www.surgicalneurologyint.com

ScientificScholar® Knowledge is power
Publisher of Scientific Journals

Surgical Neurology International

Editor-in-Chief: Nancy E. Epstein, MD, Clinical Professor of Neurological Surgery, School of Medicine, State U. of NY at Stony Brook.

SNI: Epilepsy

Editor
Manas Kumar Panigrahi, M.Ch., FACS
Krishna Institute of Medical Sciences (KIMS); Hyderabad, Telangana, India

SNI Open Access

Original Article

Intraoperative nerve stimulation during vagal nerve stimulator placement

Chie Kamada[1], Rei Enatsu[1], Aya Kanno[1], Satoko Ochi[2], Shoto Yamada[3], Ryota Sato[1], Ryohei Chiba[1], Nobuhiro Mikuni[1]

[1]Department of Neurosurgery, Sapporo Medical University, [2]Department of Neurosurgery, Maronie Street Neurological Clinic, [3]Division of Clinical Engineering, Sapporo Medical University, Sapporo, Japan.

E-mail: Chie Kamada - chie0527071@gmail.com; *Rei Enatsu - enatsur@gmail.com; Aya Kanno - ya5u31@yahoo.co.jp; Satoko Ochi - ssochi1030@gmail.com; Shoto Yamada - shoto_yamada@sapmed.ac.jp; Ryota Sato - sato0463@gmail.com; Ryohei Chiba - r.bach0690@gmail.com; Nobuhiro Mikuni - mikunin@sapmed.ac.jp

***Corresponding author:**
Rei Enatsu,
Department of Neurosurgery,
Sapporo Medical University,
Sapporo, Japan.

enatsur@gmail.com

Received: 06 April 2023
Accepted: 17 August 2023
Published: 01 September 2023

DOI
10.25259/SNI_303_2023

Quick Response Code:

ABSTRACT

Background: Vagal nerve stimulation (VNS) is a palliative treatment for refractory epilepsy and intraoperative nerve stimulation is applied to the vagal and other nerves to prevent electrode misplacement. We evaluated these thresholds to establish intraoperative monitoring procedures for VNS surgery.

Methods: Forty-six patients who underwent intraoperative nerve stimulation during VNS placement were enrolled. The vagal nerve and other exposed nerves were electrically stimulated during surgery, and muscle contraction was confirmed by electromyography of the vocal cords and visual recognition of cervical muscle contraction. The nerve thresholds and the most sensitive parts of the vagal nerve were analyzed retrospectively.

Results: The stimulation of vagal nerves induced vocal cord responses in all 46 patients; the median thresholds of the most sensitive parts and all parts were 0.2 mA (range: 0.05–0.75 mA) and 0.25 mA (range: 0.15–1.5 mA), respectively. The medial middle region was identified as the most sensitive part of the vagal nerve in the majority of participants (82.5%). In 11 patients, other cervical nerves were stimulated and sternohyoid muscle contraction was induced with a median threshold of 0.35 mA (range: 0.1–0.7 mA) in eight patients, while sternocleidomastoid muscle contraction was induced with a median threshold of 0.2 mA (range: 0.1–0.2 mA) in three.

Conclusion: Intraoperative stimulation of vagal nerves induces vocal cord responses with locational variations, and the middle part stimulation could minimize the stimulus intensities. The nerves innervating the sternohyoid and sternocleidomastoid muscles may be exposed during the procedure. Knowledge of these characteristics will enhance the effectiveness of this technique in future applications.

Keywords: Epilepsy, Intraoperative stimulation, Sternocleidomastoid muscle, Sternohyoid muscle, Vagal nerve stimulation

INTRODUCTION

Vagal nerve stimulation (VNS) is a palliative treatment for refractory epilepsy, which aims to reduce the frequency and severity of seizures. This therapy is indicated for patients with resection-unsuitable epilepsy, or as an additional treatment option.[3,11,18] VNS can cause stimulation-related adverse effects, including cough, hoarseness, dyspnea, and dysphagia, which are generally well-tolerated.[6,15] The misplacement of electrodes results in the ineffectiveness of therapy, as well as stimulation-induced neck muscle contraction.[5,6,13] This complication may also be caused by the involvement of the abnormal course of the nerve root of the ansa cervicalis[4] and reliable identification of the vagal nerve is a key point of this procedure.

