Original Article

Novel devices for intraoperative monitoring of glossopharyngeal and vagus nerves during skull base surgery

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Abstract

**Background:** Swallowing disturbance is among the most burdensome complications suffered by patients with glossopharyngeal and vagus nerve involvement in lesions adjacent the jugular foramen. For monitoring these nerves, we have developed new devices that comprised four contacts adhering to the surface of the cuff of an endotracheal tube, with attachment the posterior pharyngeal wall. To determine whether these devices are useful for monitoring the glossopharyngeal and vagus nerves and predicting postoperative swallowing dysfunction in patients undergoing removal of skull base tumors involving these nerves.

**Methods:** We studied 10 patients. Compound muscle action potentials (CMAPs) were recorded from the posterior pharyngeal wall by stimulating the glossopharyngeal or vagus nerve in order to identify the nerve course, especially in patients showing severe nerve distortion due to the tumor. Pharyngeal motor evoked potential (PhMEP) elicited by transcranial electrical stimulation were recorded in all patients. The correlation between the final to baseline PhMEP ratio and postoperative swallowing function was examined.

**Results:** Responses were obtained in six of the seven patients in whom CMAP monitoring was performed. Deterioration of swallowing function postoperatively was demonstrated in six of seven (86%) patients with intraoperative PhMEP ratios <50%. None of the three patients with intraoperative PhMEP ratios >50% showed deterioration of swallowing function after surgery, although the one patient already had severe swallowing dysfunction requiring preoperative tracheostomy.

**Conclusions:** Our novel devices were useful for monitoring the glossopharyngeal and vagus nerves in patients undergoing removal of skull base tumors involving these nerves.

**Key Words:** Compound muscle action potential, glossopharyngeal nerve, pharyngeal motor evoked potential, transcranial electrical stimulation, vagus nerve

INTRODUCTION

Intraoperative monitoring of swallowing function is important for skull base surgery in patients in whom the glossopharyngeal and vagus nerves are involved in the tumor. Motor function of these nerves have...
been monitored using needle electrodes placed in the vocal cords or pharyngeal wall, as well as surface electrodes on an endotracheal tube adhering to the vocal cords. Needle electrode placement in the vocal cords or pharyngeal wall is difficult and requires special expertise. In addition, bleeding is a potential complication of needle electrodes because the vocal cords and pharynx are highly vascular tissues. Endotracheal tube placement carries a risk of vocal cord edema due to compression by surface electrodes, especially with prolonged operative procedures.

We previously applied pharyngeal motor evoked potential (PhMEP) monitoring employing a modified endotracheal tube placed on the posterior pharyngeal muscles to predict postoperative swallowing function during skull base surgery. However, the tube had the disadvantage that attachment of the electrodes to the pharyngeal wall could not be verified. We thus developed new devices for monitoring the glossopharyngeal and vagus nerves, as surface electrodes could be more securely attached to the posterior pharyngeal wall. Herein, we report that these devices were useful for monitoring the glossopharyngeal and vagus nerves in patients undergoing removal of skull base tumors involving these nerves.

MATERIALS AND METHODS

Patients
We studied 10 patients (7 men and 3 women) with skull base tumors treated surgically at the University of Niigata from May 2011 to December 2012, in whom our new devices were used for monitoring the glossopharyngeal and vagus nerves [Table 1]. The cranial base tumors were as follows: Cerebellopontine angle (CPA) meningioma (3 patients), cerebellar hemangioblastoma (2), and CPA epidermoid, jugular foramen schwannoma, vestibular schwannoma, petroclival meningioma, and medullary venous malformation (1 each). Swallowing function was evaluated preoperatively and within the first week after surgery, according to a 3-grade scale (normal, 0 points; mild dysfunction, 1 point; severe dysfunction, 2 points). Mild dysfunction was defined as a sensation of difficulty swallowing, though the ability to swallow food and liquid was retained without the need for tube feeding. Severe dysfunction was defined as swallowing disturbance that necessitated tube feeding.

Intraoperative monitoring
We monitored the glossopharyngeal and vagus nerves by recording both compound muscle action potentials (CMAPs) and PhMEP from the posterior pharyngeal wall. These novel monitoring devices were comprised of four contacts adhering to the surface of the cuff of the endotracheal tube [Figure 1a]. Each contact was a circle 2.0 mm in diameter and the cuffs were arranged with a separation of 5 mm between contacts [Figure 1b]. This modified endotracheal tube was positionable to assure that the surface contacts of the cuff

![Figure 1](image_url)

