Making carotid surgery safer

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Carotid surgery has been shown to be beneficial in level one randomised trials. However, evidence suggests that current outcomes do not match those published in 1991. In order to make carotid endarterectomy safer in the future, it is essential to optimise patient selection and risk factor management and to maintain an obsession with surgical technique. A planned strategy of monitoring and quality control assessment can also contribute towards a sustained reduction in the peri-operative risk.

What is the current status of carotid endarterectomy?

Table 1 summarises the results from the European Carotid Surgery Trial (ECST), the North American Symptomatic Carotid Endarterectomy Trial (NASCET) and the Asymptomatic Carotid Atherosclerosis Study (ACAS)\textsuperscript{1-3}. The reason for the apparent discrepancy between the ECST and NASCET data is the differing methods of quantifying carotid stenosis. In practice, a 50% NASCET stenosis corresponds to a 70% ECST stenosis.

There has been an increase in the number of carotid endarterectomies (CEAs) performed worldwide and, inevitably, an increasing proportion are undertaken in non-trial centres. For example, in the US, >93% of CEAs are currently performed in non-NASCET centres\textsuperscript{4} and this has implications regarding the generalisability of the international trial results (see later).

Table 1 Summary of results from ECST, NASCET and ACAS\textsuperscript{1-3}

<table>
<thead>
<tr>
<th>Stenosis</th>
<th>Trial</th>
<th>Stroke incidence (%)</th>
<th>Absolute risk reduction</th>
<th>Relative risk reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Surgery</td>
<td>Medical</td>
<td></td>
</tr>
<tr>
<td>0-30%</td>
<td>ECST</td>
<td>11.8%</td>
<td>6.2%</td>
<td>-5.6% at 3 years</td>
</tr>
<tr>
<td>31-69%</td>
<td>ECST</td>
<td>16.0%</td>
<td>15.0%</td>
<td>-1.0% at 5 years</td>
</tr>
<tr>
<td>70-99%</td>
<td>ECST</td>
<td>12.3%</td>
<td>21.9%</td>
<td>9.6% at 3 years</td>
</tr>
<tr>
<td>0-49%</td>
<td>NASCET</td>
<td>14.9%</td>
<td>18.7%</td>
<td>3.8% at 5 years</td>
</tr>
<tr>
<td>50-69%</td>
<td>NASCET</td>
<td>15.7%</td>
<td>22.2%</td>
<td>6.4% at 3 years</td>
</tr>
<tr>
<td>70-99%</td>
<td>NASCET</td>
<td>9.0%</td>
<td>26.0%</td>
<td>17% at 2 years</td>
</tr>
<tr>
<td>60-99%</td>
<td>ACAS</td>
<td>5.1%</td>
<td>11.0%</td>
<td>5.9% at 5 years</td>
</tr>
</tbody>
</table>

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The long-term benefit of CEA is inextricably linked to the initial surgical risk, e.g. a unit with a 2% risk at 30 days will prevent 167 strokes/1000 CEAs long-term and only 6 operations need be performed to prevent one stroke. Conversely, a unit with a 7% complication rate will only prevent 117 strokes/1000 CEAs and 9 operations are required to prevent one stroke.5

Is there a current problem?

Although the randomised trials demonstrated a beneficial role for CEA, there are concerns about the generalisability of the results in everyday practice. Each international trial used highly selected surgeons, but current results may not match those that were published in 1991. At the same time that NASCET was being performed, Hsai audited outcome in all Medicare beneficiaries undergoing CEA. The operative mortality was almost 5 times that reported in the NASCET study. When the audit was repeated in 1996, the death rate had fallen to 1.6%, but was still more than twice that reported by NASCET in 1991. A further study has shown that the mortality rate following CEA is significantly lower in current NASCET centres, as opposed to non-NASCET centres, and that operative mortality is indirectly proportional to surgeon experience and annual operative volume.7 There is also evidence from the surgical arm of the Carotid and Vertebral Artery Transluminal Angioplasty Study8 that the 30 day risk of death by stroke was significantly higher than that reported by the ECST in 1991.

The net result of these larger, community-based studies has been to focus concern on the generalisability of the role of carotid surgery in the current era. Unless steps are taken to ensure that outcomes are at least equivalent to the international trials, the operation could fall into disrepute. Moreover, with the increasing moves towards refining the indications for CEA, surgeons could find that they are operating on a smaller proportion of symptomatic patients who are otherwise at very much higher risk of stroke, both in the natural history and possibly peri-operatively.

