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Invited Article: Recommendations of the Neurolaryngology Study Group on Laryngeal Electromyography

Andrew Blitzner M.D., DDS,
Head and Neck Surgical Group, New York, NY

Roger L. Crumley M.D., MBA,
Department of Otolaryngology-Head and Neck Surgery, University of California-Irvine, CA

Seth H. Dailey M.D.,
Division of Otolaryngology-Head and Neck Surgery, University of Wisconsin School of Medicine and Public Health, Madison, WI

Charles N. Ford M.D.,
Division of Otolaryngology-Head and Neck Surgery, University of Wisconsin School of Medicine and Public Health, Madison, WI

Mary Kay Floeter M.D., Ph.D.,
National Institute of Neurological Disorders and Stroke, National Institutes of Health, Bethesda, MD

Allen D. Hillel M.D.,
Department of Otolaryngology – Head and Neck Surgery, University of Washington School of Medicine, Seattle, WA

Henry T. Hoffman MD,
Department of Otolaryngology-Head and Neck Surgery, University of Iowa, Iowa City, IA

Christy L. Ludlow Ph.D. *
National Institute of Neurological Disorders and Stroke, National Institutes of Health, Bethesda, MD

Albert Merati M.D.,
Department of Otolaryngology – Head and Neck Surgery, University of Washington School of Medicine, Seattle, WA

Michael C. Munin M.D.,
Department of Physical Medicine and Rehabilitation, University of Pittsburgh School of Medicine, University of Pittsburgh, Pittsburgh, PA

Lawrence R. Robinson M.D.,
Department of Rehabilitation Medicine, University of Washington School of Medicine, Seattle, WA

Clark Rosen M.D.,
Department of Otolaryngology, University of Pittsburgh School of Medicine, University of Pittsburgh, Pittsburgh, PA

Keith G. Saxon M.D.,
Department of Surgery, Division of Otolaryngology, Harvard Medical School, Boston MA

Lucian Sulica MD,
Department of Otorhinolaryngology, Weill Medical College of Cornell University, NYC, NY

*Corresponding Author: Dr. Christy Ludlow, 10 Center Drive MSC 1416, Bethesda, MD 20892-1416, email: Ludlowc@ninds.nih.gov, Phone 301-496-9366.

Susan L. Thibeault Ph.D.,

Division of Otolaryngology-Head and Neck Surgery, University of Wisconsin School of Medicine and Public Health, Madison, WI

Ingo Titze Ph.D.,

University of Iowa, Iowa City, IA

Peak Woo M.D., and

Department of Otolaryngology, Mt Sinai School of Medicine, New York, NY

Gayle E. Woodson M.D.

Department of Otolaryngology-Head and Neck Surgery, Southern Illinois University, Springfield, IL

Abstract

The Neurolaryngology Study Group convened a multidisciplinary panel of experts in neuromuscular physiology, electromyography, physical medicine and rehabilitation, neurology, and laryngology to meet with interested members from the American Academy of Otolaryngology Head and Neck Surgery, the Neurolaryngology Subcommittee and the Neurolaryngology Study Group to address the use of laryngeal electromyography (LEMG) for electrodiagnosis of laryngeal disorders. The panel addressed the use of LEMG for: 1) diagnosis of vocal fold paresis, 2) best practice application of equipment and techniques for LEMG, 3) estimation of time of injury and prediction of recovery of neural injuries, 4) diagnosis of neuromuscular diseases of the laryngeal muscles, and, 5) differentiation between central nervous system and behaviorally based laryngeal disorders. The panel also addressed establishing standardized techniques and methods for future assessment of LEMG sensitivity, specificity and reliability for identification, assessment and prognosis of neurolaryngeal disorders. Previously an evidence-based review of the clinical utility of LEMG published in 2004 only found evidence supported that LEMG was possibly useful for guiding injections of botulinum toxin into the laryngeal muscles. An updated traditional/narrative literature review and expert opinions were used to direct discussion and format conclusions. In current clinical practice, LEMG is a qualitative and not a quantitative examination. Specific recommendations were made to standardize electrode types, muscles to be sampled, sampling techniques, and reporting requirements. Prospective studies are needed to determine the clinical utility of LEMG. Use of the standardized methods and reporting will support future studies correlating electro-diagnostic findings with voice and upper airway function.

Introduction

The Neurolaryngology Study Group, a long standing discussion group addressing both basic sciences and clinical aspects of neurolaryngology, convened a workshop focusing on the use of laryngeal electromyography (LEMG). A multidisciplinary panel of experts included scientists in neuromuscular physiology, electromyography, physical medicine and rehabilitation, neurology, and laryngology, who met with interested members from the American Academy of Otolaryngology Head and Neck Surgery Neurolaryngology Subcommittee and the Neurolaryngology Study Group to address the use of LEMG for electrodiagnosis of laryngeal disorders.

