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The Value of Transcranial Doppler in Predicting Cerebral Ischaemia During Carotid Endarterectomy

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Objectives: *transcranial Doppler (TCD) measurement of middle cerebral artery velocity (MCAV) is an indirect method of assessing cerebral blood flow and therefore predicting patients at risk of stroke during carotid endarterectomy (CEA), and may be used to determine the need for shunting. This study evaluates the accuracy of three accepted TCD criteria in predicting the need for a shunt.*
Design: *prospective study.*
Methods: *one hundred and twenty consecutive CEA were performed under loco/regional anaesthesia. Patients monitored by TCD and Awake neurological examination were included. Shunts were inserted if there was neurological deterioration. Awake patient monitoring was compared with the three TCD criteria.*
Results: *inadequate TCD recordings were obtained in 16 operations (13%). In the remainder (104 cases), 12 developed symptoms of cerebral ischaemia and required a shunt (12%). Comparisons with the three accepted criteria were as follows: (1) m MCAV <30 cm/s had a sensitivity, specificity, PPV and NPV of 92%, 49%, 19%, and 98%, respectively; (2) clamp/pre-clamp ratio <0.6 had a sensitivity, specificity, PPV and NPV of 92%, 75%, 33% and 99%, respectively; (3) greater than 50% reduction in m MCAV had a sensitivity, specificity, PPV and NPV valves of 83%, 77%, 32% and 97%, respectively.*
Conclusions: *TCD flow velocities are not a reliable method for detecting cerebral ischaemia and therefore determining the need for a shunt in CEA.*

Key Words: Carotid endarterectomy; TCD criteria; Selective shunting.

Introduction

Shunting during carotid endarterectomy remains controversial and while there is no conclusive data to support or refute the use of routine or selective shunting in carotid surgery, there is consensus that either policy is preferable to a policy of routine non-shunting.[1,2] Techniques including stump pressure measurement, electroencephalography, regional cerebral blood flow measurements, near infrared spectroscopy and transcranial Doppler have all been used to monitor cerebral haemodynamics during CEA, although no single method has been shown to be superior or to produce a better outcome following surgery.[2]

Transcranial Doppler (TCD) measures velocity in the middle cerebral artery (MCAV). There are three accepted criteria used for determining the need for a shunt during carotid endarterectomy, as follows:
(1) A mean MCAV (m MCAV) less than 30 cm/s;[3–5]
(2) A clamp/pre-clamp ratio less than <0.6;[5]
(3) A greater than 50% reduction in m MCAV on carotid clamping.[6]

Awake patient monitoring under local/regional anaesthesia seems the most reliable method of predicting the need for a shunt following carotid clamping and can be regarded as the gold standard for intraoperative monitoring.[1,7] Studies validating TCD criteria against awake patient monitoring have yielded contradictory results.[8,9] This study evaluates the reliability of these TCD criteria in predicting the need for shunting, by comparing TCD parameters against awake patient monitoring in patients undergoing CEA under local anaesthesia.

Patients and Methods

Between July 1995 and May 2000, 120 CEAs were performed under local anaesthesia at the Royal United Hospital Bath. TCD monitoring was not possible in 16

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Table 1. Demographics and risk factors in 91 patients undergoing CEA.

Risk factors		Patients	%
Gender	Male	71	78
Smoking		13	14
Diabetes		10	11
Hypertension		47	52
Coronary artery disease		35	38

cases because of the absence of a temporal window (13%). One hundred and four procedures in 91 patients monitored by both awake patient monitoring and TCD are included for analysis. The median age was 71, with a range of 46–88 years. Patient demographics are shown in Table 1.

The indications for the 104 CEA are listed in Table 2. Thirteen patients had non-simultaneous bilateral procedures. Eighty-three percent of procedures were for symptomatic disease. All procedures for asymptomatic disease were performed as part of the ongoing ACST (Asymptomatic Carotid Surgery Trial), which includes five cases performed prior to coronary artery bypass surgery.

All patients had duplex proven severe (>70%) ipsilateral carotid artery stenosis. The degree of contralateral disease is shown in Table 3. Fifteen cases had had previous contralateral CEA for symptomatic disease.

