State of the Art of Laryngeal Electromyography

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Abstract Laryngeal electromyography (LEMG) has been utilized for nearly 70 years in the evaluation of voice and swallowing disorders, but many controversies still exist regarding the utility and interpretation of the data it provides. Applications have been developed for using LEMG in the evaluation of vocal fold paralysis, dysphagia, laryngeal sensation, and even voice production research. LEMG data interpretation and standardization of results between different investigators are ongoing challenges. Current research is expanding the role for needle and surface LEMG techniques to study the larynx in states of health and disease. This review summarizes recent advances in LEMG and discusses the current controversies in the use of LEMG in modern otolaryngology.

Keywords Larynx · Laryngeal electromyography · Dysphonia · Dysphagia · Laryngeal sensation · EMG · Vocal fold paralysis · Recurrent laryngeal nerve · Motor unit action potential · MUAP · Surface-evoked laryngeal sensory action potential · SELSAP · Voice production · Laryngology · Superior laryngeal nerve · Surface EMG

Abbreviations

LEMG Laryngeal electromyography
UVFP Unilateral vocal fold paralysis
MUAP Motor unit action potential

TA	Thyroarytenoid
TA-LCA	Thyroarytenoid-lateral cricothyroid muscle complex
RLN	Recurrent laryngeal nerve
SELSAP	Surface-evoked laryngeal sensory action potential
SLN	Superior laryngeal nerve

Introduction

Laryngeal electromyography (LEMG) has been studied for nearly 70 years and continues to have broad applications in the evaluation of laryngeal pathology. Weddel first introduced the technology in 1944, demonstrating the clinical potential of LEMG [1]. The technique was refined throughout the last century to allow for investigation of vocal physiology and the role of laryngeal muscles in phonation. Authors such as Faaborg-Andersen, Buchthal, and Hirano [2–4] made significant contributions to the literature and helped to advance LEMG in clinical settings. LEMG continues to have a variety of applications in otolaryngology including diagnosis and prognosis of vocal fold immobility or hypomobility, localization of vocal cord injections, evaluation of neurological and muscular disorders affecting the larynx, and perioperative laryngeal nerve monitoring. Recent evidence based reviews and guidelines have been published regarding efficacy, methodology, and data interpretation of LEMG results [5, 6, 7•]. This article highlights these recent publications regarding the use of LEMG in the management of patients with voice and swallowing disorders and provides a current summary of the progress and potential pitfalls in the use of LEMG.

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Qualitative Versus Quantitative LEMG Analysis in Vocal Fold Immobility

LEMG has a long history of use in the evaluation of vocal fold paralysis (UVFP) and paresis, although Sataloff et al. [5] have only been able to demonstrate class IV evidence supporting its use for this purpose in a recent metareview. Misono and Merati [8•] recently conducted an evidence-based review of the etiologies, symptoms, evaluation, and treatment of unilateral UVFP. In their review, they acknowledge the growing interest in the use of LEMG in the evaluation of UVFP, but did not address the utility of LEMG in prognosis for the broader group of diagnoses characterized by vocal fold immobility including vocal fold paresis and cricoarytenoid joint fixation. Gavanozzi also utilized LEMG to assist in the diagnosis of the cause of vocal fold immobility. Patients with suspected paresis, mechanical fixation or suspected articular disease were excluded from their study. They also were able to show that LEMG has high specificity and positive predictive value for detecting neuromuscular damage in UVFP [9]. Many of the papers published on LEMG over the years have been cohort studies without controls, and further work is needed to more clearly define the role of LEMG in neurolaryngological assessment.

Many practitioners have found LEMG to be of great clinical use despite this lack of definitive evidence. This lead directly to the 2009 recommendations of the Neurolaryngology Study Group on LEMG [6], which concluded that LEMG is useful in diagnosis of UVFP and paresis despite providing a primarily qualitative means of assessing the neurological status of the vocal fold. Qualitatively abnormal electromyography findings in symptomatic patients are known to correlate with motion abnormalities [6] although qualitative examination interpretation is highly dependent upon recorder experience and is graded on subjective scales [10]. The 2009 Recommendations of the Neurolaryngology study group therefore described a LEMG ordinal rating scale from 0 (no discharges) to 4+ (high activity) for qualitative exam finding types such as prolonged insertional activity, fibrillation potentials, positive sharp waves, polyphasic waves, fasciculations, and complex repetitive discharges. Voluntary motor unit recruitment could then be judged qualitatively by the electromyographer with graded vocal tasks. This type of standardization of qualitative LEMG findings may allow for improved comparison of exam findings between electromyographers and across institutions.