**Table 1: Features of skull base tumor patients**

| Age/sex | Diagnosis             | Pre-signs      | CMAP (%) | PhMEP (%) | Swallowing function grade |
|---------|-----------------------|----------------|----------|-----------|--------------------------|
|         |                       |                |          |           | Pre* | Post* | Post-Pre** |
| 72/M    | CPA meningioma        | VIII           | +        | 56        | 0    | 0    | 0          |
| 63/M    | Jugular foramen schwannoma | IX-XI        | +        | 86        | 1    | 1    | 0          |
| 62/M    | Vestibular schwannoma | V, VIII, ataxia | - | 0        | 0    | 2    | 2          |
| 55/F    | Petroclival meningioma | VIII         | -        | 44        | 0    | 1    | 1          |
| 79/F    | Cerebellar hemangioblastoma | Ataxia   | +        | 20        | 0    | 2    | 2          |
| 64/M    | CPA epidermoid        | Ataxia        | +        | 48        | 2    | 2    | 0          |
| 67/M    | Medullary angiomia    | Tracheostomy  | +        | 66        | 2    | 2    | 0          |
| 63/M    | Cerebellar hemangioblastoma | None      | -         | 29        | 0    | 2    | 2          |
| 55/F    | CPA meningioma        | Ataxia        | +        | 48        | 0    | 1    | 1          |
| 46/M    | CPA meningioma        | Tracheostomy  | NA       | 34        | 1    | 2    | 1          |

CPA: Cerebellopontine angle, CMAP: Compound muscle action potential, PhMEP: Pharyngeal motor evoked potential, NA: Not available, *0: Normal function, 1: Mild dysfunction, 2: Severe dysfunction, **Postminus preoperative scores. 0: No changes, 1: Mild deterioration, 2: Severe deterioration
were attached to the pharyngeal musculature on the side ipsilateral to the lesion. After positioning, the cuff was inflated with 10 mL of air and thereby secured in place [Figure 1c].

Our methods of intraoperative PhMEP monitoring have already been described elsewhere in detail.[2] Following the induction of anesthesia with a short-acting agent for neuromuscular blockade, neuroanesthesia was maintained by intravenous infusion of propofol and fentanyl. Constant voltage stimuli, consisting of 5 rectangular pulses with 1-ms interstimulus intervals, were generated with a D185 stimulator (Digitimer Ltd., UK). Corkscrew electrodes were placed at positions C3 or C4 and Cz to evoke the PhMEPs. The cathode was always positioned at Cz, and the anode on the contralateral side. PhMEPs were recorded from three pairs of the four contacts. Intraoperative monitoring was based on the PhMEP with the largest amplitude among the responses obtained from the 2-paired contacts. A Viking monitoring system (Nicolet Biomedical, Inc., Madison, WI, USA) was used. The bandpass filter was set at 200–3000 Hz. The applied stimulus was adjusted to supramaximal intensity, and ranged from 280 to 406 V (mean, 323 V). The highest value obtained before the microsurgical procedure was taken as the baseline response. The ratios of final PhMEP amplitude (at dural closure) to baseline PhMEP amplitude (shown as percentages) were used for the evaluations.

Bipolar stimulators for CMAP monitoring were utilized. Current was delivered using a 0.2-ms pulse duration and a pulse frequency of one per second. Stimulus intensity was 1.0 mA. If reliable CMAPs were not obtained at this intensity, the current was increased in 1.0 mA increments until 3.0 mA was reached. The CMAPs from the posterior pharyngeal wall were recorded at the paired contacts with the largest amplitude in PhMEPs employing transcranial electrical stimulation. We used exclusively CMAP monitoring to identify the courses of the nerves with severely distorted anatomy.

RESULTS

Pre-and postoperative swallowing function

Four of the ten patients had swallowing dysfunction (1 point in 2 patients and 2 in 2) prior to surgery [Table 1]. In only one (Patient 10) of the four patients, swallowing function deteriorated from mild (1 point) to severe dysfunction (2 points) postoperatively. The other three patients showed no changes. Five of the six patients who had normal swallowing function preoperatively developed swallowing disturbance postoperatively (mild, 2 patients; severe, 3). The change in pre-versus postoperative swallowing function grade was 0 in four patients, 1 in three patients, and 2 in three patients.

Intraoperative PhMEP and CMAP recordings

In all patients including two who underwent tracheostomy preoperatively, valid PhMEPs were obtained from the paired contacts adherent to the cuff of the endotracheal tube [Table 1]. In six patients, CMAPs were recorded by stimulating the glossopharyngeal or vagus nerve running along the surface of the tumor [Figure 2, Patient 9]. CMAP monitoring was not used in the remaining three patients because the glossopharyngeal and vagus nerves could be anatomically identified intraoperatively. The one remaining patient (Patient 10) did not have available CMAP data, although the nerves we identified as the glossopharyngeal and vagus nerves were stimulated. There were no side effects of the electrical stimulation, such as unexpected movements of the extremities, seizures, or pharyngeal swelling.

PhMEPs and postoperative swallowing function

Swallowing function deteriorated postoperatively in six of seven (86%) patients with an intraoperative PhMEP ratio <50% [Figure 3, Patient 8]. The one remaining patient (Patient 6) already had severe swallowing dysfunction (2 points) before surgery and there was no change in function postoperatively. None of the three patients with intraoperative PhMEP ratios >50% showed deterioration of swallowing function after surgery, although the one patient (Patient 7) already had severe swallowing dysfunction requiring tracheostomy before surgery.

