

4D flow characteristics of cerebrospinal fluid dynamics at the craniocervical junction and the cervical spinal canal in patients with Chiari malformation type I

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Introduction

Patients with Chiari malformation are only insufficiently characterized by a mere morphologic analysis of their extent of tonsillar ectopia. In contrast, analysis of cerebrospinal fluid (CSF) dynamics holds promise for better identifying patients, who are symptomatic due to the malformation and who may benefit from surgical craniocervical decompression¹. So far, 2D phase contrast (PC) imaging has been the mainstay for the analysis of cerebrospinal fluid dynamics in patients with Chiari malformations. However, as a single slice technique 2D-PC imaging is limited by its restricted spatial coverage. The unidirectional encoding of flow velocities falls short in adequately characterizing complex flow phenomena and analysis of grey-scaled images leaves much room for interpretation. Conversely, 4D-PC flow imaging is increasingly appreciated for its potential in providing a comprehensive and concise insight into complex flow phenomena. In the present study we aimed at identifying characteristic 4D CSF flow patterns in patients with Chiari malformation type I and at providing a detailed 4D analysis of quantitative flow measures of the CSF pulsations at the craniocervical junction and the cervical spinal canal.

Methods

All MR measurements were acquired on a 1.5 Tesla Achieva scanner (Philips, Best, the Netherlands) with a standard 16 channel head and neck coil. CSF flow patterns were studied in 10 healthy volunteers and 15 patients with Chiari malformation type I. In 9 patients an associated pre-syrinx was present. Time resolved 3D phase contrast images were acquired with the 3D stack orientated sagittally covering the craniocervical junction and the entire cervical thecal sac. A retrospectively ECG-triggered, T1-weighted, segmented gradient echo sequence (T1-TFE) with the following sequence parameters was used: TR and TE was set to "shortest" resulting in a TR of 8.6 - 9.5 ms and a TE of 5.4 - 6.3 ms slightly varying with encoding velocity, flip angle: 5°, acquired isotropic resolution: 1.5 mm (reconstructed voxel resolution: 1mm), sense factor: 2. Encoding velocity in volunteers was set to 10 cm/sec for all directions unless higher velocities were noted on 2D scans when velocity was increased to 15 cm/sec (n=3). In patients the encoding velocity was uniformly adjusted to 20 cm/sec due to the expected flow disturbances with increased flow velocities. Number of heart phases acquired ranged between 12 and 14 depending on heart rate. Arrhythmia rejection was enabled. Imaging time varied between 8 and 14 minutes depending on individual heart rate and encoding velocity factor. Phase contrast images were postprocessed using dedicated software (GTFlow 1.3.11, GyroTools, Zurich, Switzerland) allowing for flow quantification and visualization. Peak flow velocities were measured at levels of the foramen magnum and every cervical vertebra during systolic and diastolic heart phases. Furthermore, overall peak flow velocities within flow jets were determined. Flow pathlines were calculated and visualized, typical flow patterns in healthy volunteers and patients were identified.

Results

The 3D phase contrast sequence allowed for flow quantification and visualization in all individuals. In healthy volunteers CSF flow was homogenously distributed in the subarachnoid space anterior and anterolateral to the brain stem and the spinal cord with the flow directed caudally during systole (see image 1) and cranially during diastole. Flow velocities were closely related to width of subarachnoid space ($r < 0.89$, $p < 0.001$). At the level of the foramen magnum peak flow velocity was 3.6 ± 2.0 cm/sec during systole and 3.0 ± 1.3 cm/sec during diastole. Maximal flow velocities were found at the level of the fifth cervical vertebra (8.2 ± 2.4 cm/sec in systole and 4.8 ± 1.1 cm/sec in diastole). In contrast, in patients flow velocities were significantly higher at the level of 1st (8.3 vs. 3.7 cm/sec, $p < 0.01$) and 2nd cervical vertebra (7.7 vs. 4.4 cm/sec, $p < 0.05$). On qualitative flow analysis, grossly altered CSF flow patterns were found in 12 out of 15 Chiari patients with bilateral flow jets found anterolateral to the brain stem at the level of the craniocervical junction. In 7 patients there was a clear flow jet accentuation on one side (image 1&2: examples of right sided flow jet accentuation) with focal neurologic symptoms present at the same side in 4 of these patients. In the other 3 patients symptoms were present on either side. In 4 patients bidirectional flow was noted on phase contrast images consistent with flow vortices well depicted by the pathline visualization (image 2 with arrows indicating direction of flow vortices). Comparing Chiari patients with and without pre-syrinx, peak systolic jet velocities at the level of the 1st and 2nd cervical vertebra tended to be higher when pre-syrinx was present (-11.6 ± 5.4 vs. -8.4 ± 1.7 cm/sec; $p = 0.23$, image 3).