Can carotid surgery be made safer?

The simple answer to this is yes, but requires close attention to patient selection, optimisation of risk factors and modification of surgical technique. This chapter will not, however, discuss risk factor management any further.
Patient selection

In an ideal world, a multi-disciplinary team comprising neurologists, stroke physicians and surgeons should collaborate to ensure that appropriate patients are referred for carotid surgery. In the real world, this will largely be dictated by rapid access to neurologists who have an interest in stroke and the number of dedicated stroke physicians.

There is no proven role for CEA in patients with vertebrobasilar or non-hemispheric symptoms. At present, we advocate elective CEA in patients with a 70–80% stenosis (ECST criteria) who have had carotid territory symptoms within the preceding 6 months. The ECST and NASCET have both shown that patients with more severe degrees of stenosis continue to derive benefit from carotid surgery for 12 months following their most recent event\(^1\). Thus, we would now offer endarterectomy to patients with a symptomatic 80–99% stenosis for up to 12 months after their last event. The indications for surgery in asymptomatic patients remain controversial, despite the ACAS findings\(^3\). At present, CEA for asymptomatic disease comprises 15% of our operative workload and is almost exclusively applied to patients with severe bilateral disease or contralateral occlusion.

In practice, once a decision to operate has been made, the procedure should be performed as soon as possible because of the high risk of stroke in the first few weeks after onset of symptoms. In the past, there has been a policy of delaying endarterectomy for 6 weeks in patients with a completed stroke. This evolved because of fears of haemorrhagic transformation of an ischaemic infarct. However, there is increasing evidence that the improvements in peri-operative patient care and monitoring have made it safe to operate on these patients within 1 month of their stroke, provided they have made a good early recovery\(^9\). Our unit currently advocates urgent CEA in patients with crescendo TIAs and those very rare patients with stroke in evolution. In practice, urgent CEA comprise < 5% of our overall practice. We do not advocate emergency CEA following acute stroke unless this occurred in the immediate period following endarterectomy.

It is hoped that combining the ECST and NASCET databases will enable clinicians to identify particularly high risk patient subgroups and also, perhaps, exclude lower risk patients from unnecessary surgery. It is also imperative that a uniform method of quantifying stenosis is agreed and future research must be directed at evaluating the role of plaque morphology and stroke risk.

Surgical technique

It seems intuitively obvious that by ensuring good training of young surgeons in the art of carotid surgery, early and late outcomes will
improve. However, there may be a natural reluctance on the part of vascular surgeons to delegate CEA to their trainees because of a perception that the rate of complications will inevitably increase. However, there is increasing evidence that trainees can receive a comprehensive training in carotid surgery without compromising outcome. Adherence to this training doctrine is essential if the current increase in operative workload continues. In order to ensure effective training, there must be a large enough case mix within individual centres as outcomes may be directly related to an individual surgeon's experience and annual operative volume. In reality, it is difficult to define the exact number of cases required, but it would seem reasonable for a surgeon to perform a minimum of 25 CEAs per annum. It may be, therefore, that there will be increasing calls to centralise carotid surgery in larger regional centres. This will increase the experience within units and will inevitably facilitate better training, research and multi-disciplinary team input. In addition, it makes provision for peri-operative monitoring more cost-effective.

**Operative technique**

All surgeons must maintain obsessional attention to technical detail. A thorough knowledge of anatomy is essential to minimise cranial nerve injury. Surgeons should avoid undue dissection around the common carotid artery, carotid bifurcation and distal internal carotid artery. There are two reasons for this: the first is to minimise the risks of thromboembolism, while the second is to avoid the functional elongation of the carotid artery that occurs when the bifurcation is fully mobilised. Finally, surgeons should remain aware that inadvertent technical error is the principal cause of operation-related stroke and avoid the tendency to ascribe blame to the shunt, patch, monitoring method, or even the patient, should adverse outcomes arise.