All patients undergoing local anaesthesia were given a pre-medication of 20–30 mg of temazepam (according to body weight) and 25 mg promethazine 1.5 h pre-op. Local anaesthesia consisted of local infiltration and superficial cervical blocks using a combination of 0.5% bupivicaine and 1% xylocaine containing 1:200 000 adrenaline. No further sedation was given during the procedure, but some patients required additional local anaesthetic, usually because of discomfort during deep dissection (up to 10 ml 1% xylocaine). Direct neurological examination assessed contralateral motor function by asking the patient to squeeze a ball in the contralateral hand, move their feet and answer questions to confirm their level of consciousness. An anaesthetist was present during the procedure and a vascular technologist was present to perform non-invasive vascular assessment. TCD monitoring was performed using the Sci-Med PC-Dop 842 with a 2 MHz pulsed wave Doppler transducer (Sci-Med Ltd, U.K.), and the probe was secured with an elastic headband.

Intravenous heparin (50 IU/kg) was administered prior to cross clamping with carotid arterial clamps being applied in the following sequence; external, common and internal. The mean middle cerebral artery mean velocity (m MCAV) was continuously monitored and recorded at each stage of the procedure, but did not determine the need for shunting. Any patient unable to move a contralateral limb (Focal deficit) or who became unresponsive to questioning (Global deficit) was deemed ischaemic and treated with a shunt. Standard endarterectomy with selective Dacron patching was performed. Completion duplex examination was performed as a quality control measure.

Values expressed refer to medians and interquartile range. Continuous variables were analysed by the Mann–Whitney *U*-test. Statistical significance was taken at the 5% level. The efficacy of TCD in determining the need for shunting was evaluated using awake patient monitoring as the gold standard. Sensitivity, specificity, positive predictive value (PPV) and negative predictive values (NPV) were calculated for each of the following TCD criteria:

Table 2. Operative indications for 104 CEA procedures.

Operative indications		No. of procedures	%
Ipsilateral	Amaurosis fugax	14	14
	TIA	47	45
	Stroke	20	19
Global/vertebrobasilar symptoms		5	5
Asymptomatic		18	17

Table 3. Degree of contralateral stenosis as assessed by duplex.

Degree of contralateral stenosis	Duplex criteria	No. of procedures	%
Mild	<50%	57*	55
Moderate	50–69%	10	10
Severe	>70%	25	24
Occlusion		12	11

* Includes 15 cases who had had previous contralateral CEA.

Table 4. Procedures in which cerebral ischaemia developed on carotid clamping.

Patient	Sex/Age	Symptoms	Contra lateral disease	Neurological deficit	TCD criteria for shunting: m MCAV after clamping (cm/s)	% reduction of m MCAV on clamping	Clamp/pre-clamp ratio
1	M/85	TIA	Mild	Global	81†	14*	0.9‡
2	M/69	TIA	Mild	Global	0	100	0
3	M/74	TIA	Mild	Global	12	60	0.4
4	M/71	TIA	Occluded	Global	10	83	0.2
5	M/70	CVA	Severe	Focal	12	50	0.5
6	M/70	CVA	Operated	Focal	11	54	0.5
7	F/79	CVA	Moderate	Global	25	50	0.5
8	M/64	CVA	Mild	Focal	26	60	0.4
9	M/67	Vertebrobasilar	Mild	Global	16	50	0.5
10	F/83	Amaurosis fugax	Occluded	Global	29	59	0.4
11	M/75	Asymptomatic	Mild	Global	12	52	0.5
12	F/69	TIA	Severe	Global	25	42*	0.6

†, ‡, * Indicate false negatives for given TCD criteria.

(1) m MCAV <30 cm/s on clamping;
(2) Clamp/pre-clamp ratio less than 0.6;
(3) >50% reduction in m MCAV.

As none of the bilateral procedures were concurrent, the analysis is based on the number of procedures performed, not the number of patients.

Results

Cerebral ischaemic symptoms occurred during 12 CEA procedures. In all cases the apparent neurological deficit was reversed by shunt insertion (Table 4). The following results are expressed as medians with interquartile range in brackets.

