CSF cervical flow computed from 1D model vs. MRI Data

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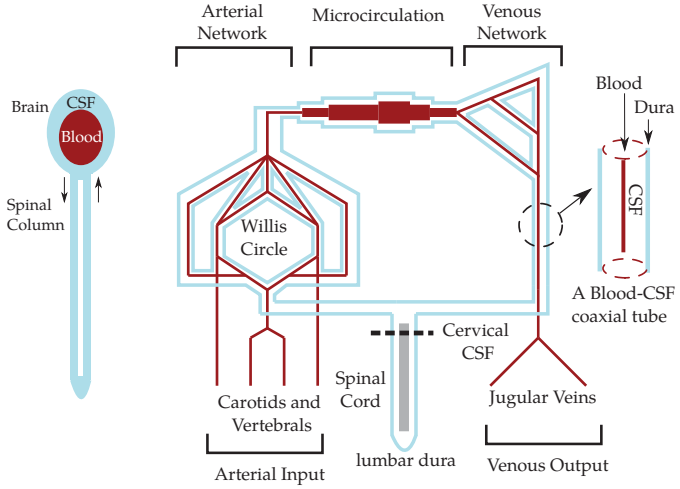
Motivation

The first objective of this study is to build a 1D model of the dynamics couplings between the blood cerebral vasculature, the cranial CSF, the spinal CSF and the spinal cord. Particular attention is given to the effect of mechanical properties of the CSF network on the cervical (C2-C3) CSF flow.
The second objective is to compare the 1D model outputs to MRI Data from healthy and pathological (hydrocephalus) patients.

Methods

Figure (1) presents the 1D craniospinal CSF-blood coupled model. Blood flows from carotids and vertebrals vessels to jugular veins. Each blood vessel is enclosed within a vessel representing the subarachnoid space (dura-mater) where the CSF flows.



For the blood vessel, we have :

$$\begin{cases} \dfrac{\partial A_b}{\partial t} + \dfrac{\partial (U_b A_b)}{\partial z} = 0 \\ \dfrac{\partial U_b}{\partial t} + U_b \dfrac{\partial U_b}{\partial z} + \dfrac{1}{\rho_b} \dfrac{\partial P_b}{\partial z} = \dfrac{2\sqrt{\pi}}{\rho_b \sqrt{A_b}} \tau_b \end{cases}$$

For the spinal and cranial SS, we have :

$$\begin{cases} \dfrac{\partial A_c}{\partial t} + \dfrac{\partial U_c (A_c - A_b)}{\partial z} + \dfrac{\partial (U_c A_c)}{\partial z} = 0 \\ \dfrac{\partial U_c}{\partial t} + U_c \dfrac{\partial U_c}{\partial z} + \dfrac{1}{\rho_c} \dfrac{\partial P_c}{\partial z} \\ = -\dfrac{2\sqrt{\pi}}{\rho_c (A_c - A_b)} (\sqrt{(A_c)} \tau_{cb} - \sqrt{(A_c)} \tau_{cs}) \end{cases}$$

System closure: a tube law.

$$P_t = E_l \left(\frac{A}{A_0} - 1 \right)$$

A is the cross-sectional area, U is the axial mean velocity, P is the pressure and τ is the wall shear force.

Results : Input Blood Signal and resulting Cervical CSF Signal

CSF pressure values ranges between 3 and 4 mmHg before the age of one year, and between 10 and 15 mmHg in adults. Cervical CSF flows predicted by CFD models in litterature ranges between 1 and 4 mL/s .