While LEMG is considered an essential component in laryngeal assessment by some, others have expressed reservations. A lack of agreement exists on methodology, interpretation, validity, and clinical application of LEMG. Some practitioners claim that LEMG is an invaluable component of dysphonia assessment. Others point to the lack of scientific evidence supporting its use; most published reports are class IV retrospective non-blinded case series¹. In their 2004 evidence-based review of 584 articles, Sataloff, Mandel, Mann, and Ludlow² concluded that LEMG was “possibly useful for the injection of botulinum toxin” but that

evidence to support other uses was lacking. This contrasts with the clinical use of LEMG by some in the community³.

The charge was to examine the basic science and advance relevant points of consensus⁴. The examination was to include the current status of LEMG technology, and the clinical experience of leaders in the field. Five reviewers addressed a particular question regarding the use of LEMG by refining the question into a testable hypothesis. Next, they examined provisional support for the applicability, methodology, and validity of LEMG for the hypothesized purpose beyond the review in 2004². A conclusion could only be reached if there was a body of knowledge available to either reject or confirm a hypothesis. Finally, after identifying voids and key remaining questions, the reviewers were asked to describe what additional studies are needed, and feasible designs that could be executed.

The process was constrained by the available data, which are likely to change and self-correct over time. With the cumulative growth of knowledge over time, some concepts will be retained and others abandoned. Medical practice is constrained by the incomplete mastery of available knowledge; the limitations in current medical knowledge; and the difficulty in distinguishing between the first two⁵. The goal of this report was to reduce the level of uncertainty by clarifying the limitations of knowledge about LEMG and identify what needs to be learned.

The purpose of this review was *not* to conduct an evidence-based review regarding the specificity and sensitivity and reliability of LEMG as this was previously addressed in the extensive evidence-based review published in 2004². Rather the need was to move the field to the next step by identifying what parameters must be considered in attempting to develop standardized methods for LEMG for use in prospective controlled blinded assessments of LEMG sensitivity, specificity and reliability for identification, assessment and prognosis for neurolaryngological disorders.

Definitions

Peripheral versus Central Nervous System Disorders

LEMG is considered of use in diagnosis and assessment of peripheral and central neurological disorders affecting laryngeal function and to differentiate neurolaryngological disorders from other disorders causing changes in laryngeal function such as cricoarytenoid joint fixation. Peripheral neurolaryngological disorders may affect either efferent lower motor neurons and/or afferent/sensory neurons, neuromuscular junctions and/or muscles (in myopathies), while central neurological disorders (CNS) affect the firing rates of motor neurons, upper motor neurons, or central sensory pathways in the spinal cord, brainstem, or brain (Figure 1). Vocal fold paralysis can be caused either by traumatic peripheral nerve injuries, neuropathies affecting axons⁶ or central disorders such as laryngeal motor neuron death^{7,8} or brain stem stroke⁹. LEMG has potential for distinguishing between peripheral and CNS disorders and to differentiate vocal fold paresis/paralysis from other factors producing vocal fold immobility such as joint fixation.

Qualitative Electromyography (EMG)

Qualitative EMG samples the discharge patterns of muscle fiber action potentials (MFAP) and motor unit action potentials (MUAP), the waveform emitted by simultaneous activation of all the muscle fibers innervated by the axon of a single motor neuron. Motor units in large muscles may include many muscle fibers (1000 fibers/axon). In contrast, given the small number of human laryngeal muscle fibers¹⁰ and the numbers of mammalian laryngeal motoneurons¹¹, the laryngeal motor neurons likely innervate only a small number of fibers. Given these differences, experience recording the typical MUAPs of laryngeal muscles is needed to interpret whether or not the MUAP patterns are abnormal to identify denervation, reinnervation

or muscle disease. The electromyographer must be familiar with the typical MUAP shape and hearing the sound of MUAPs from a particular muscle to identify MUAP abnormalities in that muscle.

Several aspects of LEMG can be identified. *Insertional* activity is the burst of activity that occurs when the electrode is first inserted or moved in a muscle. This normally lasts no more than 300 ms after needle movement and can be described as normal, reduced, or increased/prolonged with a description of the waveform and its discharge rate (as presented on p. 1478 in ¹²). Activity prolonged beyond needle insertion is termed spontaneous activity, which may include *fibrillation potentials*, i.e. spontaneously discharging muscle fibers seen as short duration MFAPs (less than 5 ms in duration). However, the identification of fibrillation potentials depends upon the normal durations of MUAP in a particular muscle. Normal laryngeal muscle MUAPs which contain few muscle fibers per motor unit, are often less than 5 ms in duration with peak to peak amplitudes of 200 microvolts^{13,14}. *Positive sharp waves* are also spontaneous short duration MFAPs always in the positive (downwards) direction. Both have a regular pattern of discharge and are associated with denervation. *Complex repetitive discharges* (CRD) occur in chronic myopathies and neuropathies due to ephaptic transmission between muscle fibers where one muscle fiber serves as a pacemaker cell for others. CRDs start and end abruptly, and have a harsh, machinery-like sound. *Fasciculations* are spontaneous discharges of entire motor units originating either from the motor neuron or distally along the axon, in an irregular pattern sounding like raindrops on a tin roof. Fasciculations occur in neuropathy or motor neuron diseases such as amyotrophic lateral sclerosis.

