2nd European Fluid Dynamics Conference (EFDC2)
26 – 29 *August* 2025*, Dublin, Ireland*

Streaming flow in the ventricles of the human brain.

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Recent discoveries on human brain flow using MRI (Fultz et al. 2019) [1] showed the importance of neural-induced flow waves during sleep for possible cleansing of toxins from the brain liquid, the cerebrospinal fluid (CSF). This discovery might have large consequences on the understanding of human diseases like Alzheimer and others where toxic plugs are built up in the brain. It was found that the neural activity during sleep drives this pulsating flow situation and is responsible for the exchange of the liquid from the cerebrospinal fluid. So far, experimental and numerical flow studies of CSF transport in the human brain have focused mostly on steady flow (source of CSF in the 4th ventricles, sink is into the aqueduct) or pulsating flows with low amplitude, related to the pressure variations in the blood vessels. Surprisingly, the above cited study focusing on the fluid transport across the aqueduct during sleep showed large waves of CSF in- and outflow in a rhythmic oscillatory manner for several pulses (wave packets of 3-4 pulses, pulse separation 2 sec, repetition of these wave-packets in 20-30 sec).

The published results in Fultz et al. (2019) and our fluid-mechanical interpretation of those led us speculate on the possible importance of streaming in the ventricles, known in oscillating flows as an additional means for improved transport and mixing. One popular example of this net-streaming effect is the improved gas exchange in the lung, which results from streaming caused by differences in the velocity profiles during in- and exhalation in the branching tree of airways. A flow study on the streaming in the human brain ventricles is done herein using CFD and PIV in a mock flow circuit. Experiments are run for an 4:1 upscaled version under similitude rules, which offers better optical access. The characteristic data of the pulses and ventricle geometries derived from the data of Fultz et al. show peak velocities of 20mm/s when entering the aqueduct, which has an average diameter of about 2.5mm. This leads to peak Reynolds-numbers of about 1800. An estimation of the Wormesley number $Wo = d_{Aq}\sqrt{\omega/\nu}$ (Maeda et al., 2023) [2] leads to a value about Wo = 3.13, which clearly indicates the possibility of streaming.

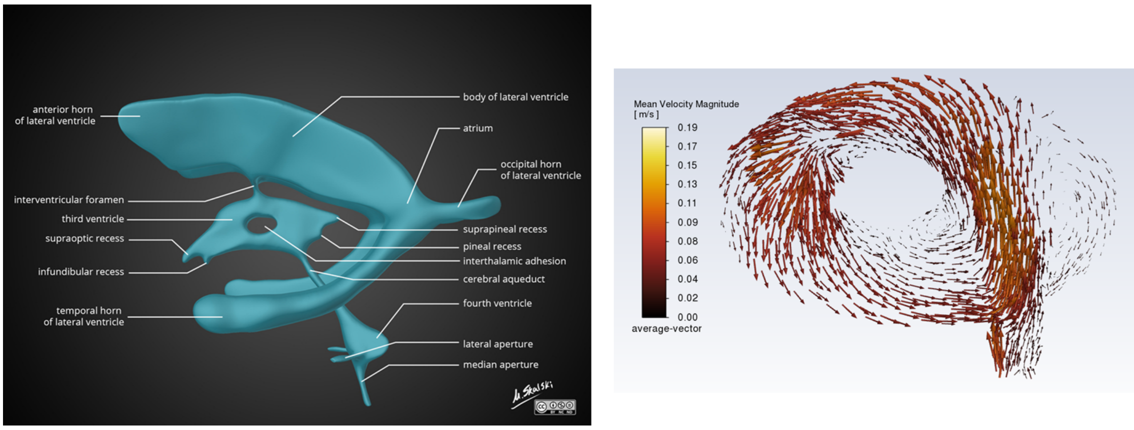

Figure 1: Left: illustration of the brain ventricle anatomy, taken from Skalski (2015). Right: close-up view of the net streaming flow pattern in the third ventricle after several pulses (from CFD).

Fig. 1 shows the CFD-result of the flow inside the third ventricle, which is connected at the lower end to the aqueduct and at the upper side via the foramen to the 4ths ventricles. The CFD simulation result shown in Fig 1 right is presenting the net streaming flow pattern, obtained from averaging the flow fields over several pulses. Interestingly, the result show an overall counter-clockwise swirl, which is contributing to the mixing of the CSF in the third ventricle. This may contribute to the "washing" effect via the induced net-streaming of circulation.

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[1] Fultz et al, *Science* **366**, 628-631 (2019)
[2] Maeda et al., *J. Biomech.* **156**, (2023)