

Intraoperative Laryngeal Electromyography in Children With Vocal Fold Immobility

Results of a Multicenter Longitudinal Study

Stephen C. Maturo, MD; Nicole Braun, BSN, RN, CPN; David J. Brown, MD; Peter Siao Tick Chong, MD; Joseph E. Kerschner, MD; Christopher J. Hartnick, MD

Objectives: To determine whether laryngeal electromyography (LEMG) can predict recurrent laryngeal nerve function return in children and whether LEMG can aid in the management of vocal fold immobility (VFI).

Design: Prospective case series.

Setting: Tertiary pediatric aerodigestive centers.

Patients: Twenty-five children aged 14 days to 7 years at the time of first LEMG (mean age, 21.4 months) with VFI who underwent flexible fiberoptic laryngeal examination, intraoperative LEMG of the thyroarytenoid muscles, and 12-month follow-up.

Main Outcome Measures: To compare results of LEMG with flexible fiberoptic laryngeal examination in children with vocal fold paresis and to determine if LEMG can predict vocal fold return.

Results: In children who had a patent ductus arteriosus ligation, the LEMG data suggest that if there is no activity 6 months after injury, then the nerve is unlikely

to regain function. In 3 of 3 children with central causes of VFI, normal LEMG findings predicted return of nerve function 2 to 7 months before vocal fold movement on fiberoptic examination. Finally, in 3 of 3 children with idiopathic VFI, LEMG predicted return within 2 to 14 months of vocal folds with normal findings.

Conclusions: Intraoperative LEMG is a safe, easy-to-use method for determining the likelihood of recurrent laryngeal nerve function return in children who have undergone patent ductus arteriosus ligation, in children with centrally correctable lesions, and in children with idiopathic VFI. More work is needed in the area of pediatric LEMG, but it is possible that LEMG data can be used to aid in management strategies and provide families with more information to make better informed decisions regarding their child's care.

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Author Affiliations:

Department of Otolaryngology, Massachusetts Eye and Ear Infirmary, Harvard Medical School, Boston (Drs Maturo and Hartnick); Department of Otolaryngology, Children's Hospital of Wisconsin (Ms Braun and Drs Brown and Kerschner) and Medical College of Wisconsin (Drs Brown and Kerschner), Milwaukee; and Department of Neurology, Massachusetts General Hospital, Boston (Dr Chong).

VOCAL FOLD IMMOBILITY (VFI), a challenging management issue in pediatric otolaryngology, is most commonly distinguished as unilateral (UVFI) and bilateral (BVFI) dysfunction. Recent reports demonstrate an almost equal occurrence of BVFI and UVFI.¹ Unilateral VFI and BVFI are different pathophysiologic and clinical entities with distinct symptoms and etiologies.^{2,3} Unilateral VFI is most commonly due to iatrogenic causes, such as cardiothoracic surgery.^{1,4,5} Congenital BVFI is the most common presentation of BVFI, with various etiologies, such as neurologic or idiopathic.^{1,2,5,6}

Management of UVFI and BVFI is also distinct, with multiple interventions possible depending on the severity of the child's

airway, voice, and swallowing symptoms. It has been generally accepted in the adult literature to wait at least 1 year before performing more permanent procedures for VFI. This period has been extended even further in children because the literature has suggested that vocal fold function may return many years later.^{1,6} There is no simple test or procedure to help predict return of vocal fold function. In adult patients, laryngeal electromyography (LEMG) has been used to help guide management decisions, but it has not been widely investigated in children.

Current pediatric LEMG studies are limited due to variable objectives, various LEMG techniques, and nonstandardized follow-up.⁷⁻¹³ Wohl et al⁹ evaluated 32 patients during a 5-year period (only 13 of the 32 patients had UVFI or BVFI) and

found LEMG to be of limited utility in children relevant to management decisions. Berkowitz,⁷ in a study of 4 children with idiopathic BVFI, found normal LEMG activity in all the patients yet no clinical movement after more than 3 years of follow-up. In a follow-up study of 2 additional patients, Berkowitz et al¹² found that LEMG combined with intercostal EMG improved diagnosis and guided tracheostomy decannulation decisions. Jacobs and Finkel⁸ evaluated 8 patients with LEMG and found it helpful to differentiate vocal fold fixation from paralysis while also aiding in decision making. Ysunza et al¹³ studied in-office LEMG in children aged 11 to 16 years with UVFI. High rates of sensitivity and specificity were found, yet there was no comment about whether their technique provided prognostic value.¹³