Much of the debate relating to improving the safety of CEA has been restricted to the role of patching and shunting. Each have their detractors and supporters and, for the most part, surgeon preference is largely dictated by how they were taught. An overview of the available randomised trials of routine patching versus routine primary closure has shown that patching confers a 3-fold reduction in the 30 day risk of stroke and carotid thrombosis. There is no evidence that the type of patch (vein or prosthetic) influences outcome. Few randomised trials have evaluated whether a policy of routine shunting is preferable to either selective shunting or no shunting. At present, an overview of the published results shows no difference in outcome between routine and selective shunting, although methodological problems have confounded
the interpretation of many of these studies. However, there is increasing consensus that a policy of routine or selective shunting is preferable to a policy of routine no-shunting.

**Monitoring and quality control assessment**

Ever since the first CEA was performed, surgeons have been aware of the paradox that the very operation that is undertaken to prevent stroke in the long-term can itself precipitate a stroke in the early postoperative period. Accordingly, surgeons have developed a number of monitoring methods to improve outcome. However, despite the plethora of published literature, it is surprisingly difficult for an impartial reader to draw a firm conclusion as to whether such a policy alters outcome.

The principle underlying the role of monitoring is that prevention should be easier than treatment of an acute stroke following surgery. Relatively few studies have prospectively audited the exact cause of peri-operative events, but evidence suggest that the majority are intra-operative (i.e. apparent upon recovery from anaesthesia). Thromboembolism predominates over haemodynamic causes, even in high risk individuals with little or no reserve.

There are many reasons why a policy of monitoring and quality control assessment has failed to alter outcome in the past. The most obvious include a failure to ask the correct questions and the flawed assumption that one single monitoring modality is infallible and superior to all others. For example, most monitoring techniques have been designed to identify haemodynamic failure during carotid clamping and thereafter to develop criteria for selective shunting. However, clamp ischaemia is a relatively rare cause of intra-operative stroke and little attention has been directed towards identifying and preventing thromboembolism. Thus, is it reasonable to blame the EEG for having failed to prevent a stroke secondary to embolisation of thrombus following restoration of flow if no attempt was made to identify and remove this beforehand?

There are a number of methods for monitoring cerebral perfusion intra-operatively (stump pressure measurement, cerebral blood flow measurement, transcranial Doppler (TCD) ultrasound, EEG, evoked potentials, near infra-red spectroscopy, awake testing and jugular venous oxygen saturation). The only method capable of detecting embolisation is TCD. Intra-operative quality control methods include angiography, duplex ultrasound assessment, continuous Doppler wave assessment and angioscopy. To date, no randomised trial has compared a programme of monitoring with no monitoring on overall outcome. However, a number of studies have shown that quality control methods
will identify some form of technical error in about 25% of patients\textsuperscript{17-19} and that introduction of some form of monitoring and quality control assessment may be associated with a reduction in peri-operative stroke risk\textsuperscript{20,21}.

**Evolution of the Leicester monitoring protocol**

The Leicester protocol evolved as a result of a systematic, prospective audit of 800 CEAs between 1992 and 1999. Prior to 1992, the 30 day risk of death or stroke in our unit was 6% and this was within national and international guidelines. In a pilot study of 100 patients, Gaunt compared intra-operative TCD, completion B-mode imaging, completion angioscopy and continuous wave Doppler assessment of the endarterectomy zone and noted that minor or major technical error was present in 12% of patients. No additional information was provided by B-mode imaging or continuous wave Doppler over TCD and angioscopy\textsuperscript{22}.

TCD immediately warns the surgeon of spontaneous embolisation during the dissection phase of the procedure thus enabling modification of operative technique. In our centre, the routine use of TCD has been associated with a 50% reduction in the incidence of intra-operative embolisation\textsuperscript{23}. TCD also ensures that middle cerebral artery blood flow velocity (MCAV) remains in excess of 15 cm/s, a threshold previously shown to correlate with loss of cerebral electrical activity\textsuperscript{24}. If necessary, this threshold can be achieved by pharmacological elevation of blood pressure. Transcranial Doppler monitoring also immediately identifies shunt malfunction. It is often naively assumed by surgeons that having inserted a shunt, no further problem can occur. However, evidence suggests that up to 3% of shunts malfunction\textsuperscript{25}. In practice, one of the commonest reasons for poor shunt flow is impaction of the distal shunt lumen against a distal carotid kink or loop. Transcranial Doppler is also the only method capable of diagnosing on-table carotid thrombosis. This extremely rare condition can be diagnosed by a decline in MCAV to levels observed during carotid clamping in association with increasing rates of embolisation. In our last 800 CEAs, we have encountered two cases of on-table carotid thrombosis and on both occasions, the condition was immediately diagnosed by TCD thereby enabling the surgeon to re-explore the artery and remove the thrombus. In the absence of transcranial Doppler, the surgeon would only have become aware of a major problem when attempts were made to awaken the patient.

