Carotid Endarterectomy Improves Cognitive Function in Patients with Exhausted Cerebrovascular Reserve


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Objective. To investigate changes in cognitive function following carotid endarterectomy (CEA).

Design. Prospective study with controls.

Methods. CEA patients \( (n = 159) \) were compared to a urology surgery control group \( (n = 20) \). In CEA patients cerebrovascular reserve (CVR) was measured preoperatively. During surgery emboli and blood flow velocity in the middle cerebral artery were measured by transcranial Doppler (TCD) and cerebral oxygen saturation (CsO\(_2\)) by near infrared spectroscopy. Cognitive function was measured preoperatively and at 5 days and 8 weeks postoperatively using a standardised computer battery of tests.

Results. Only 8% of patients had normal CVR bilaterally. The median number of emboli during CEA was 12 (range 0–181). On carotid clamping, TCD velocity fell a median of 41% and cerebral oxygen saturation by 5%. Attention deteriorated compared to controls 5 days following CEA \( (p = 0.003) \) and this deterioration was related to the rise in TCD velocity on declamping \( (r = -0.3, p = 0.002) \). Median attention reaction times improved significantly by 8 weeks \( (p = 0.001) \) especially in patients’ with severely impaired CVR before surgery \( (p = 0.02) \).

Conclusions. Attention improved at 2 months following CEA in patients with impaired CVR. CEA may offer more than reduced stroke risk to patients with impaired CVR.

Key Words: Carotid endarterectomy; Cognitive function; Cerebrovascular reactivity.

Introduction

The influence of carotid endarterectomy (CEA) on cognitive function remains controversial; some studies showing benefits\(^1\) –\(^5\) and others not.\(^6\) Perioperative cognitive change may be influenced by the presenting symptom, the number of emboli entering the cerebral circulation during surgery and the dominance of the relevant cerebral hemisphere.\(^1\)–\(^3\)\(^,\)\(^7\) The degree of stenosis may be relevant\(^8\) as animal studies suggest that hypo-perfusion has significant influences on learning and memory.\(^9\)–\(^11\) However, global measures of cognitive function may be insensitive to changes in specific cognitive functions and most studies have failed to include suitable controls.\(^1\)\(^,\)\(^2\) The effect of learning on repeated testing and the inappropriate intervals between cognitive testing also need to be considered.\(^12\)\(^,\)\(^13\)

Cerebrovascular reserve (CVR) to inhaled carbon dioxide is a surrogate measure of autoregulation and the adequacy of collateral supply. CVR is impaired in patients with carotid stenosis as the microcirculation is already vasodilated in an attempt to improve impaired cerebral blood flow.\(^14\)\(^,\)\(^15\) If the cerebral microcirculation is maximally dilated then CVR is exhausted. CVR improves in the ipsilateral middle cerebral artery following CEA due to the restoration of blood flow and cerebrovascular tone.\(^16\) –\(^18\) Improved collateral blood supply to the contralateral cerebral hemisphere via the circle of Willis leads to improved CVR in both cerebral hemispheres.\(^16\)\(^,\)\(^17\) The effects of this recovery in CVR on cognition are unknown. CVR can be measured non-invasively using a simple bed-side transcranial Doppler (TCD) test of MCA blood flow velocity, which relates closely to changes in absolute cerebral blood flow.\(^19\)\(^,\)\(^20\) TCD is non-invasive and can also be used to record embolisation to the cerebral circulation. Near infrared oxygen spectroscopy (NIRS) measures regional cerebral oxygen saturation (CsO\(_2\))
in the frontal or middle cerebral artery territory. The absolute \(CsO_2\) value varies considerably between individuals.\(^{21}\) However, the change in \(CsO_2\) is reproducible and correlates closely with changes in middle cerebral artery blood flow velocity on TCD and with jugular bulb oxygen saturation, especially when the sensor is placed over the middle cerebral artery territory.\(^{19}\) \(CsO_2\) is also consistent with invasive measurements of brain tissue oxygenation and cerebral perfusion pressure in patients with severe head injury.\(^{22}\) The combination of NIRS and TCD can be used to identify periods of cerebral hyper- and hypoperfusion.\(^{19}\)

Preoperative CVR, intraoperative embolisation, hyper- and hypo-perfusion may all play a role in changes in cognitive function after CEA. We used a comprehensive battery of objective and validated computer-generated cognitive tests on patients before and after CEA to carefully document changes in different aspects of cognitive function. We also investigated the relationship between cognitive change, preoperative CVR and intraoperative changes in middle cerebral blood flow velocity, cerebral embolisation and regional \(CsO_2\).

