Automatic Segmentation and Analysis of Carotid and Middle Cerebral Artery using 3D CUBE MRI with iMSDE blood suppression

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Target audience: Radiologists who are seeking for better risk management of patients with carotid and intracranial atherosclerosis diseases.

Purpose: Atherosclerotic plaques presenting within extra- and intra-cranial arteries are known to be risk factors for subsequent stroke. High resolution carotid artery vessel wall MRI can visualize high-risk morphologic factors of plaques in vivo and help patient risk stratification [1]. 3D imaging approaches are promising for its large coverage and high SNR efficiency [2]. 3D FSE acquisitions use variable-flip-angle refocusing pulses to maintain signal over a longer ETL, and have been shown to demonstrate a high signal-to-noise ratio (SNR) efficiency as well as intrinsic black-blood effects compared with conventional 3D FSE sequences [3]. Improved motion-sensitized driven-equilibrium (iMSDE) provides better blood suppression than traditional spatial saturation and double inversion-recovery (DIR) methods [4]. Automatic segmentation methods applied to 3D FSE allow morphologic and geometric quantification of atherosclerotic plaques. This study aims to investigate the automatic segmentation and analysis of carotid and middle cerebral artery (MCA) using CUBE combined with iMSDE blood suppression.

Methods: (a) Carotid scan protocols: Seven healthy volunteers and seven patient with >30% carotid stenosis indentified by ultrasound underwent 3D T1w/T2w FSE (CUBE, GE Healthcare, Waukesha, WI) of the carotids in a 1.5T system (Discovery MR450, GE Healthcare, Waukesha, WI) using a 4 channel phased-array neck coil (PACC, Machnet BV, Elde, The Netherlands). The volunteers were also imaged using an in-house developed iMSDE prepared CUBE for comparison with the product CUBE sequence. The iMSDE preparation time was fixed at 15ms, with a first moment (m_1) of 330 $mT*ms^2/m$, which was empirically found to be the minimum value sufficient for blood suppression. T1w and T2w CUBE parameters for the carotid were: TR/TE (T1w): 440ms/10.8ms; TR/TE (T2w):1800ms/58.9ms; 14cm*14cm FOV, 224*224 matrix, 0.625mm* 0.625mm in-plane resolution, 1.2mm slice thickness (interpolated to 0.6mm), 36 coronal slices; NEX=2; ETL (T1w) = 24; ETL (T2w) = 46. Scan time was 4:30 minutes for T1w CUBE and 7:00 minutes for T2w CUBE. **(b) MCA scan protocols:** One healthy volunteer underwent 3D CUBE of the middle cerebral arteries (MCA) at 1.5T using a standard 8 channel brain array. Another two healthy volunteers underwent 3D CUBE of MCA in a 3T system (Discovery MR750, GE Healthcare, Waukesha, WI) using a standard 12-channel head coil. T2w CUBE at 1.5T: TR/TE = 2500ms/79.6ms; 24cm*24cm FOV, 320*320 matrix, 0.75mm*0.75mm in-plane resolution, 1.2mm slice thickness (interpolated to 0.6mm), ETL = 100, NEX =1, 120 sagittal slices, scan time 7:00 minutes. T2w CUBE at 3T: TR/TE = 2000ms/50ms; 20cm*18cm FOV, 416*384 matrix, 0.48mm*0.47mm in-plane resolution, 1.0mm slice thickness (interpolated to 0.5mm), ETL = 100, NEX=1, ARC acceleration factor 1.5, 70 sagittal slices. Scan time 4:40 minutes. **(c) Post-processing:** The lumen boundary of the carotid and MCA were automatically segmented by in-house MATLAB software and reconstructed using the vascular modelling toolkit (VMTK[5]). 3D geometry and central lines of the arteries were generated automatically. Diameter and area stenosis was automatically calculated using in-house software. Automatically reformatted 2D images which were perpendicular to the vessel central lines were generated using VTK.

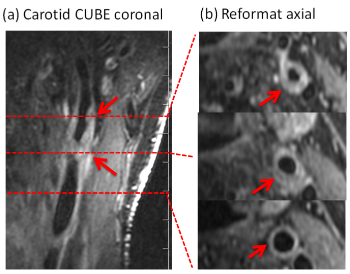

Figure 1. CUBE MRI of a patient with a significant plaque. (a) CUBE images in acquired coronal plane; (b) Reformatted CUBE images in the axial plane.

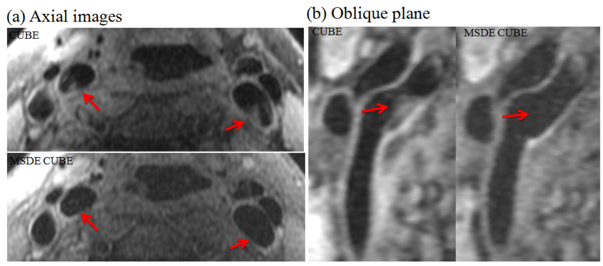

Figure 2. CUBE MRI of a normal volunteer's carotid. (a) CUBE (top) and iMSDE CUBE (bottom) images in the axial plane; (b) Reformatted CUBE (left) and iMSDE CUBE(right) images in an oblique plane. Note the suppression of residual blood signal on the iMSDE preparation (arrowed).

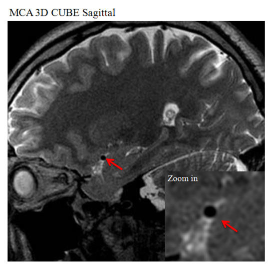

Figure 3. T2w CUBE MRI of the middle cerebral artery of a healthy volunteer.

Result: Good blood suppression and overall image quality were achieved in both the MCA and carotid by 3D iMSDE-CUBE (Figure 1&3). T1w iMSDE CUBE achieved significantly better blood suppression compared to T1w CUBE, with lumen signal-to-noise ratio (SNR) 3.5±0.5 vs. 5.0±1.0, p=0.0001 (Figure 2). However, T1w iMSDE CUBE had a significantly lower CNR (13.4±2.6 vs. 25.0±4.6, p<0.0001) compared to standard CUBE due to the inherent T_2 weighting added by the iMSDE preparation. Arterial geometry was successfully segmented and measures of stenosis were derived from the T1w CUBE. Reformatted 2D images which were perpendicular to the central lines were successfully generated, which clearly showed the actual plaque burden.

Discussion: CUBE MRI achieved good image quality and isotropic resolution both in the carotid and MCA. Blood suppression in CUBE was further improved by iMSDE preparation. The inherent T_2 weighting of the iMSDE preparation in T1w CUBE significantly decreased the total CNR. However this is not an issue with T2w iMSDE CUBE where the iMSDE preparation time can be included in the effective TE.

Conclusion: iMSDE-prepared CUBE can aid automatic segmentation and analysis for the morphologic and geometric quantification of carotid and middle cerebral artery.

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