The foundation for the present study is based on the work by Scott et al¹⁴⁻¹⁶ in a series of articles describing a simplified LEMG technique performed in a clinical and animal research setting. In their first study,¹⁴ a simplified, safe technique using standard nerve integrity monitors (NIM-Response 2.0 System; Medtronic ENT USA Inc, Jacksonville, Florida) was found to be useful in management decision making in more than half the children studied. Follow-up studies^{15,16} in canines demonstrated the utility of the technique in predicting nerve function return in dogs that had experienced a crush injury. Based on the previously mentioned studies, the primary objective in this study was to evaluate a larger pediatric cohort with VFI by using flexible fiberoptic laryngoscopy and LEMG with at least 1 year of clinical follow-up to determine whether LEMG could predict function return. A second objective was to determine whether LEMG could help with clinical decision making.

METHODS

Approval for this study was obtained from the institutional review boards of the Massachusetts Eye and Ear Infirmary, Boston, and Children's Hospital of Wisconsin, Milwaukee. Informed consent forms were signed by the parents or guardians after a detailed discussion concerning the risks and benefits of the procedures. A prospective, password-protected database was maintained about the children involved in the study.

The inclusion criteria for the study were as follows: (1) younger than 18 years, (2) total vocal fold impairment on flexible endoscopy, (3) intraoperative LEMG performed, and (4) at least 12 months of clinical follow-up including interval flexible endoscopy.

Each child underwent fiberoptic laryngeal examination (FOE) on presentation and at various times during the ensuing year depending on the diagnosis. Return of vocal fold function was defined as a marked difference in vocal fold abduction and adduction on FOE. The otolaryngologists (S.C.M., D.J.B., J.E.K., and C.J.H.) performing the FOEs were not blinded to the LEMG findings. Each child underwent at least 1 LEMG in the setting of formal direct laryngoscopy, bronchoscopy, and suspension laryngoscopy with direct palpation of the vocal folds.

The present technique for airway evaluation and LEMG has been described in detail elsewhere,¹⁴ but a brief description follows. Adequate general anesthesia was obtained using a combination of remifentanyl hydrochloride and propofol. A single intraoperative dose of dexamethasone (0.5 mg/kg) was given. All the patients were placed in suspension using the Benjamin-Lindholm laryngoscope. Anesthesia was lightened until the child

was breathing regularly and spontaneously. Monopolar grounding electrodes (Medtronic ENT USA Inc) were placed subcutaneously into the right shoulder. Paired, monopolar, subdermal monitoring needle electrodes (spaced 2.5 mm apart) from the NIM-Response 2.0 Kit were placed endoscopically into the thyroarytenoid muscle of each vocal fold using laryngeal alligator forceps. Impedance values were confirmed; low impedance reflected accurate placement of electrodes, and high impedance required electrode repositioning. Intraoperative LEMG was recorded from both thyroarytenoid muscles during spontaneous respiration. Recordings were taken using the NIM-Response 2.0 monitor factory settings (EMG display: 80 Hz to 2 kHz [-6 to 3 dB at 500 Hz]; EMG audio: 120 Hz to 1.7 kHz [-6 to 3 dB at 500 Hz]; sweep speed: 50 milliseconds [5 milliseconds per division]; and gain values: 50 and 200 μ V). Video and audio recordings were then made using a digital video recorder (Med X Change DRS2; Med X Change Inc, Bradenton, Florida), which was connected to the NIM-Response 2.0 monitors via audio and video outputs using a video converter (TView Micro XGA; Focus Enhancements Inc, Campbell, California). The acoustic signal and video data were reviewed later by a senior neurologist with EMG training (P.S.T.C.). The neurologist was blinded to the clinical history and examination findings of the patients. The LEMGs were analyzed for the presence of normal-appearing motor unit action potentials (MUAPs), abnormal-appearing MUAPs, and overall comparison between the 2 sides.

RESULTS

Twenty-five children (14 boys and 11 girls) were evaluated. The mean age at the first LEMG was 21.4 months (age range, 14 days to 7 years). All the children had at least an initial FOE, 1 LEMG, and follow-up FOE, with clinical follow-up if necessary at least 12 months after the initial diagnosis. Seventeen children (68%) underwent a single LEMG, 6 (24%) underwent 2 LEMGs, and 2 (8%) underwent 3 LEMGs. There were no complications related to the placement of electrodes. We found that in very young infants, the needles could not be placed simultaneously into each thyroarytenoid owing to size limitations. Recordings then were taken sequentially and did not affect the outcomes of the study.

