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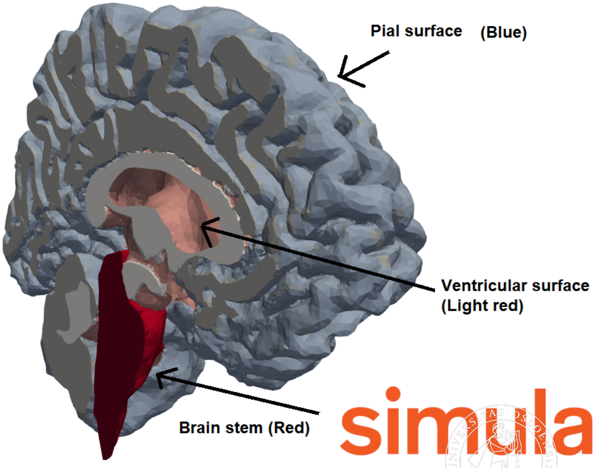
Fluid and solid interaction modelling of cerebral functions

Lars Willas Dreyer



Hydrocephalus 2025 World Congress

September 6, 2025

A rough outline

The talk will be split into three parts:

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1) What is cerebral continuum mechanics (CCM)?

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2) CCM and NPH, how do they relate?

A rough outline

The talk will be split into three parts:

1) What is cerebral continuum mechanics (CCM)?
2) CCM and NPH, how do they relate?
3) CCM and you: Bridging models and measurements.

Cerebral continuum mechanics

- Continuum mechanics- study of the physics of fluids and solids

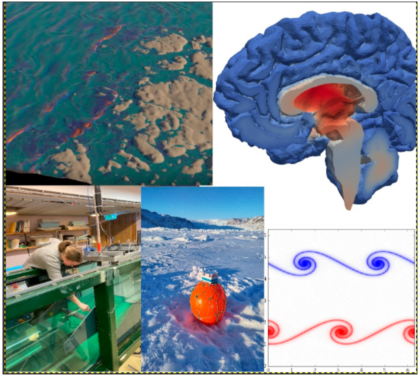

Figure: Mechanics research activity at UiO. (With Øystein Lande, Karen Samseth, Jean Rabault and Mikael Mortensen)

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Cerebral continuum mechanics

- Continuum mechanics- study of the physics of fluids and solids
- One such application, the CNS

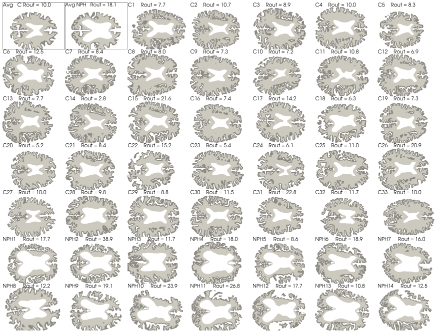

Figure: Figure from Dreyer et al. 2024

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Cerebral continuum mechanics

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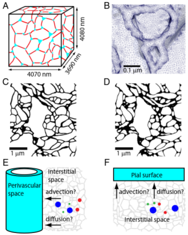
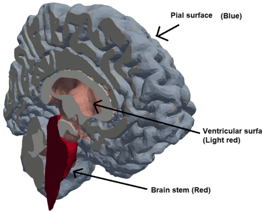
- Models across scales



Microscale



Macroscale

Figure: Left: Holter et al. (2017), right: Dreyer et al. (2024)

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Cerebral continuum mechanics

- Continuum mechanics- study of the physics of fluids and solids
- One such application, the CNS
- Models across scales
- The glymphatic system

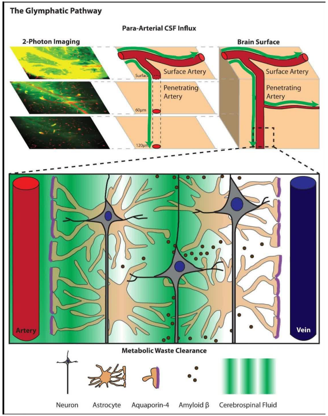

Figure: By Jeffery J. Iliff, from Wikimedia under the public domain

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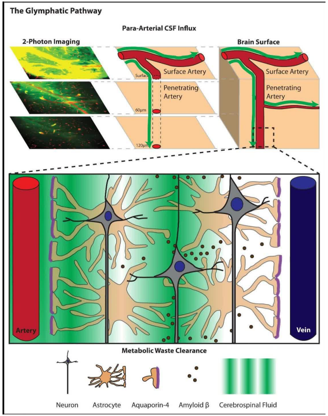
Cerebral continuum mechanics

- Continuum mechanics- study of the physics of fluids and solids
- One such application, the CNS
- Models across scales
- The glymphatic system
- But how do we work?



