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REVIEW

Anesthetic Management of Patients for Vagal Nerve Stimulator Placement: A Narrative Review

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Abstract: Vagal nerve stimulation (VNS) is an established neuromodulation therapy used in the treatment of drug-resistant epilepsy and treatment-resistant depression. This therapy is expanding to avenues in autonomic disorders, heart failure, and chronic migraine. Utilization of this therapy is continuing to grow, and anesthesiologists will increasingly encounter patients undergoing primary implantation or revision of VNS devices. Understanding of device mechanisms, implantation techniques, and physiologic responses to vagal stimulation is imperative to safer perioperative management. This narrative review summarizes current evidence regarding vagal nerve anatomy, VNS device components, perioperative assessment, intraoperative considerations, and postoperative complications. A targeted literature review was performed to identify clinical trials, cohort studies, device safety analyses, and review articles related to anesthetic management of VNS implantation. Preoperative considerations include evaluation of seizure control, prior surgical history, psychiatric comorbidities, and familiarity with magnet function for terminating or increasing stimulation. Intraoperatively, the proximity of the surgical field to the airway requires secure endotracheal tube positioning and alternes to displacement. Direct manipulation of the cervical vagus nerve can elicit bradycardia, hypotension, and, rarely, asystole. Further, electrocautery use should be minimized, with bipolar techniques being preferred to decrease the risk of lead or generator damage. Postoperative management involves appropriate analgesia without excess respiratory depression, prevention of seizure recurrence, and recognition of complications. Hematoma, pocket infection, lead fracture, pulse generator migration, and vocal cord dysfunction are device-related and transient physical complications. Overall, anesthetic management for VNS implantation must take an individualized and comprehensive approach that encompasses patient-specific factors, surgical technique, and device characteristics.

Keywords: vagal nerve stimulation, neuromodulation, perioperative considerations, epilepsy, surgical implantation

Introduction

Vagal nerve stimulation (VNS) is a neuromodulation therapy used predominantly in the management of refractory epilepsy and, less commonly, treatment-resistant depression.[1] VNS has been increasingly utilized since its approval by the U.S Food and Drug Administration in 1997.[2] A growing number of patients are undergoing implantation or revision of these devices as the scope of neuromodulation therapies expands.[2] Thus, familiarity with perioperative management of patients undergoing VNS placement is increasingly important.[3] Despite drug-resistant epilepsy and depression having distinct disease processes, both involve abnormal brain signaling that can be influenced by vagus nerve stimulation. VNS works by sending electrical impulses through the vagus nerve to the brain, which can affect activity involved in seizure regulation and mood pathways.[4]

Implantation of the vagal nerve stimulator involves a cervical incision to expose the left vagal nerve, which is typically selected due to its lessened cardiac involvement compared to the right.[5] Electrode leads are then placed around the nerve, and a second incision is made for placement of the pulse generator subcutaneously in the anterior chest.[6] Although the procedure is well standardized, there are unique anesthetic challenges. The surgical field lies near the airway, which may require cautious endotracheal tube positioning and attentiveness for displacement or airway

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obstruction during surgery.[3] In addition, vagal nerve stimulation can induce bradycardia, hypotension, or other hemodynamic challenges, which further shows the importance of attentive anesthetic monitoring.[3] Patients undergoing VNS placement often have mood disorders, epilepsy, or autonomic dysfunction, and these underlying conditions can impact perioperative risk.[1]

Despite the widespread use of VNS implantation, perioperative management strategies vary widely.[3,5] Prior surgical history, patient size, anatomy, comorbidities, device type, and individual responses to treatment all contribute to the lack of conformity involving anesthetic management and placement of the device.

This narrative review aims to give an overview of the significant considerations involved in the anesthetic management of patients undergoing VNS implantation. We outline the pertinent anatomy and physiology of the vagal nerve, describe the components of the vagal nerve stimulator device, highlight preoperative and intraoperative management strategies, and discuss postoperative challenges and device-related complications.