Eighteen children had UVFI and 7 had BVFI. The most common cause of UVFI was peripheral injury: iatrogenic due to patent ductus arteriosus (PDA) ligation (n=12), brain tumor resection (n=3), recurrent laryngeal nerve sacrifice due to involvement with thyroid cancer (n=1), double aortic arch repair (n=1), and status post tracheoesophageal fistula repair (n=1). The most common cause of BVFI was central (3 children with Arnold-Chiari malformations and 1 with central nervous system dysgenesis). Three patients with BVFI were idiopathic (no history of trauma or surgery along with normal brain imaging findings).

No patient with a history of PDA ligation and absent or abnormal MUAPs on LEMG recovered clinical vocal fold motion (**Table 1**). In the 12 patients in this group, the initial EMG was performed 1 month to 6 years after surgery. Five of the 12 patients had their initial LEMG within 6 months of their PDA ligation, whereas the other 7 patients had their initial LEMG 6 months to 6 years after surgery. One child had normal-appearing LEMG 3 months after ligation and clinical return of function 8

Table 1. Summary of Patients With Left UVFI Who Underwent PDA Ligation

Patient No.	Time From Surgery to LEMG	Results, Left/Right Vocal Folds	Follow-up Status of Left Vocal Fold
1	5 mo	No MUAPs/normal MUAPs	No movement at 12 mo
2	12 mo	No MUAPs/normal MUAPs	No movement at 18 mo
3	1 and 7 mo	No MUAPs/normal MUAPs	No movement at 12 mo
4	4 and 6 mo	No MUAPs/normal MUAPs	No movement at 12 mo
5	12 mo	No MUAPs/normal MUAPs	No movement at 24 mo
6	12 mo	No MUAPs/normal MUAPs	No movement at 12 mo
7	6 mo	No MUAPs/normal MUAPs	No movement at 12 mo
8	5 y	No MUAPs/normal MUAPs	No movement at 5 y
9	3 mo	Normal MUAPs/normal MUAPs	Normal bilateral movement at 8 mo
10	6 y	No MUAPs/normal MUAPs	No movement at 6 y
11	7 mo	No MUAPs/normal MUAPs	No movement at 12 mo
12	5 y	Large, singular, infrequent spikes/normal MUAPs	No movement at 5 y

Abbreviations: LEMG, laryngeal electromyography; MUAPs, motor unit action potentials; PDA, patent ductus arteriosus; UVFI, unilateral vocal fold immobility.

Table 2. Summary of Patients With Brain Tumor Resections and UVFI

Patient No.	Diagnosis	Time From Surgery to Initial LEMG	Results, Right/Left Vocal Folds	Follow-up
1	Ependymoma Left VFI	18 mo	Normal MUAPs/abnormal MUAPs	No left movement 2 y after surgery; reinnervation procedure performed
2	Ependymoma Left VFI	6 mo	Normal MUAPs/abnormal MUAPs	No movement on left side 12 mo after surgery
3	Left VFI (unknown pathologic diagnosis; records unavailable)	3 mo	Normal MUAPs/abnormal MUAPs	No movement on left side 12 mo after surgery

Abbreviations: LEMG, laryngeal electromyography; MUAPs, motor unit action potentials; UVFI, unilateral vocal fold immobility.

Table 3. Summary of Patients With Iatrogenic UVFI

Patient No.	Diagnosis	Time From Surgery to Initial LEMG	Results, Right/Left Vocal Folds	Follow-up
1	Invasive thyroid cancer Left VFI	4 mo	Normal MUAPs/electrical silence	No movement on left side at 12 mo
2	Double aortic arch repair Right VFI	2 y	Abnormal MUAPs/normal MUAPs	No movement on right side at 3 y
3	TEF repair Left VFI	9 mo	Normal bilateral MUAPs	Continued left-sided VFI at 12 mo; continues to be observed

Abbreviations: LEMG, laryngeal electromyography; MUAPs, motor unit action potentials; TEF, tracheoesophageal fistula; UVFI, unilateral vocal fold immobility.

months after surgery. Two children had serial LEMGs separated by 6 months and 2 months, and both had neither evidence of MUAPs nor vocal fold movement on each occasion and at 1-year follow-up.

