Endotracheal tube electrodes to map and monitor activities of the vagus nerve intraoperatively

Technical note

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Difficulty swallowing due to damage of the vagus nerve is one of the most devastating complications of surgery in and around the medulla oblongata; therefore, intraoperative anatomical and functional evaluation of this nerve is crucial. The authors applied endotracheal tube surface electrodes to record electromyography (EMG) activity from vocal cords innervated by the vagus nerve. The vagal nucleus or rootlet was electrically stimulated during surgery and vocalis muscle EMG activities were displayed by auditory and visual signals. This technique was used successfully to identify the vagus motor nerve and evaluate its integrity during surgery. The advantages of this method compared with the use of needle electrodes include safe simple electrode placement and stable recording during surgery. In cases involving a pontine cavernoma pressing the nucleus or a jugular foramen tumor encircling the rootlet, this method would be particularly valuable. Additional studies with a larger number of patients are needed to estimate the significance of this method as a means of functional monitoring to predict clinical function.

Key words • cavernoma • endotracheal tube electrode • intraoperative mapping • jugular foramen • vagus nerve
Vagal nerve monitoring

Anesthetic Procedure

General anesthesia was induced with thiopental sodium and thiopental and maintained with fentanyl and propofol. Vecuronium bromide was injected only during the induction of anesthesia, and no additional neuromuscular blocking agents were administered during the surgical procedure. Routine monitoring of heart rate and arterial blood pressure were continuously conducted.

Surgical Procedure

Tumors in the brainstem or fourth ventricle were surgically treated via a midline suboccipital approach, and jugular foramen tumors were removed via a lateral suboccipital approach. In all patients, the tumors were gross totally removed, which was confirmed on postoperative MR imaging.

Positioning of Electrodes

As an intubation technique, the endotracheal tube embedded with the electrodes is placed under direct vision by the anesthesiologist so that the bilateral true vocal cords are in contact with the paired stainless-steel wire electrodes symmetrically.

Electromyography Recording

Recording ground and nerve stimulator anode subdural electrodes are placed on the patient’s shoulders. All electrodes are connected to the interface box (NIM-Response, Medtronic Xomed), a monitor continuously tracking EMG activity with a built-in pulse generator for electrically evoked signals. Proper tube placement is confirmed by checking recording electrode impedances of less than 5 kohms, with an imbalance of less than 1 kohm. A bipolar stimulator (tips 1.3 mm apart; Medtronic Xomed) is used with an amplitude of 0.2 to 0.5 mA, a stimulus duration of 100 μsec, and a rate of four bursts per second. An initial

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**TABLE 1**

Neurological status and characteristics in 11 patients who underwent vagal monitoring*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Histological Diagnosis</th>
<th>Tumor Location</th>
<th>Time</th>
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<th>CN VII</th>
<th>CN VIII</th>
<th>CN IX/X</th>
<th>PPRF</th>
<th>Sensory Function</th>
<th>Motor Function</th>
<th>Cerebellar Sign</th>
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* CN = cranial nerve; PPRF = parapontine reticular formation; SI = status improved, SS = status same, SW = status worsened; − = no deficit, + = deficit present.

**FIG. 1.** Photographs of the endotracheal tube surface electrodes. Bilaterally paired wire electrodes are exposed for 30 mm at the glottis level and skewed anterolaterally for vocal cord contact (bidirectional arrows). **Upper:** Lateral view. **Lower:** Magnified view of the inset including the tip, cuff, and right (R, dotted line) and left (L, double lines) paired electrodes.
stimulation intensity of 1 mA is applied to elicit a distinct and stable muscle response. The intensity is then reduced to determine the threshold stimulation application (0.2–0.5 mA), which is fixed during surgery. An event threshold level of 100 μV was used in the current study. Vocalis muscle EMG activities are displayed by audio and visual signals, so that the operator receives immediate auditory feedback while the assistants visually follow the EMG activity. When anatomical landmarks are visible, the area responsible is determined by repetitive stimulation with increasing 1- to 2-mm distances after the initial electrical response lateral to the hypoglossal triangle. When anatomical landmarks are not clearly visible, the floor of the fourth ventricle superolateral to the obex is stimulated until the initial response is recorded.