Vagal Nerve Anatomy and Physiology

The vagus nerve originates from nuclei in the medulla oblongata, including the dorsal motor nucleus, nucleus ambiguous, nucleus solitarius, and spinal trigeminal nucleus.[7] It exits the skull from the jugular foramen and descends within the carotid sheath, between the internal jugular vein and the internal carotid artery.[8] As the longest cranial nerve, it contains both sensory and motor fibers and has several cervical branches before entering the thorax.[6] The vagus nerve provides parasympathetic innervation to the heart, lungs, and upper abdominal organs and forms an essential neural connection between the brain and visceral organs.[9]

The vagus nerve integrates autonomic and immune signals while playing a role in the parasympathetic nervous system, mediating the rest and digest functions and inflammatory regulation.[9] It also participates in the cholinergic anti-inflammatory pathway, which highlights its immunomodulatory capacity.[9] Additionally, the gut-brain axis relies on the vagal signals, which influence mood, cognition, and neurobehavioral processes.[10]

The vagus nerve serves as a neuroendocrine-immune integrator that maintains homeostasis across the body systems.[11] The nerve contains predominantly unmyelinated C-fibers and a smaller proportion of myelinated A- and B-fibers, which transmit visceral sensory information and autonomic output.[11] Neurotransmission is primarily cholinergic, though noncholinergic and non-adrenergic pathways also contribute to its vast physiologic effects.[11] Additionally, vagal stimulation can influence inflammation, mood regulation, and pain perceptions.[9] These diverse autonomic, immune, and neurobehavioral functions provide the foundation for therapeutic vagal nerve stimulation and highlight the importance of understanding cervical vagal anatomy during device placement.

Overview of Vagal Nerve Stimulator and Device Components

The VNS system includes components allowing for precise targeting of neuromodulation. The implantable pulse generator, primarily positioned in the left anterior chest, is a battery-powered device that sends electrical signals.[5] A lead connects the generator to an electrode wrapped around the left cervical vagus nerve via a subcutaneous pathway.[5] These components work together to provide stimulation based on individual patient needs.

Additionally, many systems use an external magnet control to allow patients to change stimulation. The magnet can add an additional burst or stop the stimulation, depending on device programming.[2] There are also operating modes, such as manual, automatic, and chronic stimulation, for different clinical scenarios.[2]

Both invasive and noninvasive VNS systems can be implemented. Invasive systems involve surgical implantation of pulse generators and leads connected to the vagus nerve, while noninvasive systems target branches of the vagus nerve using surface electrodes.[12] There is a spectrum of implanted stimulators and transcutaneous systems that deliver current through the skin.[12] Transcutaneous VNS may be particularly advantageous in patient where invasive implantation is not feasible or difficult, such as those with prior radical neck dissection or extensive cervical scarring.[13] There are many hardware generations and models, which allow clinicians to make individual adjustments and cater to patient needs. Recent generations of implantable stimulators use closed-loop generators that detect physiological signals and adjust stimulation in real time.[2] These devices aim to engage afferent and efferent vagal pathways of multiple organ systems to regulate autonomic tone.

Preoperative Considerations

It is essential that understanding of the device, its functions, and potential interactions with anesthetic care are considered in preoperative assessment for patients undergoing vagus nerve stimulator (VNS) implantation. Clinicians should be aware of the external magnet, as it can temporarily inhibit or increase stimulation, and may be used intraoperatively to manage seizures or apnea events.[14] Close monitoring for seizure activity and airway compromise is important for patients undergoing this procedure for seizure control. Overall, anesthesiologists should be aware of the mechanics of vagal nerve simulation devices.

Preoperative planning must also consider potential interactions between the VNS device and anesthetic or surgical interventions. Potential issues include device interference, hemodynamic changes, and respiratory complications.[15] Anesthetic planning should consider vagal nerve stimulation activation on autonomic tone and the cardiac rhythm.[16] Additionally, during placement of the device, bradyarrhythmia and asystole can occur during device implantation or activation.[17] This procedure may exacerbate sleep-disordered breathing due to autonomic effects.[18] Overall, preoperative preparations should integrate the patient's neurologic, respiratory, and cardiovascular status with an understanding of VNS function.

Intraoperative Considerations

Intraoperative management of vagus nerve stimulator placement may present challenges due to the potential for vagal-mediated hemodynamic instability as well as technical considerations associated with device implantation.[16]

Patients are typically placed in the supine position with the head extended and contralaterally rotated to optimize access to the left vagus nerve.[16,19] General anesthesia with endotracheal intubation is a common approach that provides a secure airway during neck manipulation and lead tunneling.[19] While rare, regional or local anesthesia have been reported in select cases, however general anesthesia with endotracheal intubations remains the standard approach for primary VNS implantation.[20]

Propofol-based total intravenous anesthesia offers advantages in reducing airway reactivity and facilitating rapid emergence.[21] Opioid choice should balance adequate analgesia while minimizing respiratory depression. Neuromuscular blockers can be used safely.[14]

Implantation of the electrodes requires manipulation of the common carotid artery and internal jugular vein within the carotid sheath.[19] The common carotid artery is medial to the vagus nerve while the internal jugular vein is lateral inside the sheath.[19] In reoperation cases, scar tissue and adhesions may make dissection of the vagus nerve from surrounding vasculature challenging.

