High-resolution carotid MRA and plaque MRI at 3T: Initial clinical experience and validation of semi-automated plaque characterization

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Purpose

The aims of this study are (1) to describe the prevalence and characteristics of carotid plaque components that can be identified with *in vivo* 3T MR imaging (MRI); (2) to validate plaque characterization at 3T by a semi-automated program (Pathway MRI, Inc) and compare with manual segmentation; (3) to explore the correlation between lumen morphology (smooth, irregular, ulceration) seen with high resolution carotid contrast-enhanced MR angiography and of MR identified carotid plaque components controlling for the degree of carotid stenosis in a cohort of asymptomatic patients with known atherosclerotic carotid stenosis.

Introduction

Carotid plaque composition based on 1.5T *in vivo* MRI has been shown to be accurate and reproducible when compared to corresponding histology sections from carotid endarterectomy (CEA) specimens. [1] Evidence suggests that plaque components and their location within the plaque may play an important role in plaque progression, plaque rupture, and clinical symptoms of TIA or stroke. [2-4] In this study we propose to extend *in vivo* multi-contrast carotid plaque imaging to 3T including both pre-contrast and post-contrast T1 weighted images as well as 500 micron resolution carotid contrast-enhanced MR angiography in the evaluation of patients with known atherosclerotic carotid stenosis. This may increase the percentage of studies that can be interpreted due to improved SNR in shorter exam times compared to 1.5T MR imaging. Computer aided systems have been shown to assist in the evaluation of cardiovascular disease. We will compare manual and semi-automated plaque characterization using a prototype program from Pathway MRI, Inc based upon CASCADE. [5] Lastly, correlation of plaque components with lumen morphology will be performed similar to prior work comparing invasive angiography to histology of carotid endarterectomy (CEA) specimens. [6]

Methods

Dedicated 3T carotid surface coils were placed on either side of the neck at the level of the carotid bifurcations. High resolution non-contrast 3D time-of-flight MR angiographic images (partition thickness 1 mm, every 0.5 mm), non-contrast T2 weighted plaque images with double inversion recovery pulse [7], pre- and post-contrast T1 weighted plaque images with quadruple inversion pulse [8] were obtained through both carotid bifurcations with the following parameters: FOV 14-16 cm, matrix 256x256, slice thickness 2 mm, 1-2 NEX, each lasting 4-5 minutes. First-pass high resolution MR angiogram was obtained using elliptical centric phase reordering with 14-16 cm, matrix 256x256, slice thickness 0.8 mm reconstructed every 0.4 mm, 1 NEX, TR/TE/flip angle of 6 mseconds/1.1 mseconds/30° and lasted approximately 55 seconds. Blinded plaque characterization was performed manually as well as semi-automatically using software from Pathway MRI, Inc. Initially, an experienced carotid plaque reader adjudicated any differences. Histological correlation has now begun and will be presented as gold-standard to validate the plaque characterizations. Bivariate analysis was used to assess the relationship between lumen morphology and the following characteristic: stenosis grade, fibrous cap status, area of soft plaque (lipid rich necrotic core with or without hemorrhage), calcifications, location of hemorrhage, presence of loose connective tissue and enhancement.

Results

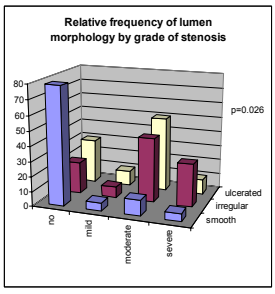
Twenty-four patients have been enrolled to date with 1 patient study excluded due to poor image quality (96% success rate). Two patients had complete occlusion and one patient had left CEA in 1985 with surgical clips resulting in metal artifact that precluded imaging of one carotid. Three other patients had surgical clips from CEA in the past 10 years that did not demonstrate any appreciable metal artifact. Of the remaining 43 carotid bifurcations, 14% were graded as severe stenosis (70-99%), 30% with moderate stenosis (50-69%), 7% with mild stenosis (30-49%), and 49% with no stenosis by NASCET criteria (<30%). The 500µ resolution carotid CE MRA demonstrated good or excellent intra-arterial contrast with little or no venous contamination in 22 of 24 patients. Ulceration was seen 23% cases, lumen irregularity was noted in 33% of cases, and the stenosis was smooth in the remaining 44%.

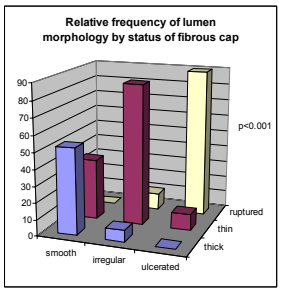
Bivariate analysis confirms statistically significant correlation between lumen morphology (smooth, irregular, ulceration) and higher grade stenosis (none, mild, moderate, severe, $p<0.026$), fibrous cap status (thick, thin, ruptured, $p<0.001$), calcifications (none, deep, juxtaluminal, protruding ,$p<0.001$), hemorrhage (none, deep, juxtaluminal ,$p<0.001$); a moderate association with soft plaque area (small, moderate, large, $p<0.052$). These correlations remained statistically significant when controlling for the grade of stenosis. No association of lumen morphology with presence of loose connective tissue or enhancement was found.

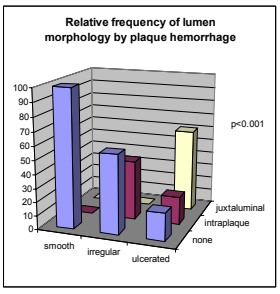
There was a good correlation between manual and semi-automated plaque characterization in 9 of 13 cases where both were available. In two cases the manual characterization mistook a calcification for part of non-enhancing soft plaque (1) and loose connective tissue for hemorrhage (1). In two cases the semi-automated characterization underestimated the size of the soft plaque. In an additional 4 cases, small regions of loose connective tissue or soft plaque were detected with semi-automated characterization alone. The color coded output of plaque characterization also quickly gave visual feedback to the manual reviewer which helped increase confidence in the initial blinded manual characterization. Based upon lumen morphology and plaque characterizations, the patients were placed into three groups of low, mid, and high risk for plaque progression.

Conclusion

High resolution 3T carotid CE MRA and plaque imaging was successful in vast majority of patients making it reasonable to consider for clinical use. In a select group of asymptomatic patients with known carotid stenosis, the addition of high resolution MRA/MRI helped confirm the degree of stenosis as well as demonstrated a remarkable amount of complex plaque morphology that was not expected on screening duplex ultrasound. The vascular surgeon taking care of these patients has decided that patients with ulcerations, fibrous cap rupture, juxtaluminal hemorrhage, and/or large region of soft plaque will be seen in clinic more frequently and will be placed on maximal lipid lowering and antiplatelet therapies. All patients in this study will be followed in 6-12 month intervals to help determine the natural history of the various plaque components.







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