Intraoperative laryngeal electromyography in children with vocal fold immobility: A simplified technique

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Summary

Objectives: The primary objective of this study was to determine whether a simplified technique for intraoperative laryngeal electromyography was feasible using standard nerve integrity monitoring electrodes and audiovisual digital recording equipment. Our secondary objective was to determine if laryngeal electromyography data provided any additional information that significantly influenced patient management.

Methods: Between February 2006 and February 2007, 10 children referred to our institution with vocal fold immobility underwent intraoperative laryngeal electromyography of the thyroarytenoid muscles. A retrospective chart review of these 10 patients was performed after institutional review board approval.

Results: Standard nerve integrity monitoring electrodes can be used to perform intraoperative laryngeal electromyography of the thyroarytenoid muscles in children. In 5 of 10 cases reviewed, data from laryngeal electromyography recordings meaningfully influenced the care of children with vocal fold immobility and affected clinical decision-making, sometimes altering management strategies. In the remaining 5 children, data supported clinical impressions but did not alter treatment plans. Two children with idiopathic bilateral vocal fold paralysis initially presented with a lack of electrical activity on one or both sides but went on to develop motor unit action potentials that preceded recovery of motion in both vocal folds.

Conclusions: Our findings suggest that standard nerve monitoring equipment can be used to perform intraoperative laryngeal electromyography and that electromyograph

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1. Introduction

Vocal fold paralysis (VFP), defined as vocal fold immobility due to dysfunction of the motor component of the laryngeal nerves, remains the second most common cause of neonatal stridor after laryngomalacia, accounting for 10% of congenital anomalies affecting the larynx [1]. Presentation varies depending on whether paralysis is unilateral or bilateral, with unilateral VFP typically manifesting as aspiration and dysphonia and bilateral VFP presenting with cyanosis and retractions. Both unilateral and bilateral VFP may present with stridor [2]. There are a number of causes of VFP including iatrogenic (following surgical procedures such as ligation of a patent ductus arteriosis or repair of a tracheoesophageal fistula), neurological disorders, birth trauma, and idiopathic. The overall incidence of VFP is rare but increasing and likely reflects better diagnostic capabilities to visualize the infant vocal fold and to trace the course of the recurrent laryngeal nerve (RLN), in addition to an overall improvement in survival rates of infants and children with multiple medical problems [1,3]. Work-up of VFP typically involves evaluation with flexible laryngoscopy, as well as direct laryngoscopy, bronchoscopy, and palpation of the vocal folds under anesthesia to distinguish between mechanical fixation and paralysis.

Treatment of VFP is based on the symptom complex, with the most severely affected children requiring tracheotomy for upper airway obstruction or feeding tube placement for aspiration. The mainstay of treatment for unilateral vocal fold paralysis (UVFP) is speech and swallow therapy aimed towards preventing aspiration. For young children where conservative measures fail and they suffer aspiration, or for older children with significant dysphonia, which is not improved with voice therapy and which compromises social interaction, surgical options include injection laryngoplasty, thyroplasty (with or without arytenoid repositioning procedures), or more recently, ansa cervicalis to RLN anastomosis [4–6]. The goal of these procedures is to close a persistent glottic gap, by providing a firm, midline (if still immobile) surface to which the contralateral mobile vocal fold can oppose. This improved glottic closure allows for better phonation and reduced aspiration. The rate of surgical interventions in children is far lower than that of adults, owing mainly to a high rate of successful speech and swallow therapy with subsequent learned compensatory measures, higher rate of spontaneous recovery in the pediatric population, and surgical conservatism based upon concerns related to the effect of surgery on growth centers in the maturing larynx [7].