Three children had brain tumor resections and UVFI (**Table 2**). Two of these children had previously documented BVFI, but on their first referrals at our institutions, the diagnosis was found to be UVFI. The first child had reported BVFI 9 months after surgery, with documented recovery on initial examination of the right vocal fold at 12 months. Eighteen months after surgery, the left vocal fold was still immobile and the LEMG demonstrated normal MUAPs on the right side, but the left side had abnormal MUAPs, with large motor units firing rapidly, yet intermittently. Two years after surgery, the left vocal fold was still immobile. The second patient had reported BVFI 2 months after surgery, and on first evaluation 6 months after surgery, the right vocal fold moved, and the

LEMG demonstrated normal MUAPs on the right side, yet the left side showed dull, intermittent MUAPs significantly different than the right side. Twelve months after surgery, the left vocal fold is still immobile. The third patient was a 13-month-old infant who presented with left VFI 3 months after a brain tumor resection. Her initial LEMG 3 months after surgery demonstrated normal MUAPs on the right side, but the left side showed fast-firing MUAPs with significantly reduced frequency. Similar LEMG findings were found 6 months after surgery, and her vocal fold remained immobile 1 year after surgery.

The 3 remaining children with UVFI were single instances of iatrogenic injury (**Table 3**). A 7-year-old girl had invasive thyroid cancer, and the operative notes demonstrated the tumor invading the left recurrent laryngeal nerve, necessitating nerve sacrifice. Immediately after surgery, her left vocal fold was immobile. The LEMG performed 4 months after her surgery demonstrated nor-

Table 4. Summary of Patients With Central Causes

Patient No.	Diagnosis	Initial LEMG Timing	Results	Follow-up
1	Arnold-Chiari s/p shunt BVFI	7 mo after shunt	Bilateral MUAPs	Bilateral movement at 18 mo
2	Arnold-Chiari s/p shunt BVFI	6 mo after shunt	Bilateral MUAPs	Bilateral movement at 10 mo
3	Arnold-Chiari s/p shunt BVFI	11 mo after shunt	Bilateral MUAPs	Bilateral movement at 13 mo
4	CNS dysgenesis BVFI since birth	4 y of age	Electrically silent bilaterally	No movement

Abbreviations: BVFI, bilateral vocal fold immobility; CNS, central nervous system; LEMG, laryngeal electromyography; MUAPs, motor unit action potentials; s/p, status post.

Table 5. Summary of Patients With Idiopathic Causes

Patient No.	Diagnosis	Age at Initial LEMG	Results	Follow-up
1	BVFI	4 mo	Right with MUAPs Left without MUAPs	Right movement at age 18 mo, left immobile
2	BVFI	2 wk	Bilateral MUAPs	Bilateral movement at 2.5 mo of age
3	BVFI	2.5 y	Bilateral MUAPs	Bilateral movement at age 3 y, decannulated

Abbreviations: BVFI, bilateral vocal fold immobility; LEMG, laryngeal electromyography; MUAPs, motor unit action potentials.

mal MUAPs on the right and electrical silence on the left; 12 months after surgery, her vocal fold was still immobile. A 2½-year-old girl with a history of a double aortic arch repair at 2 months of age had an immobile right vocal fold more than 2 years after surgery. She had LEMGs separated by 3 months that demonstrated normal left-sided MUAPs and infrequent MUAPs on the right. A 1½-month-old boy underwent a tracheoesophageal fistula repair at 3 weeks of age resulting in left VFI. His first LEMG was performed at 9 months of age, with bilateral MUAPs. At 12 months of age, his left vocal fold was still immobile, but he continues to be observed.

Four children had BVFI due to central causes (**Table 4**). The family of a 4-year-old boy with known central nervous system dysgenesis and a tracheotomy since 1 month of age was interested in possible decannulation. An LEMG did not reveal any MUAPs. An attempt at surgery to hasten decannulation was delayed, though, because the child was aspirating. The other 3 children with BVFI all had similar clinical presentations, with Arnold-Chiari malformations treated with shunts. They all had bilateral normal LEMG findings within 1 year of shunt placement; and within 11 months of LEMG, vocal fold motion recovered.

