Magnetic Resonance Imaging-Based Assessment of Carotid Atheroma: a Comparative Study of Patients with and without Coronary Artery Disease

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Background: Functional magnetic resonance (MR) imaging of atheroma using contrast media enables assessment of the systemic severity of atherosclerosis in different arterial beds. Whether black-blood imaging has similar ability remains widely unexplored. In this study, we evaluate whether black-blood imaging can differentiate carotid plaques of patients with and without coronary artery disease (CAD) in terms of morphological and biomechanical features of plaque vulnerability, thereby allowing assessment of the systemic severity nature of atherosclerosis in different arterial beds. *Methods:* Forty-one patients with CAD and 59 patients without CAD underwent carotid black-blood MR imaging. Plaque components were segmented to identify large lipid core (LC), ruptured fibrous cap (FC), and plaque hemorrhage (PH). These segmented contours of plaque components were used to quantify maximum structural biomechanical stress. *Results:* Patients with CAD and without CAD had comparable demographics and comorbidities. Both groups had comparable prevalence of morphological features of plaque vulnerability (FC rupture, 44% versus 41%, $P = .90$; PH, 58% versus 47%, $P = .78$; large LC, 32% versus 47%, $P = .17$), respectively. The maximum biomechanical stress was not significantly different for both groups (241versus 278 kPa, $P = .14$) respectively. *Conclusions:* Black-blood imaging does not appear to have the ability to differentiate between the morphological and biomechanical features of plaque vulnerability when comparing patients with and without symptomatic atherosclerotic disease in a distant arterial territory such as coronary artery. **Key Words:** MRI—carotid—coronary artery disease—black-blood imaging—functional imaging.

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Introduction

Carotid atherosclerosis is a predominant cause of ischemic cerebrovascular events. Due to the systemic nature of atherosclerotic disease process, more than 1 arterial bed may be affected simultaneously.[1] Plaque burden in 1 arterial bed (such as carotid) can predict the severity of the burden of atherosclerotic disease in a distant territory (such as coronary) and also clinically predict future cardiovascular events.[2,3] Functional magnetic resonance (MR) imaging of atheroma using contrast media (CM) such as ultrasmall superparamagnetic particles of iron oxide (USPIO) has been used effectively to demonstrate the systemic inflammatory nature of atherosclerosis. Carotid plaques of patients with symptomatic carotid artery disease have greater inflammatory burden than the asymptomatic contralateral-side carotid plaques.[4] The carotid plaque inflammatory burden of the latter is greater than those with truly asymptomatic carotid artery disease.[5] Patients with symptomatic coronary artery disease (CAD) but having truly asymptomatic carotid artery disease have greater carotid inflammatory plaque burden than those without CAD.[6]

Functional assessment of atheroma requires administration of CM. Black-blood MR imaging, however, enables identification of high-risk plaque features such as fibrous cap (FC) rupture and plaque hemorrhage (PH) without the need for CM.[7] Black-blood MR imaging also enables assessment of biomechanical structural stresses within atheroma,[8] which have been observed to have a strong association with subsequent cerebrovascular ischemic events.[9] Based on the above, carotid plaques of patients with symptomatic and asymptomatic carotid artery diseases can be differentiated.[8,10] Whether black-blood carotid imaging enables differentiation of carotid plaques of patients with and without CAD, thereby allowing assessment of the systemic severity nature of atherosclerosis in different arterial beds, remains predominantly unexplored. In this article, we assess and compare the morphological features of atheromatous carotid plaques of patients with and without CAD. The biomechanical structural stresses of the 2 patient cohorts are also compared.

Methods

One hundred consecutive patients with duplex confirmed carotid artery disease were recruited for the present study. Of these patients, 41 were diagnosed with CAD and 59 without CAD. CAD was diagnosed according to American Heart Association guidelines by a consultant physician in a hospital setting.[11] All these patients underwent high-resolution carotid MR imaging. Approval from an institutional ethics committee was obtained for this project. All patients gave written informed consent before recruitment.

Inclusion criteria comprised patients with internal carotid artery stenosis from 30% to 99% on duplex ultrasound imaging and adequate MR image quality to identify the lumen wall and outer boundary of the arterial wall.[10] Exclusion criteria included patients with previous carotid endarterectomy, cardiac arrhythmias, or coagulation disorders; those who were undergoing thrombolysis; and those who had cardiac pacemakers or metal implants.

MR Acquisition

High-resolution carotid MR imaging of the research participants was conducted in a 1.5-T MR imaging system (Signa HDx; GE Healthcare, Waukesia, WI), which consisted of a 4-channel phased-array neck coil (PACC; Machnet BV, Elde, The Netherlands). Movement artifact was minimized using a dedicated vacuum-based head restraint system (VAC-LOK Cushion; Oncology Systems Ltd, Shrewsbury, United Kingdom) to maintain the head and neck in a comfortable position and aid in close approximation of the surface coils. After an initial coronal localizer sequence, axial 2-dimensional time-of-flight MR angiography was carried out to identify the location of the carotid bifurcation and the stenosis on either side. Axial images were sliced 3 mm apart through the common carotid artery following the carotid bifurcation to the extent that stenosis can be identified on the time-of-flight sequence and the whole carotid plaque could be imaged.

The following electrocardiography-gated fast spin-echo pulse sequences were used to delineate various plaque components such as FC, lipid content, and PH: T1 weighted (repetition time/echo time: $1 \times RR/7.8$ m/s) with fat saturation, proton density weighted (repetition time/echo time: $2 \times RR/7.8$ m/s) with fat saturation, T2 weighted (repetition time/echo time: $2 \times RR/85$ m/s) with fat saturation, and short tau inversion recovery (repetition time/echo time/inversion time: $2 \times RR/42$ m/s/150 m/s). The field of view was 10×10 cm and the matrix size was 256×256. The in-plane spatial resolution achieved was of the order of $.39 \times .39$ mm.

Image Analysis and Computation of Biomechanical Stresses

The degree of luminal stenosis was assessed according to the European Carotid Surgery Trial (ECST) criteria. Plaque components were assessed using criteria previously published in detail,[11] using plaque segmentation software CMR Tools (Cardiovascular Imaging Solutions Ltd., London, United Kingdom). As previously described, FC disruption was defined as the presence of FC discontinuity and cavity formation in the plaque.[11] The plaque component areas (square millimeter) were determined using a previously published method[11] and were used for volumetric quantification of plaque components.[12] A plaque was considered to have large lipid content if it occupied more than 25% of the total plaque volume.[13]