When an axon is first damaged and the muscle fibers are denervated, spontaneous discharges usually only occur when the muscle fibers are stimulated directly by needle movement. Spontaneous activity begins to develop after about a week, with positive waves and fibrillations. Over weeks to months, intact neighboring axons may sprout to reinnervate adjacent denervated muscle fibers. Because the axonal sprouts are thin and poorly myelinated, their conduction is slower than the original axonal branches resulting in asynchronous activation of muscle fibers with increased MUAP durations and more complex waveforms. These MUAPs are *polyphasic potentials* with multiple baseline (zero) crossings (at least four zero crossings producing five phases)¹². Only if the same complex waveform reappears many times can a polyphasic MUAP be distinguished from chance simultaneous firing of multiple MUAPs.

Motor Unit Recruitment Patterns

With increased force of muscle contraction, MUAPs firing rates increase and additional MUAPs are recruited. The recruitment pattern should change from a few slowly firing MUAPs that can be individually distinguished, to a larger number of MUAPs firing at faster rates, producing a full "interference pattern" when MUAPs overlap interfering with the detection of individual MUAPs. Motor neurons are typically recruited in an order from the smallest to largest, referred to as the Henneman size principle¹⁵. During soft phonation small slowly firing thyroarytenoid motor units should be recruited in contrast with valsalva. By using graded tasks, the electromyographer can judge whether the person can recruit their muscles normally. Qualitative judgments can estimate whether or not the patient has "no, poor, moderate or slightly reduced" voluntary recruitment of laryngeal motor unit firing.

The qualitative examination screens several muscles to identify prolonged insertional spontaneous activity and screen for fibrillation potentials, positive sharp waves, complex repetitive discharges and fasciculations. An ordinal rating scale from 0 to +4 is usually used with 0 representing no discharges and 4+ filling the entire baseline with discharges and being most abnormal¹⁶.

Qualitative EMG is highly dependent upon the experience of the individual with the particular muscles being tested. Even experienced electromyographers familiar with sampling MUAPs in larger muscles may erroneously identify laryngeal muscle MUAPs to be fibrillation potentials because of smaller amplitudes and of shorter durations in laryngeal MUAPs than other muscles¹³.

Synkinesis

Abnormal muscle activation patterning occurs when the axon from an intact motor neuron for a different muscle has reinnervated a muscle that was previously denervated^{17,18}. For example, if fibers in a posterior cricoarytenoid muscle are reinnervated by axons that normally innervate the thyroarytenoid muscle, then MUAPs within the posterior cricoarytenoid muscle may be more active for vocal fold closure rather than for vocal fold opening producing an abnormal synkinetic pattern of activity. Synkinesis may be difficult to define; the adductor muscles and the cricothyroid are normally active during both phases of respiration¹⁹ and during both vocal fold closing and opening for speech and non-speech gestures²⁰. In addition, the posterior cricoarytenoid muscle is normally active during high pitched phonation²¹. Although different types of patterns have been proposed as indicative of abnormal reinnervation^{22,23}, the accuracy of detection of synkinesis in prospective blinded controlled studies needs to be determined.

Quantitative Electromyography

Quantitative electromyography (QEMG) developed in an effort to objectively differentiate weakness caused by muscle disease from that caused by diseases of the peripheral nerve. Normative data on MUAP characteristics for each muscle across different age groups was gathered for objectively determining if a MUAP within a particular muscle was abnormal^{13, 24}. Some studies have gathered quantitative data on the MUAPs of each of the laryngeal muscles^{25–28}. Generally, myopathies and neuromuscular junction diseases will produce short duration small amplitude MUAPs, while neuropathic conditions produce long duration, large amplitude MUAPs.

MUAP Quantification

Initially QEMG was done manually and was labor intensive. Now, commercially available machines support automatic detection of MUAPs with normative values stored for lookup of expected MUAP amplitudes and durations for different muscles. None of these machines currently have normative values for laryngeal muscle MUAPs. This would aid standardized testing of the thyroarytenoid muscle to assess the integrity of the recurrent laryngeal nerve (RLN) and the cricothyroid muscle to assess the external branch of the superior laryngeal nerve (eSLN).

For QEMG on laryngeal muscles, changing the depth and rate of breathing and easy phonation are useful for isolating individual units^{14,19,29}. Commercially available EMG machines have automatic programs for detecting repeated firings of the same MUAP. The operator can identify a unit and store parameters from other firings of the same MUAP. The amplitude and duration can be compared with the norms for that muscle in a person of the same age range when the same EMG electrode is used. These computerized systems make QEMG much less time consuming and cumbersome than previous manual methods and need to incorporate normative data for laryngeal muscles.

