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Review Article

Vagus Nerve Stimulation in the Pediatric Population for Refractory Epilepsy

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Abstract

Vagus nerve stimulation (VNS) is an established neuromodulatory intervention for pediatric refractory epilepsy. This article reviews the mechanism of action, indications, surgical technique, and outcomes of VNS, and presents the institutional experience of the Bab El Oued University Hospital Neurosurgery Department since 2020. Over a series of approximately 20 procedures per year, seizure frequency was reduced by 70% in patients older than 12 years and by approximately 50% in younger patients. Complete seizure freedom was achieved in 2% of cases. Complications were rare and generally transient. These results are consistent with data from the international literature and support the progressive integration of VNS into the therapeutic algorithm for pediatric refractory epilepsy.

Keywords: *Vagus Nerve Stimulation; Refractory Epilepsy; Pediatric Neurosurgery; Neuromodulation; Seizure Outcome*

I. Introduction

Vagus nerve stimulation (VNS) is an invasive neuromodulatory technique that delivers chronic, intermittent electrical impulses to the left vagus nerve via a bipolar helical electrode. The electrode is connected to a programmable pulse generator implanted subcutaneously in the left chest wall. First approved by the US Food and Drug Administration (FDA) in 1997 for adjunctive treatment of refractory partial-onset seizures in adults, VNS has progressively been extended to the pediatric population and to a broader spectrum of epileptic syndromes.

The device operates independently of antiepileptic drug (AED) regimens and represents an alternative for patients who are not candidates for resective surgery or who have failed multiple pharmacological lines of treatment. Its safety profile and relatively low rate of serious complications have contributed to its increasing use in pediatric centers worldwide.

II. Mechanism of Action

The precise mechanism by which VNS exerts its antiepileptic effect remains incompletely understood. Three principal hypotheses have been advanced, which are not mutually exclusive.

A. Electrophysiological Hypothesis

VNS modulates cerebral electrical activity by disrupting pathological EEG synchronization. The afferent vagal signal propagates through the brainstem to desynchronize thalamocortical networks involved in seizure generation and propagation. (1,2)

B. Hemodynamic Hypothesis

Positron emission tomography (PET) studies performed during VNS therapy have demonstrated increased regional cerebral blood flow in the dorsocentrorostral medulla (site of the dorsal vagal complex), the hypothalamus, the insular cortex, and bilaterally in the thalami. These perfusion changes may reflect modulation of brainstem centers involved in seizure control. (1,2)

C. Neurochemical Hypothesis

Vagal afferent fibers project primarily to the nucleus tractus solitarius (NTS), which in turn relays signals to the locus coeruleus (LC) and other monoaminergic nuclei. Stimulation of these pathways has been postulated to attenuate seizure activity through increased noradrenaline release in the prefrontal cortex and modulation of cortical excitability via serotonergic and GABAergic networks. (3,4,5)

Although VNS demonstrably influences brain electrical activity and neurotransmitter dynamics via thalamocortical pathways, its precise mechanism of action at the cellular level remains to be fully elucidated.

III. Indications

The clinical indications for VNS in the pediatric population have progressively broadened beyond the initial FDA-approved label to encompass off-label applications supported by accumulating evidence.

A. FDA-Approved Indications

The FDA-approved indications for pediatric VNS include: children older than 12 years with refractory partial-onset epilepsy in whom surgical resection is contraindicated after multidisciplinary evaluation including video-EEG or stereo-EEG (SEEG); patients presenting with AED toxicity or intolerable side effects precluding adequate pharmacological management; families declining intracranial resective surgery; and patients with persistent or recurrent seizures following prior epilepsy surgery. (6)

B. Off-Label Indications

Multiple studies have demonstrated the efficacy of VNS in children younger than 12 years and in patients with refractory generalized epilepsy syndromes, including Lennox-Gastaut syndrome, Doose syndrome, and West syndrome. Although not formally FDA-approved for these indications, the cumulative evidence supports their inclusion in clinical practice guidelines at experienced centers. (7,8,9)

IV. Equipment

Implantation of a VNS system requires the following components:

- A programmable pulse generator (approximately the size of a stopwatch), implanted subcutaneously in the chest wall, powered by a lithium battery with a mean lifespan of approximately 41.3 months.

- A helical bipolar stimulation electrode designed to wrap around the cervical vagus nerve without requiring direct grasping of the neural tissue.

- A computerized external programming system allowing non-invasive adjustment of stimulation parameters (frequency, pulse width, current amplitude, and duty cycle).