In the 3 children with BVFI due to idiopathic causes, LEMG predicted recovery (**Table 5**). In 1 patient, LEMG performed at 4 months of age demonstrated normal-appearing MUAPs in the right vocal fold and then recovered 14 months later. The left vocal fold never demonstrated MUAPs on 2 separate occasions separated by 12 months, and 32 months after surgery was clinically without evidence of movement. A second patient was referred at age 24 months with BVFI. The LEMG at age 30 months showed relatively normal bilateral MUAPs, but the clinical examination did not demonstrate any move-

ment. On follow-up examination 6 months later, both vocal folds were moving. In a third patient, there was BVFI on FOE performed at 2 weeks of age for mild inspiratory stridor. The LEMG performed at that time revealed bilateral MUAPs. A tracheotomy was delayed as the child was gaining weight and had no difficulty breathing, and on reevaluation at 2½ months of age, both vocal folds were mobile.

COMMENT

The present clinical and LEMG findings in children who had VFI due to PDA ligation suggest that if there are no normal-appearing MUAPs by 6 months then it is highly unlikely that vocal fold function will recover. Five patients who had LEMG before 6 months all had negative LEMG findings, and none recovered function. This finding agrees with those of studies^{5,17} showing low recovery rates after nerve injury due to PDA ligation. Furthermore, serial EMGs may not be needed because most of the children in this study had a single EMG with multiple confirmatory FOEs and more than 12 months of follow-up. One patient who is interesting in this study is the child who had normal left-sided MUAPs 3 months after surgery and whose vocal fold function returned 8 months after surgery. The operative reports were unavailable to review for this patient, but most likely the recurrent laryngeal nerve was not transected or clipped in this child but rather temporarily stunned, needing only time before it regained function.

What is the clinical utility of an LEMG in a patient with VFI after a PDA ligation? How does LEMG change one's management strategy? Children with UVFI rarely need intervention for airway concerns, but as the re-

view by Truong et al⁵ demonstrated, close to one-third will need some sort of intervention for voice or swallowing symptoms. One of the most prevalent and important disabilities secondary to UVFI associated with PDA ligation is dysphagia.¹⁸ Various temporary or permanent procedures, such as injection laryngoplasty, medialization thyroplasty, and nerve reinnervation, are available to aid in symptom control. The clinical utility of LEMG may then be earlier intervention in the young child for a more permanent procedure. Although most children with UVFI do not need repeated injection laryngoplasties, some continue to have symptoms that warrant consideration for permanent procedures. For example, a child with UVFI who continues to aspirate despite repeated injection laryngoplasties may benefit from an earlier thyroplasty or nerve reinnervation procedure. This may seem to be an aggressive approach, but there is increasing data that multiple anesthetic exposures can have detrimental effects on the developing brain.¹⁹⁻²¹ The LEMG findings cannot be taken in isolation because they need to be interpreted in the clinical context, but the present findings suggest that waiting years before performing a permanent procedure may not be entirely necessary in patients who underwent PDA ligation who have LEMG without MUAPs and FOE follow-up.

The clinical utility of LEMG with idiopathic BVFI is more nuanced than with UVFI due to PDA ligation. Berkowitz⁷ reported that LEMG has no prognostic implications for idiopathic congenital BVFI. In a series of 4 patients, all had normal MUAPs, but despite some appreciable improvement in movement in 2 patients, none of the 4 patients had clinically significant improvement during mean follow-up of 45 months. In a follow-up study of 2 patients, Berkowitz et al¹² found respiration-related LEMG to be of prognostic benefit in 1 of 2 children. The difficulty in using LEMG to predict nerve return in idiopathic BVFI may be explained, as Berkowitz^{3,7} points out, by a brainstem or muscle disorder that prevents co-ordinated laryngeal muscle contraction. The present study evaluated only 3 such patients, thus it is unreasonable to definitively comment on the clinical application of LEMG in idiopathic BVFI. Yet, when the results of these data and the complete results of Scott et al¹⁴ on idiopathic causes are analyzed, it seems that LEMG may be able to predict whether function will return. In the 3 patients herein, if the LEMG had evidence of normal or relatively normal MUAPs, vocal fold function would eventually recover. The timing of the recovery is difficult to predict, though, based on LEMG. Abnormal LEMG findings did not predict that the nerve would not recover, though, because in a few patients, the initial LEMG was without MUAPs, yet function returned. Patients without evidence of MUAPs likely need serial EMGs along with close FOE follow-up before definitively commenting on the likelihood of recovery. More investigation is needed to determine the utility of LEMG in idiopathic BVFI where reported clinical recovery rates range from 50% to 60%.^{1,2}