We have previously reported an intraoperative monitoring technique to prevent electrode misplacement.[2] However, the vagal nerve and other nerves, such as the ansa cervicalis, cervical plexus, and accessory nerve, could be exposed during VNS placement,[2,5,17] and the thresholds of these nerves to induce muscle response have not yet been clarified. A more precise understanding of this region is necessary to differentiate between these nerves. Therefore, this study evaluated the thresholds of vagal and other nerves for muscle response to establish intraoperative monitoring procedures during VNS surgery.

MATERIALS AND METHODS

Patients

We enrolled 46 patients who underwent intraoperative nerve stimulation during VNS placement between March 2013 and May 2022 at our institute. The patients' ages ranged from 5 to 68 years and 24 were male. This study was approved by the Institutional Review Board of Sapporo Medical University Graduate School of Medicine (IRB# 292–101). Our monitoring protocol was previously introduced using a part of the current data.[2]

Intraoperative nerve stimulation

We performed vocal cord monitoring to map the vagal nerve following a previously described protocol.[2,10] A single dose of remifentanil and propofol was used to induce general anesthesia. Muscle relaxants were only administered during intubation. Endotracheal tube electrodes (Medtronic Xomed, Jacksonville, FL) were used to record the electromyographic (EMG) activity of the vocal cords.[2,10] The electrodes were placed to locate the paired stainless steel wire electrodes in contact with the vocal cords, and correct tube placement was confirmed by recording an electrode impedance of <5 kΩ. The neutral electrode and nerve stimulator anode electrode were placed on the patient's shoulder. All electrodes were connected to an interface box (NIM-Neuro 3.0, Medtronic Xomed). EMG activity was recorded using visual and audio signals. The vagal nerve was approached through a left neck 4–5-cm transverse skin incision beside the cricoid cartilage. The vagus nerve was exposed for a length of 3 cm below the carotid bifurcation and above the origin of the recurrent laryngeal nerve. The exposed vagus nerve was divided into three parts of 1 cm in length: Caudal, middle, and rostral. The rubber sheet was laid under the vagus nerve. A monopolar stimulation was applied to six points on the exposed vagal nerve (medial caudal, lateral caudal, medial middle, lateral middle, medial rostral, and lateral rostral) with a cathode emitting a 100-μs width stimulus at a rate of four bursts per second to evaluate EMG activity [Figure 1a]. The exposed nerves were also stimulated to differentiate from the vagal nerve [Figures 1b and c]. Stimulus intensity was gradually raised from 0.05 mA to 2.0 mA. Vocalis muscle activity was confirmed using endotracheal tube electrodes, and neck muscle contraction was detected by visual inspection. Nerves in which electrical stimulation induced no response were excluded from the analysis.

Data analysis

Among the six points on the vagal nerve (medial caudal, lateral caudal, medial middle, lateral middle, medial rostral, and lateral rostral), the point at which the lowest intensity stimulus-induced vocalis muscle activity was regarded as the most sensitive. The most sensitive point was located and referred to in the operative record or intraoperative monitoring reports of 40 patients. The thresholds of the most sensitive parts and all parts were evaluated. Furthermore, the other exposed nerves were stimulated during surgery, and the corresponding thresholds were evaluated.

RESULTS

VNS induced vocal cord responses in all 46 patients. None of the patients experienced complications suggestive of electrode misplacement, such as contraction of the neck muscles. The median thresholds of the most sensitive parts and all parts were 0.2 mA (range: 0.05–0.75 mA) and 0.25 mA (range: 0.15–1.5 mA), respectively [Figure 2a]. The medial middle part was the most sensitive part of the vagal nerve in the majority of the population (33 of 40 patients: 82.5%), followed by the lateral middle (29 of 40 patients: 72.5%), lateral caudal (12 of 40 patients: 30%), medial caudal (10 of 40 patients: 25%), lateral rostral (5 of 40 patients, 12.5%), and medial rostral (4 of 40 patients: 10%) parts [Figure 2b].

The other nerves were exposed and stimulated. Contraction of the sternohyoid muscle was induced in eight patients at a median threshold of 0.35 mA (range: 0.1–0.7 mA) [Figure 2c]. Contraction of the sternocleidomastoid muscle was induced at the median threshold of 0.2 mA (range: 0.1–0.2 mA) in the remaining three patients.