- Optionally, a cranial nerve stimulator equipped with a stimulation probe positioned at the level of the vocal cords, used to identify the vagus nerve intraoperatively during revision surgery or in cases of electrode malfunction; this device is not required for primary implantation.

V. Surgical Technique

1. Patient Positioning and Anatomical Landmarks

The patient is placed in the supine position with the head fully extended to maximize exposure of the left sternocleidomastoid (SCM) muscle. Two skin incisions are planned: a horizontal cervical incision along the left neck skin crease, equidistant between the mastoid process and the sternal notch, centered over the C4 vertebral level; and a left chest incision approximately 5 cm below the clavicle and 5 cm medial to the deltopectoral groove.

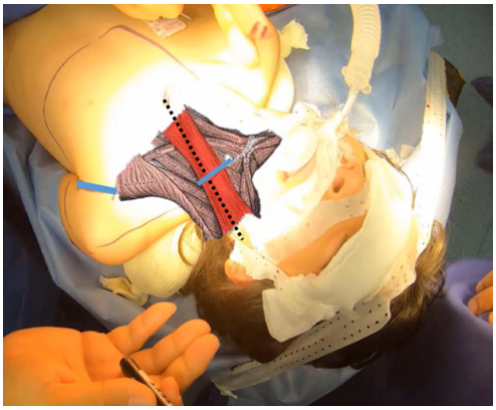

Figure 1. Position and anatomical landmarks.

2. Cervical Incision and Dissection

The platysma muscle is divided horizontally. Dissection is carried along the medial border of the SCM muscle to expose the carotid sheath. The common carotid artery is identified medially, and the internal jugular vein is retracted laterally. The vagus nerve is localized within the posterolateral groove between these two structures.

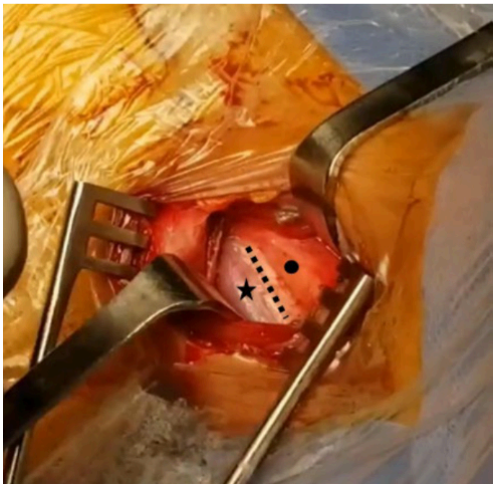

Figure 2. The carotid artery (●) and the internal jugular vein★

3. Vagal Nerve Dissection

The nerve is carefully dissected over a minimum length of 3 cm to allow adequate electrode placement. Particular attention must be paid to preserving the cardiac branches of the vagus nerve. The epineurium is left intact; the nerve should not be grasped directly with forceps. A vessel loop may be used for gentle mobilization during the procedure.

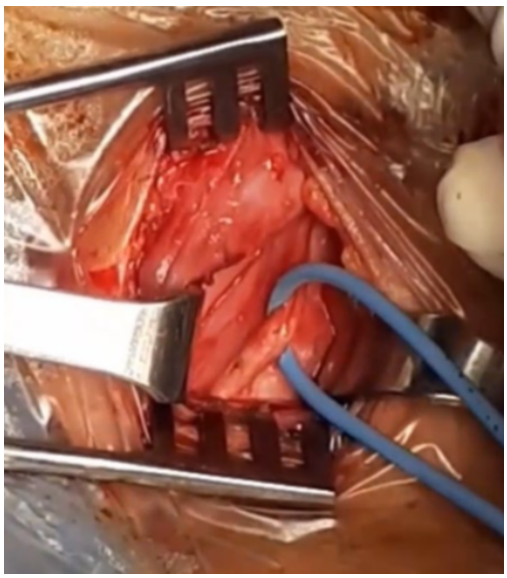

Figure 3. Dissection of the vagus.

4. Chest Incision and Pocket Creation

The chest incision is made approximately 5 cm below the clavicle and 5 cm medial to the deltopectoral groove. The pulse generator is placed either in the subcutaneous plane or beneath the pectoralis major muscle, depending on the patient's adipose tissue volume and body habitus. A subcutaneous tunnel is then created between the cervical and chest incisions to allow passage of the electrode cable.