Bradycardia and transient asystole are well-documented intraoperative risks during vagal nerve stimulator lead placement and impedance testing.[16] Several studies have demonstrated that direct manipulation of the vagus nerve or initial stimulation can produce abrupt vagally mediated bradyarrhythmia.[3,16] Adequate anesthetic monitoring should be done to detect hemodynamic instability.

To prevent damage to the vagal nerve stimulator or insulation of the leads, electrocautery should be avoided.[16] When electrocautery is necessary, bipolar cautery is preferred over monopolar.[16] When monopolar cautery is unavoidable, the grounding pad should be placed so that there is minimal current flow across the generator site.[16] These precautions may reduce the risk of insulation damage or future lead malfunction.

The procedure includes two incisions: the left cervical incision for lead placement and the left upper chest incision for placement of the generator.[5,19] Multimodal analgesia, including local anesthetic infiltration, acetaminophen, and low-dose opioids as needed, may provide effective analgesia for both sites.[22]

Postoperative Management

After implantation of the vagus nerve stimulator, patients should be monitored with standard procedures for electrocardiography, pulse oximetry, and vital signs.[16,23] Airway patency should be noted after neck manipulation and extubation, and hemodynamic stability should be monitored for vagally mediated bradycardia or hypotension.[16,24] Because primary VNS implantation involves placement of permanent hardware, perioperative antibiotic prophylaxis is

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commonly considered to reduce the risk of generator pocket infection.[25] Patients should also be monitored for post-operative dysphonia, as left sided vocal cord palsy is a rare, but possible complication.

Postoperative neurologic management should focus on seizure control, particularly if the vagus nerve stimulator was placed for refractory epilepsy. Immediate resumption of antiepileptic medications is important, and intravenous or alternative formulations should be administered if enteric intake is delayed.[26] Timing and parameters of initial device activation should be determined before patient discharge.

Pain arises from the cervical incision and the subcutaneous generator pocket. Inadequate analgesia may cause hypertension, tachycardia, and agitation.[27] Opioid overuse should be avoided to prevent respiratory depression. Local anesthetics, acetaminophen, NSAIDS, regional nerve block, or short-acting opioids may be used for pain management. Postoperative nausea and vomiting may arise.[16] Prophylactic antiemetics should be considered, especially when opioids are used.[28]

Device Related Complications

Device-related complications following vagus nerve stimulator implantation may occur in both the early postoperative period and long term.[29] Hardware issues, lead integrity problems, generator pocket complications, and stimulation-related adverse events are possible.[29] Awareness of these complications is critical for physicians, and these risks should be made known to the patient.

The most significant device-related complications involve the vagal nerve stimulator leads or the generator system.[29] Reported hardware complication rates vary from 0.2–3.7%.[29] Lead fracture is the most common cause of device malfunction.[29] Lead fracture or insulation degradation typically causes an immediate loss of therapeutic benefit or intermittent vagal nerve stimulation.[30] Radiography may confirm the complication, and surgical correction is usually necessary.[30]

Lead disconnection at the connector block is less common but may result in sudden cessation of vagal nerve stimulation or sporadic device activation.[30] Improper routing or excessive tension placed on the stimulator leads during implantation may increase the risk of late dislodgment or fracture.[31]

Generator malfunction is rare but can occur due to battery depletion, manufacturing defects, or internal circuitry issues. In some cases, spontaneous "auto-on" behavior or irregular, unintended stimulation patterns have been described, which require urgent evaluation and possible reprogramming.[29]

The subcutaneous generator pocket may result in hematoma or seroma formation, which may cause localized pain, swelling, and increased risk of infection.[32] Poorly fitting generator pockets may create excess tension on the overlying skin, increasing the likelihood of device migration or erosion through the skin.[33] Pocket infections may require explanation due to difficulty neutralizing the infection on implanted hardware.[34,35]

Stimulation-related complications may arise in a dose-dependent manner and may improve with parameter adjustments. Voice alteration, throat discomfort, cough or choking sensation during stimulation, dyspnea, dysphagia, obstructive apneas, hypopneas, and chest discomfort are possible complications that generally decrease with long-term use for most patients.[14,16,36]

