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Clinical Study

Somatosensory evoked potentials in carotid artery stenting: Effectiveness in ascertaining cerebral ischemic events

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ABSTRACT

Somatosensory evoked potentials (SSEP) have been used in various endovascular procedures and carotid endarterectomy, but to our knowledge no literature deals exclusively with the utility of SSEP in carotid artery stenting (CAS). The purpose of this study was to evaluate the efficacy of SSEP in detecting cerebral ischemic events during CAS. We conducted a prospective study in 35 CAS procedures in 31 patients during an 18 month period. Thirty-three patients without near occlusion underwent stenting using dual protection (simultaneous flow reversal and distal filter) combined with blood aspiration, while two patients with near occlusion underwent stenting without dual protection. All 35 patients underwent SSEP monitoring. SSEP were generated by stimulating median and/or tibial nerves and recorded by scalp electrodes. During the aspiration phase post-dilation, seven patients (20%) exhibited SSEP changes with a mean duration of 11.3 ± 8.5 minutes (range: 3–25 minutes), three of whom later developed minor stroke/transient ischemic attack. Diffusion-weighted imaging showed new lesions in 10 patients (28.6%). Change in SSEP exhibited mean sensitivity of 100% (95% confidence interval, 0.29–1.0) and specificity of 88% (95% confidence interval, 0.71–0.96) in predicting clinical stroke post-CAS. Intra-procedural SSEP change was predictive of post-procedural complications ($p = 0.005$, Fisher's exact test). Longer span of SSEP change was positively correlated with complications ($p = 0.032$, Mann–Whitney test). Intra-procedural SSEP changes are highly sensitive in predicting neurological outcome following CAS. Chances of complications are increased with prolongation of such changes. SSEP allows for prompt intra-procedural ischemia prevention measures and stratification to pursue an aggressive peri-procedural protocol for high risk patients to mitigate neurological deficits.

1. Introduction

Somatosensory evoked potentials (SSEP) have been used in different neurosurgical procedures for decades with varying degrees of success in ascertaining ischemic events, usually in conjunction with electroencephalogram (EEG), cerebral oximetry and stump pressure measurements [1–8]. The standard SSEP technique utilizes the dorsal column-lemniscal system to non-invasively assess the functional integrity of the somatosensory cortex [4,9]. Monitoring SSEP in the median nerve (MN) and/or tibial nerve (TN) is a technically simple and proven method in determining ischemic events in middle cerebral artery territory [1,4,6,9].

Carotid artery stenting (CAS) is a less invasive revascularization alternative to carotid endarterectomy (CEA). Risk of stroke due to intra-procedural hemodynamic disturbances or debris migration from internal carotid artery plaques causing distal embolism is the main complication of CAS [10,11]. Peri-procedural minor ischemic stroke incidence following CAS is twice that of CEA [12]. Rates of new diffusion-weighted imaging (DWI) lesions following CAS are as high as 50%, three times those of CEA [13]. Occurrence of these minor strokes despite rapid advances in technology and technique suggests that there is room for improvement in terms of intra-procedural neuroprotection.

The benefits of SSEP in CEA [1,6,8] and various endovascular techniques [2–4,7] have been well established. However, the authors are unware of any literature in the English language that has exclusively reported on SSEP monitoring in CAS. The aim of this

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study is to determine the effectiveness of SSEP in detecting cerebral ischemic events during CAS.

2. Materials and methods

2.1. Patients

The Institutional Review Board approved the study protocol. All patients undergoing CAS from October 2013 to March 2015 at Hiroshima University Hospital, Japan were included in this prospective study. Written consent was obtained from all participants. After excluding cases with inadequate/unreadable recordings due to decrease in signal/noise ratio, 35 CAS procedures in 31 patients (28 men, mean age 72.6 ± standard deviation [SD] of 6.3 years, range: 58–83) were included in the final study. Five patients underwent bilateral CAS, four of them in the same setting and one after a 5 week interval. One patient undergoing bilateral CAS on the same day refused SSEP on the second side. All except two cases of near occlusion underwent CAS using dual protection (simultaneous flow reversal and distal filter) combined with blood aspiration [14].

2.2. Time-of-flight MR angiography and DWI

MRI was performed on a 3 Tesla MRI unit (Signa Excite HD 3.0T; General Electric, Milwaukee, WI, USA) using an eight channel NeuroVascular phased array coil.

Maximum intensity projection images from time-of-flight MR angiography were obtained using the following parameters: repletion time 20 ms; echo time 3.4 ms; flip angle 18°; field of view 240 × 240 mm; matrix 256 × 160 (recon 512 × 512); and slice thickness 2.4 mm.

Both pre- and post-procedural DWI ($b = 1{,}000\ s/mm^2$) were obtained using spin echo planar imaging sequences oriented in the axial plane; effective gradient 40 mT/m; slew rate 150 mT/m/ms. The parameters were: repetition time 5000 ms; echo time 73.2 ms; NEX 1; field of view 220 × 220 mm; slice thickness 6 mm; intersection gap 1.0 mm; number of slices 20; data acquisition matrix 128 × 128 mm; one acquisition.