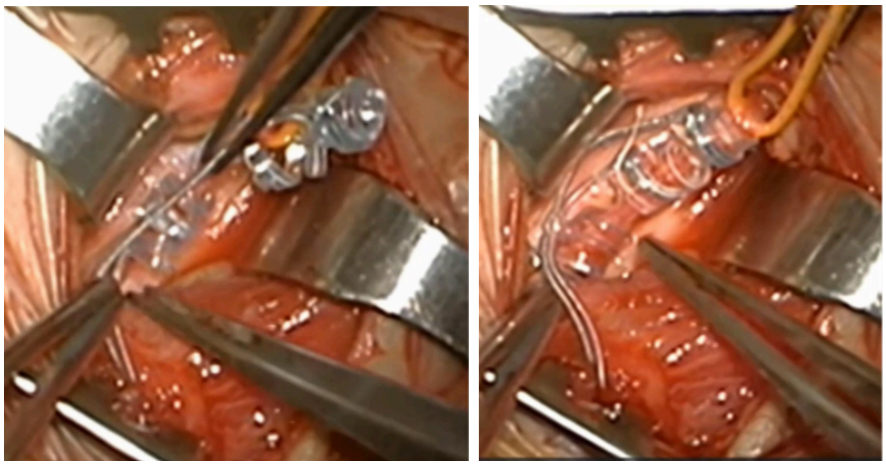

Figure 4. Position of leads.

5. Electrode Placement

Electrode positioning begins with the distal helix. This step is performed under magnification (operating microscope or surgical loupes) using two surgical instruments to handle the small wires terminating at the helices, avoiding direct contact with the silicone coils during wrapping. The main technical challenge consists in carefully coiling the three silicone helices around the nerve without traction or torsion.

6. Generator Connection and System Verification

The electrode cable is connected to the pulse generator, which is positioned in a deep plane to protect it from superficial mechanical stress. Following connection, a system diagnostic is performed to verify pulse generator–electrode integrity and to measure nerve–electrode impedance, confirming adequate contact.

Per standard protocol, active stimulation is not initiated until at least two weeks postoperatively. Stimulation intensity is subsequently increased in 0.25 mA increments under neurologist supervision. The titration period to reach final therapeutic parameters typically spans three to six months. Standard plain radiographs of the neck and chest are useful for identifying hardware complications, including electrode cable fracture.

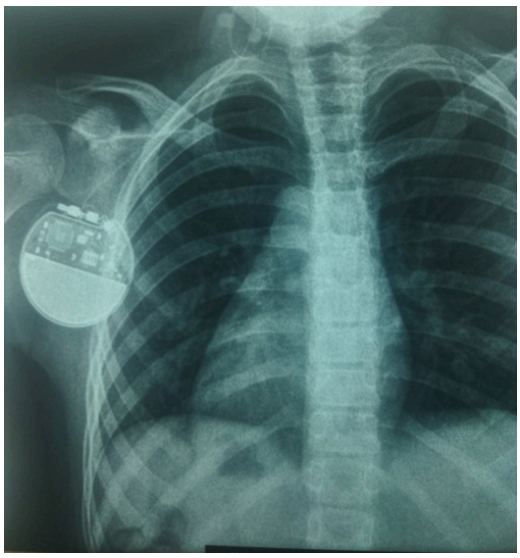

Figure 5. Basic radiographic imaging.

VI. Outcomes — Literature Data

A. Seizure Frequency Outcomes

Seizure outcomes are classified using the modified Engel and McHugh scales. The literature consistently reports a 50–75% reduction in seizure frequency regardless of epilepsy type. (17) Complete seizure cessation is uncommon, occurring in approximately 7.8% of cases. (12,17) No statistically significant difference in VNS outcomes has been established between children younger than 12 years and older pediatric patients. (17) No reliable predictive factor for treatment response has been identified. (17) Several studies have additionally demonstrated improvements in attention, cognition, and overall quality of life, independent of seizure reduction, suggesting that earlier VNS consideration in refractory epilepsy management may be warranted. (10,11,12)

B. Cost-Effectiveness

The total cost of device procurement and surgical implantation is estimated at approximately USD 10,000. Economic analyses indicate that this expenditure is offset within three years, particularly in pediatric patients who benefit from a longer life expectancy with reduced seizure burden. (13–16) Cost savings are attributable to documented reductions in intensive care unit admissions, emergency department consultations, head trauma-related hospitalizations, and a decrease in AED polypharmacy. (15,16,17)

VII. Complications

Complications associated with VNS are generally rare and of limited severity. The most frequently reported adverse effects are mild, well-tolerated neck pain at the site of stimulation, hoarseness of voice, and cough occurring during stimulation cycles. (15,17) Dysphagia and vocal cord paralysis are exceptional. Superficial wound infections may occur but are typically managed with antibiotic therapy without surgical re-intervention. Lead fracture, resulting in device malfunction, is uncommon, with a reported incidence of approximately 0.6%. (17) Generator replacement is required after a mean of 41.3 months, depending on stimulation parameters. (17)

VIII. Institutional Experience — BAB EL OUED UNIVERSITY HOSPITAL

A. Material and Methods

1. Patient Selection

VNS implantation at our institution began in 2020, with an average of 20 procedures per year. Patient selection followed established criteria.

