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Airway Management And The Hypoglossal Nerve Stimulator For Obstructive Sleep Apnea Patients

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Abstract

The pathophysiology of obstructive sleep apnea (OSA) relates to anatomical and non-anatomical factors. Anatomical considerations correlate to narrowing of the pharynx. When present, non-anatomical factors can intensify the severity of OSA and ease of collapsibility of upper airway tissue. The negative consequences of untreated OSA are well-defined and many treatment options are available. The novel hypoglossal nerve stimulator makes for a viable treatment option in patients who do not tolerate more traditional therapy, such as continuous positive airway pressure (CPAP), and meets eligibility requirements of device implantation as outlined by the Food and Drug Administration (FDA). The Inspire® Hypoglossal Nerve Stimulator has been FDA-approved since 2014. With countless reports of OSA patients who struggle to comply with CPAP therapy, this device appears to have widespread application. As successful implementation of the Hypoglossal Nerve Stimulator (HNS) continues to grow, the anesthesia provider should be informed on how to safely provide anesthetics for patients with the hypoglossal nerve stimulator. This article discusses the pathophysiology of the obstructing nature of OSA and evaluates how airway management could differ in the future with anesthetized spontaneously breathing OSA patients that have the novel hypoglossal nerve stimulator compared to patients managed by more traditional therapies.

Keywords: Obstructive sleep apnea, pathophysiology of obstructive sleep apnea, obstructive sleep apnea treatment, hypoglossal nerve stimulator, upper airway stimulation, airway management.

Airway Management and the Hypoglossal Nerve Stimulator for Obstructive Sleep Apnea Patients

As defined by Barash et al. (2017), obstructive sleep apnea (OSA) is the intermittent obstruction of the upper airway during sleep, which leads to oxygen desaturation and hypercarbia. These intermittent desaturations lead to nighttime awakening; manifesting into chronic sleep deprivation and subsequent daytime somnolence. In the untreated patient, chronic pulmonary hypertension and right heart failure can eventually develop secondary to the severity and frequency of the patient's obstruction. OSA patients receiving sedation, opioids, and/or volatile inhalation agents are extraordinarily susceptible to intraoperative and post-operative respiratory depression and airway obstruction induced by anesthetic agents. The high susceptibility to respiratory depression and airway obstruction can be attributed to the ease of airway collapse and sleep deprivation seen in OSA patients.

According to the American Academy of Sleep Medicine (AASM) (2014), it is estimated that OSA affects over 25 million adults in the United States alone. Motamedi et al. (2009) emphasize the prevalence of this disease and estimate nearly one in five adults have at least mild symptoms of OSA, whereas 1 in 15 adults have moderate to severe symptoms. Barash et al. (2017) suggest that roughly 26% of U.S. adults between the ages of 30 and 70 have OSA, with increasing incidence related to the epidemic of obesity.

Anesthesia providers are often the first to detect the presence or risk of OSA and should be cautious and vigilant in the preparation and administration of an anesthetic to a patient with known/unknown OSA (Butterworth et al., 2018). For that reason, it is imperative to understand how to correctly identify patients at risk for OSA. A safe anesthetic starts with a thorough history and physical examination performed by the anesthesia provider in the pre-operative setting.

Simply asking if a patient has sleep apnea or sleep disturbances is insufficient. More detail can be obtained by including the following questions in the pre-operative interview: Has anyone told you that you snore at night? Has anyone ever observed you stop breathing in your sleep? Do you feel tired and groggy when you wake up? Do you fall asleep during the day? Do you have headaches that occur in the morning? These questions can help clue the anesthesia provider in on whether or not a patient is at risk of having OSA and dive deeper into a patient's preanesthetic history and physical to formulate the safest anesthetic plan (Ogan & Plevak, 1998).

If a provider is concerned about a patient's risk for OSA, utilizing a screening tool for OSA can be beneficial. Screening tools such as the STOP-BANG questionnaire, Epworth Sleepiness Scale, or the Berlin questionnaire are available. According to a cross-sectional study of 1,003 sleep clinic patients by Oktay Arslan et al. (2020), the STOP-BANG questionnaire is the most sensitive tool in identifying high-risk OSA patients when compared to the Berlin questionnaire or the Epworth Sleepiness Scale.

Bernhardt et al. (2021) performed a systematic review and meta-analysis of observational studies assessing the diagnostic value of OSA screening questionnaires and found similar results, stating that the STOP-BANG questionnaire had the highest sensitivity to detect OSA but lacked specificity. This review aims not to discuss the accuracy of different OSA screening tools in detail; however, these screening tools can help the anesthesia provider identify patients with an increased risk for OSA.