In the current study, vagal rootlets involved in the jugular foramen tumor were identified by repetitive stimulations on the tumor, which was removed piece by piece. During surgery, the surgeon repeatedly stimulated the suspect area delineated before resection so that the amplitude of the evoked potentials were compared intraoperatively. Electrode impedance and imbalance values were periodically checked during the surgical procedure to ensure continued proper intralaryngeal electrode contact without dislocation of the endotracheal tube.

Other Neurophysiological Mapping and Monitoring

The other cranial nerves to be monitored, in turn, depended on the location of the patient’s space-occupying lesion, as determined during the preoperative evaluation. Electrodes were placed bilaterally on the left and right sides to monitor the abducens,7,9 facial,6 accessory,7 and hypoglossal nerves.15 As is routine at our institution, motor-evoked potentials elicited by electrical stimulation to scalp electrodes, somatosensory evoked potentials after median and tibial nerve stimulation, and far-field brainstem auditory evoked potentials were recorded to monitor the functional integrity of these pathways in the brainstem.

Results

Evaluation of the Vagal Nucleus

In four patients with tumor in the rhomboid fossa (Cases 1, 2, 9, and 10), preoperative evaluation showed no functional deficits in association with the cranial nerves. Anatomical landmarks such as facial colliculus, stria medullaris, median sulcus, and hypoglossal triangle were identified visually or neurophysiologically. Electromyography activities of the vocalis muscles were evoked by stimulating only a small area in the ipsilateral floor of the fourth ventricle, caudal to the stria medullaris, lateral to the hypoglosal triangle (identified as the area that produced a response in the intrinsic tongue muscles and usually located close to the obex), and medial to the cerebellar peduncle. No EMG response was detected in vocalis muscles contralateral to the stimulated side. There was no change in evoked EMG activity during surgery and no deficit in clinical vagus nerve function between pre- and postsurgery periods.

In five patients with tumor originating from the caudal portion of the rhomboid fossa or with pontine cavernoma (Cases 3–6 and 11), facial colliculus, stria medullaris, and vagal/hypoglossal trigonum were difficult to identify before tumor resection. Mapping played a significant role in providing anatomical orientation before tumor resection in these patients. The vagal nuclei were successfully identified as the area on the ventricle floor that elicited an EMG response on the vocal cord. A pontine cavernoma accompanied by a space-occupying hematoma bisected the left and right vagal nuclei in the patients in Cases 4 and 11 and pushed both nuclei to the same side in the patient in Case 5 (Fig. 2). In these patients, vocalis muscle EMG activities enlarged soon after removal of the space-occupying hematomas in the brainstem, and improvement of vocal cord motion was diagnosed 1 week after surgery.

Evaluation of Vagal Rootlets

In two patients with jugular foramen neuroma and me-
Vagal nerve monitoring

Fig. 3. Case 8. Preoperative contrast-enhanced MR image (A) demonstrating a meningioma extending to the jugular foramen. Intraoperative photograph (B) of the tumor in the cerebromedullary cistern and involving the lower cranial nerve roots, which are invisible except for a certain portion of the accessory nerve. Before tumor resection, no EMG response was elicited by electrical stimulations (site indicated by solid circle in B) on the tumor (preresection tracing). The tumor was removed piece by piece, until electrical stimulations on it elicited the first EMG response (during resection, upper tracing), followed by further removal of the tumor with confirming subsequent increases of EMG amplitudes (during resection, lower tracing). Finally, vagal rootlets were preserved between the brainstem and jugular foramen, maintaining good EMG responses (postresection tracing) on their proximal site (indicated by solid circle in C). Asterisk indicates the jugular foramen in B and C.

Complications

No complication was observed on placement of the endotracheal tube electrodes on the vocal cord and stable electrode placement during surgery was confirmed by checking recording electrode impedances. There was no sign of an abnormal change in heart rate and arterial blood pressure intraoperatively, nor of neurapraxia during a more than 2-month follow-up period, despite repetitive neural stimulations.