Treatment of bilateral vocal fold paralysis (BVFP) is also predicated upon symptoms, with some children watched with careful observation until one or both vocal folds exhibits spontaneous recovery with ensuing improvement of symptoms. Initially a tracheotomy may be placed to maintain a safe airway. Prognosis for recovery from this condition depends on the etiology of the paralysis, with high rates of recovery for neurological VFP. Interestingly, the highest rate of spontaneous recovery is observed in children with idiopathic bilateral VFP [2]. Predicting recovery of RLN function in infants and children with VFP remains a challenge for the otorhinolaryngologist. Forty percent of adults who suffer iatrogenic injury will recover vocal fold function, and this nearly always occurs within a year following presentation [8]. In contrast, longer recovery courses are observed in children but there is also an improvement in the rate of overall recovery. For example, 50% of children who recover from iatrogenic VFP do not improve until after a year from onset [2]. In regards to other causes of VFP, only one third of adults with idiopathic VFP improve [9], while nearly two-thirds of children with idiopathic VFP will recover, with spontaneous resolution reported as far out as 11 years following onset of paralysis [2]. For this reason, as well as concerns regarding when to intervene in the growing larynx and how such intervention will affect subsequent development, the timing of more permanent or invasive interventions for VFP remains controversial in the pediatric age group. Many centers advocate at least one year of observation to allow for spontaneous recovery of vocal fold function before potentially voice-altering procedures such as arytenoidectomy or vocal fold lateralization are performed to achieve decannulation; some argue for a longer period of watchful waiting [10]. Prior studies in adults with RLN injury have demonstrated that there is a role for the use of laryngeal electromyography (L-EMG) in predicting vocal fold recovery in the adult population [11]. There are no large studies evaluating the efficacy of L-EMG in predict-
Children with vocal fold immobility

2. Materials and methods

Approval was obtained from the institutional review board for human research at Massachusetts Eye and Ear Infirmary for a retrospective chart review of 10 patients who were referred to our institution for vocal fold immobility between February 2006 and February 2007. Upon presentation, patients underwent flexible laryngoscopy to confirm the diagnosis. Children were taken to the operating room for direct laryngoscopy, bronchoscopy, and suspension laryngoscopy with direct palpation of the vocal folds to assess for passive mobility. All aspects of the procedures below were performed by a senior otolaryngologist (CJH). After adequate general anesthesia was obtained using remifentanil and propofol, a single intra-operative dose of dexamethasone (0.5 mg/kg) was given. All subjects were placed in suspension with the Benjamin—Lindholm laryngoscope. Anesthesia was lightened until the child was breathing regularly and spontaneously.

2.1. Technique of laryngeal electromyography

In the early stages of this study, EMG was performed using conventional equipment. Both thyroarytenoid (TA) muscles were sampled during spontaneous respiration using endoscopically placed concentric needle electrodes (Viasys Healthcare Neurocare, Madison, WI), which were inserted using laryngeal forceps. Reference electrodes were placed subcutaneously in the right shoulder. Monitoring was performed using the TECA/Medelec Synergy system, version 8.2 (Viasys Healthcare NeuroCare, Madison, WI). Low-frequency filter settings were set at 50 Hz, and high-frequency filter settings were set at 5 kHz. Recordings were made with gain values of 50 μV and 200 μV and a sweep speed of 100 mS (10 mS per division).

In subsequent cases, the NIM Response system (Medtronic ENT USA, Inc. Jacksonville, FL) was utilized in an attempt to determine if intraoperative laryngeal EMG could be performed using equipment already present in the operating room. Monopolar grounding electrodes (Medtronic ENT USA Inc., Jacksonville, FL) were placed subcutaneously into the right shoulder. Paired, monopolar, subdermal monitoring needle electrodes (spaced 2.5 mm apart) from the NIM 2 Response kit (Medtronic ENT USA Inc., Jacksonville, FL) were placed endoscopically into the TA muscle of each vocal fold using laryngeal alligator forceps. Intraoperative L-EMG was recorded from both TA muscles during spontaneous respiration. Recordings were taken using the NIM 2 Response monitor (Factory settings: EMG display: 80 Hz – 2 kHz (–6 + 3 dB at 500 Hz), EMG Audio: 120 Hz – 1.7 kHz (–6 + 3 dB at 500 Hz), sweep speed 50 mS (5 mS per division), and gain values of 50 μV and 200 μV).

