Time Series Method for Automated Segmentation of Blood Vessels and CSF Lumens

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INTRODUCTION

Dynamic phase-contrast (PC) MRI is being used for quantification of pulsatile motion and flow in many clinical applications. In order to achieve accurate and consistent flow measurements, a reliable automated method for segmentation of the lumen region is needed. Accuracy and reproducibility of manual techniques depend on the observer's skill level. In addition, the observer performance is affected by the selection of the window and level set up. Automated schemes improve reproducibility. However, their performance highly depend on the image contrast to noise level and image complexity. Most schemes (1-2) use spatial information within the phase and/or the magnitude image as a basis for boundary identification. A novel method for lumen segmentation has been developed. The difference in temporal information from pixels located in the lumen and in the surrounding tissue is used as a segmentation criterion. Since multiple images are being used, this approach utilizes information with inherently higher contrast to noise. The performance of the new method was evaluated and compared with manually traced lumens of arteries, veins, and CSF conduits.

METHODS

Five observers with different skill level used a manual and the automated technique to analyze 15 data sets. Each set included two series of 32 cine PC-MR images; a high velocity encoding scan to measure blood flow through the internal carotids, vertebral arteries, and jugular veins, and a low VENC scan to measure CSF flow at the level of C2 (3). The methods were implemented using the IDL programming language (Research System Inc., CO). The time-series method includes 5 steps: 1. Selecting a reference pixel location/s inside the lumen area, 2. Obtaining the time-varying velocity reference waveform at the selected pixel location, 3. Generating a cross-correlation (CC) map by calculating the CC values between the velocity waveforms at each pixel location and the reference waveform. (A CSF PC-MRI image and the corresponding CC map are shown in Fig. 1). 4. Automatic determination of an optimal CC threshold value to be used as a segmentation criterion, and 5. Tracking the boundary of regions in the CC map with values above threshold. Five reference pixels were selected in various regions within the lumen. An optimal CC threshold value is determined from a histogram of the number of pixels with CC value above the threshold for different threshold values (Fig. 2). The CC threshold is obtained from the region where the histogram is relatively flat (region B). In this region, lowering of the threshold does not result with significant increase in the number of segmented pixels. The lumens' area (in number of pixels) and mean flow rates were calculated using both the manual and the automated techniques. The standard deviation (SD) of the lumen area, the mean flow and the % change in cross-sectional area from manual to automated technique for each lumen type were calculated for each observer.

RESULTS

Lumen area measurements obtained with the time-series technique were 4-5 times more reproducible. The observers' mean SD for the lumen area was 2 pixels for arteries (both for internal carotid and vertebral arteries), 4 pixels for the jugular veins, and 7 pixels for the CSF lumen. The cross-sectional areas obtained with the automated technique were 15-67 % larger using the automated technique (the larger % change were for smaller lumens, i.e., the vertebral arteries). Lumen sizes obtained by the skilful observers had the smallest difference between the automated and the manual techniques. The increase in average flow rates ranged from 8% (CSF) to 23% (vertebral arteries).

DISCUSSION

The time series technique performed reliably even in complex anatomy such as were the epidural veins are adjacent to the CSF lumen (Fig. 1). The performance of the time-series method was independent of the observer skill level as indicated by the small mean SD of the lumens' area. This is attributed in part to the fact that selection of threshold value is optimized and is not user dependent. The larger lumen area consistently obtained with the time-series technique suggests improved accuracy. Since velocity values at the edge are close to the background values with the manual technique they are often not included. In addition, CC maps provide quantitative information on the intra and inter-lumen variability and distribution of flow patterns and therefore may become a powerful flow analysis tool.

REFERENCES


Figure 1. Left: One of the 32 PC-MRI images of CSF flow. Right: CC map obtained using a reference waveform from pixel location marked by the x.

Figure 2. Histogram of the number of pixels with CC value above the threshold for different threshold values. The optimal threshold value is obtained from the relatively flat portion (region B).