Correlation of carotid artery stump pressure and neurologic changes during 474 carotid endarterectomies performed in awake patients

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Purpose: A carotid artery stump pressure (SP) of <50 mm Hg and abnormal electroencephalography (EEG) changes have been suggested as indications for selective shunting in patients undergoing carotid endarterectomy (CEA) under general anesthesia. We attempted to determine the optimal SP threshold that correlated with neurologic changes in awake patients undergoing CEA using cervical block anesthesia (CBA) and performed a cost comparison with EEG monitoring.

Methods: Between July 1, 1995, and December 31, 2004, SP was measured during 474 CEAs performed under CBA by inserting a 19-gauge butterfly needle into the common carotid artery. A saline-filled intravenous bag in the patient's contralateral hand was connected to pressure tubing to generate waveforms with hand squeezing that could be visualized on a monitor. Systemic pressure was maintained approximately 10 mm Hg higher than baseline. Accurate SPs were confirmed by the finding of flatline waveforms after internal carotid artery clamping. Selective shunting was performed when neurologic changes occurred (aphasia, inability to squeeze the contralateral hand, decreased consciousness), regardless of SP. During this same period, 142 patients underwent CEA using GA, and SP was also measured.

Results: Shunting was necessary because of neurologic changes in 7.2% (34/474) of all CEAs performed using CBA: 0.9% (3/335) with SPs ≥50 mm Hg systolic vs 1.0% (4/402) with SPs ≥40 mm Hg systolic, and 22% (31/139) with SPs <50 mm Hg systolic vs 42% (30/72) with SPs <40 mm Hg systolic. If these 474 CEAs had been performed using GA, shunts would have been used in 29% (139/474) of patients for a SP <50 mm Hg systolic vs 15% (72/474) for a SP <40 mm Hg systolic. In patients not shunted, the perioperative stroke/death rate was 1.2% in patients (4/332) with SPs ≥50 mm Hg vs 1.0% (4/398) with SPs ≥40 mm Hg. Three of the four strokes occurred >24 hours postoperatively and were unrelated to lack of shunting and ischemia. There was no significant difference in the percentage of patients with SPs ≥50 mm Hg who underwent CEA using CBA (70%, 335/474) vs GA (67%, 96/142) during this time period. At our hospital, charges for SPs measurement, including anesthesia charges and tubing, were $229 per case vs $3439 per case for EEG monitoring. Use of SP measurements in these 474 patients would have resulted in reduced charges of $1,521,540 compared with EEG monitoring if CEA had been performed under GA.

Conclusion: Using 40 mm Hg systolic as a threshold, the need for shunting (15%) and the false-negative rate (1.0%) for SP in our series were equivalent to the results of EEG monitoring during CEA reported in the literature. However, charges for SP measurements are dramatically lower compared with EEG monitoring. Our results suggest that a carotid artery SP ≥40 mm Hg systolic may be considered as an equally reliable but more cost-effective method to predict the need for carotid shunting during CEA under GA compared with EEG monitoring, but further investigation is warranted. (J Vasc Surg 2005;42:684-9.)

Despite the expected increased frequency of balloon angioplasty and stenting to treat carotid artery disease in the future, carotid endarterectomy (CEA) will likely be necessary to treat many patients with stroke (CVA), transient ischemic attack (TIA), and asymptomatic carotid stenosis. Choice of anesthesia and use of routine or selective shunting when performing these operations remain controversial. Even for surgeons such as ourselves, who prefer cervical block anesthesia (CBA) in the awake patient, there are occasionally patients who require general anesthesia (GA) because of patient anxiety, neck fixation, repeat carotid surgery, or claustrophobia.[1,2]

Controversy persists as to the optimal method to assess cerebral perfusion when performing these operations under GA. Many, if not most, vascular surgeons currently prefer electroencephalography (EEG) monitoring. However, our group and others have reported using carotid artery stump pressure (SP) as a method to determine the need for selective shunting under GA.[3-10] In a review of the literature, Whitley and Cherry[10] reported that a SP <50 mm Hg is generally accepted as an indication for selective shunting when CEAs are performed under GA.[10] Results of EEG monitoring and SP measurements using both GA[11-15] and CBA[16-18] have been reported.