**Methods**

One hundred and fifty-nine consecutive English-speaking patients undergoing CEA for symptomatic internal carotid artery stenosis of at least 70% based on preoperative duplex assessment were invited to give informed consent and participate.

**Cerebrovascular reserve (CVR)**

CVR to inhaled carbon dioxide was measured on the day before surgery using a standard TCD technique.\(^{14}\) Patients lay supine whilst two 2 MHz probes (Neuroguard CDS, USA) were positioned over the temporal windows and secured using a headband to insonate the middle cerebral arteries. Mean middle cerebral blood flow velocity was then recorded in resting patients (i) while breathing room air, (ii) after inhalation of 5% carbon dioxide in air and (iii) after hyperventilation. The CVR was calculated and graded according to Ringelstein;\(^{14}\) normal CVR being greater than 85%, mild impairment 66–85%, moderate impairment 34–65% and severely impaired being below 34%.

**Carotid surgery**

CEA was performed by the same surgical and anaesthetic team using a standardised technique. General anaesthesia was maintained by isoflurane in 50% oxygen and nitrous oxide, delivered by intermittent positive pressure ventilation. End-tidal \(CO_2\) was kept in the range 36–40 mmHg to stabilise cerebral blood flow. Heart rate and arterial blood pressure were continuously monitored by 5-lead electrocardiography and a cannula inserted into the contralateral radial artery. A pulse oximeter (Marquette) was placed on the contralateral middle finger to continuously display peripheral oxygen saturation. Following full exposure of the carotid bifurcation, Heparin (5000 IU) was given intravenously prior to cross-clamping and was not reversed.\(^{23}\) On carotid clamping, the fall in middle cerebral flow velocity was recorded by TCD (Neuroguard CDS, USA) and the fall in regional cerebral oxygen saturation (\(CsO_2\)) was measured by reflected NIRS using the Somanetics INVOS 3100A instrument (Somanetics, USA). The use of these instruments is described below and the indication for inserting a Javed Intraluminal shunt was a fall in middle cerebral flow velocity by TCD of 80% or greater and/or a fall in \(CsO_2\) of more than 12%. Following CEA, the arteriotomy was closed with a Dacron patch unless the internal carotid was greater than 6 mm in diameter when primary closure was performed.

**Cerebral monitoring during CEA**

**Transcranial Doppler (TCD)**

Middle cerebral artery blood flow velocity was measured by 2 MHz TCD insonation at 45–50 mm depth continuously but recorded every 5 min. The Doppler settings were: power 100%, range 10 dB, sweep speed 8 ms and gain 8 dB.

The number of emboli entering the ipsilateral middle cerebral artery were counted continuously using criteria from the international consensus on microembolic detection:\(^{24}\) embolic signals should be transient lasting less than 300 ms, at least 3 dB higher than that of the background blood flow signal, unidirectional, within the Doppler spectrum and accompanied by an audible ‘snap’, ‘chirp’ or ‘moan’.

**Regional cerebral oxygen saturation (\(CsO_2\))**

\(CsO_2\) was measured by Somanetics Invos 3100A (USA) using sensors with two detectors separated from a near infrared light source by 30 and 40 mm. The computer algorithm subtracts the oxygen spectroscopy of light reflected through blood in the scalp, skull and superficial brain to the 30 mm detector from that of light reflected from deeper brain to reach the
40 mm detector giving the CsO₂, which is a measure of oxygen saturation in brain tissues. As 80% of the blood in the brain is on the venous side of capillaries CsO₂ is a measure of oxygen extraction.

### Cognitive function

Cognitive function was measured using a standardised battery of tests produced and validated by Cognitive Drug Research Ltd (Reading, UK). Patients responded to visual stimuli presented on a computer screen by pressing one of two buttons. A practice session was used to familiarise patients with the equipment and to reduce learning effects.

Several aspects of cognitive function were measured. Reaction times were measured in milliseconds (ms). Accuracy values were corrected for guessing according to Frey and Collier and expressed as an index. Sum variables were calculated as follows:

1. Overall Memory Reaction Time (RT) = sum of word, picture and memory scanning reaction times; a measure of memory speed.
2. Overall Attention RT = sum of simple, choice and number vigilance reaction times; a measure of speed in attention tests.
3. Overall RT = sum of all reaction time tests (1 + 2 above).
4. Overall Accuracy = sum of accuracy scores for word recognition, picture recognition and memory scanning.

