Carotid Artery MRI: Extending Current Techniques for Clinical Application

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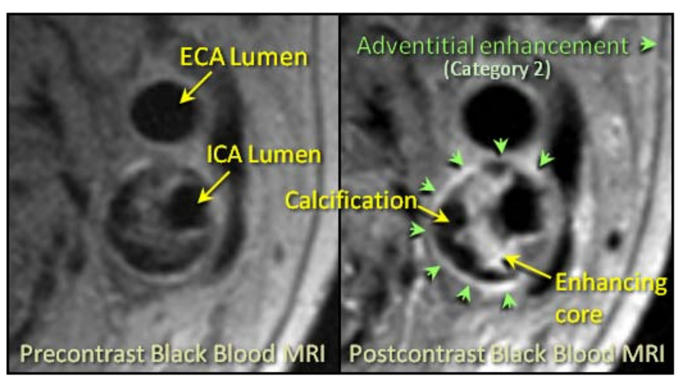
High-resolution MRI has emerged as a powerful tool for characterizing atherosclerotic plaque components, ultimately enabling the identification of anatomic features that are known to predispose to rupture with the consequent clinical event. Recently, much attention has focused on the identification by MRI of the thin fibrous cap, large lipid core, and the presence of intraplaque hemorrhage[1-3], all of which have been shown to be important determinants of stroke risk when identified in carotid plaque. Intraplaque hemorrhage is of particular interest in that it is thought to lead to the development of the thrombogenic lipid core and contributes to plaque progression[4].

Gadolinium-contrast is routinely administered for contrast-enhanced MR angiography to enable greater coverage and improved signal especially in areas of reduced flow. When gadolinium administration is implemented for high-resolution plaque MRI, there is a considerable gain in the accuracy and reliability of plaque component characterization. This is especially helpful for lipid core delineation[5-6] and this technique has provided insight into the development and prevention of the thrombogenic core in population-based studies[7-8]. The contrast-enhanced high-resolution plaque MRI technique can be integrated with the contrast-enhanced MRA to provide detailed luminal information along with an assessment of important plaque features such as cap thickness, core size, calcification, and ulceration. Furthermore, the mask image acquired during the MRA acquisition can be used to detect intraplaque hemorrhage with high sensitivity, specificity and accuracy, without necessitating additional scan time[9]. Perhaps the most important clinical application of MRI is for identifying these features of plaque vulnerability and disruption in angiographically occult atherosclerotic lesions[10].

Beyond these anatomic features of plaque vulnerability, contrast-enhanced MRI may be useful for identifying plaque neovascularity. There is growing literature indicating that neovascularization of plaque is also associated with stroke risk and is specifically associated with the development of the thin cap, large core, and macrophage accumulation within plaque[11-13]. Furthermore, there is evidence that neovascularity can lead to the development of intraplaque hemorrhage because of microvascular incompetence[14]. Preliminary studies by ultrasound[15], CT[16], and dynamic contrast-enhanced MRI[17] have shown our ability to image neovascularity based on contrast-enhancement within the adventitia where neovessels are thought to arise, though the clinical implications of its detection have been unclear. We have shown that contrast-enhanced high-resolution plaque MRI can be used to reliably categorize the degree of adventitial enhancement as a measure of neovascularity (category 0: absent; category 1: <50% outer wall enhancement; category 2: ≥50% outer wall enhancement) (Figure) , and this is strongly associated with having had a recent TIA or stroke independent of the presence of intraplaque hemorrhage, which is also strongly associated with having had a recent TIA or stroke [18]. Although these were previous events and prospective studies are pending, it is noteworthy that the risk of stroke in the territory of a previously symptomatic plaque is increased compared to that of an asymptomatic plaque with a similar degree of narrowing [19]. Moreover, stenosis was not found to be associated with events, emphasizing the importance of identifying these features over conventional angiography for stroke risk assessment.



References:

1. Chu B, Kampschulte A, Ferguson MS, et al. Hemorrhage in the atherosclerotic carotid plaque: a high-resolution MRI study. *Stroke.* 2004;35(5):1079-1084. Epub 2004 Apr 1071.

2. Yuan C, Mitsumori LM, Ferguson MS, et al. In vivo accuracy of multispectral magnetic resonance imaging for identifying lipid-rich necrotic cores and intraplaque hemorrhage in advanced human carotid plaques. *Circulation.* 2001;104(17):2051-2056.

