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Microembolic Signals Detected by Transcranial Doppler Sonography During Carotid Endarterectomy and Correlation With Serial Diffusion-Weighted Imaging

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Background and Purpose—Embolic events are a major cause for procedure-related strokes after carotid endarterectomy (CEA). Transcranial Doppler sonography can reveal embolic events as microembolic signals (MES) during CEA. MES during declamping and shunting are frequently detected. MES during shunting are rare and known to be correlated with the neurological outcome of the patient. In the present study, we analyzed the occurrence of MES within different stages of CEA and whether MES within those stages were correlated with cerebral ischemia, as detected by diffusion-weighted imaging (DWI), and brain infarction, as detected by contrast-enhanced MRI.

Methods—Thirty-three patients were monitored intraoperatively for MES using transcranial Doppler sonography. DWI was performed within 24 hours before and after surgery. Positive postoperative DWI led to reexamination with contrast-enhanced T1-MRI 7 to 10 days after CEA for detection of cerebral infarction.

Results—MES were detected in 32 of 33 patients. The highest number of MES was found during shunting and declamping. A significant correlation was found between MES and DWI-lesions during dissection. A significant correlation was found between MES during dissection and shunting, and nonsignificant correlation was found between MES and the occurrence of cerebral infarction.

Conclusion—MES could be regularly detected during CEA. Dissection and shunting seem to be the most vulnerable stages of the procedure. (*Stroke*. 2004;35:e373-e375.)

Key Words: carotid endarterectomy ■ carotid stenosis ■ cerebral embolism ■ magnetic resonance imaging

Neurological deficits after carotid endarterectomy (CEA) are rare, occurring in up to 5% of patients. Embolism, occurring within or directly after the procedure, accounts for >60% of all procedure-related strokes.¹

Microembolic signals (MES) detection is possible during CEA using the correct setting of transcranial Doppler sonography (TCD) hardware² and the definition for MES recently suggested.³ In previous studies, the number of detectable MES varied within different stages of CEA.^{4,5} The highest number of MES was found during declamping and shunting. During dissection and wound closure, detection of MES was significantly correlated to the neurological outcome.^{4,5}

Diffusion-weighted imaging (DWI) detects cerebral ischemia with high accuracy and within an hour after the event. Our previous studies showed DWI-lesions after CEA occurring in 15 of 88 patients and found a significant correlation between the volume as well as the number of the DWI lesions and the development of brain infarction.⁶

The aim of the present study was to correlate MES within different stages of CEA and cerebral ischemia as detected by

DWI in addition to brain infarction as detected by contrast-enhanced MRI.

Materials and Methods

Patient Selection

A consecutive series of 40 patients were included in this study. TCD was technically impossible in 7 patients. Thirty-three patients with an average age of 64.5 years were analyzed (Table). Except for one symptomatic patient, the stenoses in all other patients exceeded 70%. All patients gave written informed consent and underwent neurological examination 2 days before and after CEA.

Surgical Procedure

CEA with obligate shunting using a BARD-Shunt (IMPRA Inc) and arteriotomy closure with a preclotted Dacron patch (InterVascular) was performed under general anesthesia.

TCD

TCD was performed using a Multidop X4 (DWL). (Software TCD 8 for MDX, 2MHz probe, diameter 1.7 cm, insonation depth 44 to 58 mm, scale -100 and +150 cm/s, sample volume 5 mm, 128-point

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Patient Characteristics

Initials	Gender	Symptomatology	Dissection	Clamping 1	Shunting	Clamping 2	Declamping	Total	DWI	Vol (mL)	T1- MRT	Neurological Deficit
L.J.	M	Asymptomatic	0	0	0	0	2	2	Negative	0	Negative	Negative
P.A.	M	Asymptomatic	0	0	0	0	2	2	Negative	0	Negative	Negative
L.H.	F	Asymptomatic	0	0	0	0	17	17	Negative	0	Negative	Negative
J.K.	M	Asymptomatic	0	0	0	0	22	22	Negative	0	Negative	Negative
G.G.	M	TIA	0	0	0	0	3	3	Negative	0	Negative	Negative
B.K.	M	TMB	0	0	0	0	0	0	Negative	0	Negative	Negative
F.E.	M	TMB	0	0	0	0	7	7	Negative	0	Negative	Negative
S.A.	M	Asymptomatic	0	0	1	0	7	8	Negative	0	Negative	Negative
K.A.	M	Asymptomatic	0	0	1	16	11	28	Negative	0	Negative	Negative
Be.I.	F	PRIND	0	0	1	0	8	9	Negative	0	Negative	Negative
Ke.H.	M	Asymptomatic	0	0	3	8	28	39	Negative	0	Negative	Negative
R.J.	M	TIA	0	0	3	0	2	5	Negative	0	Negative	Negative
G.E.	M	Asymptomatic	0	0	4	18	37	59	Negative	0	Negative	Negative
J.A.	M	Infarction	0	0	4	0	7	11	Positive	0.34	Positive	Negative
Bi.I.	F	TMB	0	1	4	0	19	24	Negative	0	Negative	Negative
H.E.	M	Asymptomatic	0	0	5	0	2	7	Negative	0	Negative	Negative
S.C.	M	Asymptomatic	0	0	5	0	41	46	Negative	0	Negative	Negative
KM.	F	Infarction	0	0	5	0	9	14	Negative	0	Negative	Negative
K.H.	M	TIA	0	2	10	2	13	27	Negative	0	Negative	Negative
P.K.	M	Asymptomatic	1	0	0	0	1	2	Negative	0	Negative	Negative
S.C.	M	Asymptomatic	1	0	1	0	5	7	Negative	0	Negative	Negative
B.A.	F	Asymptomatic	1	0	2	0	1	4	Positive	0.2	Negative	Negative
W.A.	F	TMB	1	0	4	0	15	20	Negative	0	Negative	Negative
W.E.	M	Infarction	1	0	9	0	28	38	Negative	0	Negative	Negative
W.K.	M	Asymptomatic	2	0	1	0	4	7	Positive	0.02	Negative	Negative
W.R.	M	TMB	2	0	6	15	5	28	Positive	0.1	Positive	Negative
K.T.	M	Asymptomatic	3	0	0	0	4	7	Negative	0	Negative	Negative
S.H.	M	Asymptomatic	3	0	13	3	33	52	Negative	0	Negative	Negative
S.P.	M	TIA	5	0	4	0	10	19	Positive	0.08	Positive	Negative
L.G.	M	Asymptomatic	6	0	0	0	3	9	Negative	0	Negative	Negative
L.A.	M	TIA	11	0	5	1	21	38	Positive	0.06	Negative	Negative
U.H.	M	Infarction	12	0	34	0	10	56	Positive	6	positive	Broca's aphasia
S.G.	M	Asymptomatic	13	0	7	0	4	24	Positive	0.04	negative	Negative