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Our 2024 model setup

Dreyer *et al. Fluids and Barriers of the CNS* (2024) 21:82
https://doi.org/10.1186/s12987-024-00582-0

Fluids and Barriers of the CNS

RESEARCH **Open Access**

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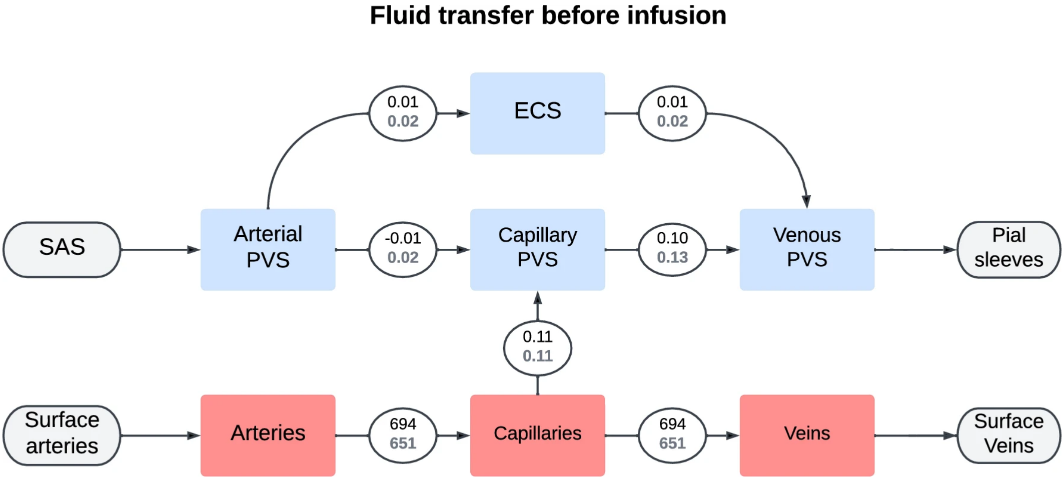
Modeling CSF circulation and the glymphatic system during infusion using subject specific intracranial pressures and brain geometries

Lars Willas Dreyer[1,3], Anders Eklund[2], Marie E. Rognes[1,7], Jan Malm[6], Sara Qvarlander[2], Karen-Helene Støverud[2,4], Kent-Andre Mardal[1,3,5,7*] and Vegard Vinje[1,5,8]

Our 2024 model setup



Building a NPH model

1. Decide on model target: (Ventriculomegaly, infusion tests or other.)

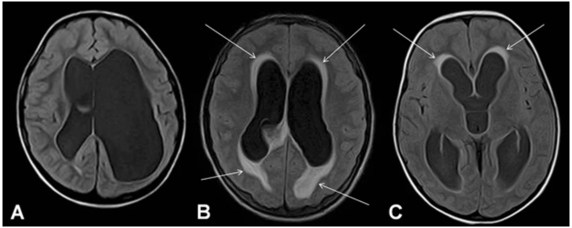


Figure: Figure from Kartal and Algin (2014)

Building a NPH model

1. Decide on model target:
2. Decide on governing equations.

Our 2024 model

Fluid flow in seven compartments. Transport of blood/water through pressure differences.

$$C_i \frac{\partial p_i}{\partial t} = -\frac{\kappa_i}{\mu_i} \nabla^2 p_i + \sum_{i \neq j} \omega_{i,j} (p_i - p_j). \tag{1}$$

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Building a NPH model

1. Decide on model target:
2. Decide on governing equations.
3. Literature review, what do we know?

From: Modeling CSF circulation and the glymphatic system during infusion using subject specific intracranial pressures and brain geometries

