Automatic planning for regional perfusion imaging

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INTRODUCTION: Recently, a method based on Arterial Spin Labeling (ASL) allowing imaging of individual flow territories has been proposed [1]. This technique, dubbed Regional Perfusion Imaging (RPI), could become a valuable clinical tool for evaluation of patients with cerebro-vascular disorders. RPI is based on pulsed ASL with inversion slabs positioned to selectively label water in arteries of interest. Apart from optimization of the ASL sequence [2], careful positioning of the labeling slabs is required for successful imaging of perfusion territories. The planning can be done using time-of-flight (TOF) images covering neck and lower brain (up to the circle of Willis) region. However, due to vascular tortuosity, manual planning is a time consuming and very operator dependent process, which may hinder clinical utility of RPI. Here, we propose a method for automatic planning that is both fast and requires only minimal user input.

METHODS: Automatic planning is based on the processing of TOF images done in three steps. First, the vessels are segmented slice-by-slice using mathematical morphology [3]: top-hat operator; thresholding; and filtering by opening. In a second step, left and right internal carotid arteries (ICA) and the posterior circulation (including posterior and basilar arteries) (POST) are labeled through constrained reconstruction by iterative 3D geodesic dilation from manually placed markers of these arteries. Usually two markers per artery are sufficient for reconstruction. Finally, a plane that separates one artery from the others is found using Fisher's linear discrimination algorithm [4] with the vessel coordinates defining classification feature-space. By computing the distance from the plane to voxels and finding it's maximum, the width of the labeling slab can be determined. Since the plane orientation is defined by it's normal vector, signed distance can be used to estimate labeling efficiency, defined here as the number of voxels from each of the arteries inside or outside the labeling slab.
The above alghorithm was tested on TOF images from 6 healthy volunteers (age 18-37) acquired on a clinical 3T scanner (Philips Medical, Best, Netherlands) with the following parameters: TR/TE/flip = 22ms/4.6ms/19°, FOV=230mm, recon = 512x512, 210 slices, thickness = 1.6mm gap = -0.8mm, acquisition time=4m50s. The accuracy of the automatic planning was evaluated by comparing its labeling efficiency with the one obtained by manual planning (based on the same segmentaion). Regional perfusion imaging was then performed using QUASAR [5], based on these plane definitions.

RESULTS and DISCUSSION: The Automatic Labeling of Flow territories (ALF) tool was implemented using IDL 6.1 (RSI, Boulder, USA). For speed reasons, the processing is done in a subvolume containing both ICAs and posterior arteries. Processing time for a typical subvolume ($\sim 5 \cdot 10^6$ voxels) is 7-10 seconds for vessel segmentation step, and 10-15 seconds for reconstruction on a standard PC (P4 3.2GHz, 2GB ram). Finding a plane between two arteries ($\sim 2 \cdot 10^3$ voxels each) takes less than 1 second. The plane equation together with position parameters of the TOF image allows computing the angulations and offsets of the desired inversion slab so that they can be read directly by the MR scanner.
Figure 1 shows the results of the three processing steps on lower and upper TOF slices in one volunteer. Despite the simplicity of the algorithm, vessel segmentation and reconstruction is fairly accurate. In two subjects, due to poor development of one of the posterior arteries, small segments were missing, but with additional markers the largest part of these arteries could still be reconstructed. A regional perfusion map obtained by automatic planning is shown in figure 2. Table 1 shows the labeling efficiency by automatic and manual planning averaged across all subjects. For a given labeling scheme, the numbers represent the percentage of voxels inside the labeling slab, relative to the total number of voxels in the artery selected for labeling. In this study, manual labeling was performed by an experienced operator. No statistical difference was found between both methods (unpaired T-test). The main utility of automatic planning is to have consistent and operator independent results for regional perfusion imaging which is needed for repetitive or group studies especially if several MR sites are involved.

scheme	LICA		RICA		POST	
	Auto	Manual	Auto	Manual	Auto	Manual
LICA	**99.8 ± 0.5**	**99.6 ± 0.4**	0.0	0.0	0.3 ± 0.4	0.7 ± 0.8
RICA	0.0	0.0	**100.0**	**96.7 ± 7.0**	0.2 ± 0.2	0.2 ± 0.4
POST	0.2 ± 0.4	0.2 ± 0.3	0.7 ± 1.5	0.1 ± 0.2	**93.0 ± 4.0**	**93.5 ± 4.0**

Table 1: Labeling efficiency by automatic or manual planning (LICA/RICA – left/righ ICA; POST – posterior and basilar arteries)

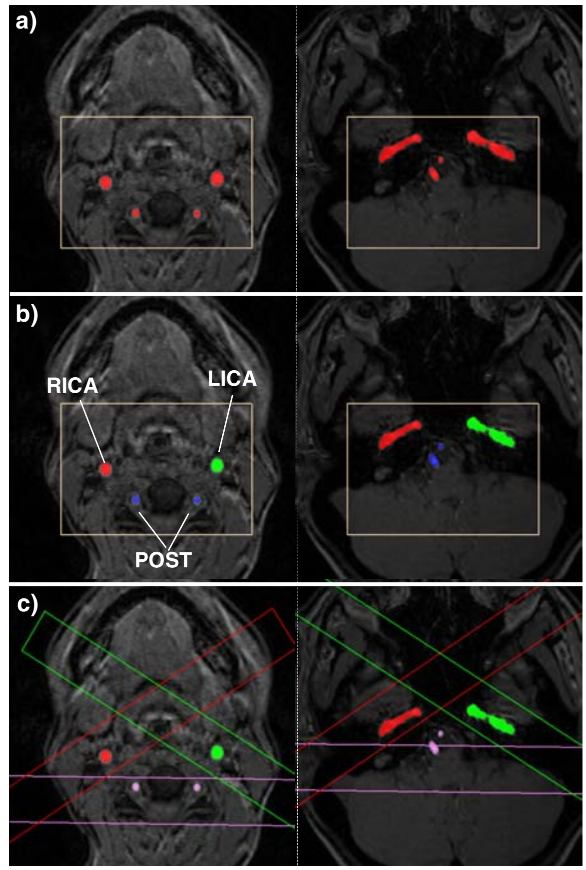

Fig.1: Processing steps a) vessel segmentation b) reconstruction from markers c) final labeling slabs

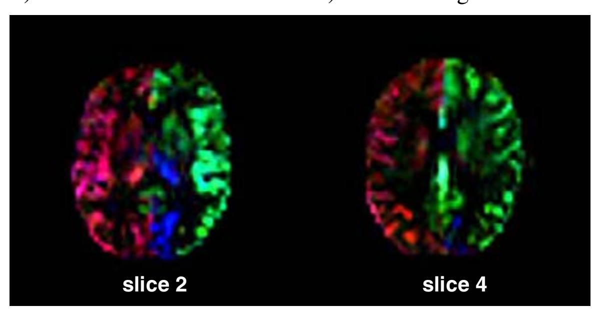

Fig.2: Regional perfusion maps obtained by automatic planning

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ACKNOWLEDGEMENTS: NHGA-RPR/04012, NMRC/0919/04