DISCUSSION

In the present study, VNS induced vocal cord responses in all 46 patients, and the locational variation of threshold ranged between 0.05 mA and 1.5 mA. The middle parts were most sensitive in 72.5–82.5 % of patients, the caudal parts in 25–30%, and the rostral parts in 10–12.5%. These results

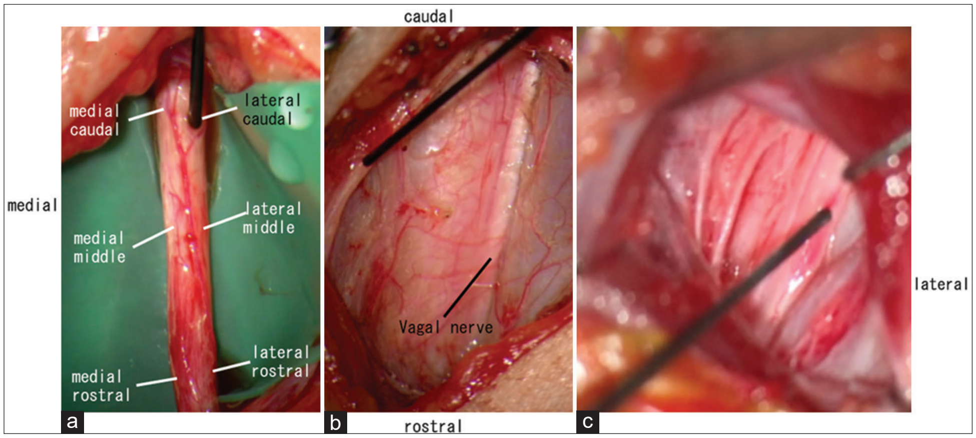

Figure 1: (a) Six points on the exposed vagal nerve (medial caudal, lateral caudal, medial middle, lateral middle, medial rostral, and lateral rostral) were stimulated, and the electromyographic activity of the vocal cords was recorded to check the thresholds. (b) The exposed nerve was stimulated and sternohyoid muscle contraction was induced. (c) The exposed nerve was stimulated and sternocleidomastoid muscle contraction was induced.

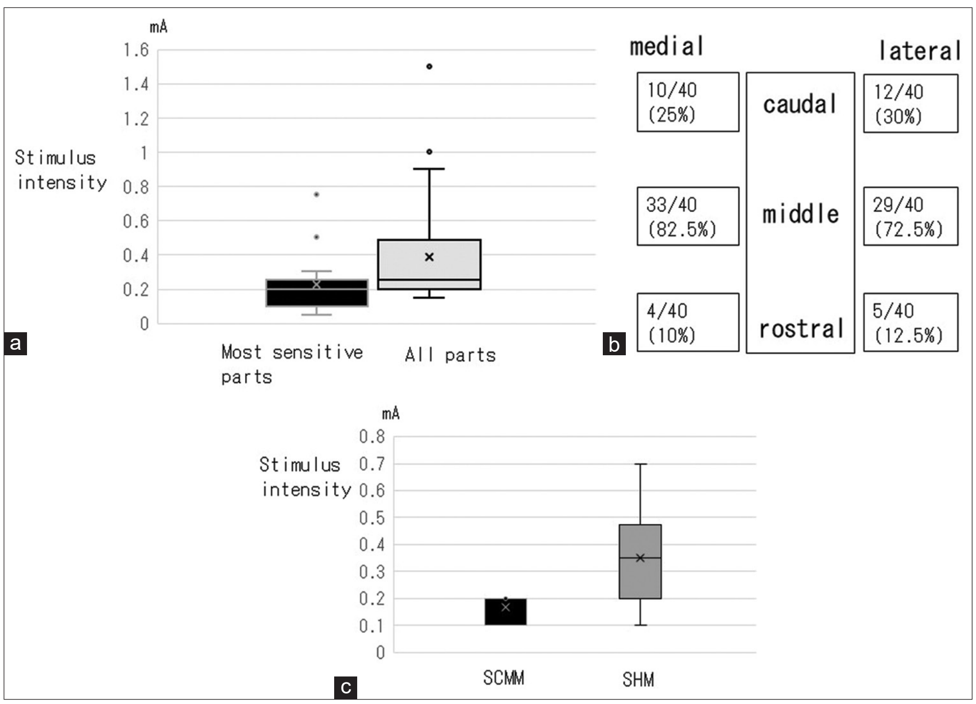

Figure 2: (a) The threshold of the most sensitive parts and all parts of the exposed vagal nerve to induce a vocal cord response. (b) The number and percentage of times each part was identified as the most sensitive part in all 40 patients. The medial middle parts were the most sensitive part of the vagal nerve in the majority of participants, followed by the lateral middle, lateral caudal, medial caudal, lateral rostral, and medial rostral parts. (c) The threshold of nerves to induce sternocleidomastoid and sternohyoid muscle contraction. SCMM: Sternocleidomastoid muscle, SHM: Sternohyoid muscle.