In this era of cost-conscious medicine, health-care providers are expected to perform interventions safely but also with cost efficiency.[19] We attempted to determine if there was an optimal SP threshold that correlated with neurologic changes in awake patients undergoing CEA with CBA

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and performed a cost comparison with EEG monitoring at our hospital.

PATIENTS AND METHODS

Between July 1, 1995, and December 31, 2004, SP was measured during 474 CEAs using CBA at Pennsylvania Hospital. Indications for surgery were asymptomatic 70% to 99% internal carotid artery diameter stenosis in 74% of patients (351), TIAs in 20% (93), and strokes in 6% (30). Types of closure included prosthetic patches in 53% of patients (251), vein patches in 9% (43), primary standard endarterectomy closure in 18% (83), and eversion endarterectomy in 20% (97). In the last 5 years we have essentially abandoned primary closure and in the last 3 years have begun performing eversion endarterectomy more liberally. An additional 71 patients underwent CEA under CBA during this time period but were not included in the series because SPs were not measured or recorded.

There was no selection bias. The data were entered weekly during the study period in our computerized registry (Microsoft Access). Cases were evenly distributed between surgeons operating during this time period.

All 474 patients underwent insertion of a radial arterial line for systemic pressure monitoring. Our technique to measure SP involved insertion of a 19-gauge butterfly needle into the common carotid artery. The common carotid artery systolic pressure was compared with the radial artery systolic pressure to determine if any significant inflow arterial stenosis in the innominate or proximal common carotid artery was present.

A saline-filled intravenous bag was taped in the patient's contralateral hand and connected to pressure tubing to generate waveforms with hand squeezing that could be visualized on an anesthesia monitor. Systemic pressure was maintained with intravenous pressor agents by our anesthesiologists approximately 10 mm Hg higher than baseline before and during the entire period of carotid clamping to insure that the patient was not experiencing relative hypotension.

After systemic heparinization, with maintenance of activated clotting time >200 seconds, a clamp was applied to the external carotid artery and then to the common carotid artery proximal to the needle insertion site. The peak systolic pressure was recorded as the SP. The presence of a pulsatile waveform generated through the needle after clamping the external and common carotid arteries was also noted. We assessed the patient's neurologic status by having the patient squeeze the contralateral hand and speak. Lastly, a clamp was applied to the internal carotid artery. The SP was considered accurate if the waveform became flatline at that time, indicating absence of collaterals filling the carotid artery between the clamps. Frequent neurologic assessment was continued throughout the period of carotid clamping.

Selective shunting was performed when neurologic changes occurred, including aphasia, inability to squeeze the contralateral hand, or decreased consciousness. In a small number of patients, selective shunting was performed

Table I. Need for shunting based on stump pressure

CEA under cervical block anesthesia	
Total = 7.2% (34/474)	
SP >50 mm Hg sys = 0.9% (3/335)	SP <50 mm Hg sys = 22% (31/139)
SP >40 mm Hg sys = 1.0% (4/402)	SP <40 mm Hg sys = 42% (30/72)
CEA under GA, depending on SP criteria*	
SP >50 mm Hg sys = 0.0% (335/474)	SP <50 mm Hg sys = 29% (139/474)
SP >40 mm Hg sys = 0.0% (402/474)	SP <40 mm Hg sys = 15% (72/474)

CEA, Carotid endarterectomy; *SP*, stump pressure.

*Potential need for shunting if these 474 patients had undergone CEA under GA and guidelines for shunting had been followed based on SP.

Table II. Stroke/death related to shunting in 474 patients undergoing carotid endarterectomy using cervical blockade anesthesia

Total (474) = 1.3% (6)	
Not shunted (440) = 0.9% (4)	SP >50 mm Hg sys = 1.2% (4/332)
Shunted (34) = 5.9% (2)	SP >40 mm Hg sys = 1.0% (4/398)

SP, Stump pressure.

at the discretion of one surgeon when there was a history of CVA or TIAs because of concern that these patients might be predisposed to stroke even with a high SP.

Charges at our hospital were based on patient billing figures supplied by the hospital billing department. Note that these figures represent charges and not direct costs.