The post-clamp median (interquartile range) m MCAV (cm/s) in patients who required a shunt was 14 (11–26) cm/s, compared to 29 (20–43) cm/s in the group that did not require a shunt ($p<0.05$) (Fig. 1).

The median (interquartile range) TCD flow reductions on clamping were 53% (50–60) and 17% (17–41), respectively ($p<0.001$) (Fig. 2).

Clinical outcome

One patient with known severe ischaemic heart disease awaiting a coronary artery bypass had a myocardial infarct on day 2 and died. There were two postoperative strokes in this patient cohort. One patient not requiring a shunt and who had an apparently successful operation had an ipsilateral stroke 1 day postoperatively and died on day 10 from pulmonary complications. A second patient who developed an

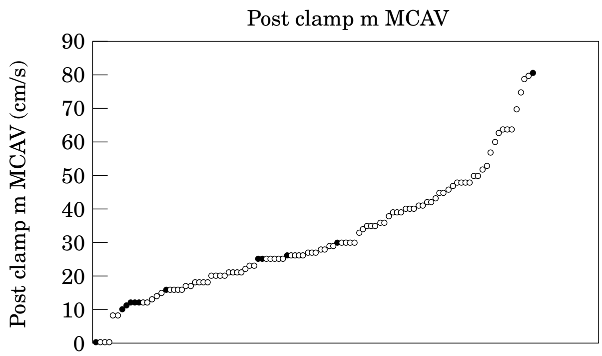

Fig. 1. Clamping m MCAV (cm/s). Distribution of m MCAV recorded after clamping in 104 procedures. (○) Procedures which did not require a shunt; (●) procedures which required shunt ($n=12$).

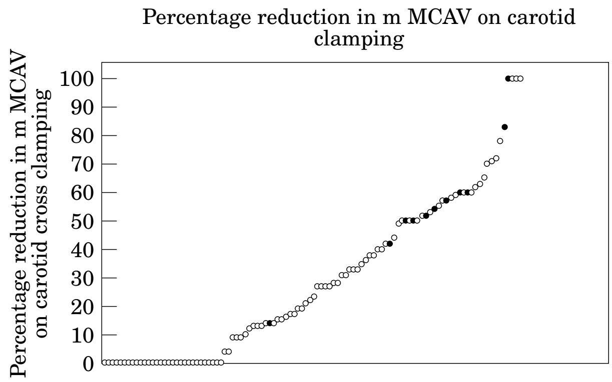

Fig. 2. Percentage reduction in m MCAV on carotid clamping. Distribution of % reduction in m MCAV recorded after clamping in 104 procedures. (○) Procedures which did not require a shunt; (●) procedures which required shunt ($n=12$).

Table 5. Clinical outcome data for patients who died or had major stroke.

Patient	Sex/Age	Death	CVA	% TCD reduction	TCD m MCAV on clamping	Shunt
1	M/63	Pulmonary – day 10	Day 1	60	12	No
2	M/64	MI – day 2	—	0	52	No
3	F/83		Day 2	57	30	Yes

Table 6. Accuracy of TCD in predicting shunting using three different criteria. Percentages shown in brackets.

TCD criteria	Sensitivity	Specificity	Positive predictive value	Negative predictive value	Accuracy
m MCAV <30 cm/s	11/12 (92)	45/92 (49)	11/58 (19)	45/46 (98)	56/104 (54)
Clamp/pre-clamp ratio <0.6	11/12 (92)	69/92 (75)	11/34 (33)	69/70 (99)	80/104 (77)
50% reduction m MCAV	10/12 (83)	71/92 (77)	10/31 (32)	71/73 (97)	81/104 (78)

ipsilateral stroke 2 days postoperatively was shunted. Completion duplex examination was normal in both patients, and both strokes were thought to be embolic in origin. The second patient made a full recovery. A third patient had a transient ischaemic attack postoperatively with full recovery. The overall combined death/stroke rate was 3% (Table 5).

TCD accuracy

Overall accuracy of differing TCD criteria in predicting the need for shunting are given in Table 6. Overall the results are disappointing, with the best overall accuracy being obtained using the greater than 50% reduction in m MCAV as a criteria for shunting (78%). The other two criteria are better in terms of sensitivity, 92% vs 83%, respectively, with the clamp/pre-clamp ratio <0.6 having fewer false positives, and a similar overall accuracy to a greater than 50% reduction in m MCAV.

