Intraoperative High Resolution Duplex Imaging During Carotid Endarterectomy: Which Abnormalities Require Surgical Correction?

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Objectives: This study evaluates high resolution, duplex ultrasound imaging for quality control of carotid endarterectomy in order to determine which technical factors were linked to residual stenosis and to define duplex criteria for re-exploration.

Design, material and methods: A consecutive series of 100 patients undergoing carotid endarterectomy were evaluated. Duplex imaging was performed prior to wound closure and repeated at 6–8 weeks postoperatively. Stenoses were classified as non-significant, moderate or severe based on duplex criteria. Intimal flaps, shelves, kinks, clamp damage and fronds were identified by ultrasound imaging.

Results: Five moderate stenoses were noted in the proximal endarterectomy site (PES), and at follow-up three had resolved. Adherent fronds were detected in 83% of vessels and resolved in all but three cases. At the distal endarterectomy site there were 10 severe and 12 moderate stenoses. Intimal flaps were associated with an increased incidence of residual stenosis (p=0.010).

Conclusions: We conclude that severe stenoses with an intimal flap should be corrected immediately. Further data is required to establish the significance of kinks. Residual intimal flaps in the PES appear to remodel. The role of completion duplex may lie in the modification of surgical technique to eradicate anatomical and haemodynamic imperfections.

Key Words: Intraoperative monitoring; Duplex ultrasound; Carotid endarterectomy.

Introduction

The reported rate of perioperative stroke following carotid endarterectomy has ranged from 3 to 22% and has largely been attributed to perioperative thrombosis or embolisation, both due to technical error.¹⁻⁵ The most common cause of early restenosis is fibro-intimal hyperplasia which may be stimulated by disruption of laminar flow caused by a technical defect. Investigators have reported that almost half the cases of early restenosis are attributable to technical factors.⁶⁻⁷ Perioperative detection of significant defects may result in vessel re-exploration, which carries the added risks of extended clamp time, reperfusion injury and the possible use of patching. It is therefore important for any quality control method to provide rapid, clear and accurate description of haemodynamic and anatomical defects.

A range of quality control techniques have been described in the literature, the earliest being simple palpation of the artery to detect a “bounding pulse”. Conventional arteriography has been used frequently but is often performed in a single plane and visualises only gross lesions, whilst minor irregularities may remain undetected.¹²⁻⁹ In addition, angiography does not provide any haemodynamic information, prolongs the operation and may increase the overall risk of the procedure. Angioscopy provides high resolution images of the vessel wall, but again it is invasive and provides only anatomical information.⁵ Duplex ultrasound has been used increasingly, since it is able to provide rapid anatomical and haemodynamic information.⁶⁻¹⁰⁻¹¹

Duplex studies evaluating the endarterectomised segment have reported a range of defects, including high velocities, intimal flaps, kinks and platelet thrombus, which have resulted in re-exploration. Furthermore, the protocol used for duplex evaluation has varied considerably between studies; some investigators have imaged the endarterectomy after wound closure,¹² whilst others have imaged the vessel directly but have been hampered by the large size of

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conventional transducer heads, which are primarily designed for transcutaneous use.

Recently, the introduction of high resolution, small transducer heads optimised for intraoperative imaging has enabled improved visualisation of the endarterectomised segment. In this study we describe our experience using a conventional linear array transducer and an optimised intraoperative probe. In addition we investigate anatomical and haemodynamic information obtained at surgery and at early follow-up, to determine duplex criteria for re-exploration and to identify which anatomical defects were important in residual stenosis.

Patients and Methods

Between June 1995 and June 1997, intraoperative colour Doppler imaging was performed on 100 patients who underwent 106 carotid endarterectomies for severe (>70%) stenosis of the internal carotid artery. There were 75 males and 31 females, the mean age of the study group was 65 ± 8 years (range 41–82 years). Twenty-eight patients were operated on for transient ischaemic attacks (TIAs), 27 for stroke, 21 for amaurosis fugax, seven for global ischaemia and 23 for asymptomatic lesions.

Carotid endarterectomy was performed under general anaesthesia with heparin anticoagulation (5000 u). Shunting was employed selectively based on stump pressure and/or middle cerebral artery blood velocity levels. Inspection of the endarterectomised segment was facilitated using 2.5 × optical magnification and the arteriotomy was then closed primarily using 6-0 prolene. An impregnated polyester patch was used in cases where the calibre of the distal internal carotid artery was small (<4 mm).