RESULTS

Of the 474 patients in this series who underwent CEA using CBA, shunting proved to be necessary because of neurologic deterioration after carotid clamping in 7.2% (34) (Table I). Of the 474 patients, 0.9% of patients (3/335) with SPs ≥50 mm Hg systolic required shunting because of neurologic changes vs 22% (31/139) with SPs <50 mm Hg. The SP waveform in one of the three patients who developed neurologic changes became flatline after carotid clamping, despite a SP of 80 mm Hg systolic, suggesting that the transducer generated an inaccurate SP value. All other SPs ≥50 mm Hg had a pulsatile waveform generated on the monitor. Of note, five patients with SPs ≥50 mm Hg systolic were shunted because of a history of recent stroke (4) or TIA (1) at the discretion of the surgeon, even though no immediate neurologic changes were noted after carotid clamping and before shunt insertion.

Compared with a threshold of 50 mm Hg systolic, the need for shunting was similar for patients with SPs ≥40 mm Hg systolic where 1.0% of patients (4/402) required shunting (Table I). However, the need for shunting was almost double (42% [30/72]) in patients with SPs <40 mm Hg systolic compared with patients with SPs <50 mm Hg

Table III. Etiology of stroke/death in 474 patients undergoing carotid endarterectomy using cervical blockade anesthesia

A, Four strokes and/or deaths occurred in patients with stump pressures >50 mm Hg systolic (1.2% [4/335]) and in patients who were not shunted (cerebrovascular accident/death rate = 0.9% [4/440]

Postoperative day	*Etiology*	*Complication*
0	Ischemia or embolus	Ipsilateral minor stroke (ptosis)
1	Hemorrhage from suture line	Ipsilateral stroke and death
3	Ischemia or embolus	Contralateral ischemic stroke
4	Hemorrhage	Ipsilateral hemorrhagic stroke

B, Two strokes and/or deaths occurred in patients with stump pressures <50 mm Hg systolic (1.4% [2/139]) and who were shunted (cerebrovascular accident/death rate = 5.9% [2/34])

Postoperative day	*Etiology*	*Complication*
0	Ischemia-difficulty placing shunt	Ipsilateral ischemic stroke
6	Ischemia or embolus	Contralateral ischemic stroke and death

Table IV. Stump pressure and indication for surgery

Indication for CEA	*% (N)*	*Neurologic changes and shunt insertion % (N)*	*No neurologic changes**
Stump pressure >50 mm Hg systolic			
Asymptomatic	74 (247)	0.4 (1)	0
Transient ischemic attack	19 (65)	1.5 (1)†	1
Stroke	7 (23)	4.3 (1)	4
Total	100 (335)	0.9 (3)	5
Stump pressure <50 mm Hg systolic			
Asymptomatic	75 (104)	20 (19)	0
Transient ischemic attack	20 (65)	25 (7)	0
Stroke	5 (7)	57 (4)	0
Total	100 (139)	22 (31)	0

CEA, Carotid endarterectomy.
*Shunt placed at discretion of surgeon.
†Flatline waveform with stump pressure = 80 (probably inaccurate stump pressure recording).

systolic. If these patients had been operated on under GA and a cutoff point of 50 mm Hg had been used, 29% of the patients would have been shunted, and if a cutoff point of 40 mm had been used, 15% would have been shunted.

The stroke/death rate in these 474 patients who underwent CEA using CBA was 1.3% (6 patients): 0.9% (4 patients) in the 440 patients not shunted vs 5.9% (2) in the 34 patients who were shunted (Table II). When the perioperative stroke/death rate in patients not shunted was further analyzed according to SP, 1.2% of patients (4/332) with SPs ≥50 mm Hg systolic vs 1.0% of patients (4/398) with SPs ≥40 mm Hg had strokes or died, or both.

Three of the four strokes in patients who were not shunted occurred >24 hours postoperatively and were unlikely related to lack of shunting and subsequent ischemia (Table III). We expect that the patient with a hemorrhagic stroke on postoperative day 4 had hyperperfusion syndrome because of complaints of headache the day before the stroke. The patient with a suture line hemorrhage on postoperative day 1 bled from a separate suture line in the external carotid artery that had been performed to endarterectomize an intimal flap in the external carotid found on completion arteriography. The patient was reexplored but suffered prolonged cerebral anoxia before an airway could be obtained and repeat surgery performed.