Turns Analysis

A quantitative approach to measuring the fullness of an interference pattern includes “turns” analysis that estimates the number of motor units being fired in the muscle using measures of the number of turns/second and mean amplitude/turn when the patient recruits the muscle at a

specific force^{30,31}. Lindestad and colleagues used voice pitch and loudness changes to control muscle recruitment and examined whether or not a “turns” analysis could quantify interference patterns across individuals. The approach was partially successful and should be examined further^{32,33}.

Quantification of EMG signals

Quantitative MUAP measures used in QEMG (Table 1) include the amplitude from the positive to the negative peak, duration from the initial deflection from baseline to the terminal return to baseline, and the phase number. The mean duration of 20 MUAPs from each muscle distinguished between myopathy and neurogenic disorders using manual methods³⁴. More automated methods such as the “Multi-MUP” method³⁵ allow for decomposition of an EMG pattern into individual MUAPs during contraction between 5–30% force. Between 20–30 MUAPs can be defined in a few minutes for detecting abnormalities³⁶. Multichannel electrodes are also useful for identifying different MUAPs within the same territory³⁷. Although used in laryngeal muscles²⁸ the accuracy for detecting laryngeal neuropathy is unknown.

Normal Laryngeal MUAP Characteristics

Faaborg-Andersen used a concentric needle electrode manually documenting the short durations (3–7 ms) and small amplitudes (100– 800 microvolts) of normal laryngeal MUAPs. Similar values were obtained using computerized quantification of manually detected units^{26,38}. Using the Multi-MUP method, reference values obtained from 40 healthy volunteers with a concentric electrode in the cricothyroid and thyroarytenoid muscles, had mean MUAP durations of 4.5 ms and mean amplitudes of 350 microvolts in the thyroarytenoid and 280 in the cricothyroid²⁷. On the other hand, normative values obtained from normal adults between 20 and 75 years using a concentric *bipolar* electrode in the thyroarytenoid muscles found MUAP mean durations of 1.70 ms that increased with age; doubling after 60 years¹⁴. These differences in normative values illustrate the need for standardizing electrodes and techniques before developing norms for detecting pathology using laryngeal QEMG.

EMG Electrodes

To quantify MUAPs, the same electrode type must be used as was used in obtaining reference values because of differences in recording areas between electrode types (Table 2). Filter settings must also be consistent. The monopolar electrode picks up from a large circular region with an uptake region 1.5 times that of the concentric electrode¹². Dedo compared the specificity of concentric and bipolar concentric needle electrodes in denervated thyroarytenoid muscles^{39,40} adjacent to intact cricothyroid muscles. The concentric electrode in a denervated thyroarytenoid picked up potentials from the intact cricothyroid while no potentials were recorded with the bipolar concentric electrode in the denervated thyroarytenoid along side an intact cricothyroid. Unfortunately the bipolar concentric electrode is no longer commercially available. Most reports on MUAP characteristics in the thyroarytenoid and cricothyroid muscles have used the concentric electrode and therefore this electrode is preferred despite its lesser selectivity. One study employed commercially available single fiber EMG (SFEMG) electrodes and provided normative data on 10 adults in their 30's. Measures of fiber density and jitter may have clinical utility⁴¹. SFEMG is preferred for the diagnosis of neuromuscular junction abnormalities^{42,43}.

Operators

Recording from the laryngeal muscles is technically difficult although methods are well described in the literature⁴⁴. Otolaryngologists who regularly inject botulinum toxin into thyroarytenoid muscles for treatment of spasmodic dysphonia are skilled in performing LEMG; however, few have had training in reading MUAP signals. An otolaryngologist and an

experienced electromyographer with clinical neurophysiology training (either a neurologist or physiatrist) should work as a team to develop experience with the specific attributes of normal laryngeal muscles.

Equipment

Commercially available EMG machines have a range of features. Some simply have 1–2 channel EMG amplifier inputs to a laptop with a speaker and display the EMG trace(s). More specialized EMG machines allowing for automatic MUAP detection and analyses and are essential for QEMG.

Proposed Uses for LEMG

1. Injection for Botulinum Toxin

The 2004 evidence–based review² concluded that LEMG was "possibly useful for the injection of botulinum toxin." However, other approaches are available for the injection of botulinum toxin into the thyroarytenoid and/or the lateral cricoarytenoid muscles in adductor spasmodic dysphonia such as: a peroral approach that allows visual confirmation of placement⁴⁵ or use of the point-touch approach using anatomical landmarks⁴⁶. For injection of the posterior cricoarytenoid muscle in abductor spasmodic dysphonia, there are also other approaches besides LEMG such as using a channeled nasolaryngoscope⁴⁷. When the endoscopic technique was compared with percutaneous injection with LEMG neither approach reduced symptoms and no difference in outcome was found between the two approaches⁴⁸. To date, no comparisons have been conducted between the use of LEMG and peroral or point-touch approach for injection of adductor spasmodic dysphonia⁴⁹.

