Value of Diffusion-weighted MRI During Carotid Angioplasty and Stenting


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Introduction. The incidence of neurological injury following carotid angioplasty and stenting is of great interest to those advocating it as an alternative to endarterectomy in the management of critical carotid stenosis. A significant inter-observer variation exists in determining the presence or absence of a neurological deficit following the procedure. Objective imaging would be advantageous. In this study, we sought to assess diffusion weighted MRI as a diagnostic tool in evaluating the incidence of neurological injury following carotid angioplasty and stenting (CAS).

Patients and methods. The first 110 cases of CAS in our unit were included in this series. The procedure was abandoned in three patients. Patients underwent intracranial and extracranial MR angiography, together with diffusion-weighted MRI (DWI) prior to and following CAS and had a formal neurological assessment in the intensive care unit after the procedure.

Results. One hundred and ten procedures were attempted in 98 patients. Twenty-eight percent were asymptomatic. Following CAS, 7.2% of patients had a positive neurological exam (two major strokes with one fatality) and 21% had positive DWI scans, equating to a sensitivity of 86% and a specificity of 85% for DWI in detecting cerebral infarction following CAS. The positive predictive value of the test was 0.3 and negative predictive value 0.99. The major stroke and death rate was 1.8%. While the use of a cerebral protection device appeared to significantly reduce the incidence of cerebral infarction (5% vs. 25%, p=0.031) this may be a reflection of the learning curve encountered during the study.

Conclusion. The incidence of subclinical DWI detected neurological injury was significantly higher than clinical neurological deficit following CAS. Conventional methods of neurological assessment of patients undergoing CAS may be too crude to detect subtle changes and more sensitive tests of cerebral function are required to establish whether these subclinical lesions are relevant.

Keywords: Carotid stenting; MRI scanning.

Introduction

Carotid endarterectomy (CEA) is an effective method of stroke prevention in certain selected populations.1–4 Developments in carotid angioplasty and stenting (CAS) techniques in recent years have generated an increasing interest in this procedure as it seeks to find its’ place amongst the treatment options for critical carotid stenosis. While the largest randomized trial of carotid angioplasty published to date, the CAVATAS trial, demonstrated equivalence between it and CEA, the peri-procedural stroke rate of 10% was felt by many to be excessive.5 Cerebral protection devices (CPD) were not used during this study and less than one-third of cases were stented following angioplasty, steps which are now regarded as standard practice.

As such the findings of this trial have been largely discounted.

Assessment of cerebral injury following carotid stenting is of great interest to those promoting it as an alternative to CEA. Clinical examination of the patient may detect gross neurological changes, but more complex methods such as cognitive testing6 are necessary to detect more subtle cerebral injury. One of the explanations offered for the high event rate seen in the CAVATAS trial was that the patients were examined by a neurologist rather than a vascular surgeon to determine whether they had had a neurological insult or not and thus it was more likely that subtle changes which would have been missed by vascular surgeons were picked up and labeled as infarcts.5

Clearly some objective form of imaging is necessary to resolve this issue. Computed tomography (CT) scanning and standard T2 weighted magnetic resonance imaging (MRI) will demonstrate infarct tissue but
not acutely ischaemic regions as similar signal characteristics of recent and chronic stroke limit the ability to determine the acuteness of an infarct. Diffusion-weighted MR imaging (DWI) allows confident diagnosis of stroke when performed within 6–7 days of the ictus and has been shown to be approximately 98% accurate with some studies finding 100% sensitivity and specificity7,8 (Fig. 1).

DWI evaluates changes in molecular movements with normal diffusional motion, leading to signal loss. In acutely ischaemic lesions diffusion is decreased. Therefore, areas of acute ischaemia will have less signal loss than normal areas leading to increased signal intensity (SI) on DWI scans. Areas of chronic infarction have more signal loss than normal areas and thus demonstrate decreased SI on DWI. The abnormal SI declines approximately 10–14 days after symptom onset.

The aim of this study was to review our experience with magnetic resonance imaging in performing CAS and to assess its usefulness in diagnosing cerebral injury following carotid intervention.

**Patients and Methods**

The first 110 carotid angioplasty and stent procedures performed in 98 patients at our institution were included in this study. Mean age was 68.7 years (range 53–88) and 68% of patients were male. Twenty-nine patients (26.3%) were asymptomatic but had evidence of inadequate crossover circulation at the level of the circle of Willis on a pre-procedural intracranial MR angiogram (MRA). The procedures were performed by a team of vascular surgeons and an interventional radiologist with a special interest in MR. Local ethical approval was obtained for this study and patients provided informed consent before entering the study.

