The Influence of Body Position on Cerebrospinal Fluid (CSF) Circulation

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1. Review of CSF circulation

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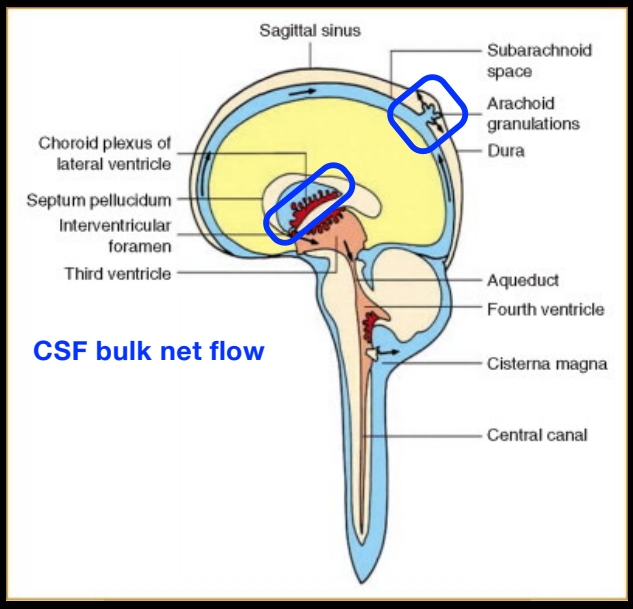
CSF Circulation



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CSF and Glymphatic system

Plog et al, Annu. Rev. Pathol., 13, P. 379, 2018

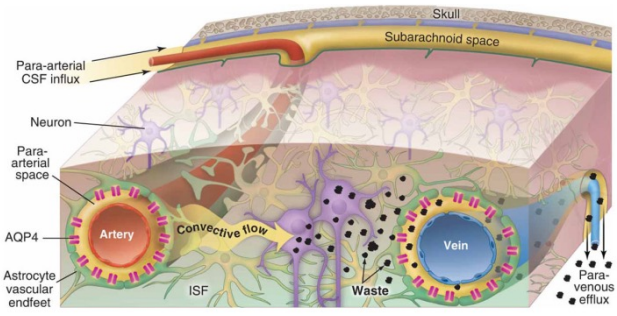

Figure 1. Overview of the circulation of CSF and ISF through the glymphatic pathway
The bulk flow of CSF into brain specifically within the perivascular spaces of penetrating arteries drives interstitial metabolic waste products toward perivenous spaces, and ultimately from the cranium via several post-glymphatic clearance sites, including arachnoid granulations, meningeal lymphatic vessels, and along cranial and spinal nerve roots. AQP4 water channels densely expressed within astrocyte end-foot processes circumscribing both arteries and veins act to reduce the resistance to CSF movement from periarterial spaces into the interstitium, and from the interstitium into perivenous spaces. Reproduced with permission from (77).

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Drivers of CSF Pulsation

- Vascular pulsation
- Respiration (12% from natural breathing)
- Muscular contraction [Xu et al, Sci. Rep., 6, P. 31787, 2016]

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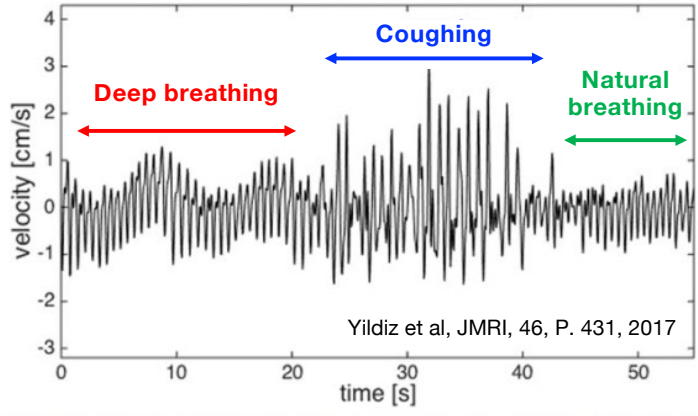
CSF velocity at the foramen magnum measured with real-time phase contrast (PC) MRI



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2. Posture dependence of CSF flow in normal population

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Upright and Supine CSF Flow

Why?