Pathophysiology of Obstructive Sleep Apnea

The pathophysiology of OSA primarily involves the pharynx, a passageway that houses the muscles and tissues involved in breathing. OSA patients have altered upper airway anatomy, which can compromise the patency of the pharynx. This leads to the obstructive characteristic of

OSA, resulting in cessation of airflow and consequential oxygen desaturation associated with the disease process. When comparing upper airway imaging of patients with and without OSA, OSA patients have a smaller cross-sectional area of the pharynx. The primary cause of this anatomic narrowing is attributed to cervical obesity, which is the accumulation of adipose tissue deposition encompassing the pharynx, neck area, and throat muscles (Heiser & Eckert, 2019). Research shows that the exact location of adipose tissue buildup is crucial in the OSA disease process. To emphasize this finding, Heiser and Eckert (2019) go on to say that the amount of fatty tissue in the tongue of OSA patients is higher than the amount of fatty tissue in the tongue of non-OSA patients that are equally obese.

Another anatomic contributing factor to OSA is central obesity. Central obesity, as defined by the World Health Organization criteria, is a waist circumference of greater than 94 cm for men and a waist circumference of greater than 80 cm for women or a waist-to-hip ratio of greater than 0.90 in men, and a waist-to-hip ratio of greater than 0.85 in women (Owolabi et al., 2017). Central obesity leads to increased intra-abdominal pressures that influence the diaphragmatic position and negatively impact the degree of caudal tracheal traction, also known as axial tension, exerted on the upper airway (Stadler et al., 2009). These compounding factors contribute to the increased likelihood of upper airway collapse. The deleterious effects are amplified in the supine position, particularly during sleep, when compensatory mechanisms to airway collapse are diminished. Stadler et al. (2009) state that caudal tracheal traction is linked to decreased upper airway collapsibility and extraluminal tissue pressure in anesthetized rabbit studies, thus suggesting a mechanical interdependence between the diaphragm, intrathoracic, and upper airway structures.

For this reason, caudal tracheal traction is one crucial aspect that helps maintain pharyngeal patency. Caudal tracheal traction is compromised in the centrally obese patient. In addition, central obesity contributes to a decrease in lung volume secondary to excessive visceral fat deposition, which in turn decreases caudal tracheal traction (Stadler et al., 2009).

Anatomic collapsibility of the upper airway plays a vital role in the cessation of airflow; however, OSA is not solely an anatomical issue. OSA would occur in the awake patient if that were the case. An observational study by Tong et al. (2019) used dynamic magnetic resonance imaging (MRI) to demonstrate that caudal tracheal displacement is more pronounced during inspiration in awake OSA patients when compared to awake healthy individuals. This study helps support the same idea that Stadler et al. (2009) pioneered. Softer pharyngeal muscles and greater inspiratory forces in OSA may emphasize the need for greater tracheal excursion present in awake patients. These findings support the idea that tracheal displacement assists in the maintenance of pharyngeal patency during wakefulness (Tong et al., 2019). Caudal tracheal traction is negatively impacted in the sleeping or anesthetized OSA patient, contributing to ease of upper airway collapsibility observed in these patients.

Non-anatomic factors that contribute to the OSA disease process include the ineffective function of the upper airway dilator during sleep, decreased pharyngeal muscle reactivity and effectiveness, and changes in the cortical excitation threshold. The cortical excitation threshold contributes to patient arousal related to airway obstruction. The alteration in cortical excitation threshold contributes to the variability and instability seen in the respiratory control system of OSA patients. The extent to which these non-anatomical factors contribute to the disease process varies significantly between patients (Heiser & Eckert, 2019). Mention of non-anatomical factors associated with OSA is not aimed to diminish the importance of craniofacial anatomic conditions

that contribute to narrowing of the pharynx, but rather to emphasize the complexity of other pathogenetic factors associated with the OSA disease process.

Obstructive Sleep Apnea Severity Classification

The American Sleep Apnea Association (ASAA) helps define the different severity levels of OSA through a number referred to as the apnea-hypopnea index (AHI) score. AHI scores indicate the number of times a patient stops breathing (apnea event) plus the number of times a patient has shallow breathing (hypopnea event) every hour on average. For each apnea and hypopnea event to count, the event must last at least 10 seconds in duration. The AHI score is then calculated by dividing the number of events by the number of hours of sleep. Mild OSA is considered an AHI score of 5-15. Moderate OSA is considered an AHI score of 15-30. Severe OSA is considered an AHI score of 30+ (ASAA, 2020).