The pre-procedural MRI protocol performed at our institution consisted firstly of an extracranial MRA to assess the aortic arch for abnormalities of vessel origin, e.g. bovine-type arch or ostial stenosis, disease of the arch itself which could be a potential source of embolism, and the type of aortic arch (i.e. type I, II or III). In addition, the extracranial MRA is also useful in assessing vessel redundancy and the presence of a distal tandem lesion, either of which could interfere with the deployment of a cerebral protection device. Secondly, an intracranial MRA with T1 and T2 weighted images, together with a DWI scan is performed. The intracranial MRA allows for assessment of cerebral crossover circulation as this influenced the decision to intervene in patients with an asymptomatic lesion. The MRA technique, which was

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**Fig. 1.** Cerebral infarct (arrowed) seen on DWI but not on standard T2 weighted MR.
employed was breath-hold gadolinium-enhanced imaging, which gave good resolution with minimal artefact. The DWI scan is performed as a baseline to exclude recent infarcts. In addition, apparent diffusion coefficient (ADC) maps were obtained in order to reduce the rate of false positives due to residual T2 weighting present in the imaging sequence (‘T2 shine-through’). A post-procedural DWI scan was also performed prior to discharge to look for new infarcts. Most patients were discharged the day following the procedure once the post-procedural DWI was completed.

All symptomatic patients with greater than 70%, and asymptomatic patients with a greater than 80% internal carotid artery stenosis on duplex ultrasound were considered for CAS. The presence of inadequate crossover circulation at the level of the Circle of Willis on the intracranial MRA, while not a prerequisite for treatment, strengthened the case for intervening on asymptomatic patients, as did the presence of silent acute lesions on the pre-procedural DWI. Contraindications were the presence of a type III aortic arch, extensive calcification at the level of stenosis or the presence of a tortuous internal carotid artery distal to the lesion, which would prevent the safe deployment of a cerebral protection device.

Via a right groin puncture the common carotid was catheterised using either a Hinck or Simmons catheter. Using a wire exchange technique a Rosen or Amplatz wire was placed in the ECA and a guide catheter positioned in the distal CCA to act as a platform. The lesion was then pre-dilated gently with a 3 mm balloon if the surgeon and radiologist thought it necessary and a cerebral protection device positioned in the ICA distal to the lesion. The stent was then deployed and post-dilated if the surgeon thought it necessary. Completion arteriography was performed and the patient returned to the intensive care unit for a 24 h period of monitoring. Following return to the ICU the patients underwent separate neurological assessment by both the intensive care consultant and the vascular surgeon who performed the procedure. We defined a ‘minor’ event as one resulting in no residual neurological findings following CAS. These manifested in six symptomatic patients as minor self-limiting deficits. Two patients suffered a major disabling stroke, one of whom died, giving a major stroke and death rate of 1.8%. In both cases, the procedures were uneventful with normal DWI scans and duplex images of the stent post-operatively. The patient who died was non-compliant with his clopidogrel medication, suffering in-stent thrombosis 18 days post-procedure, leading to a fatal stroke. The second patient suffered a stroke within 24 h of the procedure, duplex confirmed stent patency with normal flow patterns. Following the procedure this patient developed acute pulmonary oedema secondary to congestive cardiac failure, which may have contributed to the hypotensive middle cerebral artery stroke. The presence or absence of symptoms prior to intervention had no effect on the incidence of either clinical, or subclinical DWI detected, neurological injury.

Seven of the eight patients who had positive findings on their post-operative neurological exam had positive DWI scans while 16 patients had positive DWIs despite being clinically asymptomatic (Table 1). In total 23 patients (21%) had positive DWI scans following the procedure, yielding a sensitivity of 85% and specificity of 86% for DWI in detecting positive neurological findings following CAS. The positive predictive value of the test was 0.33 while the negative predictive value was 0.99.

Use of a cerebral protection device was associated with a significantly lower incidence of both clinical and DWI-detected subclinical cerebral infarcts (Fig. 2). The incidence of clinically detected stroke was 5% in the protected group and 25% in the group who underwent unprotected CAS ($p=0.031$, Fisher’s exact test). A similar finding applied to the incidence of DWI-detected subclinical infarcts, with 18% of those who had a CPD deployed having positive scans vs. 33% of the unprotected patients ($p=0.047$, Fisher’s exact test). However, all 12 of the patients who were

| Table 1. Comparison of neurological examination with DWI scans following CAS |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
|                             | Neuro+                      | Neuro−                      | Total                       |
| DWI+                        | 7                           | 16                          | 23                          |
| DWI−                        | 1                           | 86                          | 87                          |
| Total                       | 8                           | 102                         | 110                         |

Results

Three of the 110 procedures were abandoned, giving a procedural success rate of 97.3%. Reasons for abandonment were failure to cross the lesion in two cases and total occlusion of the internal carotid artery in the third. The two cases where the lesion could not be traversed were subsequently managed successfully with CEA.