The benefit of completion angioscopy is that it can be performed prior to restoration of flow. Its main role is the detection of luminal thrombus and intimal flaps. The disadvantage of angiography and duplex
assessment is that flow must be restored before any examination can be performed and thus any luminal thrombus may have embolised by then.

The original pilot study and a similar study performed two years later confirmed that a policy of intra-operative TCD and completion angioscopy was associated with virtual abolition of intra-operative stroke, but no change in the 3% rate of postoperative thrombotic stroke. On two occasions, TCD monitoring was continued into the early postoperative period and we observed that the onset of thrombotic stroke was preceded by 1–2 h phase of increasing embolisation. In a much larger series, Levi demonstrated that 60% of patients with sustained postoperative embolisation progressed on to a thrombotic stroke. The association between increasing embolisation and postoperative carotid thrombosis has now been documented on three continents.

In an attempt to prevent postoperative thrombosis, we administered intravenous dextran therapy to all patients following restoration of flow. Although this was associated with abolition of thrombosis, there was an increased incidence of neck haematomas, cardiac failure and one death through dextran-mediated multi-organ failure. We subsequently hypothesised that TCD could be used to monitor patients in the early postoperative period and, thereafter, identify those with increasing rates of embolisation in order to guide selective dextran therapy. In a pilot study of 100 patients, Lennard administered dextran to 5% of patients, embolisation ceased in every case and no patient suffered a stroke. Since October 1995, we have implemented an integrated programme of monitoring comprising intra-operative TCD, completion angioscopy and 3 h of postoperative TCD monitoring in 500 patients. Intra-operative TCD specifically altered management decisions in 1.8% of patients, including the diagnosis of one case of on-table carotid thrombosis. Intimal flaps were repaired in 3% and fragments of luminal thrombus were removed in 4% following angioscopy. The source of these luminal thrombi was bleeding from the vasa vasorum on to the highly thrombogenic endarterectomised surface. In practice, they can be surprisingly adherent and resistant to blind irrigation with heparinised saline.

TCD monitoring in the early postoperative period indicates that about 50% of patients will have one or more emboli detected, but only 5% will develop sustained embolisation within the first 3 h. Our current protocol is to administer an incremental dose of dextran to patients with more than 25 emboli detected in any 10 min period of monitoring, or who have large emboli which distort the MCA waveform. Dextran is administered as a 20 ml bolus followed by an infusion initially starting at 20 ml/h. If the rate of embolisation does not diminish, the dose is increased incrementally to a maximum of 40 ml/h. Once the rate of embolisation has started to decrease, the dextran is continued for a further 12 h. Since implementing...
this protocol, we have not had to re-explore any patient for postoperative carotid thrombosis, but 36% of patients receiving dextran have required increases in the dosage suggesting that administration of a single dose of dextran will not control the rate of embolisation in all patients.

Implementation of the current protocol has been associated with a 60% sustained decline in the peri-operative complication rate as compared to before 1992. The intra-operative stroke rate has fallen to 0.2% and no patient in the current series has progressed onto a thrombotic stroke. Overall, the death/disabling stroke rate in the 500 patients was 1.6% and the death/any stroke rate was 2.2%, despite the fact that > 50% of the procedures were performed by trainees under supervision. Of particular note was the fact that >50% of the complications followed either intracranial haemorrhage or cardiac pathology. The incidence of ipsilateral embolic stroke was 0.8%.

**Conclusions**

Carotid surgery has been shown to be beneficial in level one randomised trials. However, evidence suggests that current outcomes do not match those published in 1991. In order to make CEA safer in the future, it is essential to optimise patient selection and risk factor management and to maintain an obsessional approach to surgical technique. It is our firm opinion that a planned strategy of monitoring and quality control assessment can also contribute towards a sustained reduction in the perioperative risk. Finally, surgeons must never accept that peri-operative stroke is an inevitable and unavoidable complication of carotid surgery. Every surgeon is responsible for his/her own results and these must be quoted, rather than the results from the international trials, to justify practice. It is imperative that all surgeons continuously audit their own results, preferably independently, and continually strive to review all aspects of their practice.

**References**