DWI of carotid atheroma - detection of lipid rich necrotic core

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Background and Purpose

Multi-contrast magnetic resonance imaging (HR-MRI) has previously been used to identify both degree of stenosis and plaque morphology for carotid atheroma [1, 2]. Lipid rich/necrotic core (LR/NC), which is difficult to identify on MRI, has importance in not only predicting risk but also in the monitoring of disease progression and response to treatment such as statin therapy [3]. Previous studies applying conventional spin echo diffusion-weighted imaging (DWI) to ex-vivo carotid specimens have reported that DWI improved classification of plaque components [4]. A similar study using apparent diffusion coefficient (ADC) maps reported different ranges of ADC values in LR/NC and fibrous cap tissue [5]. The aim of this study was to examine if DWI can be applied in vivo to differentiate LR/NC from other plaque components as shown in ex vivo studies.

Materials and Methods

28 patients (21 males) with moderate/severe carotid stenosis were recruited and imaged on at 1.5T *(Signa HDx, GE Healthcare, Waukesha, WI)* using a bilateral four-channel phased-array carotid coil *(PACC, Machnet BV, Eelde, The Netherlands)*. Multi-contrast images were obtained over the stenotic section of artery using cardiac-gated, fat suppressed double inversion recovery fast spin echo sequences (T_1W, dual echo T_2W/PDW and STIR). A single shot diffusion weighted echo planar imaging sequence without cardiac gating was used to obtain diffusion-weighted images (parameters given in Table 1). Spatial saturation bands were applied superiorly/inferiorly to suppress blood signal and anteriorly/posteriorly to minimise phase wrapping artefact. Diffusion gradients were applied in the x, y and z axes and apparent diffusion coefficient (ADC) maps were computed.

The multi-contrast images were segmented manually to identify the vessel wall, lumen and plaque components. The regions of interest (ROIs) were then transferred onto the ADC maps and the mean ADC value for each ROI was recorded. Inter-observer variability was assessed by two readers independently performing the analysis. For cases where carotid endarterectomy was performed, specimens were stained using Nile Red to detect the presence of lipid [6]. Quantitative ADC values for LR/NC and fibrous cap were compared using a linear mixed effect model (P<0.05 was considered significant). An intraclass correlation coefficient (ICC) was used to compare the results from the two readers.

Table 1: Imaging Parameters

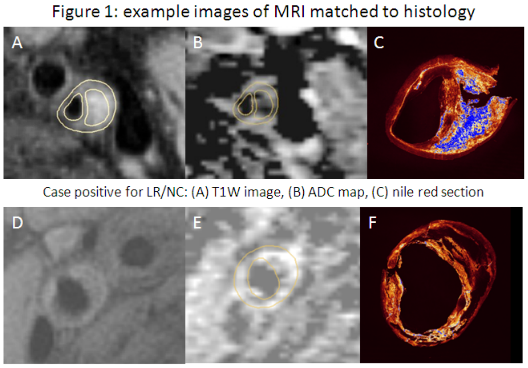
	T_1W FSE	T_2W/PDW FSE	STIR FSE	DW-EPI
FOV (cm)	10x10	10x10	10x10	16x8
Matrix	256x256	256x256	256x256	128x128
NEX	2	2	2	16
TR (ms)	~850 (1R-R1)	~1700 (2 R-R)	~1700 (2 R-R)	2200
TE (ms)	7.7	99.7/7.7	99.7	~75
Slice thickness (mm)	3	3	3	3
ETL	12	16	24	-
b-value (s/mm^2)	-	-	-	0/500
Fat Suppression	Yes	Yes	TI = 150ms	Yes
In-plane resolution (mm)	0.39	0.39	0.39	1.25

Results

Of the 28 patients recruited, 26 had imaging suitable for analysis: the 2 failures were due to claustrophobia and poor quality multi-contrast imaging. Nineteen proceeded to surgery. Of the 26 patients analysed 14 were symptomatic. A total of 120 diseased slice locations were analyzed which represented a total of 143 arterial locations (median = 4, range 2-12 per patient). A total of 141 arterial locations demonstrated fibrous cap and 63 contained LR/NC (example images shown in figure 1). Thrombus was visible in 21 arterial locations.

There was a significant difference in ADC values between the delineated fibrous cap and LR/NC regions (P<0.0001). The mean fibrous cap ADC value was 1.04 x10^{-3} mm^2/s (± SD 0.30 x10^{-3} mm^2/s) whilst the mean LR/NC ADC value was 0.73 x10^{-3} mm^2/s (±0.23 x10^{-3} mm^2/s), see Figure 2. The mean ADC values in the thrombus regions were 1.3 x10^{-3} mm^2/s (± SD 0.40 x10^{-3} mm^2/s). The ICCs from the two readers were 0.60 and 0.84 for LR/NC and fibrous cap respectively.

Figure 1: example images of MRI matched to histology



Case positive for LR/NC: (A) T1W image, (B) ADC map, (C) nile red section

Case negative for LR/NC: (D) T1W image, (E) ADC map, (F) nile red section

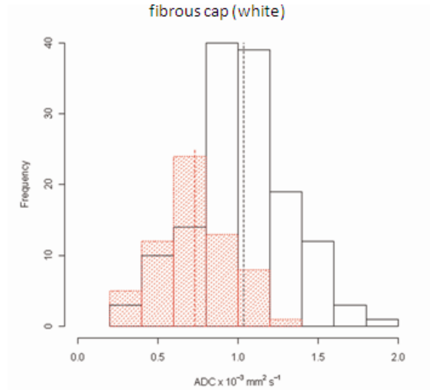
Discussion

This study used a standard clinical diffusion-weighted echo planar sequence, whereas ex vivo studies has used spin echo DWI [4, 5]. This study found a significant difference between the ADC values for LR/NC and FC which agreed with previous ex vivo work [5]. This difference in ADC values matches previous ex vivo DW imaging which demonstrated a high signal intensity for LR/NC on DWI (which would correspond to a low ADC value) [4]. One ex vivo study demonstrated that for DWI the signal intensities for fibrous cap, thrombus and calcification were all similarly low, with lipid-rich necrotic core being the only component that was differentiated as having a high signal intensity [4]. This would lead to an expectation of a high ADC value for thrombus. The occurrence of intraplaque haemorrhage was low in this study but the limited data from this study on thrombus does seem to support this trend. A recent study considering ADC mapping of the carotid wall in both normal and diseased individuals (total of 11 subjects) produced a range of ADC values [7]. The mean ADC value for normal vessel was found to be high (1.28 x10^{-3} mm^2/s), higher than the value found in this study for fibrous tissue, but the values for diseased vessels were given for the plaque as a whole so were not comparable with this study.

In this study there were two false positive cases of LR/NC on multi-contrast imaging, using accepted MR criteria [8], that were not confirmed on histology. The ADC values for these supposed lipid regions were not consistent with the values for LR/NC but matched those demonstrated for fibrous cap.

The advantages of DWI are that it appears to distinguish LR/NC well from other plaque components and provides quantitative data for analysis. Another advantage to DWI is that it does not require the use of contrast agents and there are subgroups of patients for whom this is not suitable, for example those with allergies and renal disease (commonly seen in the atherosclerotic population) and therefore there is a role for a method of unenhanced imaging that can differentiate plaque components.

Figure 2: Mean ADC values for LR/NC (red) and fibrous cap (white)



Conclusion

This in vivo study indicates that DWI can be used to distinguish LR/NC and the fibrous cap and may provide additional benefit in delineation of plaque morphology.

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