In all 10 children, video and audio recordings were made using a digital video recorder (Med X Change DRS2, Med X Change Inc., Bradenton, FL), which was connected to the TECA and NIM 2 Response monitors via audio and video outputs using a video converter (TVview MicroXGA, Focus Enhancements Inc., Campbell, CA). The acoustic signal and video data were later reviewed by a senior neurologist with electromyography training (PSTC).

Four patients underwent serial intraoperative L-EMG using the NIM 2 system to assess for any change in the level of electrical activity in each TA muscle over time.

3. Results

Over the course of 1 year, 10 children between 2 weeks and 13 years of age were referred to our...
were identified. Details are listed in Table 2. Disorders, such as an Arnold Chiari malformation, MRI of the brain and brainstem. No neurological with congenital vocal fold immobility underwent to iatrogenic causes. All patients who presented patients (66%) had vocal fold paralysis attributable (idiopathic) (see Tables 1 and 2). The six remaining patients (of patients affected with VFP of unknown etiology transient, idiopathic, bilateral VF paralysis activity prior to return of VF motion:

3.1. Case 1. Serial L-EMG detects electrical activity prior to return of VF motion: transient, idiopathic, bilateral VF paralysis JL was an 18-day-old boy born full term by suction-assisted vaginal delivery, who had stridor immediately after birth. In the newborn nursery he was able

Table 1 Comparison between Massachusetts Eye and Ear Infirmary (MEEI) and a summary of the Great Ormond Street Hospital for Children experience with VFP over a 14 years period by Daya et al. [2]

<table>
<thead>
<tr>
<th>Type of VFP</th>
<th>MEEI (n = 9 cases)</th>
<th>Daya (n = 102 cases)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unilateral</td>
<td>(5/9) 55%</td>
<td>(49/102) 48%</td>
</tr>
<tr>
<td>Bilateral</td>
<td>(4/9) 45%</td>
<td>(53/102) 52%</td>
</tr>
<tr>
<td>Acquired</td>
<td>(6/9) 66%</td>
<td>(57/102) 56%</td>
</tr>
<tr>
<td>Congenital</td>
<td>(3/9) 33%</td>
<td>(45/102) 44%</td>
</tr>
<tr>
<td>Neurological</td>
<td>(0/9) 0%</td>
<td>(16/102) 16%</td>
</tr>
<tr>
<td>Idiopathic</td>
<td>(3/9) 33%</td>
<td>(36/102) 35%</td>
</tr>
<tr>
<td>Birth trauma</td>
<td>(6/9) 66%</td>
<td>(44/102) 43%</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>(0/9) 0%</td>
<td>(5/102) 5%</td>
</tr>
<tr>
<td>Recovery</td>
<td>MEEI (n = 13 VFs)</td>
<td>Daya (n = 65 cases)</td>
</tr>
<tr>
<td>Neurological</td>
<td>(5/7) 71%</td>
<td></td>
</tr>
<tr>
<td>Idiopathic</td>
<td>(3/5) 60%</td>
<td>(18/28) 64%</td>
</tr>
<tr>
<td>Birth trauma</td>
<td>(2/8) 25%</td>
<td>(12/26) 46%</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>(0/1) 0%</td>
<td></td>
</tr>
</tbody>
</table>

12 weeks following his initial exam, the patient returned for evaluation. His stridor had nearly resolved and was present only when crying. He had a strong voice and was gaining weight. A follow-up intraoperative L-EMG using the NIM 2 system demonstrated MUAP in both TA muscles. The right TA muscle remained electrically silent, without evidence of fibrillations or positive sharp waves suggesting denervation (see Fig. 1B). Repeat flexible laryngoscopy while the patient was awake, again demonstrated bilateral vocal fold immobility. In light of these findings and the patient’s stability during the preceding 4-week rehabilitation course, the child was discharged home. A repeat L-EMG and fiber-optic exam was scheduled for 2 months later.

Twelve weeks following his initial exam, the patient returned for evaluation. His stridor had nearly resolved and was present only when crying. He had a strong voice and was gaining weight. A follow-up intraoperative L-EMG using the NIM 2 system demonstrated MUAP in both TA muscles (see Fig. 1C). Flexible laryngoscopy in the office confirmed full and symmetric motion of both vocal folds. He has done well in follow-up.