The main concern with BVFI is the safety of the airway. Six of the 7 patients with BVFI in this study had tracheostomies. Historically, children with BVFI have been treated with a tracheotomy and watchful waiting. The argument

can be made that watchful waiting for years is acceptable, but multiple studies²²⁻²⁵ have demonstrated that pediatric tracheotomies have the potential for significant morbidity and affect the psychosocial element of the child and family. The utility of LEMG with BVFI, then, likely rests with children who have a tracheotomy and decannulation is the goal. If a child has LEMG findings consistent with likely vocal fold return, then one should continue to wait, with frequent follow-up and fiberoptic examination. This information may seem important for research purposes only, but we found that it is invaluable clinically because parents are more comfortable with waiting if they know that the results of LEMG suggest vocal fold motion return and ultimately avoidance of invasive procedures. If there is no evidence of MUAPs, then serial LEMGs every 3 to 6 months may be appropriate before committing to a permanent procedure. More research is needed to comment on how long one should wait when no MUAPs are present before invasive procedures are performed to widen the airway and hasten decannulation. More important, as continued research into LEMG is conducted, we may get a better sense of the average time to recovery rather than the wide range that is quoted in the literature based on retrospective case series.

In the 4 patients with BVFI due to central causes, LEMG predicted return of function. The results of LEMG in the patient with central nervous system dysgenesis are not surprising given that he is 4 years old and has never had vocal fold motion. This result is not inconsequential, though, for if the patient was not aspirating, his parents were ready for a cordotomy with hopes of future decannulation. Before the findings of LEMG, the parents were hesitant to do any permanent procedure without further confirmatory information. The LEMG predicted vocal fold function in children with Arnold-Chiari malformations within 2 to 11 months of clinical return of function. This finding did not change the clinical management, but at the least it provided the families with hope that their children may eventually have functional recovery.

Infants with a history of brain tumor resections, double aortic arch repair, and tracheoesophageal fistula repair all resulting in UVFI deserve special comment. In each child who had a brain tumor resection, their affected vocal fold showed MUAPs, but they were significantly abnormal (fast-firing units suggesting a peripheral lesion) compared with the functioning side. The LEMG findings demonstrated one of the nuances of LEMG where an experienced electromyographer can analyze the subtleties of the LEMG. In 1 of these patients, who had been observed for 2 years, the findings of the LEMG were the deciding factor for the parents to proceed with a reinnervation procedure because they did not feel that their child's aspiration symptoms were significantly changed after injection laryngoplasty. Concerning the child with a double aortic arch repair, the first evaluation was more than 2 years after surgery. Her immobile right vocal fold on 2 separate occasions demonstrated abnormal MUAPs, which was significantly different than the left side, which had normal MUAPs. The child was aspirating, and the parents decided to perform injection laryngoplasty. The child with the tracheoesophageal fistula repair demonstrated bilateral normal MUAPs 9 months after surgery, yet his left vocal fold was still immobile 1 year after surgery. This child

will continue to be observed to determine whether the right vocal fold regains function. All the previously discussed cases highlight the complex nature of nerve function and LEMG studies. The MUAPs do not guarantee clinical movement because their quality and frequency determine whether they result in coordinated muscle firing. Furthermore, normal MUAPs in the setting of an immobile vocal fold do not guarantee future movement because there may be synkinesis preventing coordinated firing, a decrease in the number of motor units preventing coordinated firing, or mechanical fixation, such as arytenoid fixation, interarytenoid scar, or vocal scar, preventing muscle movement.²⁶ These issues highlight the importance of having an experienced physician reading LEMGs to help sort through the findings.

When is the optimal time to perform LEMG? The adult literature can help answer this question, but one needs to keep in mind that the neurophysiologic features of the developing pediatric larynx and the etiologies of VFI are different in the 2 groups. Reviewing the adult literature on iatrogenic injury suggests that LEMG performed before 2 months after symptom onset leads to more false-positive results.²⁷ Also in adults, LEMG performed after 6 months may not be as accurate owing to synkinesis.²⁸ Timing is an important consideration in children as one would like to limit the LEMG to only 1 test to avoid multiple trips to the operating room. With pediatric LEMG, timing may depend on the presumed etiology. With iatrogenic causes, such as PDA ligation, performing a single LEMG 3 to 6 months after symptom onset/injury seems to be the most worthwhile. With suspected central etiologies, a single LEMG around the time of diagnosis would give initial information; whether additional LEMGs are needed will be based on the clinical scenario, patient's symptoms, and family discussions. It would be difficult to propose additional visits to the operating room for the sole reason of LEMG, but many children with tracheotomies require frequent trips to the operating room for airway surveillance. An LEMG would add minimal procedural time and morbidity.

