

4D flow measurement of cerebrospinal fluid pulsation at the craniocervical junction and cervical spine and its clinical potential

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Introduction

Recently time-resolved three-directional (3D) phase contrast MR imaging, also called 4D flow imaging, has increasingly been appreciated for its potential in in-vivo analysis of complex flow phenomena. With the improvements in gradient power of modern MR scanners, the gain in computational performance and the advent of state-of-the-art visualization and data processing software this new technique is becoming more readily available and is gaining attraction for its routine clinical use. So far, studies focusing on the dynamics of cerebrospinal fluid (CSF) pulsation at the craniocervical junction have used 2D phase contrast imaging for the detection of altered CSF flow in pathologies such as Chiari malformations¹. However assessing solely the through-plane flow component is insufficient for a comprehensive analysis of possible pathological CSF flow dynamics present under these conditions. The aim of this study was to test the feasibility of time-resolved 3D phase contrast MR imaging for the depiction of CSF flow at the craniocervical junction and the cervical spine and identify physiological and pathological flow patterns.

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 5 healthy volunteers and 5 patients with various pathologies at the level of the craniocervical junction or the cervical spine including Chiari I malformation with associated presyrinx and syringomyelia, Chiari II malformation with cystic syringomyelia, idiopathic syringomyelia and spinal postinflammatory arachnoidal adhesions. 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 an isotropic resolution of 1.5 mm was used. TR and TE was set to "shortest" resulting in a TR of 8.5 ms and a TE of 5.4 ms slightly varying with the venc value. Flip angle was 5°. Venc value in volunteers was uniformly set to 10 cm/sec for all directions. In patients, where flow disturbances with increased flow velocities were expected, the venc value was adjusted to 20 cm/sec. Sense factor was 2. Number of heart phases acquired ranged from 10 to 14 depending on heart rate. In addition, a single slice balanced FFE cine sequence in the sagittal plane was acquired to qualitatively capture concomitant gross motion of brain and spinal cord. 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 various levels during systolic and diastolic heart phases and flow pathlines were calculated and visualized.

Results

The 3D phase contrast sequence allowed flow quantification and visualization in all individuals. Scan time ranged from 8 to 14 minutes. In healthy volunteers only little brain motion was noted on SSFP cine images. CSF flow was predominantly homogeneously distributed in the arachnoid space anterior to the brain stem and the spinal cord with the flow directed caudally during systole (see image 1) and cranially during diastole. At the level of the foramen magnum maximal flow velocity was $3,3 \pm 1,1$ cm/sec during systole and $3,1 \pm 0,7$ cm/sec during diastole. Maximal flow velocities were found at the level of the fifth cervical vertebra ($7,4 \pm 2,1$ cm/sec in systole and $4,8 \pm 1,0$ cm/sec in diastole). In contrast, patients showed grossly altered CSF flow patterns accompanied by increased brain stem and cord motion. Predominant feature in Chiari patients were two flow jets located anterolaterally on both sides of the brain stem at the level of the craniocervical junction (image 2, arrows). Maximal velocities were markedly increased (up to 18 cm/sec). In the patient presenting with Chiari I malformation and associated presyrinx bidirectional flow was noted on phase contrast images consistent with two prominent flow vortices well depicted by the pathline visualization (image 3).

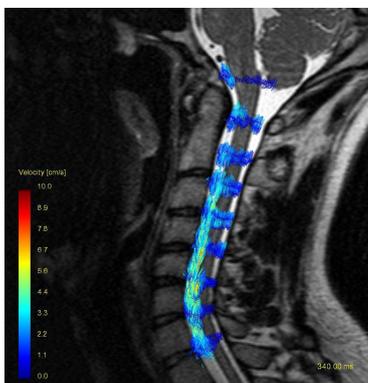


Image 1

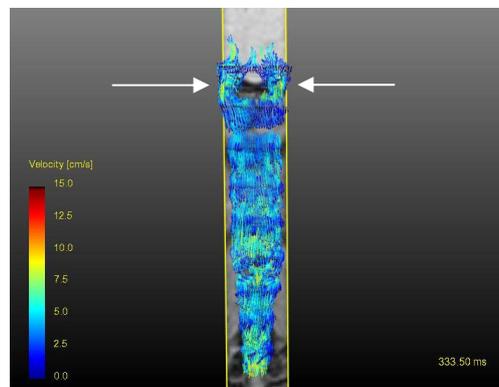


Image 2

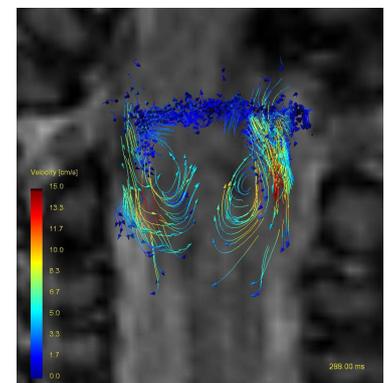


Image 3

Discussion & Conclusion:

The present study shows that cardiac gated time-resolved 3D phase contrast MR imaging on a commercially available scanner is applicable to allow for the depiction and assessment of CSF flow patterns at the craniocervical junction and the cervical spine and can help to identify physiological and pathological flow conditions under various circumstances. Maximal flow velocities at the foramen magnum in healthy volunteers were in good agreement with values reported for 2D phase contrast imaging in literature². Bidirectional flow, previously reported to be present in symptomatic Chiari patients¹, was consistent with flow vortex formation. Combined with a SSFP cine sequence time-resolved 3D phase contrast MR imaging adds valuable information on the alterations of CSF flow and brain motion dynamics that occur under pathological conditions. The large anatomic coverage of the technique furthermore allows the assessment of downstream effects of altered flow pulsations at the craniocervical junction or the cervical spine potentially responsible for syrinx formation at a more distant level.

References

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2. Struck AF, Haughton VM. Idiopathic Syringomyelia: Phase-contrast MR of cerebrospinal fluid flow dynamics at level of foramen magnum. *Radiology* 2009. 253(1):184-90