Aqueduct CSF flow measured objectively with PC-MRI

A. Wåhlin[1], K. Ambarki[1], A. Garpebring[1], J. Malm[2], R. Birgander[1], and A. Eklund[1]
[1]Radiation Sciences, Umeå University Hospital, Umeå, Västerbotten, Sweden, [2]Clinical Neuroscience, Umeå University Hospital, Umeå, Västerbotten, Sweden

Introduction: Applications in quantifying cerebrospinal fluid (CSF) flow with motion sensitive phase contrast MRI (PC-MRI) has increased continuously. Cardiac synchronization allows quantifying the CSF flows during the cardiac cycle, flows that are characterized by large oscillations and small bulk flows. The most common site of CSF flow quantification is in the cerebral aqueduct with the most frequent measure being the aqueduct CSF stroke volume. The aqueduct is a narrow geometry with a circular or elliptical cross section. It follows that these measurements are subjects to typical imperfections of PC-MRI imaging such as partial volume effects and difficulties in lumen delineation. Methods to correct for partial volume effects have been shown important in order to obtain accurate results[1], and automated methods of vessel delineation have reduced operator variability[2].

Purpose: In this study we abandoned graphically represented vessel delineations. Instead we used complex data generated by the PC-MRI in a method with the potential of objective and absolute measurement of CSF velocity and area, without restrictions by matrix resolution. We compared the complex value methodology with conventional manual segmentation for the determination of aqueduct CSF stroke volume in a group of healthy elderly.

Theory: Assuming that aqueduct CSF flow is laminar and that CSF signal magnitude is saturated, a spiral-shaped relationship of the complex signal as function of velocity can be derived for a cross section containing the aqueduct. Using a generously drawn ROI, encapsulating both the aqueduct and some stationary tissue, the complex pixel values (from amplitude and phase image pairs) can be summed, generating a single complex value for each image pair. The fit of the laminar model to the summed complex values enables calculation of the CSF velocity while avoiding partial volume errors (figure 1). In addition, the maximum spiral radius can be used in several approaches to calculate an absolute estimation of the aqueduct area. In this work we have chosen an approach utilizing the complex difference data usually provided from a PC-MRI sequence.

Methods: Forty-two healthy elderly (ages 62-82 years, 22 women and 20 men) were imaged using a typical PC-MRI protocol (venc = 20 cm/s) at a 3T Philips Achieva (Philips Medical Systems, Best, The Netherlands). Retrospective gating was performed using either ECG or a peripheral sensor. Acquisition and reconstruction matrixes were 128x128 and 256x256 respectively. Slice thickness was 5 mm and FA, TR and TE were 10º, 15 ms and 10 ms respectively. From a generously drawn ROI encapsulating the CSF flow, the complex data were used to determine CSF velocity, cross-section area and stroke volume ($SV_{complex}$). For comparison, average phase and area of carefully drawn ROI's were used to calculate the conventional aqueduct stroke volume ($SV_{conventional}$).

Results: The average $SV_{complex}$ was measured to 73±43 µl and the average $SV_{conventional}$ was measeured to 81±46 µl. There was a statistical difference between the methods (Wilcoxon signed rank, 5% significance level). A plot between the two methods together with the unity line is seen in figure 2.

Conclusion: The complex segmentation algorithm only required a generously drawn ROI to determine the velocity and area of CSF. This ROI was merely a rough localization of the cerebral aqueduct not requiring any carful delineation. The difference between the methods might be an indication of partial volume effects altering the results of the conventional method. Such errors are expected to overestimate the flow rate and thus the stroke volume[1].

References:

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2. Alperin N, Lee SH. PUBS: pulsatility-based segmentation of lumens conducting non-steady flow. Magnetic resonance in medicine. 2003;49:934-944

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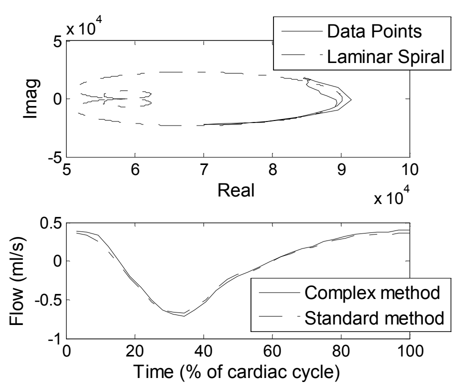

Figure 1. Laminar model fitted to complex summation values of a ROI.

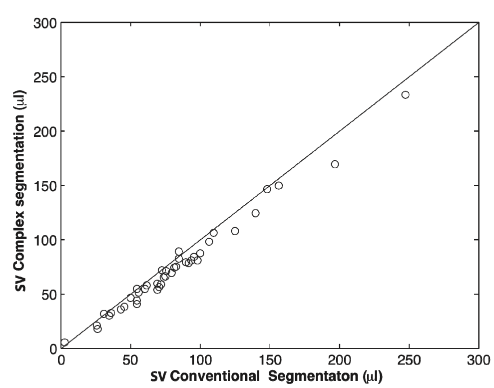

Figure 2. Aqueduct CSF stroke volume measured with two methods.