There were no significant differences ($P > .05$) in the indications for CEA in patients with SPs <50 mm Hg systolic compared with patients with SPs ≥50 mm Hg systolic (Table IV). Regardless of SP, patients tended to be more likely to require shunts for neurologic changes associated with carotid clamping when the indication for surgery was for CVA or TIA than for asymptomatic stenosis (Table IV).

There was no significant difference ($P > .05$) in the percentage of patients with SPs ≥50 mm Hg who underwent CEA using CBA (70%, 335/474) vs GA (67%, 96/142) at our hospital during this time period. Of the 474 patients in this series who underwent CEA using CBA during this time period, shunting proved to be necessary due to neurologic deterioration after carotid clamping in 7.2% of cases (34) compared with 39% of patients (55/142) whose SPs were measured and who underwent shunting when CEA was performed under GA.

A comparison of the incidence of shunting in patients who underwent CEA using GA during this time period is not truly relevant because we had not adopted a uniform

Table V. Results of electroencephalography monitoring during carotid endarterectomy

Reference	*Number of patients with neurologic changes*		*Number of patients with normal EEG*		*False-negative rate (%) of EEG detecting neurologic changes during CBA or predicting stroke after GA*
	*during CBA**	*after GA†*	*during CBA**	*after GA†*	
Schneider[13]	—	0	—	449	0.0
Ricotta[5]	—	0	—	100	0.0
Green[14]	—	3	—	449	0.7
Whittemore[15]	—	1	—	150	0.7
McCarthy[12]	—	6	—	415	1.4
Kresowik-1[11]	—	5	—	388	1.3
Kresowik-2[11]	—	10	—	388	2.6
Evans[16]	4	—	108	—	3.7
Stoughton[18]	4	—	89	—	4.5

CBA, Cervical block anesthesia; *GA*, general anesthesia; *EEG*, electroencephalography.
*Neurologic changes imply shunting was necessary during CBA because of onset of aphasia, decreased motor function or decreased consciousness in the awake patient.
†Neurologic changes signify stroke after awakening from GA for all references except Kresowik-2, where permanent and temporary neurologic events were included.

policy of selective shunting under GA based on SP. Although in general we did not shunt GA patients for SPs ≥50 mm Hg, discretion was left to the surgeon in the setting of a history of ipsilateral stroke or contralateral internal carotid artery occlusion We want to emphasize again that patients undergoing CEA under GA may be more susceptible to cerebral ischemia and these criteria may not necessarily be applicable.

Our registry database did not have information on the status of the contralateral internal carotid artery, notably the incidence of contralateral internal carotid artery occlusion, so we cannot make any conclusions regarding this risk factor and SPs and need for shunting.

Charges for EEG monitoring in a patient under GA for a 2-hour CEA, including technical fees ($1549 for the first hour, $799 per hour thereafter) and interpretation ($1100) at our hospital were $3448 vs $230 for anesthesia charges ($210) and tubing ($20) for SP measurements performed in awake patients under CBA. If these 474 patients had undergone CEA under GA, use of SP measurements would have resulted in reduced charges of $1,525,332 compared with EEG monitoring at our hospital.

DISCUSSION

Controversy remains regarding routine vs selective shunting as a means to prevent cerebral ischemia during CEA. The optimal method to assess cerebral perfusion for those who use selective shunting is also debatable. Strategies include routine shunting for patients under GA, selective shunting based on neurologic changes for patients under CBA, and EEG changes or SP measurements for patients under GA.

Routine shunting under GA. Some vascular surgeons prefer routine shunting to maintain cerebral perfusion during internal carotid artery clamping when patients are under GA; however, this technique may be associated with increased risk of stroke due to intimal damage and emboli passing through the shunt from the common carotid artery. Green et al[14] reported that technical problems were more common when shunts were used (5%) than when they were not (0.9%) and concluded that shunt use may introduce a risk of stroke due to technical factors that is equal or greater than the risk of stroke due to hemodynamic ischemia. One patient we operated on during this time period under GA with shunting clearly suffered a stroke secondary to emboli passing through the shunt.