Following closure of the arteriotomy and restoration of blood flow, colour duplex imaging of the carotid bifurcation was performed. The wound was irrigated with saline to enable coupling of the transducer to the arterial surface. A high resolution 5–10 MHz intraoperative transducer (footprint 26 × 3 mm, resolution 0.3 ± 0.4 mm) was used in all cases, and in 16 patients images were also obtained using a 4–7 MHz linear array transducer (footprint 38 × 7 mm, resolution 0.6 × 0.7 mm; Fig. 1). The transducers were placed in a sterile sleeve and all scans were performed by one experienced operator. Longitudinal B-mode ultrasound images of the common carotid artery (CCA), proximal and distal segments of the cervical internal carotid arteries (ICA) were obtained and stored to disc in digital format for subsequent analysis. Colour flow mapping was used to delineate the location of any flow irregularities. The pulsed Doppler sample volume was positioned to obtain signals from the CCA and the transducer was then systematically tracked along the bifurcation, bulb and up to the distal internal carotid artery. Blood velocity spectra were routinely recorded from the CCA and ICA and additional spectra were recorded from localised segments of increased velocity.

Stenoses were classified using conventional duplex velocity criteria as follows: (i) minor disease – <50% diameter stenosis – ICA peak systolic velocity <125 cm/s, (ii) moderate stenosis – 50–69% diameter stenosis – ICA peak systolic velocity >125 cm/s and ICA:CCA systolic velocity ratio in range 2.0–3.3, (iii) severe stenosis – 70–99% diameter stenosis – ICA peak systolic velocity >125 cm/s and ICA:CCA systolic velocity ratio >3.4. Occlusion of the ICA was confirmed by absence of flow, as demonstrated by pulsed, colour and power Doppler imaging.

B-mode images were used to identify the presence of intimal flaps, vessel kinking and fronds; the latter were only apparent during dynamic imaging. Subsequent analysis of the stored images was performed using an image analysis workstation with in-house software and caliper resolution of 0.2 mm. Measurements were taken of the intima-media thickness (IMT) at the point of transection from images of the proximal (PES) and distal (DES) endarterectomy sites. The normal IMT has been reported to lie between 0.4–1 mm; a value of greater than 1.5 mm was therefore considered to indicate intimal thickening. Prior to this study we did not use any form of completion imaging.

Previous studies have reported that residual intimal flaps may be the cause of internal carotid artery thrombosis and dissection. It was therefore decided that
Repeat duplex imaging was performed at between 6–8 weeks postoperatively. A 4–7 MHz linear array transducer was used for imaging and the same protocol as for intraoperative measurements was employed. Duplex velocity and B-mode measurements were repeated on the follow-up data. Statistical analysis was performed using regression analysis, paired and independent Student’s t-tests.

Results

Clinical

There were two deaths; one patient suffered a cardiac arrest intraoperatively requiring external cardiac massage for 20 min. Postoperatively he had an ipsilateral stroke and died on the ninth day. The second patient suffered a myocardial infarction on the second postoperative day and died the next day with no neurological defects. One patient suffered a stroke at 48 h: duplex examination showed a patent carotid artery and he was thought to have suffered an embolic event from his heart as he had a pacemaker inserted preoperatively.

There were three TIAs; one patient woke up with a weak right hand which recovered by 4 h, two patients with primary PTFE patches, for small arteries had neurological deficits in recovery which lasted 5 and 10 min, respectively. Intraoperative duplex showed no abnormality on duplex for the two TIA patients who were patched. In the third intraoperative TIA there was evidence of intimal irregularity (clamp damage?) with a moderate ICA stenosis. The mortality was 2% (2/106), the stroke and death rate 3% (3/106), TIA rate 3% (3/106) and the total neurological event for the series was 5% (5/106).

Six patients were patched primarily because of small vessel calibre. The patch obscured full imaging of the endarterectomy site; however, velocity spectra were obtained from the CCA and ICA in all patients. Figure 2 illustrates the typical appearance of an endarterectomised vessel, an intimal shelf and an intimal flap immediately after restoration of blood flow. Repeat duplex was performed in 99 cases. There were seven vessels in which follow-up duplex was not performed; three patients died due to cardiac causes and four were lost to follow-up.