Manipulation of the vagus nerve during lead placement can lead to transient or permanent vocal fold dysfunction. Vocal fold palsy occurs in approximately 1.4% of patients.[29] This may result in hoarseness, weak voice, cough, aspiration, or dyspnea.[16,37]

Rarely, vagus nerve stimulator therapy has been associated with late-onset bradyarrhythmia and atrioventricular block.[16] Stimulation of vagal fibers can exert parasympathetic effects on cardiac conduction.[16] Management may require parameter adjustment or, in rare cases, pacemaker implantation.[38]

Discussion

Vagal nerve stimulator implantation brings forth several anesthetic considerations related to patient population, device characteristics, and surgical methods. Although the procedure is generally well tolerated, differences in autonomic function, psychiatric or neurologic comorbidities, and prior surgeries may influence perioperative risk. VNS is most commonly used to help treat the symptoms of drug-resistant epilepsy and treatment-resistant depression. These populations may differ in responses to anesthesia and vagal stimulation. Epilepsy patients often require continuation of antiepileptic drugs, which may interact with anesthetic metabolism.[26] Additionally, the use of VNS is also expanding to conditions such as heart failure and migraines, which may introduce new perioperative challenges for anesthesiologists.[39] Patients with autonomic dysfunction may have altered responses to vagal stimulation, and these groups may require tailored anesthetic plans.

The closeness of the surgical field to the airway and the potential for hemodynamic changes must be accounted for during intraoperative management. Manipulation around the carotid sheath can displace the endotracheal tube, making secure tube placement and frequent assessment important. Airway vulnerability is particularly relevant in patients with limited neck mobility, obesity, or coexisting sleep disordered breathing, where minor displacement of the endotracheal tube can cause hypoventilation or obstruction. Comorbid sleep-disordered breathing is common in both epilepsy and depression populations and may increase postoperative airway risk.[18] Stimulation of the cervical vagus nerve may cause bradycardia, hypotension, or, in rare cases, asystole. Careful selection of anesthetics and meticulous hemodynamic monitoring can help reduce these risks. Opioid use should be balanced to provide pain relief but avoid respiratory depression.

Device-specific factors also contribute to intraoperative variability. External magnets can be used to temporarily interrupt or activate stimulation. This may be helpful in confirming proper device function and preventing unnecessary revisions. Electrocautery can interfere with the pulse generator or lead insulation, so bipolar cautery is preferred when possible.[16] When monopolar cautery must be used, placement of a grounding pad should minimize electrical current across the generator pocket or cervical leads.[16]

Postoperative considerations include monitoring for respiratory stability, seizure recurrence, and signs of device-related complications. Stimulation-related symptoms such as hoarseness, throat discomfort, or cough can occur but are typically transient and improve with adjustments. Pocket hematoma, seroma, infection, and lead-related complications may appear in the post-operative period. These complications should be quickly addressed to prevent loss of therapeutic effect or device failure.

Overall, VNS implantation perioperative strategies vary widely. As VNS therapy expands to treat different patient populations and newer generations of devices develop, updated management and recommendations may improve consistency and safety. Future studies should evaluate whether specific anesthetic techniques reduce stimulation-related complications. More evidence is also needed to guide perioperative management in patients with indications other than epilepsy, such as heart failure. Continued research focusing on anesthetic techniques, device interactions, and long-term outcomes is needed for best practices and optimization of care for patients undergoing VNS implantation.

Conclusion

Anesthetic management for vagal nerve stimulator placement requires awareness of the device components, surgical approach, and the physiologic effects of vagal stimulation. Differences in patient population, protocols, and autonomic function contribute to variability in perioperative risk. During implantation, care in selecting opioids and monitoring of vitals is essential to avoid respiratory depression, hypotension, or bradycardia. Device-related complications such as lead fracture, generator migration, and pocket infection can occur. Stimulation complications may include transient hoarseness, throat discomfort, or dysphagia. The results of vagus nerve stimulation are greatly dependent on patient populations. Differing outcomes across clinical populations suggest that standardized perioperative strategies and consistent post-operative follow-up may help improve safety and optimize results for patients undergoing VNS implantation.

Compliance with Ethical Guidelines

This article is based on previous studies and contains no new studies with human participants or animals performed by any authors.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas, took part in drafting, revising, or critically

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