We spend most of our lifetime in upright position

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Upright and Supine CSF and Blood Flow

Alperin et al, (2005), ***"Quantifying the Effect of Posture on Intracranial Physiology in Humans by MRI Flow Studies",*** JMRI, 22, P. 591

[Data acquired at mid-C2 with cine PC-MRI using a 0.5 Tesla GE Signa SP MRI]

Table 1
Mean and SD of Main Hemodynamic and Hydrodynamic Parameters Measured in Supine and Upright Postures*

	Supine (Mean ± SD)	Upright (Mean ± SD)
tCBF (mL/minute)	825 ± 166	724 ± 127
Venous flow in IJVs (mL/minute)	614 ± 143	304 ± 261
Venous pulsatility index	0.61 ± 0.15	0.35 ± 0.10
Osc. CSF volume (mL)	0.55 ± 0.12	0.23 ± 0.11
Max. ICVC (mL)	0.48 ± 0.15	0.89 ± 0.44
Intracranial compliance index	7.3 ± 2.6	20.2 ± 10.7
MR-ICP (mmHg)	10.6 ± 3.6	4.5 ± 1.82

* Differences are statistically significant with P value < 0.002

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Multi-Position MRI Scanner

Muccio et al, (2021) ***"Upright versus supine MRI: effects of body position on craniocervical CSF flow"***, Fluids Barriers CNS, 18:61

[Data acquired at mid-C2 with cine PC-MRI using a 0.6 Tesla FONAR UPRIGHT MRI]

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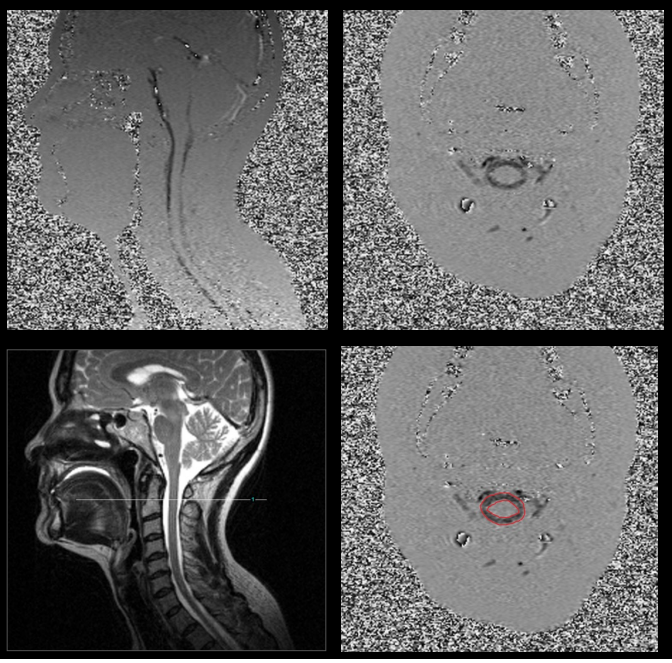
Mid-C2 Scout and ROI Drawing



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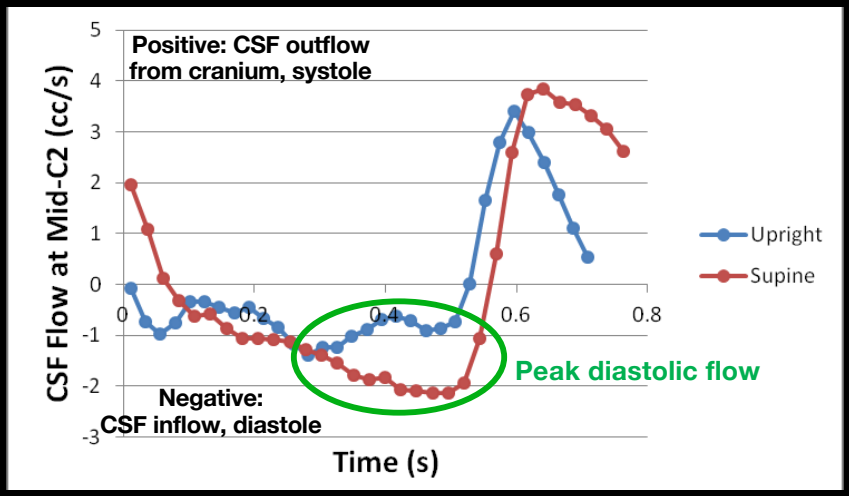
Upright CSF Flow cf. Supine