indicate that the middle part stimulation could minimize the stimulus intensities to induce vocal code responses. The vocal cord is innervated by the vagal nerve through the superior and recurrent laryngeal nerves. The recurrent laryngeal nerve branches directly originate from the vagal nerve, and the superior laryngeal nerve originates from the inferior ganglion.[7] For VNS surgery, the electrical current should be conducted primarily through direct propagation of the recurrent laryngeal nerve, rather than through inferior ganglion-mediated propagation to the superior laryngeal nerve.[14] Our results suggest that the rostral parts, closest to the recurrent laryngeal nerve, are the least involved in eliciting the vocal cord response, which is inconsistent with the previous model. We speculate that the locational variation in the threshold is caused by technical issues rather than anatomical differences. The vagal nerve is covered by connective tissue, and dissection from the connective tissue in the caudal and rostral parts of the vagal nerve tends to be insufficient due to the limited surgical space. The residual connective tissue might cause wide locational variation in the threshold. Based on the current results, we propose that careful dissection of the caudal parts with high thresholds and cathodal stimulation points is important to prevent inefficacy of VNS. In addition, the careful isolation of nerve bundles would improve the large variation of thresholds. However, the previous study reported that intraoperative neuro-monitoring does not improve voice outcomes after VNS.[8] The correlation between each threshold and clinical outcome should be clarified for future analysis.

Other nerves surrounding the vagal nerve were also exposed and stimulated in this procedure. Sternohyoid muscle contraction was induced in eight patients and sternocleidomastoid muscle contraction in three patients. The sternohyoid muscle is innervated by the ansa cervicalis,[9,12] and the nerve is activated at a stimulus intensity of 0.1–0.7 mA. The sternocleidomastoid muscle is typically innervated by the spinal root or part of the accessory nerve is well recognized, whereas it may receive innervation from the cervical plexus from C2 to 4, a branch originating from the ansa cervicalis and hypoglossal nerve.[1] Sternocleidomastoid muscle contraction was induced by stimulation at 0.1–0.2 mA. The ansa cervicalis, cervical plexus, and accessory nerve are all located close to the vagal nerve and may trigger the misplacement of electrodes on these nerves. Furthermore, the nerve root of the ansa cervicalis may descend as a single nerve trunk with the vagal nerve.[4] Misplacement of the electrodes or involvement of these nerves may cause neck muscle contraction; although this complication is rare, with an incidence rate of only 2–3%, it is a burdensome complication that nevertheless needs to be avoided.[4,5,13] In the limited operative view of the VNS, our monitoring technique accurately identified the vagal nerve and prevented this complication. Usami *et al*. reported the vagus nerve evoked potential as a marker for afferent nerve impulses [16]. We need to compare the utility of our technique with the vagus nerve evoked potential.

This study had several limitations. The first was the small number of stimulated nerves innervating the sternohyoid and sternocleidomastoid muscles; unfortunately, our results were insufficient to establish a threshold for these nerves. Second, the course of these nerves varies widely, and precise anatomical identification is difficult. Third, the vagal nerve might have been rotated by dissection. Therefore, the six points of VNS may have shifted from the original anatomical position. We laid the rubber sheet under the vagus nerve before the stimulation. The placement of a rubber sheet could align the vagus nerve and prevent nerve rotation. Fourth, visual inspection has the limitation of identifying all contracted muscles, which might have caused some muscle responses to be overlooked.

CONCLUSION

This study revealed that intraoperative VNS successfully induced vocal cord responses with a locational variation of the threshold between 0.05 mA and 1.5 mA. The middle part of the exposed vagal nerve had the highest probability of inducing a vocal cord response. Furthermore, the nerves innervating the sternohyoid and sternocleidomastoid muscles, such as the ansa cervicalis, cervical plexus, and accessory nerve, can be exposed and differentiated from the vagal nerves by electrical stimulation of 0.1–0.7 mA. A deeper knowledge of these characteristics will enhance the effectiveness and reliability of this technique.