To avoid many of the difficulties associated with cognitive testing in patients following surgery, we adhered to criteria set down by the Statement of Consensus on Assessment of Neurobehavioural Outcomes after Cardiac Surgery.

### Control patients undergoing urological surgery

Twenty elderly English-speaking patients undergoing urological surgery under general anaesthesia were recruited as controls. Controls were enrolled sequentially as they were admitted but excluded if they had cancer, previous symptomatic cerebrovascular disease, were less than 60 years of age, were not having a general anaesthetic, or if surgery was expected to be of less than 30 min duration. Informed consent was obtained and preoperative cognitive function testing carried out.

All complications in patients and controls were recorded and patients were discharged on the fifth postoperative day after completing cognitive function testing which was then repeated at 8 weeks. This cognitive data were collected onto a floppy disc for each patient and downloaded by Cognitive Drug Research Ltd (Reading, UK). Demographic and cognitive data were analysed using a computerised statistics package (SPSS for Windows).

### Results

The mean age (interquartile range or IQR) for the 159 patients undergoing CEA was 68 (62–75 years), 71% were men, 63% were hypertensive and 13% were diabetic. The indications for surgery were stroke in 35% and transient ischaemic attacks in 65%. CVR could only be measured in 95 patients either due to lack of a transtemporal window, patient reluctances or lack of adequate time before surgery.

Seven patients (4%) were re-explored in the immediate postoperative period, five for neck haematoma and two for persistent emboli on TCD. There was one postoperative stroke requiring thrombectomy on the day of surgery. Three patients had postoperative TIAs. The number of patients who had measurement of CVR as well as intraoperative TCD and CsO₂ measurements was 92.

### Cerebrovascular reserve (CVR)

CVR was normal bilaterally in only 8 (8%) of the 95 patients investigated. Median (IQR) ipsilateral CVR was 60% (47–80%) where the lower limit of normal is reported to be 86%. Only 13 (8%) had normal ipsilateral CVR, 25 (16%) had ‘mild’ impairment, 49 (31%) had ‘moderate’ impairment and 8 (5%) had ‘severe’ impairment. Preoperative CVR was not influenced by gender, hypertension or diabetes.

Median (IQR) CVR was marginally lower in those that needed a shunt at 58% (47–71%) compared to 61% (47–83%) in those where a shunt was not needed. Those patients with impaired ipsilateral CVR had greater falls in median mean middle cerebral artery velocity by TCD on clamping at 41% compared to 30% in those with normal CVR, and greater rises on declamping at 29% compared to 18%. However, these differences did not reach statistical significance.

### Middle cerebral flow and embolism by TCD

Intraoperative TCD monitoring was performed in 135 (85%) of patients; the remaining 24 did not have an adequate transtemporal window. Median (IQR)
ipsilateral mean middle cerebral blood flow velocity was 45 (34–57) cm/s initially and fell to 26 (17–38) cm/s on application of the internal carotid clamp \((p < 0.001, \text{ Wilcoxon})\) (Fig. 1(a)). A shunt was inserted in 33 (21\%) of patients according to the criteria specified above. On declamping, middle cerebral flow velocity rose to 59 (41–74) cm/s \((p < 0.001, \text{ Wilcoxon})\). The median number of emboli during CEA was 12 (range 0–181). Declamping accounted for the vast majority of emboli, which were likely to be microbubbles arising from the Dacron patch; 72 patients had more than 10 emboli and 13 (8\%) had a shower of emboli. Although TCD does not reliably differentiate solid from air emboli, those occurring during dissection before arteriotomy were likely to be particulate. Only six patients had more than 10 emboli during dissection.

Cerebral oxygen saturation (CsO\(_2\))

CsO\(_2\) data were collected in 144 patients, i.e. all those having TCD measurements and another 10 patients who did not have a transtemporal window. Median (IQR) regional CsO\(_2\) was 68\% (64–74) before clamping and fell to 65\% (58–70) on cross-clamping \((p < 0.0001)\) and then increased on declamping to 69\% (63–75) \((p < 0.001)\) (Fig. 1(b)). The fall in middle cerebral flow and CsO\(_2\) on clamping and the rises in these two measures on declamping correlated with each other \((r = 0.2, p < 0.0001, \text{ Spearman})\).