3. Yuan C, Zhang SX, Polissar NL, et al. Identification of fibrous cap rupture with magnetic resonance imaging is highly associated with recent transient ischemic attack or stroke. *Circulation.* 2002;105(2):181-185.

4. Kolodgie FD, Gold HK, Burke AP, et al. Intraplaque hemorrhage and progression of coronary atheroma. *N Engl J Med.* 2003;349(24):2316-2325.

5. Wasserman BA, Astor BC, Sharrett AR, Swingen C, Catellier D. MRI measurements of carotid plaque in the atherosclerosis risk in communities (ARIC) study: methods, reliability and descriptive statistics. *J Magn Reson Imaging.* 2010;31(2):406-415.

6. Wasserman BA, Smith WI, Trout HH, 3rd, Cannon RO, 3rd, Balaban RS, Arai AE. Carotid artery atherosclerosis: in vivo morphologic characterization with gadolinium-enhanced double-oblique MR imaging initial results. *Radiology.* 2002;223(2):566-573.

7. Wagenknecht L, Wasserman B, Chambless L, et al. Correlates of carotid plaque presence and composition as measured by MRI: the Atherosclerosis Risk in Communities Study. *Circ Cardiovasc Imaging.* 2009;2(4):314-322. Epub 2009 May 2011.

8. Wasserman BA, Sharrett AR, Lai S, et al. Risk factor associations with the presence of a lipid core in carotid plaque of asymptomatic individuals using high-resolution MRI: the multi-ethnic study of atherosclerosis (MESA). *Stroke.* 2008;39(2):329-335. Epub 2008 Jan 2003.

9. Qiao Y, Etesami M, Malhotra S, et al. Identification of Intraplaque Hemorrhage on MR Angiography Images: A Comparison of Contrast-Enhanced Mask and Time-of-Flight Techniques. *AJNR Am J Neuroradiol.* 2011;13:13.

10. Wasserman BA, Wityk RJ, Trout HH, 3rd, Virmani R. Low-grade carotid stenosis: looking beyond the lumen with MRI. *Stroke.* 2005;36(11):2504-2513. Epub 2005 Oct 2520.

11. McCarthy MJ, Loftus IM, Thompson MM, et al. Angiogenesis and the atherosclerotic carotid plaque: an association between symptomatology and plaque morphology. *J Vasc Surg.* 1999;30(2):261-268.

12. Mofidi R, Crotty TB, McCarthy P, Sheehan SJ, Mehigan D, Keaveny TV. Association between plaque instability, angiogenesis and symptomatic carotid occlusive disease. *Br J Surg.* 2001;88(7):945-950.

13. Jeziorska M, Woolley DE. Neovascularization in early atherosclerotic lesions of human carotid arteries: its potential contribution to plaque development. *Human pathology.* Aug 1999;30(8):919-925.

14. Virmani R, Kolodgie FD, Burke AP, et al. Atherosclerotic plaque progression and vulnerability to rupture: angiogenesis as a source of intraplaque hemorrhage. *Arterioscler Thromb Vasc Biol.* 2005;25(10):2054-2061. Epub 2005 Jul 2021.

15. Staub D, Patel MB, Tibrewala A, et al. Vasa vasorum and plaque neovascularization on contrast-enhanced carotid ultrasound imaging correlates with cardiovascular disease and past cardiovascular events. *Stroke; a journal of cerebral circulation.* 2009;41(1):41-47.

16. Romero JM, Babiarz LS, Forero NP, et al. Arterial wall enhancement overlying carotid plaque on CT angiography correlates with symptoms in patients with high grade stenosis. *Stroke; a journal of cerebral circulation.* May 2009;40(5):1894-1896.

17. Kerwin WS, Oikawa M, Yuan C, Jarvik GP, Hatsukami TS. MR imaging of adventitial vasa vasorum in carotid atherosclerosis. *Magn Reson Med.* 2008;59(3):507-514.

18. Wasserman BA. Advanced contrast-enhanced MRI for looking beyond the lumen to predict stroke: building a risk profile for carotid plaque. *Stroke.* 2010;41(10 Suppl):S12-16.
19. Inzitari D, Eliasziw M, Gates P, et al. The causes and risk of stroke in patients with asymptomatic internal-carotid-artery stenosis. North American Symptomatic Carotid Endarterectomy Trial Collaborators. *N Engl J Med.* 2000;342(23):1693-1700.