- Heart rate increases by 10% (from decrease of CSF systolic duration)
- Peak diastolic flow decreases by 43%
- Stroke/Oscillatory volume exchanged per cardiac cycle decreases by 36%

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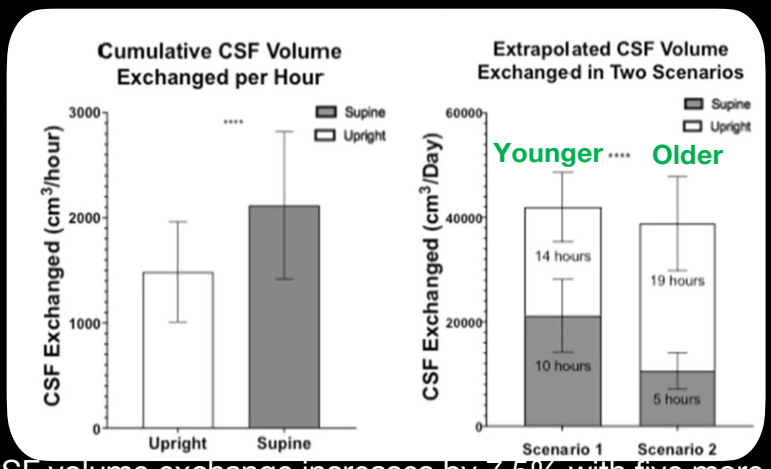
24-Hour Modeling



CSF volume exchange increases by 7.5% with five more hours in supine (sleep-mimicking) position in a 24-hour day

Potential effect on brain waste clearance and neurodegenerative diseases

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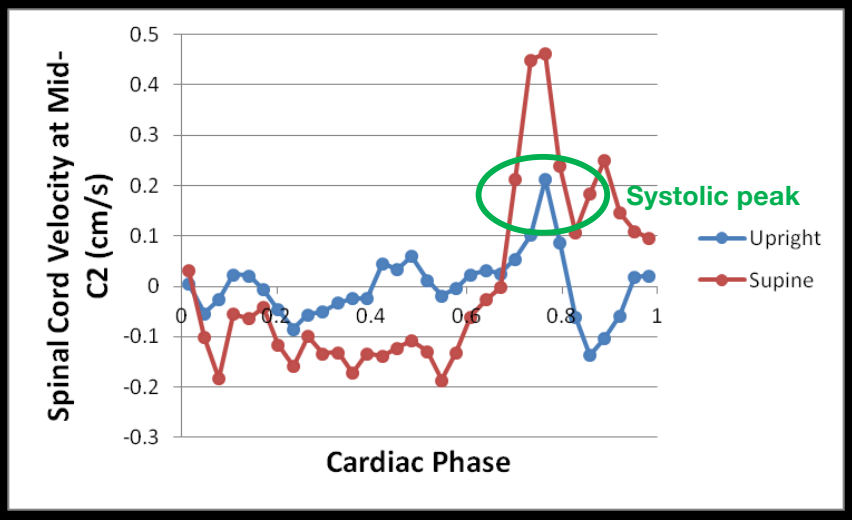
Upright Spinal Cord Pulsates Less



- Peak systolic velocity decreases by 40%
- Stroke volume per cardiac cycle decreases by 47%

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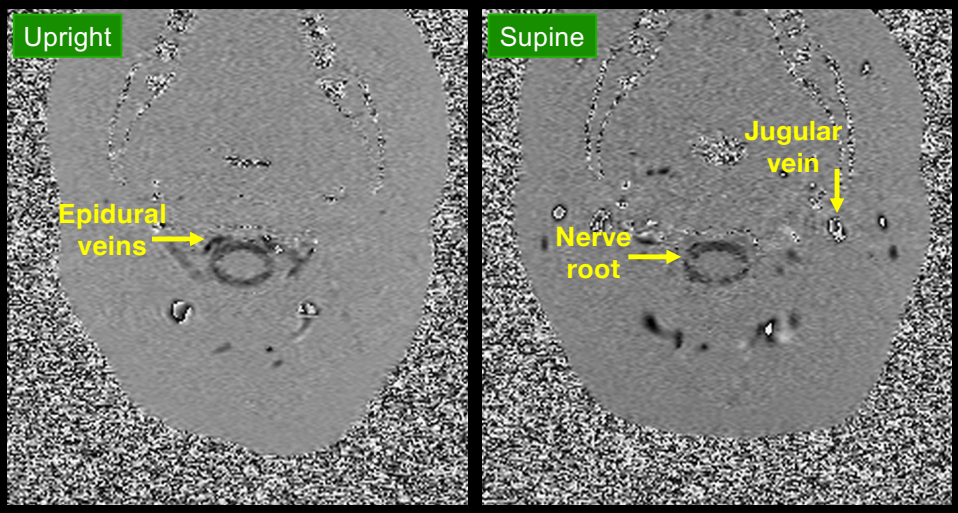
Other Postural Differences