2. Diagnosis of Vocal Fold Paresis

Vocal fold paralysis refers to a loss or impairment of motor function due to a lesion of the neural or muscular mechanism *while paresis* is a partial movement impairment also of neural or muscular origin. Partial or total vocal fold immobility should be used when the basis for the impairment is unknown or results from mechanical limitations such as a bulk effect of cancer or joint pathology (fixation or dislocation).

Laryngeal/voice dysfunction may result from vocal fold paralysis/paresis, however, some patients with vocal fold *paralysis* are asymptomatic, possibly due to adequate compensation. The prevalence of vocal fold paralysis/paresis and its significance for producing laryngeal/voice dysfunction, therefore, is unknown.

Laryngeal physiology may be impacted by vocal fold paralysis/paresis. Aerodynamic measures correlated with qualitative unblinded EMG findings in symptomatic patients with vocal fold paresis/ paralysis; those with fewer normal motor units on LEMG had higher mean translaryngeal air flows¹⁶. and poor recruitment was associated with reduced maximum phonation times and higher mean flows. Symptomatic paresis was reported to result in hyperfunction⁵⁰ or abnormal vibration, the theoretical basis of the "paresis podule"⁵¹. The impact of partial movement reductions due to neurological impairments (paresis) on airway and swallowing functions has not been well studied.

To examine whether LEMG can identify vocal fold paresis, 22 symptomatic patients had unblinded qualitative LEMG studies and laryngeal examinations and 19/22 cases were judged to have neuropathy on LEMG⁵². In another report, 13 patients underwent qualitative LEMG and 12/13 patients with clinically suspected vocal fold paresis were judged to have abnormalities on unblinded LEMG⁵³. The only patient with a normal EMG had a prior history of intubation following head injury and a stiff cricoarytenoid joint on direct laryngoscopy.

These findings suggest that in *symptomatic* patients with suspected vocal fold paresis, motion abnormalities likely reflect some degree of neurological impairment that correlate with findings on unblinded qualitative LEMG^{52,53}. The EMG findings in suspected paresis cases may be similar to paralysis as there are no different criteria⁵⁴. In a retrospective study of 50 vocal fold paresis symptomatic patients⁵⁵, unblinded qualitative LEMG indicated unilateral neuropathic findings in 60%, bilateral findings in 40% and contralateral neuropathy in 26%. Isolated eSLN involvement was indicated in 16%; isolated RLN neuropathy in 44%; and combined eSLN and RLN neuropathy in 40%, although all were unblinded qualitative exams.

Blinded studies are needed to determine if LEMG can distinguish between neurological and mechanical vocal fold impairments^{55,56}. However, the clinical utility of this information, particularly considering the disagreement regarding the prevalence of arytenoid dislocation/subluxation, is unknown.

To address the accuracy of LEMG in vocal fold paresis for detecting neurological abnormalities, prospective studies are needed to identify what LEMG findings would be expected in vocal fold paresis on qualitative and/or quantitative LEMG.

3. Predicting Recovery from Acute Unilateral Vocal Fold Paralysis/Paresis Following Recurrent Laryngeal Nerve Injury

Although LEMG has been advocated as providing prognostic information in cases of vocal fold paresis, the data are limited. If the purpose of the “prognosis” is for early management decisions, caution should be applied. Koufman and colleagues reported that LEMG altered their management 63% of the time⁵⁶. Of these, 12% were useful in differentiating paralysis from fixation, although the criteria were not provided and the change in patient care was not detailed. With regard to the 11% for whom the imaging choices were driven by EMG, no imaging modality was shown superior to the other (magnetic resonance imaging (MRI) vs. computed tomography, CT). The importance of the LEMG prognosis on surgical decision is dependent on knowing how LEMG-driven surgical outcomes are superior to other management approaches for vocal fold paralysis.

Serial LEMG examinations in the same patient over time may be helpful. A retrospective review of 31 cases of vocal fold paralysis examined between 21 days and 6 months post onset, assessed the value of qualitative LEMG in predicting persistent vocal fold paralysis⁵⁷. A poor prognosis was defined as reduced motor unit recruitment (a decreased interference pattern) with acute or chronic spontaneous activity. An excellent prognosis included a normal motor unit recruitment pattern with only a slightly decreased interference pattern and no fibrillation potentials or positive sharp waves. Fair prognosis was “moderately decreased motor unit recruitment”, a diminished interference pattern and spontaneous discharge but no complex repetitive discharges. The outcome measure was the resolution of vocal fold with substantial return of movement by 6 months post onset. The sensitivity, the percentage of cases with persistent vocal fold paralysis with fair to poor LEMG, was 91%. The specificity, the percentage of patients with good recovery who had an excellent prognosis on LEMG, was 44% (4/9 cases). A stepwise regression showed that the LEMG findings predicted 44.4% of the resolved cases. Judgment of motor unit recruitment on LEMG was most useful for prediction, but was unblinded.