DISCUSSION

In the present study, we obtained both CMAP and PhMEP recordings from the posterior pharyngeal wall using our newly modified endotracheal tube during skull base tumor surgery. The CMAP recordings facilitated identifying the course of the glossopharyngeal and
vagus nerves, especially in patients with nerves severely distorted by the tumor. The final amplitude ratios in PhMEPs, using a cut-off point of 50%, appear to predict swallowing function deterioration after surgery.

Needle electrodes have been inserted into the pharyngeal wall and soft palate for CMAP monitoring of the glossopharyngeal and vagus nerves. This method requires special expertise and is associated with a risk of bleeding from the pharynx and soft palate. It is difficult to verify the insertion of such needle electrodes and they may become dislodged from the pharynx during surgery. Recently, an endotracheal tube with surface electrodes has been used for intraoperative monitoring in patients with skull base tumors. However, this endotracheal tube can be used for monitoring of the recurrent laryngeal nerve, which innervates the laryngeal, but not the pharyngeal, muscles. In addition, severe edema of the vocal cords can occur due to compression by the endotracheal tube surface electrodes. Reintubation or tracheostomy may be required postoperatively in some patients. We have experienced two patients in whom the endotracheal tube was used for monitoring who required tracheostomy due to severe edema of the bilateral vocal cords (unpublished data). In both patients, the head was highly rotated for positioning during surgery and the operative time exceeded 10 hours. Edema of the vocal cords is a potentially important complication when the endotracheal tube is used for monitoring the glossopharyngeal and vagus nerves.

We recently reported a redesigned endotracheal tube attached to the posterior pharyngeal wall to be useful for PhMEP monitoring to predict postoperative swallowing dysfunction. However, attachment of the surface electrodes of this endotracheal tube to the pharyngeal wall could not be confirmed. The newer devices described herein have the advantage that surface electrodes adhering to the cuff are more securely attached to the pharyngeal wall due to air inflation. CMAP monitoring of the glossopharyngeal and vagus nerves was available in 6 of 7 patients in this study. Because the glossopharyngeal and vagus nerves consist of many nerve bundles, lack of CMAPs from the pharyngeal wall does not always indicate that the stimulated nerve bundles have already lost swallowing function. It is possible that these bundles innervate not the pharyngeal but rather the laryngeal muscles. This is one possible explanation for one of our patients lacking CMAP recordings despite the glossopharyngeal or vagus nerve bundles having been stimulated. Swallowing dysfunction is an extremely burdensome complication suffered by patients with skull base tumors involving the lower cranial nerves. Identifying the courses of these nerves innervating the pharyngeal muscles by CMAP monitoring using our modified endotracheal tube could potentially contribute to preserving the nerve bundles responsible for swallowing function.

In this study, the PhMEP amplitude ratio after tumor resection tended to correlate with postoperative deterioration of swallowing function, although the number of patients was small. In all three patients with PhMEP amplitude ratios >50%, preoperative states of swallowing function were unaffected by surgery, although one patient already had severe dysfunction prior to the operation. Six of seven patients with PhMEP amplitudes <50% experienced deterioration of swallowing function after tumor removal. The one remaining patient already had severe swallowing dysfunction (points 2). It may be difficult to evaluate postoperative deterioration of swallowing function, as reflected by reduced PhMEP amplitude ratios at the final examinations. Exclusion of such patients from this study, would have assured that there were no false positive or negative data assuming that patients with PhMEP amplitude ratios <50% after tumor removal had deterioration of swallowing function postoperatively. Previously, we analyzed the PhMEPs obtained with the prototype devices in 21 patients during 22 surgical procedures for the treatment of skull base tumors. A PhMEP ratio <50% was recorded during 4 of 22 procedures; in all 4 of these cases, the patients experienced postoperative deterioration of swallowing function. After 18 procedures, the PhMEP ratios remained >50%; nevertheless, after 4 (22.2%) of these 18 procedures, patients showed deterioration of swallowing function. The results implied that there were no false positive but 20% of false negative data assuming that patients with PhMEP amplitude ratios <50% at the final examination had poor outcomes of swallowing function. The present results are an improvement over previous PhMEP findings obtained with the prototype devices for monitoring glossopharyngeal and vagus nerve functions to identify correlations with postoperative swallowing dysfunction, though the number

Figure 3: Intraoperative PhMEP monitoring in a patient with a cerebellar hemangioblastoma (Patient 8, Table 1). Representative EMG recordings obtained from the posterior wall of the pharynx before tumor removal (upper) and at the final recording (lower). The final PhMEP ratio decreased to 29%.
of patients in the present data was smaller than that in the previous data. Further study of a larger patient population using these novel devices for monitoring the glossopharyngeal and vagus nerves is needed to confirm the correlation between PhMEP findings and postoperative swallowing function.

CONCLUSION

The CMAPs obtained with our newly modified endotracheal tube attached to the posterior pharyngeal wall allow the course of the glossopharyngeal and vagus nerves distorted by the skull base tumor to be identified. The final amplitude of PhMEP ratios apparently predicts postoperative deterioration of swallowing function. These new devices were useful for monitoring the glossopharyngeal and vagus nerves in patients undergoing removal of skull base tumors involving these nerves.

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