Proximal endarterectomy site

At the PES there were no severe stenoses in the common carotid artery (Table 1). However, moderate stenoses were detected in 5% (5/106) of vessels. A residual intimal shelf was noted in 31 of the 100 vessels (31%) but these did not show a significantly increased IMT \((t = 1.54, \text{ degrees of freedom } = 53, p = 0.13)\). A mobile intimal flap was noted in 18 vessels (18%) which showed a significantly increased IMT \((t = -5.58, \text{ d.f.} = 55, p = 0.001)\). Two of the five patients with moderate stenosis were associated with a residual intimal shelf and three had mobile intimal flaps. Fronds were detected in 83 of the 100 vessels studied (83%) but were less than 1 mm thick and therefore were only visible during dynamic imaging. No vessel kinks were noted at the PES.

Follow-up imaging showed that three of the moderate stenoses at the PES had resolved, whilst of the remaining two, one remained the same and the other was lost to follow-up (cardiac death; Table 1). One case, with an intimal shelf but no significant stenosis intraoperatively, progressed to moderate stenosis at 6 weeks. Comparison of IMT measurements for intraoperative and follow-up data showed a significant decrease in IMT for patients with a mobile intimal flap \((p<0.01)\). This is consistent with reconstitution of intimal flaps into the artery wall, with a remodelling of the endarterectomised segment to within the normal range. Similar remodelling was noted for vessels with a residual intimal shelf. At follow-up fronds had resolved in the majority of cases, although mobile fronds were still visible during dynamic imaging in three vessels. However, full assessment of these fronds may be limited by the reduced resolution of the transcutaneous duplex transducer.

Distal endarterectomy site

At the DES there were 10 severe and 12 moderate stenoses detected in the internal carotid artery (Table 2). All 10 patients with severe residual internal carotid stenoses were symptomatic prior to surgery. Three of the severe stenoses were patched immediately based on the velocity criteria and the identification of an intimal flap on the ultrasound image (Fig. 3). No re-intervention was performed on the remaining seven severe stenoses. In one patient the vessel was in vasospasm which resolved following administration of papaverine. In another there was a suture line irregularity that smoothed out on physical manipulation which extended the vessel. In the remaining five
Fig. 2. Intraoperative B-mode ultrasound images of the proximal endarterectomy site obtained after arteriotomy closure. At the point of transection images show: (a) no residual shelf on the posterior wall, (b) a residual shelf on both walls and (c) a mobile intimal flap on the anterior wall.

Table 1. Residual stenosis detected intraoperatively and at 6 weeks in the proximal endarterectomy site (common carotid artery).

<table>
<thead>
<tr>
<th>Intraoperative</th>
<th>6-week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
</tr>
<tr>
<td>None</td>
<td>101</td>
</tr>
<tr>
<td>Moderate</td>
<td>5</td>
</tr>
<tr>
<td>Severe</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2. Residual stenosis detected intraoperatively and at 6 weeks in the distal endarterectomy site (internal carotid artery).

<table>
<thead>
<tr>
<th>Intraoperative</th>
<th>6-week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
</tr>
<tr>
<td>None</td>
<td>84</td>
</tr>
<tr>
<td>Moderate</td>
<td>12</td>
</tr>
<tr>
<td>Severe</td>
<td>10</td>
</tr>
<tr>
<td>Occlusions</td>
<td>0</td>
</tr>
</tbody>
</table>

Fig. 3. Intraoperative B-mode ultrasound image obtained from the distal endarterectomy site after arteriotomy closure showing an intimal flap which was associated with severe stenosis. Patients no associated intimal flap could be identified but vessel kinking was observed in four (Fig. 4).

Anatomical defects and the relationship with residual stenosis in the distal endarterectomy site are shown in Table 3. Kinked vessels were noted in a total of 20 vessels (19%), eight of which were associated with stenosis (four moderate and four severe stenoses). The mean IMT was measured in 15 of these and showed significantly increased thickness for vessels with kinking ($t = -2.03$, d.f. = 44, $p<0.05$). Diffuse intimal irregularities were noted in 11 vessels (9%), three were associated with moderate stenoses, and two with an increase in IMT ($t = -0.06$, d.f. = 40, $p=0.95$). A total of nine vessels showed intimal flaps in the DES, three of which were associated with severe stenosis and were immediately patched, and a further three vessels had moderate stenoses. When diffuse intimal damage was detected it was always demonstrated...
Intraoperative Duplex Ultrasound

Fig. 4. B-mode ultrasound image obtained from the distal endarterectomy site. The intraoperative image on the left shows a kink in the internal carotid artery and follow-up imaging (right) shows rapid intimal hyperplasia at the level of the kink (arrowed).

Table 3. Wall irregularities detected at the distal endarterectomy site (internal carotid artery) and relationship with residual stenosis (moderate, severe).