Cognitive function

Cognitive function was measured preoperatively in all 159 patients and postoperatively in 158 excluding the

![Fig. 1](image)

Fig. 1. (a) Ipsilateral mean middle cerebral artery blood flow velocity measured by TCD fell from 45 cm/s to 26 cm/s on carotid clamping \((p < 0.001)\) and increased to 59 cm/s on declamping \((p < 0.001)\). (b) Ipsilateral regional cerebral oxygen saturation (CsO\(_2\)) measured by reflected near infrared oxygen spectroscopy fell from 68 to 65\% on carotid clamping \((p < 0.0001)\) and rose to 69\% on declamping \((p < 0.001)\).
one patient who suffered stroke and subsequent thrombectomy on the day of surgery and was not able to perform the cognitive test battery. CEA and control patients were well matched in terms of preoperative cognitive performance although the controls were a little older with a median age of 74 compared to 68 years for patients undergoing CEA. There was no significant difference in overall tests of cognitive function between those carotid patients who had had previous stroke and those who had not.

Five days postoperatively
Five days following surgery there were significant improvements in choice reaction time, number vigilance, word recognition and speed of memory in carotid patients but simple reaction times were slower and picture recognition less accurate (Table 1). In terms of overall performance, speed of attention was slower and accuracy poorer but memory tests were performed significantly faster (median 3232 ms from 3295 \( p < 0.0001 \)) and overall reaction time was significantly quicker at a median of 4550 ms compared with 4573 ms preoperatively (\( p = 0.003 \)).

By contrast, urology control patients only improved significantly in two of the six individual tests; speed of word and picture recognition with none of their functions deteriorating demonstrating a learning effect (Table 2). Controls were also significantly faster in overall scores for attention, memory and reaction time (\( p < 0.05 \) Mann–Whitney \( U \) test) than CEA patients at 5 days following surgery.

Two months postoperatively
The results in five out of six tests significantly improved at 8 weeks following carotid surgery. Overall performance was better with speed of memory falling by 244 ms, attention by 52 ms and overall reaction time by 319 ms, (\( p = 0.0001 \), Wilcoxon, Table 1). This was not at the expense of accuracy.

Controls were significantly faster at picture recognition only consistent with the earlier demonstrated learning effect; producing a small improvement in overall memory reaction time of 233 ms (\( p = 0.02 \), Wilcoxon, Table 2). Overall attention also failed to improve significantly in controls 8 weeks after surgery compared to preoperative results.

An analysis of cognitive change with respect to handedness was not performed as the left cerebral hemisphere is frequently dominant, even in left-handed people. Those patients undergoing left CEA achieved consistently greater improvements in speed with no less accuracy at 5 days and 8 weeks compared to right CEA but this difference did not reach statistical significance. At 5 days, those having left CEA were quicker at memory recall by 29 ms, word recognition by 34 ms and overall memory speed by 156 ms. By 8 weeks, memory recall was 69 ms faster, speed of word recognition 47 ms faster, overall memory speed 69 ms faster and overall reaction time 219 ms faster than in those having right CEA.

Carotid patients with severely impaired preoperative CVR had the greatest improvement in overall speed of attention at 8 weeks from an absolute median value of 1289 ms (1012–1443) initially to only 915 ms (832–1389), and the change that represented was statistically significant (\( p < 0.05 \), Mann–Whitney \( U \) test) (Fig. 2). This pattern of change was not influenced significantly by age or the severity of contralateral stenosis.

Total emboli counts had little or no influence on

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**Table 1. Cognitive function in carotid surgery.**