- More prominent nerve roots in supine posture
- Venous outflow shifts from jugular to epidural/smaller veins when upright
- Neck is "slimmer" when upright

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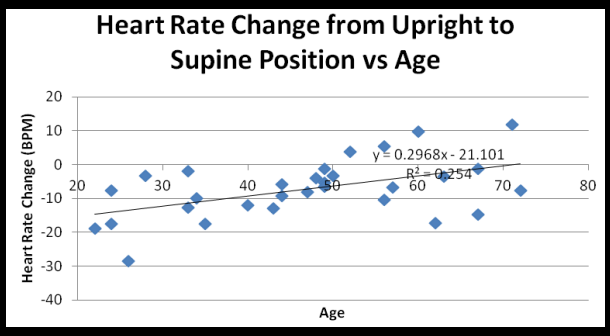
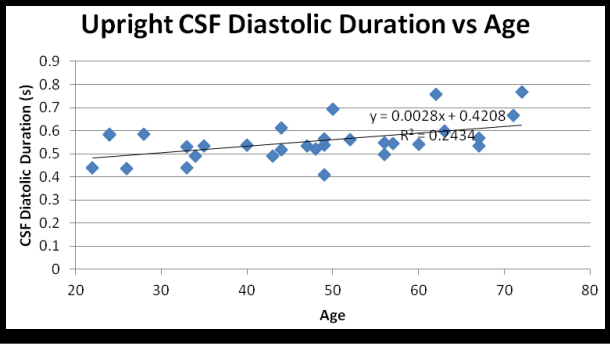
Aging Effect and Posture





- 30 volunteers
- Age range: 22 - 72 years
- Heart rate change between posture diminishes as we age
- Upright CSF diastolic duration increases as we age

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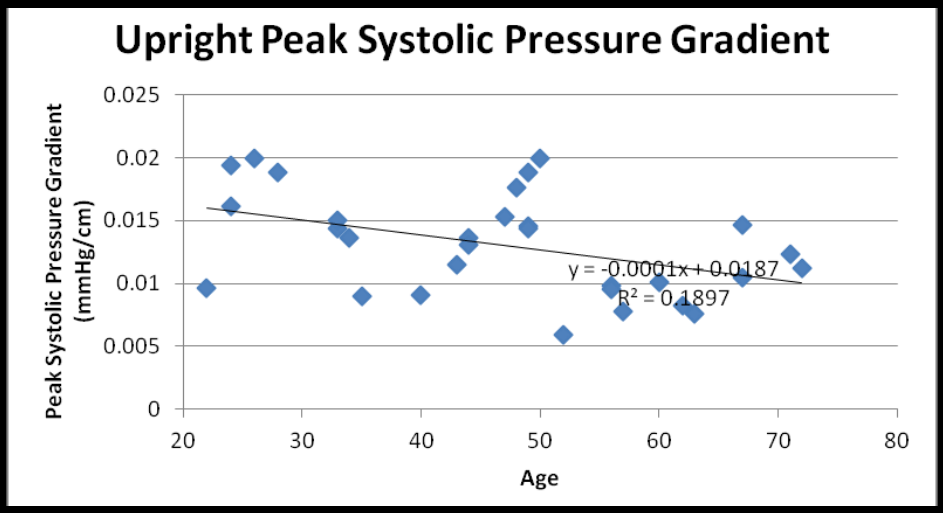
Aging Effect and Posture



- Decrease in upright peak systolic/peak-to-peak pressure gradient as we age
- CSF flow and spinal cord pulsation only show significant age dependence in upright posture, not as sensitive to aging in supine posture