<table>
<thead>
<tr>
<th>Intraoperative</th>
<th>6-week</th>
<th>Moderate</th>
<th>Severe</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>No abnormality</td>
<td>64</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Suture stricture</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Vasospasm</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Intimal flap</td>
<td>9</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Intimal damage</td>
<td>11</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Kink</td>
<td>20</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

beyond the furthest extent of the endarterectomy, and this was the level at which the distal clamp was positioned during cross-clamping; three of these vessels were associated with moderate stenoses.

At the DES follow-up was available in all 10 severe stenoses detected intraoperatively (Table 2). Three remained severe, two had remodelled to moderate stenoses, and five showed no significant lesions, which included the three patched vessels. The three persistent residual severe stenoses were in two patients who had TIA's and one who had global ischaemia preoperatively. Follow-up of the 12 moderate stenoses showed residual moderate stenoses in four. Seven had remodelled to become non-significant lesions.

Follow-up was available in 19 of the 20 kinked vessels; one patient died due to cardiac causes at 8 weeks postoperatively. Six stenoses detected intraoperatively persisted, but one had remodelled to moderate stenosis. In the non-significant group with kinking, two had developed moderate stenoses. In total, eight of the 19 kinked vessels showed significant stenosis (42%). Comparison of IMT measurements intraoperatively and at follow-up showed a significant increase for vessels with kinking ($p<0.05$; Fig. 4). Two of the three moderate stenoses with diffuse intimal damage had resolved; however, one had progressed to severe stenosis, whilst in the non-significant stenosis group, two progressed to moderate stenoses at 6 weeks.

Transducer comparison

Images were obtained in all 16 patients at the PES but the large transducer failed to produce a clear image of the DES in four cases (25%). Comparison of IMT measurements, however, showed good correlation ($r=0.93$, $p<0.01$), indicating that the improvement in imaging was largely attributable to the physical size of the transducer head rather than due to improved imaging resolution.

Discussion

It is now widely accepted that intraoperative completion assessment of carotid endarterectomy is essential. However, there is still considerable debate regarding the most appropriate technique for this
purpose. Many centres now use duplex ultrasound but a major criticism has been that inadequate images are obtained in a large proportion of cases. In this study, we describe the use of a specially designed intraoperative transducer which facilitates acquisition of high resolution images and enables imaging of all the endarterectomised segments studied except where a synthetic patch was inserted. Gelatin impregnated fluoropolymer patches are available which are transparent to duplex studies and therefore enable completion duplex in all patients.

Severe stenoses in the internal carotid artery were detected intraoperatively in 10 (9%) out of 106 carotid endarterectomies, three of which were associated with intimal flaps and four with vessel kinking. Immediate revision was performed only in the severe stenoses which were associated with intimal flaps and these remained widely patent at follow-up. Severe stenoses detected intraoperatively that were associated with suture line irregularities or vasospasm resolved and therefore did not require re-exploration. However, in the patients who did not undergo revision, vessels associated with kinking tended to show persistent severe stenoses.

Reilly et al. reported that the size of the technical defect on ultrasound imaging was related to the severity of recurrent stenosis, whilst Caps et al. reported that IMT measurements were useful in identifying which vessels were likely to restenose following endarterectomy. In our study we found that in the CCA the presence of an intimal flap and increased IMT were not associated with an increased incidence of restenosis, as only one of these defects was associated with moderate stenosis at early follow-up. The situation in the ICA is quite different. Intimal flaps were found to be the major defect in one-third of severe stenoses and a quarter of moderate stenoses, whilst kinks were the focal point of rapid intimal hyperplasia and were associated with stenosis at follow-up in eight (40%) cases.

In conclusion, we recommend re-exploration and patching for all residual severe ICA stenoses associated with an intimal flap. An argument could be made for the correction of all severe stenoses, as not all of these resolve; further data is required to elucidate this point. Residual technical defects that were not associated with severe stenosis are, however, associated with a high incidence of residual moderate stenosis at early follow-up; there is therefore a strong case for eradicating such technical imperfections. Residual intimal flaps in the CCA may be avoidable by modifications to surgical technique during transection of the plaque. Intimal shelves may also be reduced by the use of duplex before the arteriotomy to accurately identify the most proximal extent of the plaque. In addition, modifications in clamping the distal end may avoid diffuse intimal damage.

In this series there were no perioperative ICA thromboses and no relationship between perioperative neurological events and defects identified by duplex. The role of high resolution completion duplex may lie in modifications to surgical technique to produce technical refinements and thus improved outcomes for patients undergoing carotid endarterectomy.

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References


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