4. Discussion

The essential controversy that remains regarding L-EMG rests upon the question of whether or not it is
### Table 2: Details of 10 patients presenting with vocal fold immobility who underwent laryngeal Electromyography at Massachusetts Eye and Ear Infirmary from 2006 to 2007

<table>
<thead>
<tr>
<th>Case</th>
<th>Age/sex</th>
<th>Diagnosis</th>
<th>Outcome</th>
<th>History</th>
<th>FOE/DLB findings</th>
<th>Serial/single L-EMG</th>
<th>L-EMG findings</th>
<th>Clinical impact of L-EMG</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 weeks/M</td>
<td>BVFP (idiopathic)</td>
<td>Recovery of BVFP</td>
<td>Stridor, cyanosis, retractions at birth</td>
<td>BVFI/BVFP</td>
<td>Serial</td>
<td>Week 0: silent right TA, weak MUAP left TA</td>
<td>Accurately predicted recovery, L-EMG activity preceded return of function</td>
</tr>
<tr>
<td>2</td>
<td>2 months/F</td>
<td>BVFF/Grade 3 SGS</td>
<td>Tracheotomy, LTR planned</td>
<td>Stridor following prolonged intubation</td>
<td>BVFI/Grade 3 SGS</td>
<td>Single</td>
<td>MUAP in both TAs</td>
<td>L-EMG suggests immobility due to fixation alone</td>
</tr>
<tr>
<td>3</td>
<td>13 years/F</td>
<td>LVFP (iatrogenic)</td>
<td>VF injection, permanent voice procedure planned</td>
<td>Hoarseness and aspiration s/p skull base resection</td>
<td>LVFI/LVFP</td>
<td>Single</td>
<td>MUAP in right TA, silent left TA</td>
<td>Flat EMG tracings predict poor chance of recovery/permanent voice procedure planned</td>
</tr>
<tr>
<td>4</td>
<td>2 months/F</td>
<td>BVFP (idiopathic)</td>
<td>Recovery of RVFP motion, left VF remains weak</td>
<td>Stridor, cyanosis, retractions at birth</td>
<td>BVFI/BVFP</td>
<td>Serial</td>
<td>Week 0: MUAP in right TA, silent left TA week 4: MUAP in both TAs</td>
<td>Accurately predicted recovery, L-EMG activity preceded return of function</td>
</tr>
<tr>
<td>5</td>
<td>14 years/M</td>
<td>LVFF/VFP (iatrogenic)</td>
<td>VF injection, deferred adduction arytenopexy pending period of observation</td>
<td>Hoarseness s/p short term intubation</td>
<td>LVFI/LVFI</td>
<td>Single</td>
<td>MUAP in right TA, silent left TA</td>
<td>L-EMG leads diagnosis away from arytenoid fixation and towards transient paresis</td>
</tr>
<tr>
<td>6</td>
<td>4 months/M</td>
<td>LFVP (iatrogenic)</td>
<td>Persistent LVFP</td>
<td>Abnormal cry s/p PDA ligation</td>
<td>LVFI/LVFP</td>
<td>Single</td>
<td>MUAP in both TAs</td>
<td>L-EMG confirms clinical suspicion but does not clearly affect clinical management</td>
</tr>
<tr>
<td>7</td>
<td>2 weeks/M</td>
<td>RVFP (idiopathic)</td>
<td>Resolution of symptoms, family refused follow up flexible laryngoscopy</td>
<td>Stridor at birth</td>
<td>RVFI/RVFP</td>
<td>Single</td>
<td>Silent right TA, few MUAP in left TA</td>
<td>L-EMG confirms clinical suspicion but does not clearly affect clinical management</td>
</tr>
<tr>
<td>8</td>
<td>4 weeks/M</td>
<td>LVFP (iatrogenic)</td>
<td>Recovery of LVFP, underwent supraglottoplasty</td>
<td>Stridor, retractions s/p TEF repair</td>
<td>LVFI/LTM, LVFP</td>
<td>Single</td>
<td>MUAP in both TAs</td>
<td>Accurately predicted recovery, L-EMG activity preceded return of function</td>
</tr>
</tbody>
</table>
simply a research tool without clinical utility, or whether it indeed can add meaningful prognostic information regarding potential recovery of VF function. In adults with VFP, L-EMG has been useful in predicting recovery from vocal fold paralysis in select patients. Electromyographic data is most helpful in determining prognosis when obtained within 6 months and preferably within 6 weeks of onset of paralysis, as after 6 months, recovery is less likely, regardless of the EMG findings [11]. For example, if an adult who sustains RLN injury undergoes L-EMG 3 months after onset of paralysis and this exam shows fibrillations or an absence of EMG activity in the TA muscle, there is a greater than 90% chance that the injury is permanent [13]. However, if there is some degree of electrical activity noted at 3 months, this significance of this is unclear in that the presence of EMG activity months following paralysis does not necessarily portend a good prognosis [13]. In light of all of these findings, L-EMG may be useful in shortening the process of voice rehabilitation by allowing for earlier interventions [13], as its greatest utility is in accurately predicting a poor functional outcome [11,13,14].