These results are not based on prospective blinded LEMG examination. Judgments made by one electromyographer need to be replicated by others.

3. Accuracy of LEMG for Diagnosis of Neuromuscular Diseases of the Larynx

Diagnosis of myasthenia gravis (MG), the most common disorder affecting the neuromuscular junction, depends upon repetitive nerve stimulation (RNS) to affected muscles^{58,59}. Antibody production against acetylcholine in MG blocks neurotransmission to muscle fibers causing fatigue and decreased muscle response during RNS after exercise. If the response to RNS is normal and there is still a high suspicion of a neuromuscular junction disorder, then SFEMG of at least one symptomatic muscle is recommended. The study should be considered abnormal if 10% of fiber potential pairs exceed normal jitter or have impulse blockade, and/or jitter exceeds normal limits^{58,59}.

The accuracy of these guidelines has not been examined in the laryngeal muscles. One of the major obstacles is poor accessibility of the RLN for repetitive stimulation; it lies in the tracheo-esophageal groove, making reliable stimulation over many minutes extremely difficult. Moreover, needle recording is not ideal for obtaining stable motor amplitudes. Alternatively transcranial magnetic stimulation might be used although the reliability of the muscle responses with repeated placements needs to be assessed⁶⁰. At least one study has shown that SFEMG can be applied in the larynx; these standards could be evaluated for diagnostic validity for LEMG in MG. Although MG rarely affects the laryngeal muscles⁶¹, the rarity of such cases can lead to misdiagnosis^{62–66}.

4. Use of LEMG for Identification of Movement Disorders

Disorders affecting upper motor neuron firing can alter the rate and pattern of firing of motor neurons in the nucleus ambiguus in the medulla controlling the laryngeal muscles. Examples are Parkinson disease with neuronal death in the substantia nigra altering basal ganglia feedback to the cortex⁶⁷(Figure 1), multiple systems atrophy (or Shy Drager syndrome)^{68,69}, supranuclear palsy⁷⁰ and pseudobulbar palsy⁷¹. In other disorders, such as spasmodic dysphonia⁷², patients have symptoms during speech but have normal voice during laughter and cry⁷³. Voice tremor also involves laryngeal motor neuron firing abnormalities.

Often patients with laryngeal motor control disorders are taking medications, affecting LEMG. Others can imitate the symptoms of some laryngeal motor control disorders leading to difficulties in differentiating behaviorally and neurologically based movement disorders. Such disorders include muscular tension dysphonia (MTD)—a habitual misuse of the laryngeal muscles during voicing⁷⁴, psychogenic voice disorders, and malingering where the patient is imitating a voice disorder for some gain. Although MTD is thought to be due to increased muscle tone interfering with voice production⁷⁵, no quantitative/objective study has demonstrated the physiological basis for the disorder. LEMG measures proposed for laryngeal motor control disorders include: motor unit firing rate²⁸, cross-correlation of recruitment across muscles^{28,76,77}, resting levels of motor unit firing⁷⁸, recruitment on the right and left sides^{26,79} spectral analysis of frequency components in the LEMG⁸⁰; muscle bursts during phonation^{26,81}; relating muscle tone to speech symptoms⁸²; recruitment patterns across tasks⁶⁹; relationship between resting activity and task recruitment⁸³; co-contraction of antagonistic muscles⁸⁴; the percent increase for speech over rest^{85,86}; and turns/amplitude analyses of motor unit firing^{31–33}. Although some have proposed using qualitative judgments of muscle activity patterns during voice production to detect which muscles produce voice breaks^{26,87,88}, the accuracy of such judgments for differentiating motor control disorders from normal when subject identity is masked is unknown. Further, intra- and inter-rater reliability for making such judgments is unknown.

To determine if any new studies had been appeared in the literature since the publication of the evidence-based review in 2004² that pertained to the application of laryngeal electromyography in movement disorders, several searches were conducted. A PubMed search,

“laryngeal + electromyography + diagnosis + dysphonia” was conducted along with and searches for “psychogenic + voice + electromyography”, “tension + dysphonia + electromyography”, and “tremor + dysphonia + electromyography”. Only 5 studies that were published since the previous review were identified (Table 3). None of these studies nor previous studies reviewed prior to 2004 (available in Supplementary Materials Online) demonstrated that LEMG was valid for diagnosis of: upper motor neuron disorders, spasmodic dysphonia, vocal tremor, malingering or psychogenic dysphonia. The searches on “muscle tension dysphonia” and laryngeal electromyography did not identify any new studies since 2004 and “medication + laryngeal + electromyography” and “drug + laryngeal + electromyography”, did not identify any new human studies examining neuropharmacological effects on LEMG since 2004.