Ninety percent of patients had failed multiple AED regimens and presented with multifocal or diffuse epilepsy precluding resective surgery. AED toxicity or intolerable adverse effects accounted for 6% of indications. Persistent or recurrent seizures following prior intracranial surgery represented 2% of cases. In the remaining 2%, VNS was selected at family request as an alternative to ablative intracranial surgery.

2. Demographic and Clinical Characteristics

The study population included 55% female and 45% male patients, without significant sex predominance. The mean age at implantation was 12.3 years (range: 4–15 years), with 30% of patients younger than 12 years. The median preoperative weekly seizure frequency was 10 episodes. The mean number of AEDs at the time of implantation was three per patient.

Neurocognitive disorders were documented in 88.4% of patients. Regarding epilepsy classification, 50% of patients had multifocal partial epilepsy, 30% symptomatic generalized epilepsy, and 20% idiopathic generalized epilepsy. The predominant etiologies were cerebral palsy (49%), infectious causes including encephalitis and/or meningitis (20%), neuronal migration disorders such as focal cortical dysplasia (5%), and genetic or metabolic disorders (4%).

B. Results and Discussion

1. Seizure Outcomes

Seizure outcomes were evaluated using the modified Engel and McHugh scales. The mean weekly seizure frequency decreased from 10 episodes preoperatively to 3 episodes at last follow-up. Overall seizure frequency reduction was 70% in patients older than 12 years and approximately 50% in younger patients, regardless of epilepsy type.

At 6 to 12 months of follow-up, complete seizure freedom was achieved in 2% of patients, compared to 7.8% reported in the published literature. These results are compared with selected international series in Table 1.

A reduction in AED regimen was observed in 18% of patients, compared to 20% in the literature. This reduction generally occurred within one year following VNS initiation. Complete AED discontinuation was not observed in any patient, whereas rates of approximately 2% have been reported in prior series.

Objective neuropsychological evaluation was limited by logistical constraints in administering standardized assessments. Parental report, however, consistently indicated behavioral improvements in the majority of patients; the return of spontaneous smiling was the most frequently noted positive change.

Table 1. Seizure frequency reduction: comparison with published series.

Series	Seizure reduction (%)
Present series (Bab El Oued)	70%
Levy et al.	65%
Helmers et al.	70%
Murphy et al.	66%
Alexopoulos et al.	>75%

2. Complications

The most common adverse effect was mild neck pain, reported in 20% of patients, all of whom resolved spontaneously without specific treatment. This is consistent with the 18% incidence documented in the literature. Hoarseness occurred in 0.5% of patients and resolved within three months, comparable to the 0.7% reported in prior series. Cough at the time of stimulation was observed in 1% of patients and resolved following adjustment of stimulation parameters (0.7% in the literature). Superficial wound infections were recorded in two patients and managed successfully with antibiotic therapy, without surgical re-intervention. One patient required explantation of the entire stimulation system due to an allergic reaction to the silicone coating of the electrode leads.

IX. Conclusions

Implantation of a vagus nerve stimulator is a reproducible surgical procedure with a favorable safety profile; however, meticulous intraoperative technique remains essential to prevent vagal nerve injury during electrode placement and to minimize the risk of infectious complications through strict aseptic practice.

As with all functional neurosurgical interventions, optimal outcomes are contingent on sustained multidisciplinary collaboration between neurologists and neurosurgeons across patient selection, device programming, and long-term follow-up. The results of our institutional series are consistent with international data, supporting VNS as a valid therapeutic option within the management algorithm of pediatric refractory epilepsy.

Emerging non-invasive VNS modalities, including transcutaneous cervical VNS (tcVNS) and the gammaCore device, are currently under investigation and may in the future provide alternatives for patients in whom surgical implantation carries an unacceptable risk.

Conflict of Interest

The authors declare no conflicts of interest.

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None.

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