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3. Disease applications

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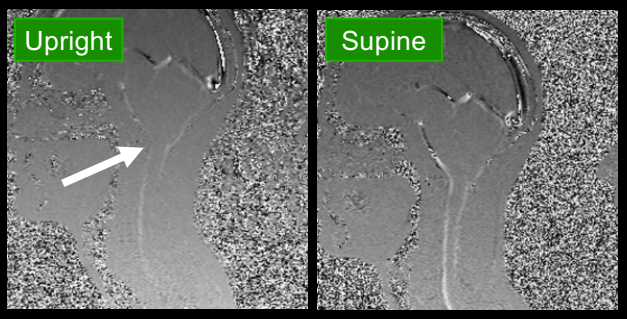
Chiari Malformation

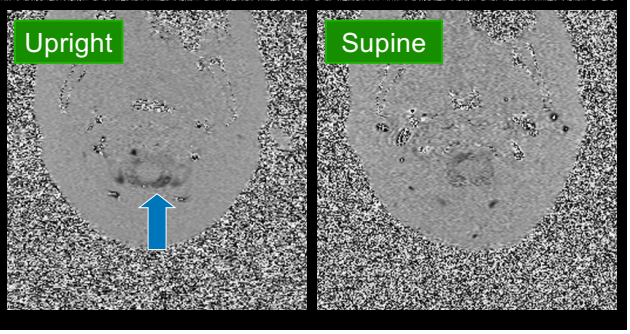
42 F
Relief of symptoms lying down

Obstruction of ventral CSF flow around clivus in the upright position (white arrow) as compared to the supine position



Mid-C2 axial slice shows higher CSF flow posteriorly (blue arrow) when upright than when supine

Chu et al, ISMRM, 941, 2009



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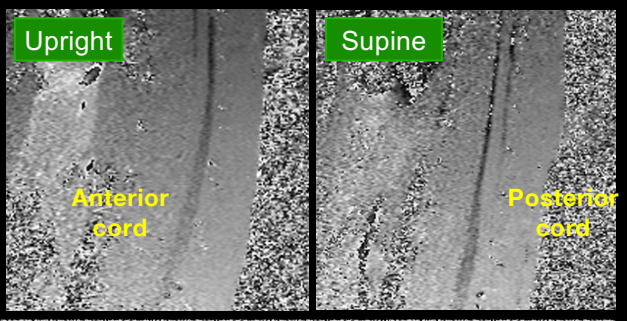
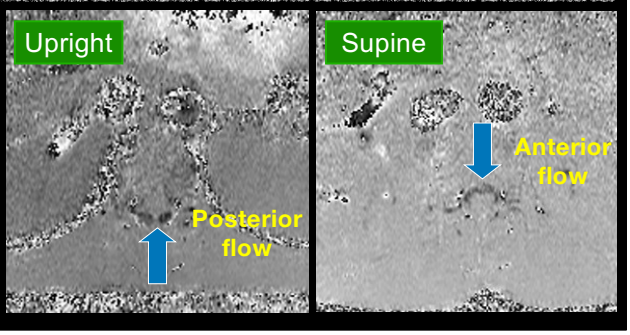
Lumbar CSF Flow

Same patient

Spinal cord moved anteriorly when upright, with corresponding CSF flow shifted to posterior region





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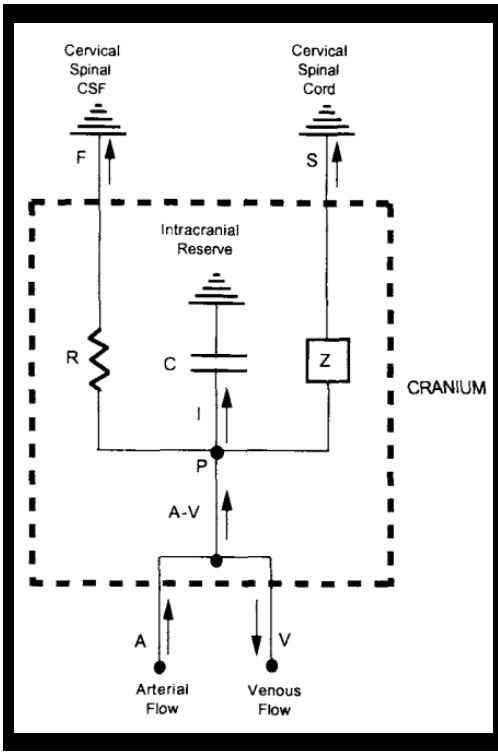