Parameter	Value	Units	Source
$\omega_{a,c}$	$1.45 \cdot 10^{-6}$	$Pa^{-1}s^{-1}$	[46]
$\omega_{c,v}$	$8.75 \cdot 10^{-6}$	$Pa^{-1}s^{-1}$	[47]
$\omega_{c,pc}$	$8.48 \cdot 10^{-10}$	$Pa^{-1}s^{-1}$	[31]
$\omega_{pa,e}$	$1.86 \cdot 10^{-7}$	$Pa^{-1}s^{-1}$	[31]
$\omega_{pv,e}$	$1.65 \cdot 10^{-7}$	$Pa^{-1}s^{-1}$	[31]
$\omega_{pa,pc}$	10^{-6}	$Pa^{-1}s^{-1}$	Estimated
$\omega_{pc,pv}$	10^{-6}	$Pa^{-1}s^{-1}$	Estimated
$\omega_{pc,e}$	10^{-10}	$Pa^{-1}s^{-1}$	Estimated
κ_a	3.63×10^4	nm^2	[31, 56]
κ_c	1.44×10^3	nm^2	[57]
κ_v	1.13×10^6	nm^2	[31, 56]
κ_e	20	nm^2	[14]
κ_{pa}	30	nm^2	[31, 56]
κ_{pc}	1.44×10^3	nm^2	[57]
κ_{pv}	1.95×10^4	nm^2	[31, 56]
ϕ_a	$1.09 \cdot 10^{-2}$	–	[58, 59]
ϕ_c	$2.31 \cdot 10^{-3}$	–	[58]
ϕ_v	$1.98 \cdot 10^{-2}$	–	[58]
ϕ_{pa}	$1.52 \cdot 10^{-2}$	–	[11]
ϕ_{pc}	$2.31 \cdot 10^{-3}$	–	[55]
ϕ_{pv}	$2.77 \cdot 10^{-2}$	–	[11]
ϕ_e	$1.40 \cdot 10^{-1}$	–	[60]

The porosities are dimensionless and are therefore marked with -

Figure: Table from Dreyer et al. (2024)

Building a NPH model

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   We want to check what our model implies

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Building a NPH model

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   We want to check what our model implies
4. Validate against known data.

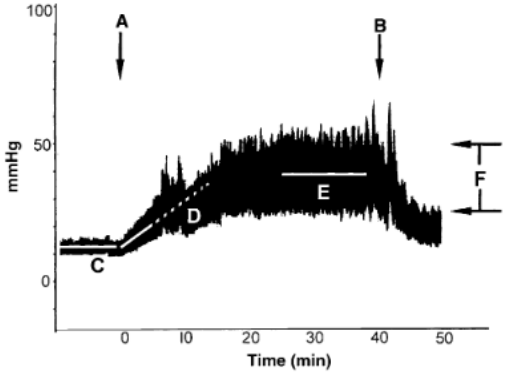

Figure: Kahlon, Sundbärg and Rehncrona (2005)

Model insights

- Model results vs.
  theoretical expectation

Model insights

- Model results vs. theoretical expectation

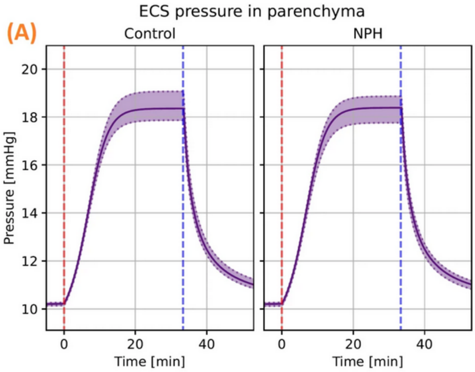

Figure: Generic infusion test. From Dreyer et al. (2024)

Model insights

- Model results vs. theoretical expectation

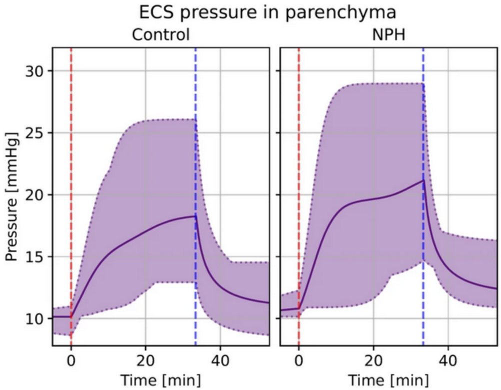

Figure: Infusion test with subject specific data. From Dreyer et al. (2024)