Obstructive Sleep Apnea and Associated Comorbidities

OSA is a systemic disorder due to repetitive drops in oxygen levels with concurrent rapid reoxygenation, which can potentiate oxidative stress to every organ in the body. Consequences of this stress include hypertension, cardiovascular disease, increase incidence of cardiovascular events such as myocardial infarction, stroke, atrial fibrillation, and insulin resistance. In addition, these consequences increase cancer incidence, increase mortality, and increase neurodegeneration (Lim & Pack, 2017). According to Hines (2017), OSA patients' comorbidities may additionally include coronary artery disease, congestive heart failure, type 2 diabetes mellitus, nonalcoholic steatohepatitis (NASH), polycystic ovarian syndrome, Graves disease, hypothyroidism, and acromegaly.

The dangers OSA patients face are compounded because these patients are at increased risk for additional perioperative complications. For example, they are three to four times as likely

to be a difficult intubation or mask ventilation. In addition, a systematic review of 61 studies with >400,000 OSA patients and 8.5 million non–OSA patients found that the presence of OSA was associated with an increased risk of post-operative morbidities such as failed reintubations, anoxic brain injury, and even mortality (Urman et al., 2019).

With such high estimates of OSA prevalence in the general population and known comorbidities and anesthetic implications associated with the OSA disease process, what types of therapies are available, and how might these therapies affect anesthetic considerations like airway management?

Therapies for Obstructive Sleep Apnea

OSA patients can prevent many of the negative comorbidities associated with the disease process through multiple treatment options. According to Batool-Anwar et al. (2016), the gold standard treatment for OSA is continuous positive airway pressure (CPAP) therapy due to its improvements in quality of life and sleep-related symptoms. CPAP functions similarly to a vascular stent, although in the case of OSA, it stents the upper airway with constant positive pressure via mask interface, thus, significantly decreasing AHI scores per hour of sleep.

Unfortunately, CPAP use remains problematic for many OSA patients due to mask discomfort, claustrophobia, pressure intolerance, and lifestyle and social considerations. In addition, patients who struggle to comply with CPAP therapy often complain of symptoms such as dry or irritated nasal pharyngeal membrane, nasal congestion, and eye irritation from air leakage around the mask (Pavwoski & Shelgikar, 2017). Lack of adherence to CPAP therapy limits the effectiveness of this treatment across all age groups. According to Sawyer et al., "Factors that influence adherence to CPAP include disease and patient characteristics, treatment

titration procedures, technological device factors, side effects, and psychological and social factors" (2011).

Another form of positive pressure therapy seen in the treatment of OSA patients is bilevel positive airway pressure (BiPAP). BiPAP was designed to administer a varying pressure between inspiratory and expiratory cycles, increasing tolerance of higher pressures on inhalation and lower pressures on exhalation. A more significant inspiratory pressure combats limitations related to upper airway inspiratory flow, which results in a greater tidal volume and unloads the workload of respiratory muscles compared to CPAP. BiPAP is designed to combat the hypoventilation and subsequent CO_2 increase seen in OSA patients (Morgenthaler et al., 2008). BiPAP therapy is another form of positive pressure ventilation; thus, the same issues of intolerance and non-compliance are present.

In addition to positive pressure therapies, newer treatment options are available. According to Foldvary-Schaefer and Waters (2017), positive pressure ventilation remains the gold standard in OSA treatment. However, innovative therapies like mandibular advancement devices, oral appliance devices, and hypoglossal nerve stimulation have become available. Oral appliance devices work by enlarging the upper airway and decreasing its collapsibility. Mandibular advancement devices are more commonly used to cover the upper and lower teeth and hold the mandible in the forward position (Gagnadoux et al., 2009). Mandibular advancement devices are generally recommended for patients with mild to moderate OSA. However, these may be utilized in severe OSA patients who are unwilling or unable to use CPAP, have good dentition, and have a Body Mass Index (BMI) below 30 kg/m^2. Although mandibular devices may prove beneficial in treating the obstruction seen in OSA, often, this

therapy results in the alteration of the patient's occlusion or dentition, requiring discontinuation of therapy.