<table>
<thead>
<tr>
<th>Tests of reaction time (ms)</th>
<th>Preoperative</th>
<th>Five days postop</th>
<th>( P ) value</th>
<th>Eight weeks postop</th>
<th>( P ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple</td>
<td>294 (257–357)</td>
<td>319 (269–378)</td>
<td>0.001</td>
<td>303 (270–353)</td>
<td>NS</td>
</tr>
<tr>
<td>Choice</td>
<td>508 (462–557)</td>
<td>499 (459–561)</td>
<td>NS</td>
<td>490 (459–551)</td>
<td>NS</td>
</tr>
<tr>
<td>Number vigilance</td>
<td>448 (413–496)</td>
<td>455 (413–496)</td>
<td>NS</td>
<td>446 (412–487)</td>
<td>NS</td>
</tr>
<tr>
<td>Memory</td>
<td>1049 (893–1353)</td>
<td>1005 (827–1229)</td>
<td>0.0001</td>
<td>993 (823–1214)</td>
<td>0.001</td>
</tr>
<tr>
<td>Word recognition</td>
<td>1140 (969–1447)</td>
<td>1074 (904–1367)</td>
<td>0.001</td>
<td>1048 (880–1284)</td>
<td>0.0001</td>
</tr>
<tr>
<td>Picture recognition</td>
<td>1030 (888–1254)</td>
<td>1079 (914–1251)</td>
<td>NS</td>
<td>960 (829–1163)</td>
<td>0.0001</td>
</tr>
<tr>
<td>Overall Attention</td>
<td>1246 (1160–1378)</td>
<td>1262 (1158–1426)</td>
<td>0.02</td>
<td>1194 (1058–1331)</td>
<td>0.0001</td>
</tr>
<tr>
<td>Overall Memory</td>
<td>3295 (2880–4108)</td>
<td>3232 (2733–3823)</td>
<td>0.0001</td>
<td>3051 (2591–3687)</td>
<td>0.0001</td>
</tr>
<tr>
<td>Overall</td>
<td>4573 (4076–5498)</td>
<td>4550 (3928–5244)</td>
<td>0.003</td>
<td>4254 (3681–4976)</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

**Tests of accuracy (accuracy index)**

| Choice                      | 93 (90–97)   | 97 (93–100)   | 0.003         | 97 (93–100)   | 0.0001         |
| Number vigilance            | 96 (86–98)   | 96 (91–100)   | 0.02          | 96 (91–100)   | 0.02           |
| Memory                      | 0.94 (0.79–1)| 0.94 (0.8–1)  | NS            | 0.94 (0.8–1)  | NS             |
| Word recognition            | 0.65 (0.5–0.77)| 0.63 (0.51–0.75)| NS          | 0.65 (0.5–0.75)| NS             |
| Picture recognition         | 0.85 (0.73–0.95)| 0.8 (0.63–0.9)  | 0.0001        | 0.83 (0.69–0.9)  | NS             |
| Overall                     | 2.36 (2.09–2.58)| 2.27 (2–2.53)  | 0.002         | 2.35 (2.18–2.55) | NS             |

All results expressed as median (IQR). Statistical analysis by Wilcoxon signed rank test (NS = not statistically significant). An increase in reaction time or a fall in accuracy index represents deterioration.
subsequent cognitive function, perhaps because the majority of emboli on declamping were microbubbles. However, patients with more than 10 emboli during dissection (before arteriotomy) were less accurate at memory recall and word recognition and both slower and less accurate at picture recognition at 5 days. They were slower at overall memory tests by 56 ms and reaction time by 82 ms. This trend, although in a very small group and not statistically significant, persisted at 8 weeks.

Discussion

Although the effects of carotid surgery on reaction times were highly variable at 5 days, overall accuracy was impaired. By 8 weeks, both memory and attention reaction times had improved in carotid patients while accuracy had recovered, whereas urology controls demonstrated minor learning effects only. The late improvement in attention in CEA patients was important as it followed a transient deterioration 5 days following surgery. Most other studies of cognitive function following CEA have shown improvements despite a range of testing methods and intervals.1–3,5 Several studies report side-specific changes in cognitive function with left-sided CEA improving verbal tests and right-sided surgery improving both verbal and visual tests.2,3 In our patients, left CEA improved speed of memory without loss of accuracy, at both 5 days and 8 weeks.

Few patients had normal 

Table 2. Cognitive functions in urology patients.

