# Measurement of subpixel motion of the lateral ventricular walls

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**Abstract:**

By taking advantage of the bright CSF signal in balanced steady state free precession (bSSFP), one can obtain high contrast images of the entire cerebral ventricular system. We used 3D cardiac gated, cine bSSFP images of the ventricles in healthy individuals to observe size changes over the course of the cardiac cycle. Using motion tracking techniques, intensity changes in the images can be translated into subpixel displacement of the ventricular wall. The technique demonstrates peak motion of approximately 70μm (0.1 pixels), primarily of the superior wall of the lateral ventricle in the superior-inferior direction. Further development of this technique will allow accurate measurement of net ventricular wall motion, which can then be correlated with net CSF outflow from the ventricle as measured in the aqueduct. It is anticipated that such information will allow more accurate computational fluid dynamics models of CSF flow to be developed based on realistic physical models of the ventricular space coupled to actual measures of wall motion.

**Introduction:**

Disorders of intracranial flow such as hydrocephalus have a marked effect not only on the bulk flow of CSF, but also on pulsatile CSF flow. For example, normal pressure hydrocephalus is associated with a marked increase in the net aqueductal CSF stroke volume. There is a large body of literature demonstrating pulsatile CSF flow throughout the craniospinal axis [1], as well as changes with disease [2]. Pulsations are presumed to be driven by the arterial pulse entering the cranium with each heartbeat, which has strong support based on the similarity in timing of intracranial arterial and CSF waveforms. However, the exact mechanism of the transfer of these pulsations from the arterial to the ventricular system remains a mystery. The pulsations have been attributed to motion of the choroid plexus [3], the third ventricle [4] or the entire brain [1]. The lack of quantitative data on the exact nature of ventricular wall motion has severely hampered our ability to develop rigorous models of diseases such as hydrocephalus. Attempts to simulate CSF flow in the brain, without quantitative information on actual ventricular motion, will produce qualitative results at best.

There have been a number of previous attempts to measure ventricular wall motion. In 1989, prior to the use of MRI flow imaging to quantify CSF flow, T1-weighted MRI images and edge-detection methods were used to infer ventricular wall motion [5]. However, based on our current knowledge that aqueductal stroke volume in healthy individuals is about 30 microliters, their estimate of 10-20% volume changes is highly questionable. Greitz [1] used MRI flow techniques to measure brain motion at selective planes through the ventricles but the ventricular walls are not clearly seen, and the entire ventricular cavity can not be scanned efficiently due to the single slice nature of phase contrast techniques. Our goal in this pilot study was to demonstrate the ability to measure ventricular wall motion over the entire ventricular volume using high resolution, high-contrast, cine bSSFP images in conjunction with an established motion tracking technique.

**Methods:**

Three healthy volunteers were studied on a 3T Philips Achieva scanner. The ventricles were imaged in both the axial and sagittal planes using a peripheral pulse, retrospectively gated 3D sequence. The sequence was a fully balanced, 3D steady state free precession technique with the following parameters: TE/TR = 3.6/7.3, FOV 18 cm, matrix 384 x 302 reconstructed to 512 x 512, ST 2 mm, 15 slices, 1 NEX, 15 frames. For this preliminary work, only half of the ventricular volume was covered in the sagittal scan.

The motion-tracking algorithm was a variation of particle image velocimetry (DPIV), a cross-correlation technique introduced by Willert and Gharib [6] for video-based flow measurements, which has been shown to work well in MRI applications as well [7]. The contrast between gray matter and CSF in the ventricle provided sufficient detail for segmentation and motion tracking of the ventricular wall. In the current application, an automated algorithm was used to subdivide and analyze each image pair along uniformly-spaced interrogation regions, and calculate a uniform planar grid of displacement vectors representing motion from frame to frame. Ventricular wall motion was extracted from the displacement map along a segmented boundary of the ventricle.

**Results:**

Wall displacement was detected to be less than a single pixel, ranging between 0.01 and 0.1 pixels. Peak motion in both the axial and sagittal planes was 0.1 pixels, or about 70 μm. Figure 1 shows a single frame in the cycle illustrating downward motion of part of the superior lateral ventricular wall. The images confirm the theoretical presumption that the ventricular wall is compressed and expanded through the cardiac cycle. However, the motion was not uniform over the surface of the ventricle, so that parts of the wall were moving inward during systole, while others were moving outward. Motion was confined to specific regions of the wall and the amplitude of motion was highly variable.

**Discussion:**

This preliminary study confirms that it is possible to produce detailed maps of ventricular wall motion using MRI. One model of ventricular motion [1], based on low-resolution flow images showing inward motion of the brain during systole, predicted a uniform inward compression of the ventricular surface in systole. Based on our high-resolution wall motion maps, this model may need to be revised. Such maps will serve a number of valuable purposes. Comparisons between ventricular wall movement and net aqueductal flow and between the timing of ventricular wall pulsations and aqueductal pulsations can both be used to confirm the extent to which various portions of the wall contribute to net ventricular outflow, and are therefore important in diseases such as hydrocephalus where this outflow is modified. Also, with improvements in the technique we will be able to produce accurate models of ventricular wall motion which can be fed into fluid dynamic models of CSF flow in order to predict how changes in intracranial compliance can affect CSF flow.

**References:**

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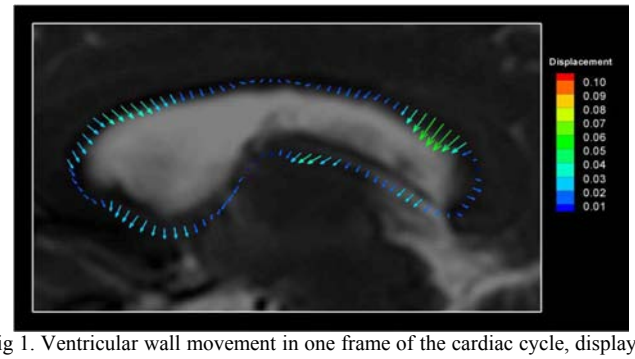


Fig 1. Ventricular wall movement in one frame of the cardiac cycle, displayed in units of fractions of a pixel (pixel size was 0.7 mm).

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