It is estimated that one in three patients do not tolerate traditional treatment options, which opens the door to alternative therapies like the Hypoglossal Nerve Stimulator (HNS). This novel treatment is available for patients with positive pressure therapy intolerance or patients in which positive pressure therapy has failed due to compliance issues (Vonk et al., 2019).

According to the Stimulation Therapy for Apnea Reduction (STAR) trials, of the 126 participants that received hypoglossal nerve stimulation therapy, 68% observed a decrease in AHI scores after 12 months of therapy. In addition, this study found that hypoglossal nerve stimulation led to significant improvements in both objective and subjective measurements of the severity of OSA (Strollo et al., 2014).

Hypoglossal Nerve Stimulator

Surgical options are available if OSA patients struggle to comply with positive airway pressure therapy and/or oral appliance therapy, such as pharyngeal surgery, sinus surgery, nasal surgery, skeletal surgery, and the novel hypoglossal nerve stimulator. The hypoglossal nerve stimulator is a device that sits in the right chest cavity, similar to a pacemaker in the left chest cavity. The device is connected to a wire attached to a small cuff that wraps around the hypoglossal nerve. During inspiration, the respiratory sensing lead communicates with a pulse generator, telling the stimulation lead to excite the hypoglossal nerve to project the tongue forward, opening the pharyngeal airway and helping maintain upper airway patency (Woodson et al., 2016). After a few weeks of healing, the device is activated in the office, and the patient is taught how to use and remotely control the hypoglossal nerve stimulator.

When the patient goes to bed in the evening, the device is turned on via remote control. However, the device will not immediately turn on. After a sleep timer delay and the patient is asleep, the respiratory sensor, which sits in the intercostal space, synchronizes to the patient's inherent respiratory pattern, allowing the pulse generator to time a pulse sent to the hypoglossal nerve electrode, causing the genioglossal muscle and upper airway dilator muscles to move forward, opening the patients' airway and preventing obstruction.

An intriguing factor regarding many of the surgical procedures relating to the head and neck is the inability of these surgeries to address the non-anatomical issues associated with OSA. OSA is complex in nature, and many patients may have issues such as abnormal hypoglossal nerve conduction or issues related to the upper airway dilator muscles involving tracheal traction, among other problems with altered respiratory center feedback loops. When these issues occur, traditional surgeries and oral appliance devices may not provide cessation of OSA symptoms or effective treatment in managing OSA when compared to the hypoglossal nerve stimulator.

Literature Review

The Inspire® HNS was used in 8 of the 12 studies included in a systematic review and meta-analysis that followed patients who received hypoglossal nerve stimulators. Constantino et al. (2019) found that the Inspire® HNS surgical success rate was 75% at the 60-month follow-up. Surgical success was defined as 50% reduction in AHI scores and an overall AHI score of less than 20. In a meta-analysis of the Inspire® HNS, Constantino et al. found that ODI scores improved by 63.6% at 60 months, showing the effectiveness and success of HNS therapy.

Neruntarat et al. (2021) performed the most recent meta-analysis on the hypoglossal nerve stimulator to date. This analysis sourced data from PubMed, Ovid MEDLINE, Cochrane Library, Web of Science, and Scopus. Five articles met the researcher's inclusion criteria totaling

990 patients participating in randomized trials or observational studies. Inclusion criteria were: all participants had to be adults (considered greater than 18 years of age), with sleep apnea or a diagnosed sleep disorder. In addition, all patients had to undergo either a traditional OSA surgical procedure or hypoglossal nerve stimulation with the Inspire® HNS implant. Traditional OSA surgeries included in the meta-analysis were uvulopalatopharyngoplasty or UPPP, Transoral robotic surgery (TORS) for tongue reduction, and other various palatal or tongue procedures. The primary outcome in comparing traditional OSA surgeries and hypoglossal nerve stimulation groups was AHI scores. Secondary outcomes were evaluated with the Epworth Sleepiness Scale, oxygen saturation nadir, success rate, cure rate, snoring, length of stay, readmission rate, and complications.

Neruntarat et al.(2021) found hypoglossal nerve stimulation to be more advantageous and successful in the management of OSA when compared to traditional OSA surgeries for selected patients. It was observed that patients who underwent hypoglossal nerve stimulator implantation had an AHI reduction (23.9 vs.15.8, $P< 0.001$), including a reduction in the oxygen desaturation index when compared to the traditional OSA surgery group. Not only did these patients benefit from significant AHI reduction, but they also had shorter hospital stays, lower readmission rates, and a lower incidence of adverse events. The researchers conclude that upper airway stimulation provided objective improvements in AHI scores, oxygen saturation nadir, success rate, cure rate, and comparable subjective outcomes in the Epworth Sleepiness Scale when compared to traditional OSA surgical procedures.