The weaknesses of this study include the relatively small number of patients with varied etiologies for VFI. This study is unique, though, because we documented LEMG and FOE findings with at least a 12-month follow-up period on all the reported patients. Twelve-month follow-up with FOE is important because it is considered the diagnostic gold standard. The FOE provides for the definitive evaluation of vocal fold function rather than basing return on questioning whether symptoms have improved. A second weakness of this study is the lack of a blinded observer to the FOE findings. There is the possibility that observational bias was present by the examining physicians in reporting changes in vocal fold movement during the 12-month period. Moreover, we acknowledge that FOE in young children is difficult and can be imprecise as others have reported.⁷ It should be mentioned, though, that the neurologist reading the present LEMGs was blinded to the clinical examination findings.

Intraoperative pediatric LEMG also depends on multiple variables. Obtaining the appropriate level of anesthesia takes an experienced anesthesiologist comfortable with spontaneous breathing techniques. Proper

placement of the electrode into the thyroarytenoid muscle in a small infant airway can be moderately difficult, but it can be aided with the use of rigid telescopes to ensure proper placement. A significant advantage of the described technique is the use of readily available equipment that can record the findings for later interpretation by an electromyographer. We understand that tertiary care hospitals with dedicated pediatric aerodigestive centers, experienced attending surgeons, and experienced pediatric anesthesiologists have resources that may not be available to all physicians. We are fortunate to belong to an institution with an experienced electromyographer who was of great help explaining the intricacies of LEMG. Reading LEMGs is subject to variation, and even among experienced electromyographers there is significant potential for misinterpretation.

In terms of the technique, we are measuring only the activity of the thyroarytenoid muscle. This may be testing only the adduction qualities of the vocal fold. We realize that some LEMG techniques also include testing of the posterior cricoarytenoid muscle and respiratory muscles to better evaluate for neuromuscular coordination of adduction and abduction, especially in children with BVFI.^{7,12} The technique could be adaptable to test the posterior cricoarytenoid muscle, but as other researchers have mentioned, it can be difficult owing to the small size of the pediatric larynx.¹² We also realize that one of the shortcomings of this technique is that when evaluating for UVFI, there is the inability to identify synkinesis. Identifying synkinesis through LEMG can be difficult using any technique, though, because there is wide neuromuscular variation even in healthy persons during breathing and speech.²⁹ There is no standardized LEMG technique in either the adult or pediatric literature. We are hopeful that the present technique, along with those of others, will continue to spur thought and innovation on pediatric laryngeal neurophysiology so that better management algorithms can be developed for patients and families.

Although the present results are encouraging for the use of LEMG in pediatric patients, future studies need to focus on obtaining measurement standardization and normative data for MUAPs. As with many complex issues in pediatric otolaryngology that are not accrued in large numbers, future LEMG studies will be possible only through multi-institutional collaboration, which has its own distinct challenges. Obtaining normative data will be a challenge because most children will not allow LEMG to be performed in an awake, outpatient setting. Future technological developments may make it possible to perform in-office neurophysiologic evaluations. Again, LEMG is far from a perfect binary test. The LEMG should be viewed as a piece of the diagnostic evaluation where good clinical judgment should be the final determinant.

In conclusion, LEMG was helpful in predicting the return of vocal fold function in pediatric patients with VFI due to PDA ligation, neurologic causes, and idiopathic causes. Laryngeal electromyography is a safe procedure that has the possibility of being a useful adjunct in the management of children with VFI. More collaborative, multi-institutional work will be necessary to accrue large numbers, refine techniques and analyses, and deter-

mine the long-term utility of LEMG. It is too early to advocate pediatric LEMG as the standard of care for evaluating VFI, yet it has the potential to provide a foundation of knowledge for a common pediatric otolaryngology condition that can be difficult to manage.

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Correspondence: Christopher J. Hartnick, MD, Department of Otolaryngology, Massachusetts Eye and Ear Infirmary, Harvard Medical School, 243 Charles St, Boston, MA 02114 (Christopher_hartnick@meei.harvard.edu).

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