

Insight into the anatomy of cerebrospinal fluid flow in the human ventricular system using MR velocity mapping

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Purpose: Our hypothesis was that time-resolved 3D MR velocity mapping, which is an established method for investigation of normal and pathologic blood flow in the vascular system, is applicable to study flow patterns of CSF in the human ventricular system. We used MR velocity mapping in combination with calculation of particle path lines from velocity vector field data to introduce a method for time-resolved 3D visualization of intracranial CSF flow patterns in healthy volunteers. In addition we investigated the influence of aging effects on both, the appearance of CSF flow categories and CSF flow velocities.

Materials and Methods: MR imaging data of the brain were collected from 40 healthy subjects (47.9 ± 15.8 y; 22 – 79 y). The age distribution did not differ significantly by a Kolmogorov-Smirnov-Z test. MRI examinations were performed on a 1.5 Tesla whole-body system (Achieva, Philips Medical Systems, Best, The Netherlands) equipped with an eight-channel head coil. Time-resolved 3D MR velocity mapping data were acquired using a 3D TFE phase-contrast (PC) sequence. Retrospective vector-ECG gating was used for covering the entire cardiac cycle. The sequence yielded 12 quantitative flow-encoded 3D data sets per cardiac cycle. The measurement parameters used were: TR/TE = 16/9 ms, SENSE = 2, turbo factor = 3, spatial resolution = $1.38 \times 1.38 \times 1.5$ mm³, and measurement time = 4.3 – 6.7 min. The individually adapted venc ranged between 2 and 4 cm/s. A local phase correction (LPC) filter was applied for eddy currents correction. In order to enable investigation of 3D velocity vectors of CSF flow velocity encoding was performed in A>>P, L>>R, and F>>H direction. For calculation of the time-resolved 3D CSF flow patterns, MR velocity mapping data were evaluated using the GTFLOW software tool (GyroTools, Zurich, Switzerland). To obtain a more detailed insight into the anatomy of CSF flow in the ventricular system, we decided to evaluate the lateral ventricles, the third, and the fourth ventricle separately.

Results: Classification of CSF flow based on calculation of 3D particle path lines over the cardiac cycle revealed one uniform flow pattern for the lateral ventricles, three categories for the third and two categories for the fourth ventricle. CSF in the lateral ventricles moves in systole from the cella media through the foramina of Monro in caudal direction, but portions of CSF remains in the lateral ventricles and travels towards the anterior horn (Fig. 1A). During diastolic phase CSF shows a unidirectional reflux of CSF from the foramina in cranial direction to the anterior horn (Fig. 1B).

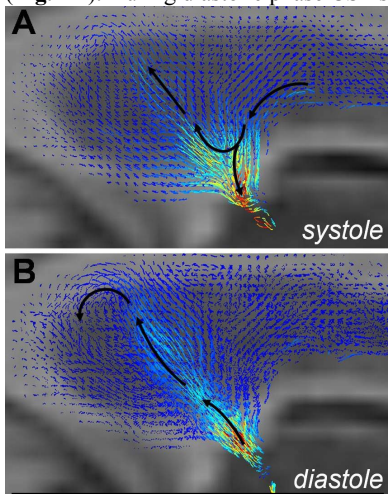


Figure 1: CSF Flow in lateral ventricles

In the first category (“single-path”, SP) for the CSF flow in the third ventricle CSF moves during the systolic and diastolic phase on a single path beneath the interthalamic adhesion along the floor of the ventricle in caudal and cranial direction, respectively (Fig. 2A&B). In the second category (“dual-path”, DP) for the CSF flow in the third ventricle CSF moves during the systolic and diastolic phase on two paths above and beneath the interthalamic adhesion in caudal and cranial direction, respectively (Fig. 2C&D). The third category (“crossing-path”, XP) shows a broad path of CSF flow almost across the whole distance of the third ventricle during both the systolic and the diastolic phases (Fig. 2E&F). Subjects showing this category had no interthalamic adhesion. The differences in CSF flow anatomy in the third ventricle are caused by differences in size of the interthalamic adhesion (white areas in Fig. 2A-D). In the fourth ventricle one portion of CSF travels directly through the ventricle and leaves it in systole via the foramina of Luschka and Magendie and in diastole via the aqueduct of Sylvius. The remaining portion of CSF forms either one large vortex (single-vortex, SV, category, coronal perspective in Fig. 3A) or two vortices rotating in opposite direction (double-vortex, DV, category, Fig. 3B). We found no significant aging effects on both the presence of a specific CSF flow pattern and on CSF flow velocities.

Conclusion: Our approach could provide new insight into the functionality of CSF and possibly opens a new door to investigate the role of CSF for physiology and metabolism of the human brain. It may furthermore serve as an adjunct for diagnosis and therapy planning of several pathologies like hydrocephalus, brain malformations, Alzheimer’s disease or other forms of dementia.

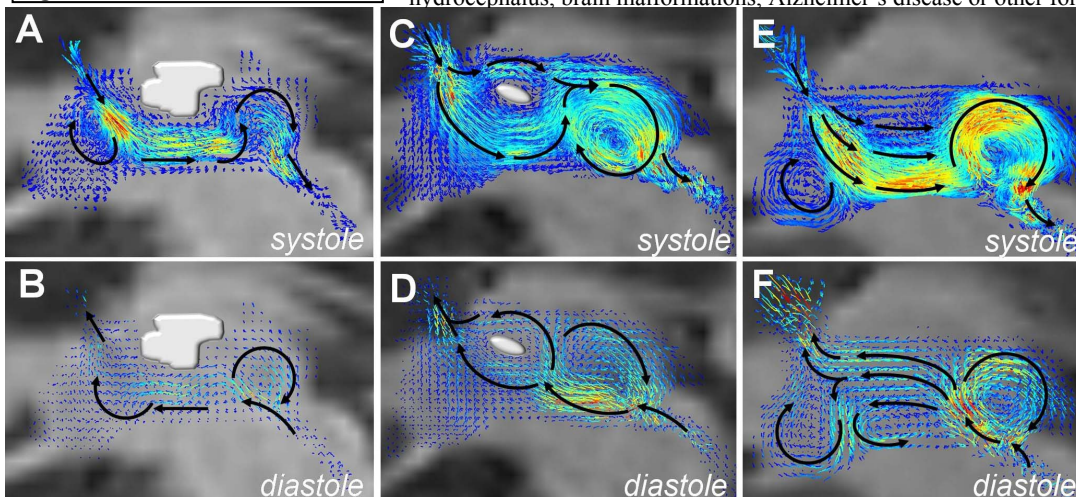


Figure 2: CSF Flow in the 3rd ventricle. A&B: single-path (SP), C&D: dual-path (DP), E&F: crossing-path (XP) category

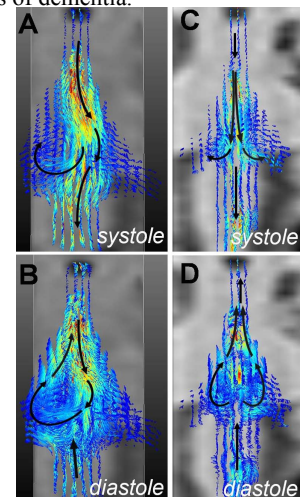


Fig. 3: CSF Flow in the 4th ventr