Analysis of ICP pulsatility and CSF dynamics

The pulsatility curve and effects of postural changes, with implications for idiopathic normal pressure hydrocephalus

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Akademisk avhandling

som med vederbörligt tillstånd av Rektor vid Umeå universitet för avläggande av teknologie doktorsexamen framläggs till offentligt förvar
i Hörsal E 04 Unod R1, Norrlands Universitetssjukhus,
fredagen den 6 december, kl. 13:00.
Avhandlingen kommer att förvaras på engelska.

Fakultetsopponent: Professor Martin U Schuhmann,
Department of Neurosurgery, Eberhard Karls University Tübingen,
Tyskland.
Analysis of ICP pulsatility and CSF dynamics – The pulsatility curve and effects of postural changes, with implications for idiopathic normal pressure hydrocephalus.

Abstract
The volume defined by the rigid cranium is shared by the brain, blood and cerebrospinal fluid (CSF). With every heartbeat the arterial blood volume briefly increases and venous blood and CSF are forced out of the cranium, leading to pulsatility in CSF flow and intracranial pressure (ICP). Altered CSF pulsatility has been linked to idiopathic normal pressure hydrocephalus (INPH), which involves enlarged cerebral ventricles and symptoms of gait/balance disturbance, cognitive decline and urinary incontinence that may be improved by implantation of a shunt. The overall aim of this thesis was to investigate the fluid dynamics of the CSF system, with a focus on pulsatility, and how they relate to INPH pathophysiology and treatment.

Mathematical modelling was applied to data from infusion tests, where the ICP response to CSF volume manipulation is measured, to analyse the relationship between mean ICP and ICP pulse amplitude (AMP) before and after shunt surgery in INPH (paper I-II). The observed relationship, designated the pulsatility curve, was found to be constant at low ICP and linear at high ICP, corresponding to a shift from constant to ICP dependent compliance (paper I). Shunt surgery did not affect the pulsatility curve, but shifted baseline ICP and AMP along the curve towards lower values. Patients who improved in gait after surgery had significantly larger AMP reduction than those who did not, while ICP reduction was similar, suggesting that improving patients had baseline ICP in the linear zone of the curve before surgery. Use of this phenomenon for outcome prediction was promising (paper II). The fluid dynamics of an empirically derived pulsatility-based predictive infusion test for INPH was also investigated, with results showing strong influence from compliance (paper III).

Clinical ICP data at different body postures was used to evaluate three models describing postural effects on ICP. ICP decreased in upright positions, whereas AMP increased. The model describing the postural effects based on hydrostatic changes in the venous system, including effects of collapse of the jugular veins in the upright position, accurately predicted the measured ICP (paper IV).

Cerebral blood flow and CSF flow in the aqueduct and at the cervical level was measured with phase contrast magnetic resonance imaging, and compared between healthy elderly and INPH (paper V). Cerebral blood flow and CSF flow at the cervical level was measured with phase contrast magnetic resonance imaging, and compared between healthy elderly and INPH (paper V). Cerebral blood flow and CSF flow at the cervical level were similar in INPH patients and healthy elderly, whereas aqueductal CSF flow differed significantly. The pulsatility in the aqueduct flow was increased, and there was more variation in the net flow in INPH, but the mean net flow was normal, i.e. directed from the ventricles to the subarachnoid space (paper V).

In conclusion, this thesis introduced the concept of pulsatility curve analysis, and provided evidence that pulsatility and compliance are important aspects for successful shunt treatment and outcome prediction in INPH. It was further confirmed that enhanced pulsatility of aqueduct CSF flow was the most distinct effect of INPH pathophysiology on cerebral blood flow and CSF flow. A new model describing postural and hydrostatic effects on ICP was presented, and the feasibility and potential importance of measuring ICP in the upright position in INPH was demonstrated.

Keywords
Cerebrospinal fluid, CSF dynamics, Intracranial pressure, Pulse pressure, Normal pressure hydrocephalus, Posture, Predictive tests, Mathematical modelling, Magnetic resonance imaging, Infusion tests