Selective shunting in the awake patient. Many vascular surgeons, ourselves included, prefer to assess neurologic changes in the awake patient during CEA under CBA, because this method is the most direct measure of cerebral ischemia.[1,2,16-18] Not all patients can tolerate CEA using CBA, but in our experience, 77% of CEA patients (474/616) at our hospital during the time period of this study were operated on with this technique. The other 23% of patients who underwent CEA under GA did so because of patient preference (claustrophobia, anxiety) or surgeon preference (radiated neck, redo surgery, high bifurcation, neck fixation due to arthritis).

Selective shunting under GA. The most widely used methods to assess cerebral perfusion when CEA is performed under GA are EEG monitoring and SP measurement. Various authors have correlated EEG monitoring and SP measurements in the awake patient and in patients under GA to determine the reliability of these methods (Tables V, VI). Selective shunting based on EEG changes is associated with the need for shunting in approximately 15% to 18% of cases.[5,8,11,13,15] If the CEAs in our series had been performed under GA, shunts would have placed in 29% of patients (139/474) if a SP <50 mm Hg systolic was used as the shunt threshold. About half as many patients, or 15% (72/474), would have been shunted using a SP <40 mm Hg systolic as the criteria. These results suggest that the incidence of unnecessary shunting would have been the same whether EEG monitoring or a SP <40 mm Hg systolic was used as an indication for selective shunting.

Table VI. Results of carotid stump pressure (SP) measurement during carotid endarterectomy

Reference	Number of patients with neurologic changes		Number of patients with high SP+		False-negative rate (%) of high SP+ detecting neurologic changes during CBA or predicting stroke after GA
	during CBA*	after GA†	during CBA*	after GA†	
Evans[16]	3	—	94	—	3.2% (>50 mm Hg sys)
McCarthy[12]	—	6	—	524	1.1% (>35 mm Hg mean)
Present series	3	—	335	—	0.9% (>50 mm Hg sys)
Haffner[9]	0	—	226	—	0.0% (>50 mm Hg sys)

CBA, cervical block anesthesia; GA, general anesthesia.

*Neurologic changes imply shunting was necessary during CBA because of onset of aphasia, decreased motor function or decreased consciousness in the awake patient.

†Neurologic changes signify stroke immediately after awakening from GA.

However, the most critical aspect of any cerebral perfusion monitoring method during CEA under GA is that the method should ideally not miss any patients who require shunting; that is, ideally, a normal EEG or SP greater than a safely established threshold would be associated with a zero rate of cerebral ischemic changes (a zero false-negative rate). The false-negative rate of EEG and SP measurements in several series are listed in Tables V and VI, respectively.

The optimal SP value above which it is safe not to place a shunt is controversial, especially since some surgeons have reported mean SP and others have reported systolic SP. Patients tolerated internal carotid artery clamping when the mean SP was >25 mm Hg as reported by Moore and Hall,[6] 40 mm Hg reported by Ricotta et al,[5] and 50 mm Hg by Hayes et al.[7] Baker et al[8] reported 940 patients who underwent CEA under GA without shunting any patients and noted a stroke rate of 1.1% in patients with SPs >50 and 4.7% for SPs <50 mm Hg. It is unclear in their report if mean or systolic SP was used. We wish to point out again that we believe the SPs in our series were accurate because SPs were confirmed by the finding of flatline waveforms after internal carotid artery clamping.

