CINE MRI

Conclusions

- Using simulations based on first principles and physiologically consistent properties we were able to extract conclusions about the dynamics of the human brain
- Validation of previous studies indicating that no large trans-parenchymal pressure gradient exists during hydrocephalus
- Validation of brain motion hypothesis – effectively simulated pulsatile CSF flow driven by expansion of the vasculature system alone

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