Information includes MES during the defined stages of the surgical procedure; total No. of MES; result of postoperative DWI, including volume and No. of DWI-lesions; and result of follow-up examination using contrast-enhanced T1-MRT and neurological deficit. TIA indicates transient ischemic attack; TMB, transient monocular blindness.

FFT, FFT length 2 mm, FFT overlap 60%, high pass filter 100 Hz, detection threshold 9dB, minimum increase time 10 ms).

The occurrence of MES during different stages of CEA was examined: (1) dissection from skin incision until first clamping, (2) clamping I from first clamping until the release of the shunt flow, (3) shunting, (4) clamping II from second clamping until second declamping, and (5) declamping from declamping until skin closure.

Imaging

MRI was performed using a 1.5 Tesla whole body imaging system (Magnetom Symphony Quantum gradient, Siemens Medical Systems). DWI was performed 1 day before and after CEA. In patients with postoperative DWI-lesions, a T1-weighted contrast-enhanced magnetic resonance tomography (MRT) was performed 7 to 10 days after CEA. A blood brain barrier disruption was assessed as definite infarction. The exact technical setting of DWI, T1-MRT, and the evaluation criteria of DWI is described elsewhere.⁶

Statistical Analysis

All calculations were carried out using SPSS (version 11.0). The nonparametric Wilcoxon rank sum test was used for correlation of the quantity of MES during the different surgical stages and the evidence of DWI lesions and brain infarction in the follow-up investigation. A value of $P < 0.05$ was considered statistically significant.

Results

Clinical Outcome

One patient developed acute postoperative neurological deficit with a Broca's aphasia.

Microembolic Detection

MES were detected in 32 of 33 patients (Table). On average, patients showed 19.4 MES ($SD \pm 16.7$). During the different

stages patients showed the following distribution of the MES. (1) Dissection: MES in 15/33 patients (45.5%), average of 4.4 MES. (2) First clamping: MES in 2 patients (6.1%), average of 1.5 MES. (3) Shunting: MES in 23 patients (69.7%), average of 5.7 MES. (4) Second clamping: MES in 7 patients (21%), average of 9 MES. At declamping, MES occurred in almost all patients (97%) with an average of 11.5 MES.

Diffusion-Weighted Imaging

Eight patients (24.2%) showed ipsilateral DWI-lesions and of these 4 patients (12.1%) developed brain infarction. Correlation between the overall number of MES and the occurrence of DWI lesions was not found ($P=0.983$). The patient with neurological deficit showed the highest MES number (56); DWI lesions and brain infarction were also detected.

A significant correlation was found between MES during dissection and detectable DWI lesions ($P=0.027$) and brain infarction ($P=0.024$). Seven of 10 patients with MES during dissection showed DWI-lesions, whereas only 1 patient with DWI lesions did not show MES. A nonsignificant correlation was found between MES during shunting and the occurrence of DWI lesions ($P=0.398$) and brain infarction ($P=0.08$).

Discussion

MES could be detected during 32 of 33 procedures. This corroborates with older studies^{1,5} in which most of the authors found MES in >90% of their patients.

The highest number of MES was detected during declamping. This is consistent with the findings of Gavrilescu and Ackerstaff.^{4,5} There was no correlation between MES and the occurrence of cerebral ischemia during declamping. A high number of harmless gaseous MES might explain these findings, but during declamping gaseous and formed MES occur.⁴ As in single frequency analysis, a differentiation between formed and gaseous MES is impossible. Further multifrequency Doppler approaches might give more evidence.⁷

We found significant correlation between MES and ischemic lesions as well as brain infarction during dissection. This corroborates older studies. Ackerstaff found a significant correlation between MES during dissection and neurological outcome in 1058 patients.⁵ This clear correlation might be

found because during dissection the target vessel is not opened, and, thus, all detectable MES are solid. Furthermore, in that stage of the procedure the fragile plaque, a source of emboli, is not yet removed and is still exposed to blood flow.

During shunting, there was a nonsignificant correlation between MES and infarction measured by MRI. These findings confirm previous studies where the quantity of MES was remarkably high during shunting,^{4,5,8} but neither a correlation between detectable cerebral ischemia on follow-up MRT⁸ or neurological outcome was detectable.^{4,5}

In summary, our findings using TCD and DWI define dissection and shunting as the most vulnerable stages of CEA as regards cerebral embolism. Atraumatic technique and early clamping might decrease the risk of cerebral infarction.

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