Sinusoidal Input Waveform

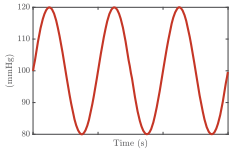


Fig. 3: Blood Pressure

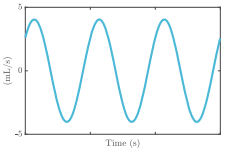


Fig. 4: Cervical CSF Flow

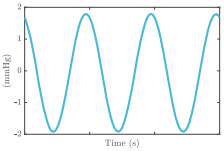


Fig. 5: Cervical CSF Pressure

Arterial Input Waveform

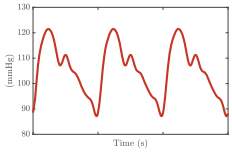


Fig. 6: Blood Pressure

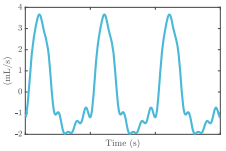


Fig. 7: Cervical CSF Flow

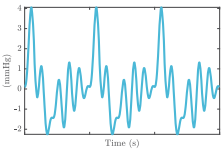


Fig. 8: Cervical CSF Pressure

Results: What are the mechanical properties of the CSF network ?

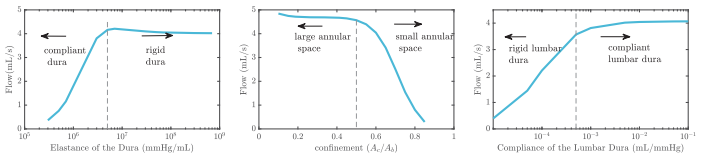
We chose to characterize the CSF network using 3 parametres :

- The confinement $\dfrac{\text{Blood Vessel Section}}{\text{Dura Section}}$.

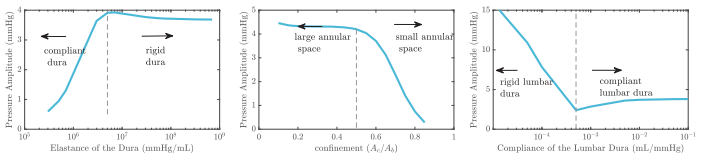
  A chosen confinement = A given CSF volume. MRI Data from litterature suggests total CSF volume vary between 150 mL and 300 mL.
- The compliance of the lumbar dura. CSF lumbar dura pressure is closely linked to Intracranial Pressure (ICP).
- The global elastance of the cranial and spinal dura.

Figures belows presents the effect of the CSF network parametres on the Cervical CSF peak Flow and pressure amplitude.

Cervical CSF (C2-C3) peak Flow

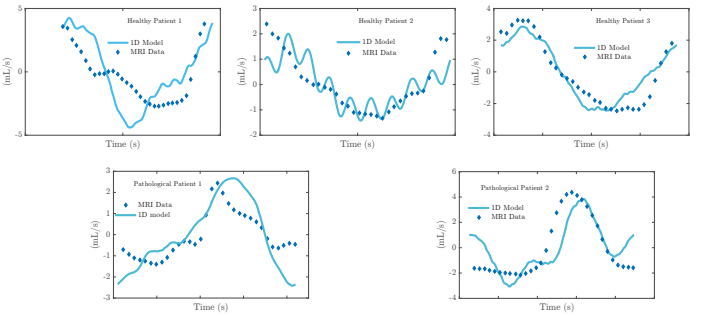


Cervical CSF (C2-C3) Pressure Amplitude



Results: Patient Specific 1D Model vs MRI Data

MRI Data from healthy and pathological patients providing flow signals and surface area of the Carotids, the Vertebrals, the Jugular Veins and the Cervical CSF region(C2-C3).



Discussion

Good agreement between 1D Model and MRI Data suggests that the Dura elastance is around 10^6 mmHg/mL, the compliance of the lumbar dura is around 10^{-4} mL/mmHg. Future work will be focusing on the optimal control modelling of the Cerebral Autoregulation mechanism.

Acknowledgements

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References

[1] Zagzoule Mokhtar & Maher Marc Cathalifaud Patricia. Wave propagation into the spinal cavity: a 1d model with coaxial compliant tubes. In *22nd Congress of the European Society of Biomechanics*, 2016.