2.3. Post-procedural evaluation

Stroke was defined as new neurological deficits lasting >24 hours. Stroke that resolved completely within 30 days was defined as minor stroke, and stroke which persisted ⩾30 days was defined as major stroke. Occurrence of major stroke, myocardial infarction, or death after CAS were defined as major adverse events. DWI acquired within 3 days before and after CAS were compared to evaluate CAS-related hyperintensities.

2.4. SSEP method

All procedures were performed under local anesthesia. SSEP were generated by stimulation using surface electrodes over MN at the wrist (± TN at ankle). For cortical recordings, the international 10/20 EEG system was followed. Scalp electrodes were placed at C3′, C4′, Cz′, and Fpz.

Pulse intensity was set above the motoric pulse threshold, but at tolerable level of abductor pollicis brevis (10–20 mA) for MN, and flexor hallucis longus (15–25 mA) for TN, recognized by visible contractions. Stimulation parameters consisted of constant voltage, 0.3 ms duration for MN and 0.5 ms for TN, with bandpass filter of 10–250 Hz. A minimum of 250 sweeps at 3.3 Hz was averaged. Recordings were done using Nicolet Viking Electrodiagnostic System (Nicolet Instruments, Madison, WI, USA).

In different settings, either unilateral or bilateral alternating side to side stimulation of MN was carried out. Bilateral MN stimulation was done in five patients, MN and TN in six, TN only in one and MN only in 23 patients. Three to four "initial control" waves were recorded at different intervals prior to inflation of occlusion balloons. All subsequent SSEP were compared with these and scrutinized. SSEP were continuously recorded during stenting.

The following definitions were used to quantify SSEP changes. A significant SSEP change was an amplitude reduction of >50% and/or latency delay (N20/P24 or P40/N48) of >10%. Changes were classified as permanent if they persisted until the end of the procedure. Any persistent deviation in the obligate waveform morphology from the initial controls was deemed urgent enough to warrant a verbal warning to the operating surgeons.

CAS protocol, procedure and post-procedural management at the study center has been previously published by Sakamoto et al. [10,14].

Statistical analysis was done using Stata 13 (StataCorp., College Station, TX, USA). Odds ratios and 95% confidence intervals (CI) were calculated using logistic regression analysis. Categorical variables were analyzed using Fisher's exact test. The Mann–Whitney test was used for quantitative variables. Unpaired t-test was used to compare means of independent groups. A p value of $\leqslant 0.05$ was considered statistically significant.

3. Results

Of the 35 CAS performed on 31 patients (mean age 72.6 ± SD 6.3 years, range: 58–83 years), seven patients (20%) exhibited significant SSEP changes. Obligate SSEP waveform morphology was aberrant and slightly earlier than clinical manifestations in four patients. In three patients, there were no corresponding clinical signs of brain ischemia. In all seven patients, SSEP changes (mean duration 11.3 ± SD 8.5 minutes, range: 3–25 minutes) started during the aspiration phase post-dilation, and operating surgeons were notified accordingly. None of the SSEP changes were permanent.

3.1. Post-procedural evaluation

DWI showed newly developed small hyperintense spots in 10 (28.6%) patients.

The overall technical success rate of CAS was 100%. The mean procedure time from femoral artery puncture to sheath removal was 82.4 ± SD 15.2 minutes. There was no incidence of a major adverse event post-procedure. Minor stroke occurred in two patients: dysarthria for 6 days and motor aphasia and hemiparesis for 7 days. Transient ischemic attack occurred in one patient, who experienced unilateral spatial neglect for 2 hours and dysarthria for 6 hours post-CAS that resolved in the next 2 hours. In patients with SSEP changes, incidence of neurological deficit was 3/7 (42.9%). None of the cases without SSEP changes exhibited any neurological deficit (Table 1–3).

From the above findings, the sensitivity and specificity of SSEP in predicting clinical stroke post-procedure were 100% (95% CI, 0.29–1.0) and 88% (95% CI, 0.71–0.96), respectively. The positive predictive value of SSEP changes for post-procedural complications was 43% (95% CI, 0.1–0.82), while the negative predictive value was 100% (95% CI, 0.88–1.0). The diagnostic odds ratio and relative risk for patients with complications with changes in SSEP were 44.3 (95% CI, 1.95–1009.6) and 25.4 (95% CI, 1.46–442.2), respectively.

An unpaired t-test for stump pressure just prior to stenting between the group with SSEP changes (mean 39.14 ± SD 6.62 mmHg) and the group without SSEP changes (mean 49.27 ± SD 18.39 mmHg) was not statistically significant (p = 0.17).

Factors including sex, age, and laterality of the procedure were not predictors of complications. New DWI lesions were strongly