STAR Trials

Strollo et al. (2014) performed a multicenter prospective single-group cohort study that followed 126 participants across the United States and Europe. 83% of participants were male,

and the mean age was 54.5 years of age after HNS implant. The authors found the median AHI scores at 12 months decreased by 68%. In addition, they found patients AHI scores dropped from 29.3 to 9, and the participants' oxygen desaturation index score decreased by 70%. The authors define the oxygen desaturation index as the number of times the blood oxygen level drops by ≥4 percentage points from the patient's baseline per hour of sleep. After the 12-month mark, Strollo et al. also performed a randomized controlled therapy withdrawal study as part of the STAR trial in which 46 responding subjects were randomized into a therapy maintenance group and a therapy withdrawal group. Minimal changes in AHI scores were observed among the 23 participants in the therapy-maintenance group compared to the 12-month scores as represented by 7.2 AHI events per hour. However, AHI scores were significantly higher at 25.8 events in the therapy-withdrawal group, indicating more severe apnea among the 23 participants that did not have the device turned on. In addition, this study's therapy withdrawal group showed an average increase in AHI scores of 18.2 events per hour, whereas the average increase in the therapy-maintenance group was 1.7 events per hour.

Post-operative Complications

Van Daele et al. (2021) set to compare the post-operative complication rates between traditional OSA surgery and hypoglossal nerve stimulation as well. The researchers obtained data for traditional OSA surgery from the National Surgery Quality Improvement Program (NSQIP) database. NSQIP is a nationally validated, risk-adjusted outcomes registry maintained by the American College of Surgeons. The researchers then obtained data related to the hypoglossal nerve stimulator from the Adherence and Outcome of Upper Airway Stimulation for OSA International Registry (ADHERE registry). The outcomes were prospectively collected by chart review of over 2,000 patients separated into two groups. The first group was referred to as

the obstructive sleep apnea surgery (OSAS) cohort and consisted of 447 individuals who met the OSA diagnosis and airway procedure eligibility criteria. After filtering for a BMI less than or equal to 35 kg/m^2, a total of 310 patients remained. The majority of this cohort consisted of overweight males with an average BMI of 29 kg/m^2 with hypertension and an average age of 42. Likewise, approximately 71% of the 310 patients studied underwent palatopharyngoplasty airway procedures.

In contrast, the HNS group consisted of 1,623 patients with an average age of 60 with hypertension as the primary comorbidity. The authors hypothesize that a lower average age in the OSAS group may be secondary to the concept that palatopharyngoplasty is less likely to be performed in older patients due to concerns of post-operative complications. The HNS cohort had a higher percentage of patients with comorbidities such as hypertension, diabetes, COPD, myocardial infarction, angina, congestive heart failure, peripheral vascular disease, and/or transient ischemic attack.

In comparing surgical times between the two cohorts, the OSAS group had a shorter operative time by an hour. The researchers propose the difference in operative times was likely related to the surgeons' learning curve. HNS is a newer procedure, so the expectation is surgical times will decrease as surgeons become more familiar with the implantation process. Regional differences account for varying lengths of stay and whether the procedure was an in-patient or outpatient procedure. In the United States, the HNS cohort had a shorter length of stay, whereas, in Europe, the OSAS cohort had a shorter length of stay. Similarly, the HNS cohort was less likely to be performed as an outpatient procedure in Europe. The authors cite local medical policy as the reason.

When comparing the 30-day post-operative complication rates, the OSAS had significantly higher rate of return to the operating room and surgical site infection. This statistic was interesting because the OSAS cohort was younger and had fewer overall comorbidities. Researchers cite post-tonsillectomy bleeding as the primary reason. With that said, HNS has shown high success with low complication rates making it a viable treatment option, particularly in the elderly population.

HNS is a new surgical intervention for OSA, and therefore there is no comprehensive database that contains data regarding patients undergoing traditional OSA surgical interventions and HNS. In addition, NSQIP does not specify the patients' OSA severity or positive airway pressure intolerance, making it difficult to assess or account for inherent similarities and differences between cohorts. Another limiting factor when comparing cohorts is differences in complications between surgeries. For example, patients undergoing HNS surgery could have a hematoma, pneumothorax, nerve injury, or device failure, whereas patients undergoing OSAS could have oropharyngeal bleeding, dehydration, dysphagia, and/or airway issues. Another limitation was the fact that there were significantly fewer patients in the OSAS cohort when compared to the HNS cohort, which may skew the comparison of the different cohorts.