Electromyography is an accepted methodology for evaluating neuromuscular disease in children [19], however the use of L-EMG in predicting VF recovery in this population is unclear. First, many of the children who develop VFP are too young for awake, volitional testing. Currently, pediatric L-EMG remains more of a research tool and no standard application has been widely accepted. Possible reasons for this relate to technical challenges in performing intraoperative L-EMG as well as a lack of data in regards to the utility of electromyography in accurately predicting VF recovery. Additionally, there is no accepted, standardized technique for performing intraoperative L-EMG and no established normal values or outcome measures exist for pediatric patients. Issues relating to children that further complicate electromyographic evaluation of VFP include understanding the pathophysiology behind congenital and idiopathic VFP and how the standard adult model, which was developed for primarily iatrogenic injury, may or may not be applicable to this disease process. The utility of L-EMG in predicting recovery from acquired pediatric VFP has not been investigated in any systematic fashion. The available data in regards to the etiology and recovery rates of pediatric vocal fold paralysis suggest higher rates of recovery for paralysis related to neurological causes. Unfortunately, the rate of spontaneous recovery in patients with iatrogenic or idiopathic VFP, which represent nearly 80% of cases in some series, is closer to 50%, with recovery occurring weeks to years after onset of paralysis [2].
It is in this group of patients, in which prognosis is less clear and recovery time is highly variable, that L-EMG may prove most helpful to clinicians. This paper does not purport to answer all of these questions. The goals of this study were to address practical issues surrounding pediatric L-EMG; mainly how it is performed, and if it is useful. Finally, we hoped to determine if serial EMG recordings improved our ability to predict VF recovery.

Our simplified method for intraoperative L-EMG addresses many of the problems described above, however some disadvantages to the technique of intraoperative assessment remain. Improvements over previously described protocols include the use of standardized equipment that does not require intraoperative modification. For example, placement of paired electrodes from the NIM Response 2 kit using laryngeal forceps is far less difficult than endoscopic placement of needle electrodes or hook-wire electrodes described in prior studies. The paired, subdermal electrodes were chosen because the 2.5 mm spacing between the two monopolar electrodes allows for thorough sampling across the length of the TA muscle. Additionally, the paired electrodes allow for two-point fixation within the muscle, resulting in less waveform variability with

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**Fig. 1** L-EMG tracings from JL at various time points. (A) Initial presentation: L-EMG tracings of the right and left TA muscles using the TECA system set at a gain of 200 µV and a sweep speed of 10 mS/division. Low amplitude MUAP in the left TA muscle with no MUAP in the right TA muscle. (B) Four weeks follow up: L-EMG tracings of the right and left TA muscles using monopolar paired electrodes and the NIM 2 Response system set at a gain of 200 µV with a sweep speed of 5 mS/division. Normal MUAP in the left TA muscle and electrical silence in the right TA muscle. (C) Twelve weeks follow up: L-EMG tracings of right and left TA muscles using monopolar paired electrodes and NIM 2 Response system set at a gain of 200 µV with sweep speed of 5 mS/division. Normal MUAP in both TA muscles.

