Automatic segmentation of vessels for MR determination of intracranial pressure

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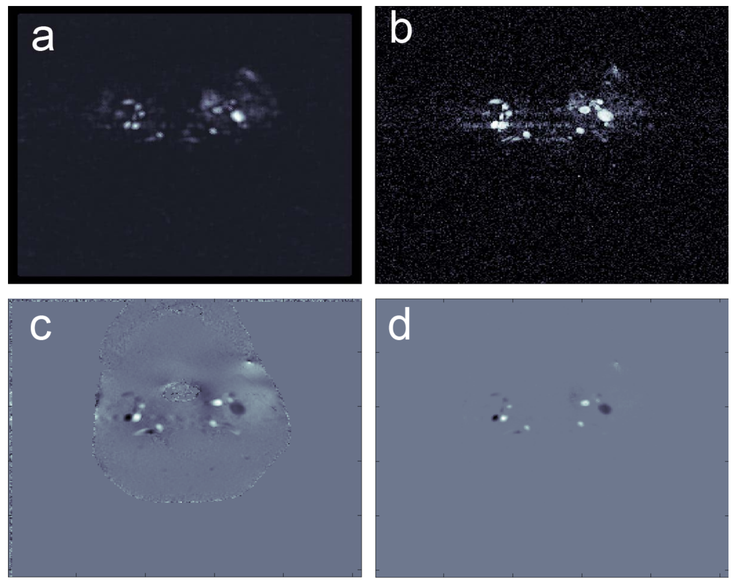
Purpose: Intracranial pressure (ICP) represents the pressure that resists the inflow of blood into the brain. Intracranial hypertension can result in ischemic brain damage and is a significant source of secondary injury in conditions such as hydrocephalus, traumatic brain injury and craniosynostosis. Unfortunately, direct measurement of ICP is highly invasive and the diagnosis of elevated ICP must often be made clinically.

Magnetic resonance imaging allows measurement of ICP by quantifying the flow of CSF and blood into and from the brain [1], which requires identification of the vessels feeding and draining the brain. However, even with semi-automatic assistance, vessel determination requires manual identification of a seed voxel for the vessels [2], after which the spatial scope of the vessels is determined by correlating the time courses of nearby vessels with the seed vessel. We have developed a fully automatic technique for identification of blood vessels and CSF for use with determination of ICP values.



Theory: We identify vessels by combining measures that contrast the signal characteristics of blood flow in vessels compared to those of stationary tissue. The initial step of the algorithm uses three metrics to identify potential vessels:
1) The correlation of the time courses of nearby voxels to each other
2) The autocorrelation of individual voxels
3) The signed area under the curve (AUC) of each voxel

The first metric (Fig 1a) will produce values relatively large values for voxels in the same vessel, which will have similar dynamics, but pairs of voxels that include stationary tissue will have a correlation near 0. The second metric (Fig 1b) will produce values closer to 1 in vessels than in stationary tissue because blood flow does not usually change discontinuously between time points, while flow values in stationary tissue will. The third metric (Fig 1c) is the net flow from each voxel, producing large signals in the jugulars and internal carotids, which carry the bulk of the flow to and from the brain.

A total figure of merit (Fig 1d) was determined by multiplying the three metrics and a set of candidate vessels was determined using Otsu's threshold [3]. The two arteries and veins with the highest average figures of merits were determined to be the carotids and jugulars.

The vertebral arteries are more difficult to identify because of the possibility of low, or even retrograde, flow, which makes identification using AUC inefficient. Instead, the figure of merit is supplemented with the standard deviation of the vessel signal and the temporal correlation with the carotid artery signal. Additionally, a geometric mask is determined to restrict the search space for the vertebral arteries to between and behind the carotids and jugulars. The vertebral arteries are determined using Otsu's threshold on the revised figure of merit.

Methods: Prospectively gated phase-contrast flow maps were acquired of a single slice containing the feeding vessels in a set of 5 patients with no indications for elevated ICP. Measurements were obtained with a spatial resolution of 0.7 mm and an encoding velocity of 70 cm/s. Segmentations were performed using both the automatic technique and manual outlining of vessels. The automatic algorithm was evaluated for identification of vessels, measured blood flow, and measured ICP.

Results: In 4 out of 5 subjects, the algorithm identified all vessels correctly. In one subject, a vertebral artery was not identified due to having an in-plane orientation. Excluding this subject, the median correlation between manual and automatic flow time courses was 0.88 (0.64-0.99). The mean difference between ICP values determined from manual and automatic segmentations was 0.6 mmHg (-0.9, 1.7), with an average ICP of 6.6 mmHg.

Discussion: Fully automatic vessel segmentation is feasible for measurement of ICP with MRI and agrees well with manual contouring of the vessels.

References:
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[3] N Otsu, IEEE Trans Systems Man Cybernetics, 1979; 9(1):62-66.