Discussion

The endotracheal tube surface electrodes successfully documented clear EMG activities from vocalis muscles intraoperatively. The EMG response was evoked only from a small area defined anatomically as the vagal rootlet and nucleus. Thus, this noninvasive method can detect specifically the EMG signals evoked from the vagus nerve. Impedance values for the endotracheal tube electrodes and signal-to-noise ratios are consistent with true needle electrode impedance values that occur in electrophysiological monitoring of the facial nerve. Furthermore, no complication was noted during surgery and the postoperative follow-up periods.

For electrophysiological monitoring and mapping of the vagus nerve during brainstem and skull base surgery, needle or hook-wire electrodes have been used after intubation. A big advantage of endotracheal tube electrodes over the more invasive tools is that their use makes for a simpler and safer procedure. When a patient is intubated with an endotracheal tube embedded with the electrodes, the placement of the surface electrodes on the bilateral vocal cords can be easily performed under direct vision. Even when poor tube positioning occurs during surgery, reestablishing electrode contact is relatively easy with the guidance of impedance and x-ray images. If the surgeon is unable to record EMG signals after direct stimulation of the brainstem and the vagal rootlets, checking the impedance and imbalance values of the electrodes and tapping the endotracheal tube are relatively easy means of determining whether the failure has a true physiological basis or if it is a consequence of the electrodes not recording properly. Regarding safety, given that the endotracheal tube electrodes are situated outside of the muscle, risks for vocal cord damage and neurological deficits are extremely small. Nerve palsy and cardiovascular side effects, such as reflex bradycardia and sinus arrest,
Electrophysiological evaluation of the vagus nerve during surgery has two basic goals. One is to identify the distinct locations of vagal rootlets and nucleus even if normal anatomy is distorted by a space-occupying lesion. Once these locations are determined, the surgeon can preserve their anatomical structure under direct vision and choose a safe route of access to the lesion. In three patients in whom normal anatomical landmarks of the floor of the fourth ventricle were made totally invisible by a brainstem cavernoma, facial nerve stimulation failed to indicate the facial colliculus/intramedullary root. In these patients, intraoperative mapping for vagal nuclei made it possible both to estimate the location of stria medullaris and facial colliculus/intramedullary root and to clarify the way in which the tumor distorted the brainstem anatomy (that is, whether the tumor bisected the left and right motor nuclei or pushed both nuclei to the same side). In addition to a careful understanding of the anatomy and function of each nucleus as well as the fibers evaluated through electrophysiological studies, what the surgeon sees in the operative field is of vital importance in mapping and monitoring.

The other goal of electrophysiological recording is to evaluate neurological functional status. Our findings support those obtained in a previous report in which the EMG response to stimulation of the vagus nerve was correlated with the preoperative functional status of the patients. In patients with preoperative vagus nerve dysfunction due to pontine cavernoma, an evoked potential from vagal nuclei on the disturbed side was weaker than that elicited from the contralateral side in which nerve function was clinically intact. Furthermore, in these patients, postoperative recovery of vocal cord motion was predicted intraoperatively by enlarged evoked EMG activities from the vocalis muscle. In another two patients with tumor involving vagal rootlets at the cerebellomedullary cistern, EMG activities from vocalis muscles became larger during tumor removal. Decompression of the tumor and/or hematoma on the vagus nerve may increase nerve conduction, thus causing clinical improvement.

As a functional monitoring method, our technique has certain limitations and requires careful consideration. Afferent pathways as well as corticobulbar tract not detected by EMG should be taken into account for functional integrity. Further research is needed to determine the relationship between intraoperative vocalis muscle EMG response and postoperative laryngeal activity. It is also noteworthy that even when the nucleus or intra-extramedullary root of the nerve has been damaged, part of the nerve distal to the damage is still electrically excitable and may transmit signals to the target muscles. Electrical stimulation of a peripheral nerve during its intracranial course central (proximal) to the sites of surgical manipulation allows for the determination of whether its structural and functional integrity is maintained. With further understanding of its advantages and limitations, our method will allow assessment of neural integrity in brainstem and skull base surgery.

References


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