Even with these limitations, the study concluded that hypoglossal nerve stimulator patients saw shorter hospital stays, a lower 30-day return to the operating room (0.1% of HNS vs. 4.8% OSAS), and lower surgical site infections (0.13% HNS vs. 0.9% OSAS) when compared to traditional OSA surgical procedures despite an older HNS cohort and subsequent higher prevalence of comorbidities (Van Daele et al., 2021).

Hypoglossal Nerve Stimulator Considerations

The device manual outlines treatment is reserved for moderate to severe OSA patients. The patient's AHI score determines the severity. The device manual defines apnea as the loss of air exchange, and hypopnea is the partial loss of air exchange. AHI scores indicate the average number of times a patient obstructs every hour. Patients who fall into the moderate to severe OSA category have an AHI score greater than or equal to 15 and less than or equal to 65. Patients who qualify for this therapy must be over the age of eighteen and must first fail or not tolerate positive airway pressure therapy (U.S. Food and Drug Administration, 2020).

Failure of positive airway pressure therapy is defined as having an AHI score greater than 15 despite using a positive airway pressure device greater than five nights per week for more than four hours per night (U.S. Food and Drug Administration, 2020). Failure can also be defined as an unwillingness to use positive airway pressure therapy as previously described.

Patients that fall into the moderate to severe OSA category and fail positive airway pressure therapy must also undergo drug-induced sleep endoscopy (DISE) to determine eligibility for device implantation. This is because the Inspire® HNS is not designed for OSA patients with concentric retropalatal collapse (Woodson et al., 2016). Therefore, DISE is crucial in determining which patients are eligible. The DISE examination evaluates the nasal passages, oropharyngeal space, and retroglossal area. In addition, DISE is performed to characterize the airway collapse pattern. The pattern and degree of collapse are scored according to the velum, oropharyngeal, tongue base, and epiglottis. Based on these scores, patients are excluded if DISE reveals complete concentric collapse at the retropalatal airway because the tongue's protrusion will not resolve that pattern of airway obstruction. (Gupta et al., 2018).

Other exclusion criteria exist for device implantation. The first exclusion criterion is the presence of any type of central or mixed apnea that makes up more than one-fourth of the patient's total AHI score. Hines (2017) defines central apnea as sleep apnea that is not associated with respiratory effort during the apnea event. The absence of respiratory effort is secondary to the instability of neural control of respiration and weakness of respiratory muscles. Upper airway stimulation would not benefit a patient who is not making a respiratory effort; therefore, it would not improve their AHI scores.

Additionally, patients who have any physical findings that could compromise the performance of upper airway stimulation should not be considered for device implantation. For example, this would be a patient who may have a tumor or growth in the airway that leads to blockage of the upper airway. Also, patients who have conditions that compromise the neurologic control of the upper airway are likewise not considered candidates. This would include patients who are unable to operate the device's remote control or do not have the necessary assistance available to help them operate the device.

Hypoglossal nerve stimulation is intended for patients with a BMI of 32 kg/m^2 or lower and is not indicated for larger patients (Woodson et al., 2016). This is echoed by the device manual, which states that patients should not receive device implantation if they have a BMI higher than 32 kg/m^2. The manual cites that these patients may have a decreased likelihood of response to treatment as the data from initial trials related to this device did not study patients with a BMI higher than 32 kg/m^2. As such, use of the Inspire® HNS in patients with a high BMI is not recommended due to the unknown safety and efficacy of the device in this population (U.S. Food and Drug Administration, 2020).

A retrospective observational study conducted by Parikh et al. (2018) set to determine the feasibility of hypoglossal nerve stimulation in patients with cardiac implantable electronic devices (CIED). The authors studied 14 male patients at five different centers across the United States who received hypoglossal nerve implantation and had some form of a CIED. Intraoperatively, testing confirmed that bipolar and unipolar hypoglossal nerve stimulation did not impact CIED sensing. In addition, it was determined that CIEDs had no oversensing episodes implying that the simultaneous use of hypoglossal nerve stimulation devices with CEIDs is safe and effective and without device-device interaction. The authors highlight the small cohort observed and acknowledge the need for continued investigation with both male and female genders represented. A case study by Ong et al. (2016) found similar evidence proving that an implantable-cardioverter-defibrillator (ICD) and the hypoglossal nerve stimulator can safely be used in the same patient. The authors say that because cardiac pacemakers and ICDs rely on similar cardiac sensing, they believe their data could be generalized to cardiac pacemakers implying that pacemakers may also be safely used in patients with HNS devices.

