Tissue characterisation of atherosclerotic carotid plaques by MRI

Abstract Carotid artery plaques with intraplaque haemorrhage or atheromatous debris have been found to be associated with an increased risk of embolic stroke. Other methods have failed to detect plaque morphology, and it is not clear whether MRI allows differentiation between prognostically and therapeutically relevant plaque types. We examined 17 carotid bifurcation plaques which had been removed in toto by MRI. For quantifying MR signal intensities (I) the contrast-to-noise ratio (CNR) was used: \( \frac{(I_{\text{Tissue}} - I_{\text{Ref}})}{SD_{\text{Ref}}} \), with normal saline (0.9%) as reference (Ref) and the standard deviation (SD) of the noise. Measurements were correlated with the histopathological appearance of “simple plaques”, consisting of fibrous intimal thickening, lipid deposits and/or atheromatous tissue with cholesterol crystals, largely calcified plaques, and “complicated plaques”, containing recent intramural haemorrhage or friable atheromatous debris. Significantly different mean CNR could be measured in the three plaque types on T1- and T2-weighted sequences \((p < 0.00001)\) and using the FLASH pulse sequence with a flip angle of 15° \((p < 0.001)\). With the T1-weighted sequence simple plaques showed a CNR of 4.4 ± 2.3, calcified plaques 4.8 ± 2.6 and complicated plaques 15.1 ± 4.3. Using this technique, each single plaque could be correctly classified, an unalterable prerequisite for a clinical application. To date, motion artefacts due to patient movement or insufficiently triggerable vessel pulsation in combination with relative long acquisition times (6–7 min) have limited in vivo investigations. If these problems could be overcome, MRI might become a valuable technique for studying carotid plaque morphology.

Keywords Tissue characterisation · Carotid artery · Atheromatous plaque · Intramural haemorrhage · Magnetic resonance imaging

Introduction

Carotid bifurcation plaques are a common source of emboli causing transient ischaemic attacks (TIA) or stroke. The occurrence of cerebrovascular ischaemic events is related to the degree of the stenosis as well as to plaque histopathology [1]. Patients with symptomatic high-grade internal carotid artery (ICA) stenosis have an increased risk of suffering major stroke or death [2, 3], an intraplaque haemorrhage and atheromatous debris can be found 2–6 times as frequently in patients with ischaemic stroke [4–6]. In asymptomatic ICA stenoses particularly, where the predictive value of the diameter reduction for the natural history is uncertain, plaque morphology could be the main prognostic criterion. Despite its significance, and the desired therapeutic consequences, plaque morphology cannot be reliably determined to date in vivo. Depending on technical
We included 25 consecutive patients undergoing carotid surgery in the study. Plaque specimens were examined only if they could be removed in toto and contained the complete intimal layer of the vessel. Specimens showing intraplaque haemorrhage due to endarterectomy or ulceration of the endothelial layer of the wall were excluded. Thus, 17 carotid artery specimens, stored in sealed tubes at 4 °C, were examined by MRI within 24 h of endarterectomy. The diameter reduction of the internal carotid artery stenosis, assessed preoperatively by Doppler- and colour-coded duplex sonography ranged from 65 % to 95 % (median 85 %). On the side of the carotid surgery, 7 patients had suffered TIA (4) or stroke (3) in the 3 months prior to endarterectomy; the other 7 were asymptomatic.

Pathology

After imaging, the specimens were fixed in 4 % neutral formaldehyde solution for 24 h, then 3-mm-thick blocks were sectioned along the plane of the images. After paraffin embedding, one section of each block was taken for histology and stained with haematoxylin and eosin. The histopathological appearance of the stenotic plaque was assessed as fibrous intimal thickening; lipid deposits, showing aggregates of foamy macrophages ("fatty streaks"); atheromatous tissue with cholesterol crystals; calcifications; recent intramural haemorrhage; or atheromatous debris with erythrocytes and decomposition products of intraplaque haemorrhage. Plaques containing intramural haemorrhage or atheromatous debris are considered "complicated plaques" because of their close relationship to ipsilateral TIA or stroke [1, 4].

Materials and methods

Magnetic resonance imaging

MRI was performed at room temperature with a supraconducting system operating at 1.5 T, using a surface coil. For each specimen T1-, proton density- and T2-weighted spin-echo (SE) sequences and gradient-echo (GRE) sequences with different flip angles of the refocusing pulse were run. The parameters were as follows: T1-weighted 450/15 [repetition time (TR) ms / echo time (TE) ms] with four signals averaged (acquisition time 5.40 min), proton density- and T2-weighted 2000/20/90 with two signals averaged (acquisition time 6.30 min); fast low-angle shot (FLASH) GRE pulse sequences 520/18 with flip angles 15-40-90°; one signal averaged and acquisition time 1.40 min. We selected 2-5 axial slices from each specimen, slice thickness 3 mm and 1-mm interslice gap. With the T1-weighted SE sequences a 100-mm field of view (FOV) and 192 x 256 image matrix yielded in-plane resolution of 0.52 mm x 0.39 mm; for the other sequences FOV was 150 mm, with resolution 0.78 mm x 0.58 mm.

Quantitative image analysis

Signal intensity measurements were obtained from the sections best representing the stenotic plaque and having no evident volume averaging with adjacent tissues. Regions of interest (ROI) from the plaque and, as a reference (Ref), from simultaneously measured normal saline solution (0.9 %) were outlined with a cursor and analysed by means of a computer program. For each ROI the mean pixel intensity and standard deviation (SD) were computed. The plaque tissue / normal saline solution contrast to noise ratio (CNR) was calculated as the plaque tissue / normal saline solution difference normalised to noise, the standard deviation of the "background" pixel signal intensity: CNR = (I_{Plaque} - I_{Ref}) / SD I_{Ref}.

Statistics

The unpaired two-tailed Student's t-test was used in all statistical comparisons.