Declaration of patient consent

Patients' consent not required as patients' identities were not disclosed or compromised.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The author(s) confirms that there was no use of Artificial Intelligence (AI)-Assisted Technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

REFERENCES

1. Brennan PA, Alam P, Ammar M, Tsiroyannis C, Zagkou E, Standring S. Sternocleidomastoid innervation from an aberrant nerve arising from the hypoglossal nerve: A prospective study of 160 neck dissections. Surg Radiol Anat 2017;39:205-9.
2. Chiba R, Enatsu R, Ochi S, Yamada S, Sasagawa A, Suzuki H, *et al.* Intraoperative monitoring for vagus nerve stimulation. World Neurosurg 2019;131:191-3.
3. Giordano F, Zicca A, Barba C, Guerrini R, Genitori L. Vagus nerve stimulation: Surgical technique of implantation and

revision and related morbidity. Epilepsia 2017;58 Suppl 1:85-90.
4. Gopalakrishnan CV, Kestle JR, Connolly MB. The "vagal ansa": A source of complication in vagus nerve stimulation. J Neurosurg Pediatr 2015;15:535-8.
5. Iriarte J, Artieda J, Alegre M, Schlumberger E, Urrestarazu E, Pastor MA, *et al.* Spasm of the sternocleidomastoid muscle induced by vagal nerve stimulation. Neurology 2001;57:2319-20.
6. Kahlow H, Olivecrona M. Complications of vagal nerve stimulation for drug-resistant epilepsy: A single center longitudinal study of 143 patients. Seizure 2013;22:827-33.
7. Kruse E, Olthoff A, Schiel R. Functional anatomy of the recurrent and superior laryngeal nerve. Langenbecks Arch Surg 2006;391:4-8.
8. Labuschagne J, Mutyaba D, Nel J, Casieri C. Intra-operative monitoring as an adjuvant to standard vagus nerve stimulation implantation. Childs Nerv Syst 2021;37:3809-16.
9. Meguid EA, Agawany AE. An anatomical study of the arterial and nerve supply of the infrahyoid muscles. Folia Morphol (Warsz) 2009;68:233-43.
10. Mikuni N, Satow T, Taki J, Nishida N, Enatsu R, Hashimoto N. Endotracheal tube electrodes to map and monitor activities of the vagus nerve intraoperatively. Technical note. J Neurosurg 2004;101:536-40.
11. Mikuni N, Usui N, Otsubo H, Kawai K, Kishima H, Maehara T, *et al.* Current status and future objectives of surgical therapies for epilepsy in Japan. Neurol Med Chir (Tokyo) 2021;61:619-28.
12. Prades JM, Gavid M, Dubois MD, Dumollard JM, Timoshenko AT, Peoc'h M. Surgical anatomy of the ansa cervicalis nerve: Which branch to use for laryngeal reinnervation in humans? Surg Radiol Anat 2015;37:139-45.
13. Rychlicki F, Zamponi N, Cesaroni E, Corpaci L, Trignani R, Ducati A, *et al.* Complications of vagal nerve stimulation for epilepsy in children. Neurosurg Rev 2006;29:103-7.
14. Shaffer MJ, Jackson CE, Szabo CA, Simpson CB. Vagal nerve stimulation: Clinical and electrophysiological effects on vocal fold function. Ann Otol Rhinol Laryngol 2005;114:7-14.
15. Spuck S, Tronnier V, Orosz I, Schönweiler R, Sepehrnia A, Nowak G, *et al.* Operative and technical complications of vagus nerve stimulator implantation. Neurosurgery 2010;67 2 Suppl Operative:489-94.
16. Usami K, Kawai K, Sonoo M, Saito N. Scalp-recorded evoked potentials as a marker for afferent nerve impulse in clinical vagus nerve stimulation. Brain Stimul 2013;6:615-23.
17. Vaughn BV, Bernard E, Lannon S, Mann B, D'Cruz OF, Shockley W, *et al.* Intraoperative methods for confirmation of correct placement of the vagus nerve stimulator. Epileptic Disord 2001;3:75-8.
18. Yokoyama R, Akiyama Y, Enatsu R, Suzuki H, Suzuki Y, Kanno A, *et al.* The immediate effects of vagus nerve stimulation in intractable epilepsy: An intra-operative electrocorticographic analysis. Neurol Med Chir (Tokyo) 2020;60:244-51.

How to cite this article: Kamada C, Enatsu R, Kanno A, Ochi S, Yamada S, Sato R, *et al.* Intraoperative nerve stimulation during vagal nerve stimulator placement. Surg Neurol Int 2023;14:312.