Another consideration for device implantation is magnetic resonance imaging (MRI) compatibility. The early models of the Inspire® HNS included the pulse generator model 3024, stimulation lead model 4063, and sensing lead model 4323. This version of the HNS was not MRI compatible. For those patients with the older implanted device, MRI scanning is contraindicated. In fact, the device manual from that model listed the need for routine MRI scanning as a contraindication to device implantation (U.S. Food and Drug Administration, 2014). However, according to the device manual of newer models, patients are eligible for specific MRI scans (U.S. Food and Drug Administration, 2020). Yu & Thaler (2020) specify that

patients with the most recent version of the hypoglossal nerve stimulator device can get MRI scans of the head and extremities without issue.

It should be noted that a new surgical technique related to implantation comes with the newer model. With careful preparation of the hypoglossal nerve, it was determined that excluding the lateral branches and including the medial branches of the hypoglossal nerve was critical in optimizing surgical success. By stimulating the hypoglossal nerve in this fashion, the tongue base protrudes due to genioglossus muscle activation, opening the airway in the retroglossal region (Gupta et al., 2018).

Precautions must also be considered as it relates to the anesthetic environment and diathermy. In patients who have the HNS already implanted, the anesthesia provider should be concerned with any form of diathermy. The device manual states energy from diathermy (this includes shortwave diathermy, microwave diathermy, or therapeutic ultrasound diathermy) can be transferred through the implanted system and cause tissue damage at the location of the implanted electrodes resulting in severe injury or death. Diathermy can damage the patient and damage the implanted components of the device, causing device failure and loss of therapy. If diathermy is used anywhere on the body (not just near the location of the implanted system), injury can occur to the patient and device, whether the generator is turned on or off. If the leads or generator remain in the body, damage can still ensue if the device is not in use (U.S. Food and Drug Administration, 2020).

If a patient already has the device implanted and is receiving subsequent surgery, the anesthesia provider should consider whether electrocautery will be used for that procedure. If electrocautery is planned, the electrocautery apparatuses should not be used near the stimulator or its leads and should not make contact with the stimulator or its leads. If cautery must be used,

bipolar cautery is preferred due to unipolar cautery transmission along the lead body, potentially causing nerve damage to the patient. Moreover, if electrocautery must be used in the vicinity of the generator, the device should be turned off (U.S. Food and Drug Administration, 2020).

If a procedure requires radiofrequency ablation, it should not be used directly over the implant site. If radiation therapy is indicated with this device, the generator should not be directly irradiated by therapeutic levels of ionizing radiation due to risk of permanent damage to the generator circuitry. If radiation therapy is indicated near the generator, then the device should be shielded, and proper function of the device should be confirmed after treatment (U.S. Food and Drug Administration, 2020).

X-ray and fluoroscopy will not affect the device generator or its leads. While ultrasound scanning poses no risk to the patient, it should not be used directly over the implant site as it could cause mechanical damage to the generator or its leads (U.S. Food and Drug Administration, 2020).

If the anesthetized patient has the hypoglossal nerve stimulator implanted and needs defibrillation or cardioversion, biphasic waveforms and energy delivered should be minimized. If paddles are used, they should be placed as far away from the implanted device as possible. When utilizing any of the discussed medical treatments, the provider should confirm normal system operations of the implanted device before the patient uses the stimulator (U.S. Food and Drug Administration, 2020).

Proposed Use of Hypoglossal Nerve Stimulator

With the surgical success rates seen in patients who have the Inspire® HNS, are there other ways to utilize the benefits this therapy offers patients? It seems reasonable that the anesthesia provider would want to utilize this device to help improve oxygenation and

ventilation in the anesthetized, obstructing OSA patient in the perioperative environment. However, there is currently no literature specifically addressing the feasibility of utilizing the HNS in the intraoperative or post-operative phase. This analysis provides a comprehensive overview of the hypoglossal nerve stimulator, its indications, contraindications, and considerations that the anesthesia provider must keep in mind related to this device. It also discusses how the device's success compares to traditional OSA surgical treatment options. Based on the current literature available regarding the hypoglossal nerve stimulator, it seems the most realistic situations in which the anesthesia provider may be able to utilize HNS therapy is the intraoperative and post-operative phase in which the patient has spontaneous respiratory effort and is obstructing.