Hemodyamically independent analysis of CSF and brain motion in Alzheimer's Disease and normal older people

Magnetic Resonance Imaging 18 (2000) 991-996
SJ Uftring, D Chu, N Alperin, DN Levin

- By removing the vascular driving waveform, one can derive 3 coupling transfer functions of the vascular pulsations to
  1. CSF flow (G_F)
  2. Intracranial reserve (G_I)
  3. Spinal cord pulsation (G_S)

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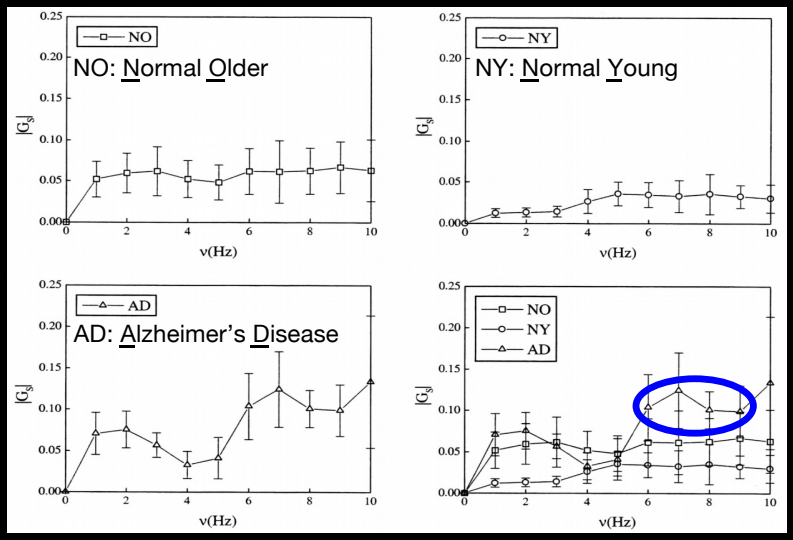
Alzheimer's Disease

Spinal cord coupling transfer function $|G_S|$ (magnitude)

as a function of frequency in supine posture



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4. Some final thoughts

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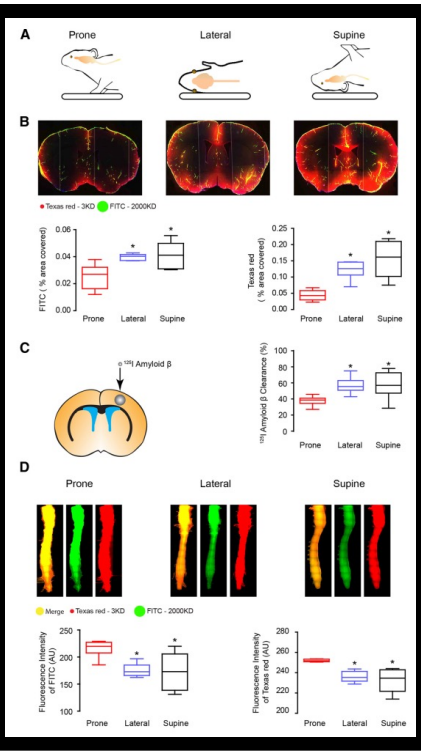
The effect of body posture on brain glymphatic transport

Lee et al, J Neurosc, 35, P. 11034, 2015

- "glymphatic transport was most efficient in the lateral position compared with the supine or prone positions"
- "posture must be considered in diagnostic imaging procedures developed in the future to assess CSF-ISF transport in humans"



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Summary

- Many significant postural differences in CSF and glymphatic flow that can affect brain waste clearance
- If there is no effect in one posture, it may show up in another posture (aging effect study)
- Spinal cord and brain pulsation could be a powerful yet often neglected diagnostic tool (Alzheimer's Disease study)
- Beneficial to sleep on the side, exercise, and more meditation to slow down brain aging

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Thank You for the Invitation and Your Attention

Acknowledgements

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In memory of
Dr. Francis W. Smith
(1943 - 2022)

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