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**Fig. 2** L-EMG tracings from Case 2 using the TECA system showing MUAP in both TA muscles at gains of 50 µV and 200 µV with a sweep speed of 10 mS/division. See Table 2 for details.
body motion than is observed with standard needle electrodes. The electrodes are ready-made, requiring no further modification for use in the pediatric larynx. Utilizing commercially available electrodes also allows for ongoing measurement of impedance. Impedance is defined as the total opposition to an alternating current in an electrical circuit; in many ways it is a measure of resistance across electrodes. Low impedance reflects accurate placement of the electrodes, and high impedance suggests an incorrectly sited probe. For this reason, a sudden increase in impedance allows for instantaneous identification of an accidentally displaced probe. The NIM Response system allows for a constant measurement of impedance, a feature that dramatically reduces the possibility of sampling error by limiting false negative results. Current intraoperative L-EMG protocols require ruling out incorrect lead placement by resiting electrodes at least three times when electrical silence is encountered [18].

Utilizing nerve-monitoring equipment that is already present in most operating rooms obviates the need for obtaining commercial EMG equipment. Employing existing machinery eliminates costs incurred in purchasing hardware and training personnel in the operation and maintenance of equipment that is unfamiliar to most OR technicians. The use of a digital video recorder allows for the storage of both audiovisual data for future viewing by a consulting neurologist, thereby negating the need for intraoperative interpretation of acoustic signals and electromyographic data.

The limitations of our technique should be noted as well. The procedure requires general anesthesia and measures EMG activity that is non-volitional, correlating with respiratory variation rather than phonatory effort. Standard L-EMG typically involves sampling of the TA and PCA muscles for evaluation of adductor and abductor function; the cricothyroid muscle is also assessed to evaluate superior laryngeal nerve (SLN) function. The presence or absence of SLN function helps localize the site of the lesion, as evaluation of the cricothyroid muscle allows for a more complete examination of the neuromuscular axis. While at least five papers have been published describing techniques for intraoperative L-EMG in children, none of these studies evaluated the cricothyroid muscles [10,15–18]. This is likely explained by the fact that the function of this muscle cannot be fully assessed during spontaneous respiration under a light plane of general anesthesia. It was for this reason that we did not attempt to sample the cricothyroid muscles using our technique.

Our method for intraoperative L-EMG also omits evaluation of the laryngeal abductors, as the paired...
in our series described in this series has limited their assessment to L-EMG evaluation of the TA muscles; in fact many of these studies obtained by L-EMG is acquired through examination of the TA muscles alone [11,13,16,18].

5. Summary

The introduction of a simplified technique for intraoperative L-EMG described in this series has made electromyography more accessible at our institution and allowed for more frequent use among children with vocal fold dysfunction. Within a single year of experience, we have evaluated 10 children with VF immobility using intraoperative L-EMG. In over half of these patients, the results of electromyographic assessment affected management. The availability of instrumentation and relative simplicity of the procedure has also allowed us to perform serial recordings as patients are followed over time. Two children with idiopathic BVFP initially presented with a lack of activity on one or both sides but went on to develop motor unit action potentials that preceded recovery of motion in both vocal folds. This observation supports the hypothesis that serial L-EMG recordings may offer more information than one-time measurements.

6. Conclusion

Intraoperative L-EMG in children remains controversial and is not widely utilized. There remain no standard modes for testing and no accepted normal and abnormal outcome metric values in children with VFP. The use of serial L-EMG may offer more information than one-time measurements, and evoked L-EMG holds promise in quantifying laryngeal innervation. We propose in this paper a simplified technique to perform both spontaneous and potentially evoked L-EMG in the hopes of facilitating further studies that may elucidate the role of this technology in the evaluation of pediatric VFP.

References