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Model insights

- Model results vs. theoretical expectation
- Parameter uncertainty lead to span in predictions

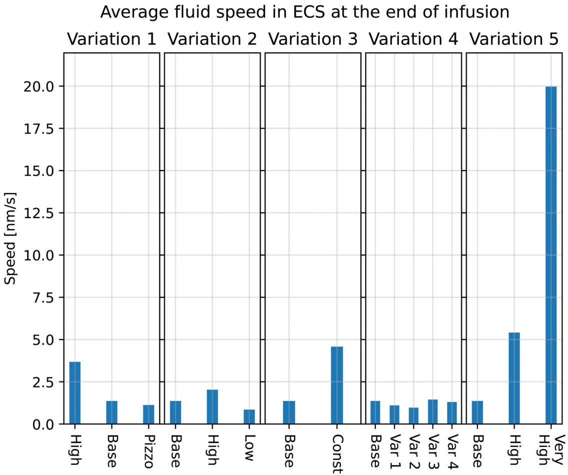

Figure: Figure from Dreyer et al. (2024)

Model insights

- Model results vs. theoretical expectation
- Parameter uncertainty lead to span in predictions
- Implications for diffusion/convection dominated transport

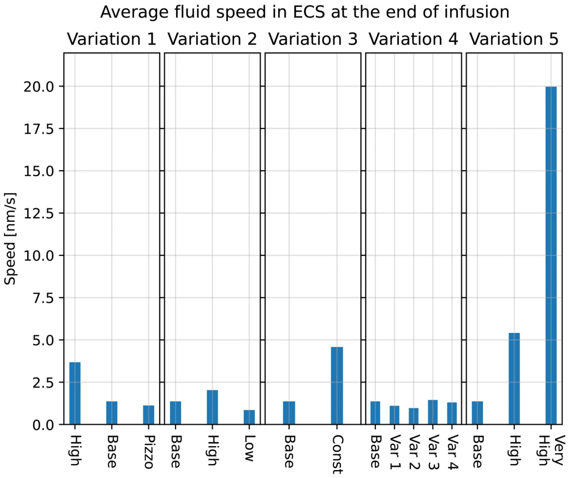

Figure: Figure from Dreyer et al. (2024)

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What can we learn from models?

- Models functions as highly flexible laboratories

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What can we learn from models?

- Models functions as highly flexible laboratories
- Goal: Explain phenomena that are difficult to measure
- And make predictions which can be verified experimentally

Bibliography

- Kartal, Merve Gulbiz, and Oktay Algin. "Evaluation of hydrocephalus and other cerebrospinal fluid disorders with MRI: an update." Insights into imaging 5.4 (2014): 531-541.
- Holter, Karl Erik, et al. "Interstitial solute transport in 3D reconstructed neuropil occurs by diffusion rather than bulk flow." Proceedings of the National Academy of Sciences 114.37 (2017): 9894-9899.
- Kahlon, Babar, Göran Sundbärg, and Stig Rehncrona. "Lumbar infusion test in normal pressure hydrocephalus." Acta neurologica scandinavica 111.6 (2005): 379-384.

Bibliography II

- Eide, Per Kristian, et al. "Sleep deprivation impairs molecular clearance from the human brain." Brain 144.3 (2021): 863-874
- Dreyer, Lars Willas, et al. "Modeling CSF circulation and the glymphatic system during infusion using subject specific intracranial pressures and brain geometries." Fluids and Barriers of the CNS 21.1 (2024): 82.
- Vinje, Vegard, et al. "Intracranial pressure elevation alters CSF clearance pathways." Fluids and Barriers of the CNS 17.1 (2020): 29.

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- Jan Malm
- Atle Jensen
- Jean Rabault
- Lars Magnus Valnes
- The 47 subjects from the study

Lars Willas Dreyer

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