This suggestion is the opinion of the author of this manuscript; however, there is no evidence yet published to support the intraoperative or post-operative use of the Inspire® HNS device. The intraoperative use of the Inspire® HNS device is suggested for patients that receive monitored anesthesia care (MAC) and spontaneously breathe during the entirety of the procedure. HNS would not aid in ventilation or oxygenation if the patient was not spontaneously breathing. If the patient is not making respiratory effort, the device cannot work.

Another consideration with utilization of HNS during procedures is the use of electrocautery. The anesthesia provider needs to ensure that bipolar cautery is used and that electrocautery is not used near the site of the implanted device or its leads. Something else to consider is how the sensing leads work. The respiratory sensing lead detects the patient's respiratory effort through a pressure-sensitive membrane that converts the mechanical energy of respiration into an electrical signal that travels to the pulse generator. The pulse generator then triggers the stimulation lead to deliver a stimulus to the medial branches of the hypoglossal nerve

via a flexible self-sizing stimulation cuff which encapsulates the hypoglossal nerve. Any MAC procedure that involves repetitive physical stimuli from the surgeon or the proceduralist could compromise the effectiveness of the respiratory sensing lead due to erroneous stimulation. Erroneous stimulation could lead to the delivery of stimuli that are not in sync with the patient's breathing pattern providing no benefit to relieving obstructions. This would likely rule out device use during any total joint procedure performed under MAC sedation with a spinal anesthetic due to excessive movement affecting the respiratory sensing lead.

Another issue with utilizing the HNS in the perioperative environment is the latent period that is programmed into the device. The latent period is designed to allow the patient to get to sleep before therapy kicks in for nightly use. However, if this period is prolonged, deep sedation with MAC could result in profound hypoventilation and subsequent hypercarbia as the device cycles through the latent period. This would also limit the feasibility of HNS device use in the perioperative environment.

Conclusion

The pathophysiology of OSA involves anatomic issues related to the pharynx, including fatty tissue deposition in the pharynx, neck area, and throat muscles resulting in a smaller cross-sectional area of the pharynx. However, the pathophysiology of OSA is not limited to solely anatomical issues. Non-anatomic issues related to OSA include ineffective function of the upper airway dilator during sleep, decreased pharyngeal muscle reactivity and effectiveness, and changes in cortical excitation threshold. The harmful effects of untreated OSA are well defined. Many problems accompany OSA patients who are not effectively treated. These problems include hypertension, cardiovascular disease, increased incidence of cardiovascular events, increased cancer incidence, increased mortality, and increased neurodegeneration. Positive

pressure therapy remains the gold standard for OSA; however, nightly positive pressure therapy use remains problematic for many OSA patients due to various lifestyle and social considerations. These may include mask discomfort, claustrophobia, and pressure intolerance. Alternative treatment methods include the novel hypoglossal nerve stimulator and traditional OSA surgeries such as UPPP, TORS for tongue reduction, and other palatal or tongue procedures. This manuscript focuses on the Inspire® HNS device and the ability to decrease AHI and ODI scores in the OSA patient, thus improving ventilation and oxygenation. The current literature favors HNS over traditional OSA surgery due to its benefits in improving AHI scores, oxygen saturation nadir, success rate, and cure rate related to OSA. In addition, HNS is favored over traditional OSA surgeries because HNS patients realize shorter hospital stays, a lower 30-day return to the operating room, and lower surgical site infections rates.

Further research is needed addressing the use of the Inspire® HNS device in the intraoperative and post-operative setting as there is no current evidence published that discusses or studies this proposal. However, the author of this manuscript hypothesizes a few scenarios in which the device use could be beneficial and feasible based on the current evidence published on the hypoglossal nerve stimulator and current anesthetic implications related to the device.

Limitations include a complete lack of evidence available addressing this topic. There are only a few published systematic reviews and meta-analyses related to the HNS device. However, stimulation of the hypoglossal nerve and genioglossus muscle seems to be an effective physiologic treatment for OSA. HNS devices have progressed over time and can now deliver the stimulus to a more precise target of the inclusion branches of the hypoglossal nerve and treat the retroglossal and retropalatal areas of the airway. It was determined that excluding the lateral

branches and including the medial branches of the hypoglossal nerve aided in opening the airway in the retroglossal region, making the treatment more beneficial.

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