The diagnostic validity of LEMG is *unknown* for upper motor neuron disorders involving the larynx, laryngeal dystonia and vocal tremor, muscular tension dysphonia, malingering and psychogenic dysphonia. The ability of LEMG to determine neuropharmacological effects on laryngeal musculature is unknown.

Several un-blinded studies compared patients and controls on measures of LEMG that could be used in future evaluations of the validity of LEMG as a diagnostic tool for laryngeal motor control disorders^{29,76,78,82,89,90}. Small prospective Class II studies should initially determine the validity and reliability of particular LEMG measures in a blinded study for differentiating between cases and controls.

Final Recommendations

The Panel concluded that there is a role for LEMG in the diagnosis of disorders of laryngeal (vocal fold) movement, for guiding injections of botulinum toxin in laryngeal muscles and as a useful tool for laryngeal research. Although other uses are ongoing in clinical practice, no consensus was reached about their utility and evaluation is needed.

Several recommendations were made to reduce the variability in the results of LEMG:

1. To standardize electrodes used for different purposes:
 - a. Concentric needles provide a uniform field for MUAP waveform analysis.
 - b. Monopolar needles are useful for guiding botulinum toxin injection in laryngeal muscles.
 - c. Bipolar hooked wires are useful for multiple muscle recordings and/or repetitive tasks.
2. A team of an otolaryngologist and an electromyographer is useful in diagnostic LEMG.
3. A basic examination will depend upon the intervention decisions that are required for a particular patient. It may include:
 - a. Recording from the thyroarytenoid/lateral cricoarytenoid complex bilaterally to compare the “affected” side with the “unaffected” side.
 - b. Recording from the cricothyroid bilaterally to compare the “affected” side with the “unaffected” side.
 - c. Additional muscles as clinically indicated.
 - d. Adequate sampling of insertional activity.

- e. Recruitment measures including numbers of units, amplitudes and firing rates.
 - f. Recordings of MUAPs (durations, amplitudes, and percent polyphasic units with identical firings).
4. Evaluation for neuropathy should consider that:
- a. Multiple criteria must be used and abnormalities must be concordant across several aspects.
 - b. Commonly available diagnostic equipment does not usually provide accurate quantitative assessment for the laryngeal muscles.
 - c. Multiple samples in 2 or 3 different locations per muscle are needed to evaluate recruitment, spontaneous activity and fibrillation potentials.
5. A LEMG report should include:
- a. The reason for the study
 - b. What procedures were performed including anesthetic agents, electrodes, muscles sampled, and adequacy of the examination
 - c. Data Tables with normative values if available
 - d. Findings
 - e. Interpretation
 - f. Clinical Comments

Future Directions for Laryngeal Electromyography

LEMG is in its early developmental stages. Future research in this area should concentrate on standardization, determining optimum utility of the technique in conjunction with videostroboscopy, and determining the value of this tool as a prognostic indicator. Evidence based studies are needed to assess the value of LEMG, and to define clinical parameters. LEMG is potentially a valuable diagnostic tool that clinicians may use to aid understanding of laryngeal abnormalities, and in many cases, may offer information helpful for deciding on recommendations for intervention. The large degree of normal variation in human laryngeal muscle activation for speech and respiratory tasks needs to be more fully examined^{19,20}.

Currently, LEMG is a qualitative examination. Further work is needed to validate qualitative examination results across centers and physicians. Reliability may be improved with quantitative methods. Prospective studies are needed to determine the clinical utility of LEMG and correlate electro-diagnostic findings with voice and upper airway functions to determine the significance of LEMG. Future studies should compare different techniques for electrode placement, employ blinded (masked) assessment and assess inter-rater and intra-rater reliability. The following measurement parameters should be evaluated for validity: MUAP duration and amplitude, serial LEMGs for the prediction of recovery and tasks to identify and measure synkinesis.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.

Peripheral innervation of the laryngeal muscles and sensory feedback to the brain stem are identified on the lower left side of the figure and upper motor neuron input pathways to the laryngeal motor neurons are identified on the upper right side of the figure in this schematic drawing. NA is nucleus ambiguus, LxC is laryngeal motor cortex, ACC is Anterior Cingulate Cortex, PAG is periaqueductal gray, BG is Basal Ganglia, Thal is Thalamus, CBL is cerebellum, SMA is supplementary motor are, RLN is recurrent laryngeal nerve, SLN is Superior laryngeal nerve, NG is nodose ganglion, and CT is cricothyroid muscle.

