Intracranial Atherosclerotic Plaque Evaluation Using Three Dimensional Isotropic Multi-Contrast MRI

Dongxiang Xu[1], Jinnan Wang[2], William S Kerwin[1], and Chun Yuan[1]
[1]*Radiology, University of Washington, Seattle, WA, United States,* [2]*Philips Research North America, Seattle, WA, United States*

Introduction:

Intracranial atherosclerotic disease (IAD) is one of the most common causes of stroke worldwide[1]. Clinically, IAD is usually diagnosed with angiography based imaging methods to detect luminal narrowing. However, autopsy studies[2] show that approximately 40% of IAD does not present with any luminal stenosis but rather only outer wall remodeling, an indicator of progression of plaque burden. To overcome this underestimation of stroke risk, analysis of the intracranial vessel wall (IVW) is crucial. Recent developments in 3D isotropic MR imaging techniques[3,4] provide sufficient wall contrast in *in vivo* MR IVW images. Due to the tortuous topology of intracranial vessels, cross sectional images reformatted based on the geometry of the arteries are desirable. However, no approaches have thus far been proposed to effectively analyze IVW images, and most current IVW analysis is still limited to arterial sections that are approximately straight. In this study, we proposed a new approach that allows effective evaluation of atherosclerotic plaques at all locations along intracranial arteries by using 3D isotropic multi-contrast MRI.

Methods and Experimental Results

Study protocol: After IRB approval and informed consent, two subjects were recruited for IVW evaluation. These subjects were scanned in a 3T clinical scanner (Philips Achieva, R2.6.1, Best, the Netherlands) with enhanced 3D black blood MSDE and 3D Time-Of-Flight (TOF) protocols. Detailed imaging parameters were: *3D MSDE*: 3D MSDE prepared T1TFE, TR/TE 10/4.8ms, flip angle 10°, FOV 160×160×32mm, Matrix 200×200×40, NSA 1, total imaging time: 4min19sec. *3D TOF*: Multi-Slab T1FFE, TR/TE 20/3.45ms, FA 20, FOV 200×200×100mm, Matrix: 200×200×100m, NSA 1, total imaging time: 3min20sec with 2x SENSE factor.

3D Multi-Contrast Analysis: Centerline searching is a powerful descriptor of vessel shape and is commonly used for vessel reformation. However, this technique cannot be applied directly to 3D MSDE data due to intracranial arteries' small size and limited signal contrast. As a result, 3D TOF data was used for centerline searching based on its strong luminal contrast. The identified centerlines were then projected onto 3D MSDE data by multi-contrast registration. The workflow is shown in Figure 1.

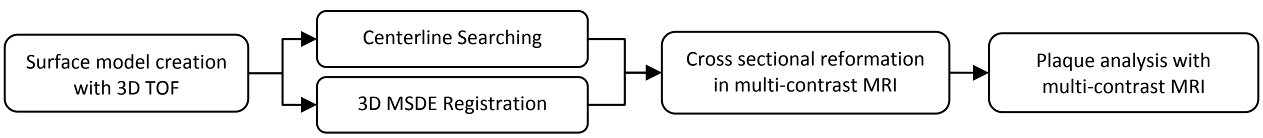

Figure 1. Workflow of Intracranial Vessel Wall Plaque Analysis with Multi-Contrast MRI

Surface Model Creation: a 3D Levelset algorithm[5] was used to conduct volume segmentation (initialized with Fast Marching Upwind Gradient). This algorithm is topology flexible and can deal with complicated shapes such as intracranial arteries. The generated surface model ***S*** is shown in Figure 2(b). Major IAD sections, including MCA and basilar, were all well represented.

Centerline Searching: The computation of centerlines is based on surface model ***S*** and uses maximal inscribed spheres[6] in Voronoi diagram for extraction. Comparing to other centerline solutions, this method has the advantage that it is well characterized mathematically and quite stable to perturbations on the surface. Implementation in VMTK package is adapted in our analysis.

Multi-contrast Registration: Since biological structure changes in the brain are minimal during imaging, the intracranial artery shape can be treated as solid and only rigid transformation is applied to register 3D TOF with 3D MSDE. The registration cost function is defined as $E = \int_{S,T} f(v,t)$ which represents the overall signal in surface model. $f(v,t)$ is the signal at location v with transformation t. The best registration is reached at ***min***{***E***}.

Cross Sectional Reformation: Once centerlines are projected to registered multi-contrast MRI, cross sectional images are reconstructed at the corresponding locations. They are perpendicular to the centerline and linear interpolated from isotropic 3D MR data.

Performance Evaluation: In this preliminary study, the proposed workflow was implemented based on VMTK and VTK packages. Multi-contrast MR data from the two subjects was processed. The resulting images show successful reconstruction of cross sectional images perpendicular to intracranial vessel. The lumen and outer wall boundaries were well characterized at both the MCA and basilar. They are of satisfactory image quality for plaque burden and morphological evaluation. A case example is shown in Figure 2.

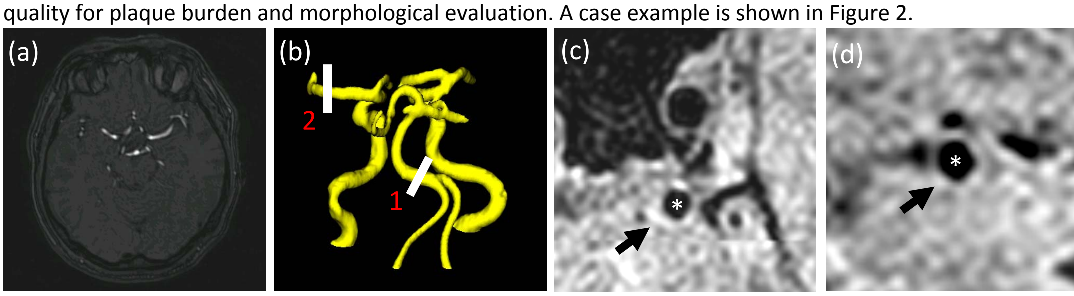

Figure 2. Multi-contrast MR data reformation. (a) 3D TOF data. (b) Surface model used for centerline searching and 3D MSDE registration. (c) and (d) are the reformatted images at basilar (1 in b) and MCA (2 in b). Asterisks indicate luminal regions and arrows point to wall boundaries.

Conclusion: In this study, we proposed a solution for intracranial plaque analysis using three dimensional isotropic multi-contrast MRI. Preliminary experiments showed satisfactory results. This processing approach will permit the study of intracranial disease in the preferred cross-sectional orientation, regardless of vessel orientation or tortuosity. Potentially, this approach can also be applied for vessel wall evaluation in other vascular beds.

Reference:

1. Gorelick et al, Stroke 2008. 2. Mazighi M et al, Stroke 2008. 3. Klein IF et al, Neurology 2006.
4. Qiao Y et al, JMRI 2011. 5. J Sethian, CUP 1999. 6. Luca A, et al, Med and Bio Eng. 2008.