SIMULATION OF CEREBROSPINAL FLUID TRANSPORT

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INTRODUCTION

It is generally accepted the pulsations of cerebrospinal fluid (CSF) are generated by two main sources – cardiac activity and respiration. As of now, mainly the cardiac related CSF pulsation was considered in various model studies [1] whereas the respiration related pulsations remained almost unconcerned by researchers.

The purpose of this study was to extend our previous model of CSF transport [2] and to incorporate pressure dependent CSF resorption and allow the simulation of infusion tests.

METHODS

A simple 5-compartmental MATLAB model of CSF spaces was developed based on our previous studies [2]. The schematic of the model are depicted on fig. 1.

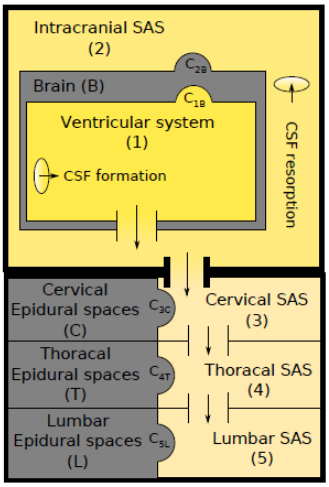

Figure 1: A schematic of the model.

The model consists of 5 compartments (indicated by integer 1-5). In accordance with literature, cardiac related pulsations is introduced intracranially (by means of B "pseudo" compartment) while the respiration related pulsation is introduced spinally from spinal epidural space (C, T and L). We assume an isothermal flow of an ideal fluid. The model equations are derived by invoking basic conservation laws

$$\dot{V}_i(t) = F_{i+}(t) - F_{i-}(t) + S_i(t),$$
$$p_i(t) - p_j(t) = R_{ij} F_{ij}(t),$$

where V_i is the volume of i-th compartment, p_i is pressure, F_{i+} and F_{i-} are flows into and out of the i-th compartment, S_i represents sources and sinks of CSF and R_{ij} and F_{ij} are resistance and flow from i-th to j-th compartment respectively. Differentiation with respect to time is denoted by a dot notation. The elastic properties of membranes between adjacent compartments are described by constitutive equation

$$\dot{V}_{ij}(t) = C_{ij}(\dot{p}_i(t) - \dot{p}_j(t)) = C_{ij}\dot{p}_{ij}(t),$$

where V_{ij} is the volume of a "cup" formed between adjacent compartments as a result of a pressure difference and C_{ij} represents the compliance of the membrane. The compliance was taken from literature [3] in the following form

$$C_{ij}(p_{ij}) = C_{ij}^0 \exp(-r_{ij}\left|p_{ij}(t)\right|^{\alpha_{ij}}),$$

where C_{ij}^0, r_{ij} and α_{ij} represent constants. The pressure dependent resorption was taken in the following form

$$S_{out}(t) = \begin{cases} 0 & \Leftrightarrow p(t) \le p_{\min} \\ C_{out}(p(t) - p_{\min}) & \Leftrightarrow p(t) \ge p_{\min} \end{cases},$$

where C_{out} is the outflow conductance and p_{min} is the treshold pressure (no resorption of pressure drops to or bellow p_{min}). An infusion component was added to each compartment to allow simulation of clinically used infusion tests (by methods of constant infusion rate and bolus injection).

RESULTS AND DISCUSSION

The result of this study is a model capable of simulating both cardiac and respiration related CSF pulsation. In accordance with literature, our model demonstrates that the dural sac acts as a low-pass filter for cardiac related CSF pulsation whereas respiration related pulsation are mostly unaffected. The model shows the respiration influence increases caudally while the cardiac influence increases cranially.

CONCLUSIONS

Our model shows good correspondence with the results of previously published models and experimental studies. The nonlinear compliance as well as the pressure driven resorption help us obtain more precise results. With this model we are also able to conduct infusion simulation tests. As a next step, it is reasonable to include intracranial blood circulation in the model. Such a step would improve the simulation and remove current limitation of the model, which is a low intracranial compliance.

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REFERENCES

1. Otahal J et al. *Adv Eng Softw* (2006), doi:10.1016/ j.advengsoft.2006.08.032.
2. Štěpáník Z et al. *J Biomech* ***41***, Suppl. 1, S520, 2008.
3. Stevens SA et al. *Math Comput Model Dyn Syst* **6**, 445–465, 2