Eight patients (7.2%) had positive neurological findings following CAS. These manifested in six patients as minor self-limiting deficits. Two patients suffered a major disabling stroke, one of whom died, giving a major stroke and death rate of 1.8%. In both cases, the procedures were uneventful with normal DWI scans and duplex images of the stent post-operatively. The patient who died was non-compliant with his clopidogrel medication, suffering in-stent thrombosis 18 days post-procedure, leading to a fatal stroke. The second patient suffered a stroke within 24 h of the procedure, duplex confirmed stent patency with normal flow patterns. Following the procedure this patient developed acute pulmonary oedema secondary to congestive cardiac failure, which may have contributed to the hypotensive middle cerebral artery stroke. The presence or absence of symptoms prior to intervention had no effect on the incidence of either clinical, or subclinical DWI detected, neurological injury.
stented in the absence of cerebral protection were in the first half of the series and it is unclear whether the higher infarct rate relates to the use of cerebral protection or is merely a reflection of the learning curve. The fact that the incidence of both DWI and clinical neurological events is still higher in the earlier half of the series even when the unprotected cases are excluded suggests that it is the latter (Fig. 3). Several CPDs were used, the Emboshield (Abbott Vascular, Illinois USA) being by far the commonest. The number of other devices used is too small to permit any useful analysis of the efficacy of one device over the other.

Other complications following the procedure included bradycardia and hypotension necessitating pharmacological correction in nine cases (9%) and a groin haematoma in one case (1%). It is the policy in our unit not to give atropine prophylactically, and use it only if bradycardia develops. Groin closure devices are used routinely, as was the case in the patient who developed a post-operative groin haematoma.

Discussion

Magnetic resonance imaging serves many useful purposes in planning a carotid stent. MR brain imaging is of value in the patient who presents with atypical symptoms in determining whether they have had an infarct or not. MR angiography permits assessment of the arch and access vessels for evidence of ostial disease or abnormal arch anatomy, as well as imaging the carotid lesion itself along with the distal vessel, to assess for the presence of a tandem lesion or vessel redundancy which could interfere with the deployment of a cerebral protection device or the carotid stent itself. The use of intracranial MRA allows some assessment of the degree of crossover at the level of the circle of Willis and may influence the decision to stent or not if the patient is asymptomatic. All the above information can be gleaned by use of standard digital subtraction arteriography, but at the cost of a 1.8–2.3% periprocedural stroke rate. Finally, pre-procedural MR scanning affords an opportunity to obtain a diffusion-weighted scan for comparison with post-operative images in order to determine whether there have been any acute infarcts or not.

Although in our study the clinical neurological event rate of 7.2% was in keeping with previously reported series (CAVATAS), the subclinical injury rate of 21%, as detected by DWI scanning, was significantly higher. Jaeger and colleagues found DWI detected infarcts in 22% of patients undergoing CAS.\textsuperscript{9} The positive predictive value of 0.33 and negative predictive value of 0.99 suggests that either DWI is too sensitive and identifies lesions that are not clinically significant, or that standard neurological examination is too crude to pick up the subtle changes associated with these lesions and more complex tests of higher cerebral function are necessary.\textsuperscript{6,10} Performing T2-weighted MR at a later stage (3–6 months) to look for areas of gliosis which match the pattern of emboli seen on the immediate post-procedural DWI might provide an answer to this issue.

One of the shortcomings of this study is the fact that patients were not seen by a neurologist following their procedure. Independent neurological review might have picked up subtle changes associated with cerebral injury which were missed by the vascular surgeon and intensive care physician who assessed the patients neurologically following CAS.

There is little doubt that small cerebral emboli, such as those which occur as a consequence of
cardio-pulmonary bypass, while not necessarily manifesting as a gross neurological deficit, can cause significant cognitive impairment.\textsuperscript{11} The same authors instating as a gross neurological deficit, can cause cardio-pulmonary bypass, while not necessarily manifesting as a gross neurological deficit, can cause serious cognitive impairment.\textsuperscript{11} The same authors investigated the use of cerebral protection devices during CAS may appear intuitively obvious it is still a controversial topic. Vos and colleagues found that use of a CPD was associated with an increased risk of microembolisation during all stages of CAS: crossing the lesion with a wire, predilatation, placement of the protection device, stent deployment and post-dilatation.\textsuperscript{12} The primary aim of this study was not to examine the efficacy of CPDs, therefore, our results to suggest that the use of a cerebral protection device reduces the incidence of both clinical and subclinical cerebral injury must be interpreted with caution. Only 12 patients in this series were stented without cerebral protection and these were all in the first half of the series. Ahmadi suggests that 80 cases constitute the learning curve or carotid stenting.\textsuperscript{13} Even though the majority of neurological symptoms and DWI positive scans occurred in the earlier group, we are unable to say if this is due to the absence of a CPD, or merely a reflection of the fact that these cases are on the early part of the learning curve. The fact that exclusion of the 12 stented patients from analysis still resulted in a higher incidence of neurological lesions or events in the earlier half of the series suggests that inexperience may have been a key factor here. It may simply be the case that the decision to introduce cerebral protection during the lifetime of this study is itself a part of that learning process. As such we can draw no further conclusions from it.

To rigorously assess the relevance of DWI scanning in carotid stenting, it will be necessary to compare the results of post-operative scans to more sensitive tests of higher cerebral function, such as tests of cognitive impairment.

References


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