One patient would have been missed by all three TCD criteria (patient no. 1, Table 4). In this case the m MCAV fell from 94 to 81 cm/s (14% reduction, clamp/pre-clamp ratio 0.9). The patient was unable to talk or squeeze the ball. Using the greater than 50% reduction criteria as an indication to shunt, a further false positive would have been identified (patient no. 12, Table 4). In this case the patient developed contralateral motor signs.

Discussion

TCD is a practical and reliable method of intraoperative monitoring, and has been used to determine the need for shunting, to confirm shunt function and to detect cerebral emboli both during and after the operation.[10] TCD criteria for selective shunting have been established by comparing TCD parameters with other monitoring modalities in patients undergoing CEA under general anaesthesia, and therefore have no gold standard for comparison. A mean MCAV (m MCAV) less than 30 cm/s correlates to a carotid stump pressure less than 50 mmHg, EEG changes and a cerebral blood flow less than 20 ml/100 g/min and is accepted as an indication for a shunt.[3–5] The clamp/pre-clamp ratio eliminates inter-individual variations, and a ratio less than <0.6 is an alternative criteria used to indicate the need for a shunt.[5] Others suggest that a greater than 50% reduction in m MCAV on clamping is an indication for shunt insertion.[6]

We believe that CEA in awake patients under local anaesthesia is as near to a gold standard for detecting the onset of cerebral ischaemia as can be assessed, particularly as all of our patients with apparent neurological deficit made a full recovery after insertion of a shunt. Two previous similar studies have produced conflicting evidence as to the reliability of TCD when validated against direct neurological examination. Cao *et al*. defined the optimal value of TCD flow velocity that is able to discriminate patients with clamp ischaemia by constructing receiver operator characteristic (ROC) curves. The study demonstrated that a greater than 70% reduction was the best TCD criteria in terms of sensitivity and specificity. In their series TCD had a sensitivity of 83%, specificity of 96%, positive predictive valve of 71% and negative predictive of 98%.[8] Increasing the sensitivity to 100% by the use of the ROC curve would lead to an unacceptably low specificity (49%), and the conclusion from this study was that TCD was not a reliable indicator of post-clamp cerebral ischaemia.

In a similar study by Giannoni, a significant difference was observed in absolute m MCAV in patients who required a shunt compared to those who did not. Using a post-clamp velocity <30 cm/s, TCD had a sensitivity of 100% and specificity of 91%. The recommendation from this study was that the criterion of m MCAV <30 cm/s resulted in too many false positives, and they concluded that a post-clamp m MCAV of <10 cm/s was a better discriminator of post-clamp cerebral ischaemia.[9]

In our study evaluating recommended TCD criteria for selective shunting by comparison with awake patient monitoring, only 12 cases required shunting (12%). Despite statistical differences in percentage reduction in m MCAV and post-clamp m MCAV between patients who required shunting and those who did not, no single TCD criterion proved to be completely reliable in predicting the need for a shunt. For this reason we cannot recommend TCD as a technique for selective shunting. In our opinion the consequences of a low sensitivity and high false negative rate are more disastrous than those of a false positive. The false negative patients in this series may well have been jeopardised without protection by shunting. This contrasts to a reported 0.5% complication rate from shunting.[11] If the criteria as suggested by Cao and Giannoni had been used, the sensitivity would have been only 20% in both cases.[8,9]

Our data confirm that TCD is not a reliable indicator for determining shunting in carotid endarterectomy. We believe that the best and simplest indicator of cerebral function is the response of the alert and co-operative patient. Whilst we appreciate that patients may have different cerebral haemodynamics under local anaesthesia compared to general anaesthesia, we feel that the conclusions from this study can be extrapolated and that TCD cannot be recommended as a means of determining whether to shunt or not under general anaesthesia. We do believe, however, that TCD does provide additional useful information such as confirming shunt function and detecting micro-emboli both during and after surgery, and its use should be continued for these reasons.[12]

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