Table 1
Clinically Used Quantification for EMG signals

Measurements on individual MUAPs	
MUAP waveform analysis	
•	Manual free run
•	Triggered
	◦ Manual marker placement
	◦ Automated marker placement
•	Decomposition into individual MUAPs
Measurement of MUAP territories	
•	Multicontact electrode mapping
•	Scanning EMG
Single fiber EMG	
•	Neuromuscular jitter
•	Fiber density
Motor Unit Number Estimation (MUNE)	
Measurements on multiple MUAPs	
Quantitative interference pattern analysis	
•	Turns and Turns-Amplitude analysis
•	Frequency spectral analysis
Kinesiological Analyses	
•	Use of standardized gestures

Table 2
 Characteristics of various electrode types, adapted from¹²

Attributes	Monopolar	Concentric	Bipolar Concentric	Single Fiber
Shape of recording field	Full circle non directional	Hemispheric directional beyond the beveled surface	Hemispheric directional from the beveled surface	Hemispheric directional from the single fiber
Uptake area	450 microns	300 microns	*	300 microns
Area of recording tip	0.24 mm ²	0.08 mm ²	Surface of 2 embedded wires (50 microns est.)	25 microns

* information not provided

Table 3
A review of Studies Published Since 2004 Relevant to the Role of Laryngeal Electromyography for the Diagnosis of Laryngeal Movement Disorders and Injection of Botulinum Toxin in Spasmodic Dysphonia.

3-1. Diagnosis of upper motor neuron disorders involving the larynx									
Author Year	Class of Study	Blinded Evaluation	Cohort Size	Comparison Groups	Dx Gold Standard	Systematic procedures	Measure(s) used	Sensitivity	Specificity
Zarzur et al., ⁷⁸	IV prospective, case control design	no	52	26 Parkinson disease 26 controls	Neurological diagnosis and assessment on Hoehn-Yahr scale on levodopa	Laryngeal EMG at rest, and during vocal tasks using a monopolar needle	Five LEMG tracings with greater than 5 motor unit racing at rest was labeled hypertonicity	73 % of patients had hypertonicity at rest	77 % of controls were without hypertonicity
Vetrugno et al., ⁶⁹	IV case series	no	3	3 patients with nocturnal stridor with multiple systems atrophy	Diagnosis of multiple systems atrophy and significant stridor in sleep on no medications at time of study	Percutaneously placed hooked suture electrodes recorded from during sleep along with surface EMG of the diaphragm, mylohyoid, and tibialis anterior	Pattern of recruitment of the PCA, TA and CT during sleep	Abnormal recruitment of TA muscle during inspiration and persistent during REM sleep, showing hypertonicity of adductor muscles during stridor	Not tested

3-2. Diagnosis of laryngeal dystonia and vocal tremor									
Author Year	Class of Study	Blinded Evaluation	Cohort Size	Comparison Groups	Dx Gold Standard	Systematic procedures	Measure(s) used	Sensitivity	Specificity
Klotz et al., ²⁰⁰⁴ ⁸⁷	IV, retrospective, case series	no	214	No controls	Voice assessment and videostroboscopy	Monopolar fine wire EMG interpretation ala Hillel ⁴	Detection of muscle spasms	Breaks detected in 68% ADSD, Tremor detected in 81%, Breaks in 67% of tremor, detected in 88% of ABSD	Not tested
Kimaid, 2004 ²⁶	IV, prospective, case series	No	25	Spasmodic dysphonia, Psychogenic, Parkinson, essential tremor	Clinical assessment with endoscopy	Monopolar EMG	Subjective Ratings of TA rest activity with bursts for phonation for SD Tremor in other groups Psychogenic had increased TA activity without bursts	N/A	N/A

3-3. Diagnosis of malinger or psychogenic dysphonia

Author Year	Class of Study	Blinded Evaluation	Cohort Size	Comparison Groups	Dx Gold Standard	Systematic procedures	Measure(s) used	Sensitivity	Specificity
Kimaid, 2004 ²⁶	IV	no	25	Spasmodic dysphonia, Psychogenic, Parkinson, essential tremor	Clinical assessment with endoscopy	Monopolar EMG	Inc TA rest activity with no bursts for phonation for psychogenic	N/A	N/A

3-4. Evidence regarding the Treatment of Laryngeal Motor Control Disorders with Botulinum Toxin Injection Using Laryngeal Electromyography

Study	Class	Design	Cohort Size	Treatment (Serotype/brand, dose)	Follow-up	Outcome Measures(1-primary 2-secondary)	Drop Outs	Adverse Events	Comments
Adler 04 ⁹¹	III	Open-label, dose-finding with examiner blinded ratings	13 ADSD	B/Myobloc [®] : 3 patients had 25 U bilateral, same 3 patients got 50 U bilateral, 10 patients got 100 U bilateral (total of 200 U)	8 weeks	1- patients rating of change from -3 to +3, at 200 U total 8 of 10 patients improved 2- blinded ratings of voice, all showed improvement	None	Hypophonia and breathiness (N=4) at 1 week improved by 4 weeks Vocal fold soreness (N=3)	Small sample size

Rating of Evidence =Unknown

Diagnosis of Muscular Tension Dysphonia—no new references were found between 2004 and 2008.

Rating Recommendation: Botulinum toxin with EMG placement is probably useful in Adductor Spasmodic dysphonia

Neuropharmacological effects on laryngeal electromyography—no new references were found between 2004 and 2008.