<table>
<thead>
<tr>
<th>Tests of reaction time (ms)</th>
<th>Preoperative</th>
<th>Five days postop</th>
<th>Change at five days (p)</th>
<th>Eight weeks postop</th>
<th>Change at eight weeks (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple</td>
<td>293 (263–341)</td>
<td>292 (278–340)</td>
<td>NS</td>
<td>303 (263–352)</td>
<td>NS</td>
</tr>
<tr>
<td>Choice</td>
<td>474 (446–542)</td>
<td>475 (439–535)</td>
<td>NS</td>
<td>476 (436–540)</td>
<td>NS</td>
</tr>
<tr>
<td>Number vigilance</td>
<td>447 (432–474)</td>
<td>443 (415–463)</td>
<td>NS</td>
<td>443 (411–491)</td>
<td>NS</td>
</tr>
<tr>
<td>Memory</td>
<td>1150 (863–1361)</td>
<td>1122 (849–1292)</td>
<td>NS</td>
<td>982 (830–1460)</td>
<td>NS</td>
</tr>
<tr>
<td>Word recognition</td>
<td>1112 (899–1325)</td>
<td>982 (878–1206)</td>
<td>0.04</td>
<td>980 (831–1161)</td>
<td>NS</td>
</tr>
<tr>
<td>Picture recognition</td>
<td>1060 (918–1352)</td>
<td>1020 (845–1260)</td>
<td>0.02</td>
<td>998 (823–1250)</td>
<td>0.02</td>
</tr>
<tr>
<td>Overall Attention</td>
<td>1282 (1201–1415)</td>
<td>1228 (1163–1325)</td>
<td>0.03</td>
<td>1256 (1134–1301)</td>
<td>NS</td>
</tr>
<tr>
<td>Overall Memory RT</td>
<td>3265 (2884–4499)</td>
<td>3117 (2580–3741)</td>
<td>0.001</td>
<td>3032 (2569–3823)</td>
<td>0.02</td>
</tr>
<tr>
<td>Overall</td>
<td>4697 (4126–6026)</td>
<td>4454 (3825–4975)</td>
<td>0.001</td>
<td>4235 (3785–5179)</td>
<td>0.008</td>
</tr>
</tbody>
</table>

Test of Accuracy index

| Choice                    | 93 (90–100)    | 97 (90–100)    | NS                      | 97 (91–100)        | NS                       |
| Number vigilance          | 96 (87–98)     | 96 (91–98)     | NS                      | 97 (92–100)        | NS                       |
| Memory                    | 0.83 (0.73–0.94) | 0.88 (0.8–0.94) | NS                      | 0.87 (0.76–0.94)   | NS                       |
| Word recognition          | 0.71 (0.54–0.8) | 0.68 (0.5–0.79) | NS                      | 0.63 (0.48–0.74)   | NS                       |
| Picture recognition       | 0.83 (0.75–0.91) | 0.8 (0.71–0.91) | NS                      | 0.8 (0.63–0.91)    | NS                       |
| Overall                   | 2.3 (2.09–2.56) | 2.3 (2.11–2.59) | NS                      | 2.39 (1.92–2.47)   | NS                       |

All results expressed as median (IQR). Statistical analysis by Wilcoxon signed rank test (NS = not statistically significant).

Although CVR has been correlated with the severity of ipsilateral internal carotid artery stenosis and the risk of stroke, many researchers categorise patients as having ‘normal’ or ‘impaired’ CVR rather than grading the severity of impairment.15,30 The falls in middle cerebral blood flow velocity and regional 

Fig. 2. The improvement in attention reaction time was greater in those patients with severely impaired CVR (p < 0.05).
ipsilaterally than those who did not, but CVR failed to reliably predict the need for a shunt. This is not unexpected as the ability to recruit collateral flow in the brain cannot be predicted preoperatively. The median number of emboli recorded during carotid surgery was only 12 compared with the mean of 61 reported by Gaunt et al. Current TCD technology fails to differentiate particulate from air emboli reliably and this was not attempted in our study. However, emboli during the initial dissection, before the artery had been opened, were likely to be particulate and potentially more damaging. Spontaneous preoperative cerebral embolisation and more than 10 emboli during the initial dissection phase of CEA have been associated with cognitive impairment previously. The number of emboli during coronary artery bypass surgery was also associated with postoperative memory deficits. These findings were supported by our study, although the results were not significant as only six patients had more than 10 emboli prior to arteriotomy.

Carotid patients with normal CVR would be expected to demonstrate little change in flow on clamping and declamping as the cerebral circulation compensates by changes in vascular tone. Patients with impaired CVR demonstrated greater changes on declamping; probably due to impaired autoregulation when full perfusion pressures were restored. Those patients with exhausted CVR gained the greatest improvements in attention scores at 8 weeks, perhaps because these were impaired by poor cerebral perfusion initially. CEA improves flow in this group of patients, which may have more significant benefits than merely reducing the risk of stroke.

Global cognitive function assessments may mask subtle changes in different aspects of cognitive function. Changes in attention were found to relate to cerebral hypo-perfusion identified by impaired CVR. We may be able to offer more than a reduction in stroke risk to some patients with internal carotid stenosis and exhausted CVR.

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References


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