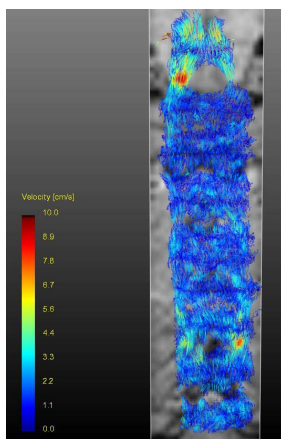


Image 1

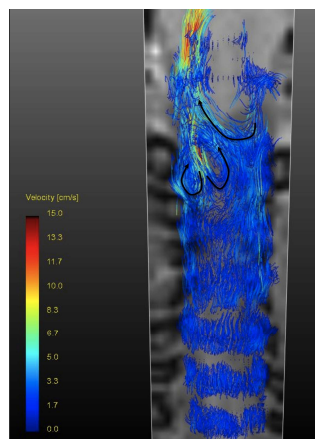


Image 2

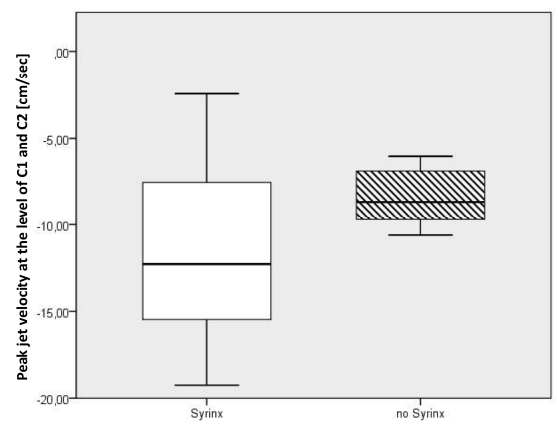


Image 3

Discussion & Conclusion:

In our study 4D-PC imaging allowed for a detailed qualitative and quantitative analysis of CSF flow dynamics at the craniocervical junction and the cervical spinal canal in patients with Chiari malformation type I. Compared to healthy volunteers, in patients flow velocities were found to be significantly increased at the upper cervical spinal canal accompanied with grossly altered flow patterns in the majority of patients. Typical flow patterns observed in patients included bilateral jet formation with or without accentuation on one side and bidirectional flow consistent with flow vortices. Interestingly, side of flow jet accentuation coincided with the side of symptoms in a number of patients suggesting a role for altered CSF dynamics in the pathophysiology of development of symptoms. There was a clear tendency towards higher flow velocities in Chiari patients with concomitant pre-syrinx. In view of the variability of flow patterns observed in our study further studies with larger numbers of patients are warranted to identify the clinical value of 4D-PC imaging in the analysis of CSF dynamics in patients with Chiari malformation.

References

1. Iskander BJ, Quigley M, Haughton VM. Foramen magnum cerebrospinal fluid flow characteristics in children with Chiari I malformation before and after craniocervical decompression. *J Neurosurg (Pediatrics)* 2) 101:169-178, 2004