In vivo 4D visualization of CSF flow: healthy volunteers and hydrocephalus

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Introduction. *In vivo* assessment of cerebro-spinal fluid (CSF) flow velocities and flow patterns is a challenging task, due to the magnetic properties of the tissue that lead to very low signal in T1-weighted sequences. However, flow patterns can be an important discriminating factor between healthy subjects and hydrocephalus patients. Single-slice and multi-slice acquisitions, relying on inflow enhancement, and computational fluid dynamics techniques based on anatomical data, were used in the literature [1]. In this work, we used a three-dimensional, time-resolved, three-directional flow-sensitive balanced SSFP sequence [2] to obtain a full three-dimensional description of CSF flow patterns in the brain of healthy volunteers and to compare it to findings in a patient with a three-ventricular hydrocephalus.

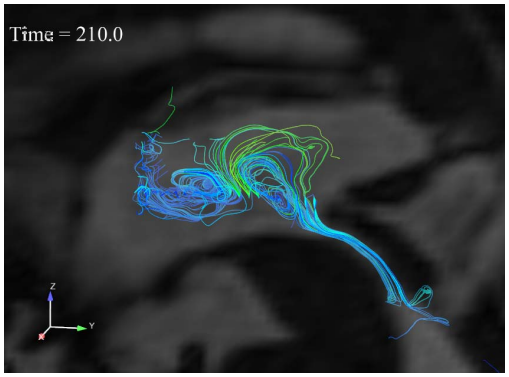

Fig 1: Flow pattern in healthy volunteer during systole

Materials and methods. A version of the optimized bSSFP sequence presented in [2], modified in order to allow parallel imaging, was used to scan on a 1.5T whole-body Avanto scanner (Siemens, Erlangen, Germany) the brain of three healthy volunteers and one patient suffering from a long standing three-ventricular hydrocephalus with a sagittal slab containing the third and the medial component of the lateral ventricles. Image resolution was 1.04x1.04x1.5mm, TR/TE 14/7ms, Venc 10cm/s, temporal footprint 112ms (8*TR). The temporal resolution was reduced to 28ms by implementing a "view sharing" approach of the flow encoding steps during reconstruction. The images were postprocessed to mask the noise and to reduce eddy current phase effects, and visualized with a commercial 3D visualization program (Ensight, CEI, Apex, NC). Vector fields and velocity streamlines were placed inside the ventricles to visualize flow patterns. A T2-weighted anatomical dataset with standard clinical parameters was also obtained for the patient in axial and coronal plane.

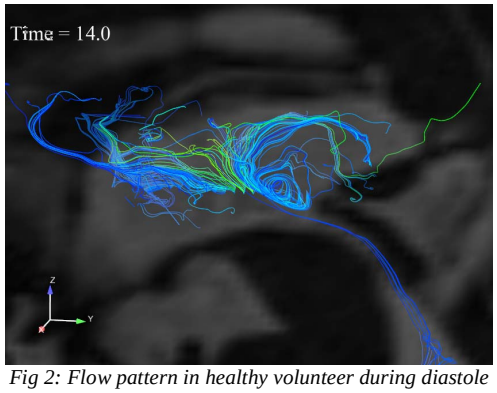

Fig 2: Flow pattern in healthy volunteer during diastole

Results. *Healthy volunteers.* The results showed the presence of two counter-rotating vortices in the third ventricle, which keep the same direction of rotation throughout the whole cardiac cycle, and are alternatively fed from the foramina of Monro (during systole, fig 1) and the aqueduct of Sylvius (during diastole, fig 2). Peak flow velocities are up to 5 cm/s in the aqueduct, but flow pulsatility is very high, resulting in little net flow in the cranio-caudal direction, which is compatible with the observation of physiological CSF production.
Patient. Despite the absence of any obstruction visible on T2-weighted anatomical imaging, no flow through the aqueduct was observed. This finding was in accordance with finding from the endoscopic investigation that was performed after the imaging, and revealed obstructive membranes. The complex flow patterns within the third ventricle visible in the healthy volunteers were not present, merely a slow pulsation in the cranio-caudal direction, with no significant net flow was visualized (figures 3 and 4). Most interestingly, flow was traced to transverse the floor of the third ventricle, indicating an inner shunt (figure 5).

Discussion/Conclusion. Three-dimensional, time-resolved, three-directional flow-sensitive balanced SSFP sequence was able to produced high SNR and enabled a comprehensive study of flow patterns and velocities. The comparison of the three-dimensional flow patterns between healthy volunteers and a patient with hydrocephalus revealed significant differences that might become helpful in the definition of the diagnosis and the therapy. We are planning to acquire more datasets from patients, in order to explore the different forms of hydrocephalus and other diseases associated with CSF flow.

References. [1] Linninger AA, *et al*., IEEE Trans Biomed Eng 2007;54(2):291-302, [2] Santini F, *et al*., ISMRM 2008, #2878

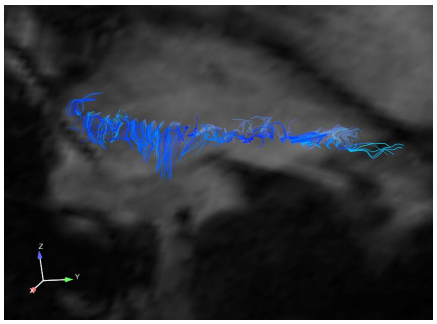

Fig 3: Flow pattern in hydrocephalus patient during systole

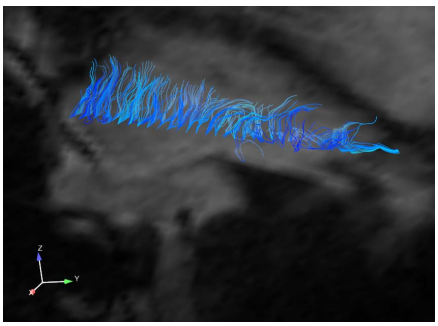

Fig 4: Flow pattern in hydrocephalus patient during diastole

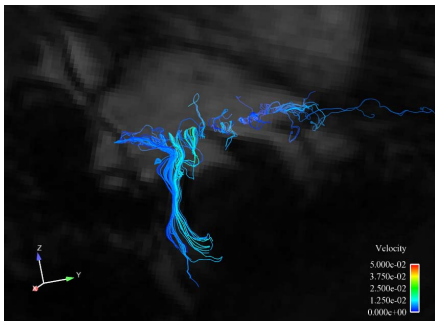

Fig 5: Flow through the floor of the 3rd ventricle