Some authors have reported low false-negative rates with EEG monitoring and need for carotid shunting. Although Schneider et al[13] reported a 0% false-negative rate associated with EEG monitoring in a series of 449 patients undergoing CEA using GA, some patients with normal EEG findings were selectively shunted because of a history of an ipsilateral stroke. If none of these patients with a normal EEG and ipsilateral stroke had been shunted, it is possible that some would have suffered ischemic neurologic events resulting in a higher false-negative rate. Although Evans et al[16] reported a relatively high false-negative rate of 3.2% for SPs >50 mm Hg systolic for CEAs performed under CBA, they actually noted a slightly higher false-negative rate of 3.7% with EEG monitoring at their institution. In a later series by Hafner and Evans,[9] none of 226 patients with SPs >50 mm Hg systolic who underwent CEA under CBA required a shunt. In a series from the Mayo Clinic, the incidence of EEG changes was only 2% when the SP was >50 mm Hg.[20] In a series from the University of Rochester, the incidence of EEG changes when the SP was >40 mm Hg was 1%, and this occurred in a patient with a recent stroke.[5] In summary, the chances of EEG monitoring missing a cerebral ischemic event under GA as reported in the literature and the incidence of cerebral ischemic changes associated with carotid clamping when the SP ≥40 mm Hg systolic in this series appear to be equivalent.

In summary, our results suggest, but do not necessarily prove, that a SP <40 mm Hg systolic should be used as a threshold for carotid shunting under GA. These findings of SP thresholds and need for shunting in awake patients may not correlate with patients under GA. Although the false-negative rate for SPs ≥50 mm Hg systolic (0.9%) was nearly identical to SPs ≥40 mm Hg systolic (1.0%), SPs <40 mm Hg systolic would reduce from 29% to 15% the need for shunting, with its potential associated complications, prolonged operative time, and difficulty of use.

Costs of EEG and SP. In our hospital, EEG charges ($3448) for a 2-hour CEA are 10 times more than the charges for SP measurements ($230). In the Schneider et al report,[13] total costs for EEG monitoring were dramatically less and were estimated to be $200 to $300 per case, although the neurologist's fee for interpretation was not included and it was unclear if the EEG technician fees were included. Indeed, in the Discussion of the paper, the authors note that their hospital charged $1700 for EEG monitoring. Other groups, along with our own, have abandoned the use of EEG monitoring for routine CEAs under GA because of associated high costs.[13,14] When cost comparisons are made with carotid artery stenting, expenses of performing CEA under GA using SP measurements should be considered.

Limitations of study. There are three limitations of our paper. First, there were relatively small numbers of patients who underwent CEA for an indication of stroke. Patients with a history of stroke are potentially more predisposed to cerebral ischemia during carotid clamping than are asymptomatic patients or patients with TIAs and therefore may be more likely to require a shunt, even in the setting of a high SP. Therefore, we can only make cautious recommendations regarding SP criteria and the need for shunting for patients with a history of ipsilateral stroke undergoing CEA under GA.

Second, we cannot be absolutely certain that the SP results and associated cerebral ischemic changes in patients who underwent CEA under CBA are applicable to patients undergoing CEA under GA. There are data suggesting that patients under GA may be more susceptible to cerebral ischemia than patients undergoing CEA using CB.[17] Alternatively, patients under GA may tolerate lower SPs than patients who received CBA because of the possible protective effect of the anesthetic.[10]

Third, five patients with SPs ≥50 mm Hg systolic were shunted at the discretion of the surgeon because of a history of recent stroke (4) or TIA (1), although there were no obvious neurologic changes immediately after carotid clamping and before shunt insertion. It is possible that these patients would have developed neurologic deficits later during the operation if a shunt had not been placed immediately. If these five patients are omitted from consideration, then the need for shunting based on neurologic changes during CEA under CBA in patients with SP ≥50 mm Hg systolic was 1.5% (5/330) instead of 0.9% (3/335).

CONCLUSIONS

When 40 mm Hg systolic was used as a threshold, the need for shunting (15%) and the false-negative rate (1.0%) for SP in our series of patients who underwent CEA were comparable to the results of EEG monitoring reported in the literature. However, charges for SP measurements are dramatically lower than EEG monitoring. A carotid artery SP ≥40 mm Hg systolic might be considered as an equally reliable but more cost-effective method to predict the need for carotid shunting during CEA under GA than EEG monitoring, although we can not be certain that these recommendations apply to patients under GA as they do for patients receiving CBA.

A prospective study analyzing death and stroke in patients undergoing CEA under GA with shunting performed only for SPs <40 mm Hg systolic would validate our results. We can only cautiously recommend this strategy for patients who have suffered preoperative strokes, because of the small number of patients operated on for this indication.

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