Quantitative analysis of LEMG is gaining popularity and has been the focus of multiple recent studies. Quantification of motor unit action potentials (MUAP) and multi-MUAPs is a well-known method of EMG analysis [11] and interference pattern and turn analysis have been described as early as the

1990s [12]. Recent work by Statham et al. [13•] showed that interference pattern is dependent on the nature of the individual MUAPs, motor unit firing rates, and the number of active motor units in a sampled field. The MUAPs may feature different amplitudes, durations, and shapes; a “turn” also occurs at the peaks and troughs of a MUAP. Their work described a retrospective case–control study quantifying turns and mean amplitude per turn for patients with unilateral UVFP and healthy controls. They demonstrated that the mean number of turns per second in the thyroarytenoid and lateral cricoarytenoid muscle complex (TA-LCA) was higher in control patients than neuropathic patients over a range of contraction intensities. The mean amplitude, however, was not significantly different between the two cohorts. They attributed the decreased number of turns per second in patients with neuropathy to decreased availability of motor units. Statham further described how motor unit waveforms and architectures remain normal with acute loss of motor units, with remaining motor units discharge at high firing rates despite the intensity of contraction [14]. They proposed that an increased motor unit firing rate (>25 Hz) with decreased turns per second (below 400 turns/second for the study) at maximal effort indicate neurogenic injury. Their work provides a linear-scale “cloud” of normal values that establish normal MUAP turn and amplitude relationships for the TA-LCA that can be used by other study groups to objectively detect decreased recruitment or signs of reinnervation and may further standardize analysis methodology.

Prognosis

LEMG has long been investigated for its prognostic value after injury to the recurrent laryngeal nerve (RLN), as treatment decisions could be significantly impacted based on a reliable prognostic tool to assess the potential for nerve function recovery. The 2009 Neurolaryngology Study Group stated that there was limited data regarding prognostic abilities of LEMG and recommended caution in the use of LEMG in evaluation of early medical treatment decisions. They recommended that serial LEMG examinations may be of use for prognostic evaluation [6]. These recommendations were based largely on the results of Munin and Rosen’s 2003 study, which gauged prognosis based on analysis of motor unit recruitment, interference pattern, and spontaneous activity [15]. They found that LEMG was able to predict persistent UVFP with a fair to poor LEMG signal on interpretation in 91 % of patients, while 44 % (4/9) of patients who demonstrated good recovery of UVFP also had an excellent prognosis on LEMG. Their analysis showed that the LEMG findings in the resolved UVFP cases showed better motor unity

recruitment in general. The Neurolaryngology Study Group also stated, however, that these results were not based on prospective blinded LEMG evaluations and therefore could not recommend broad application of these standards in clinical decision making at this time [6].

Others have attempted to define further parameters on LEMG that can improve prognostic accuracy. Rickert and colleagues recently performed a meta-analysis of ten studies examining the prognostic value of LEMG in UVFP diagnosed on laryngoscopy in 503 patients [16•]. They found that LEMG is likely most useful for predicting failure of recovery in patients with nerve injury, but is not as useful in predicting return of normal motor function. They found that LEMG had a 90.9 % positive predictive value for poor prognosis, and recommend that a LEMG suggesting poor outcome should provide some basis for earlier definitive intervention in these patients. Presence of synkinesis in the setting of good voluntary motor recruitment in UVFP has also been shown to worsen prognosis for recovery [17]. Smith et al. [18] attempted to determine if using a combination of LEMG qualitative findings in combination with quantitative turns analysis could improve prognostic accuracy in UVFP patients with voluntary motor activity. All four patients with good prognosis recovered vocal cord function, while 17/19 patients with fair/poor prognosis on their algorithm failed to regain full vocal cord motion by at least 6 months from the study. This study suggested that the prognostic accuracy of LEMG in UVFP patients with some voluntary motor activity may be improved by using a combination of qualitative and quantitative analysis. Unfortunately these studies continue to have small patient numbers, and larger multi-institutional studies need to be completed prior to routine use of LEMG in predicting utility of specific clinical interventions for patients with UVFP.

LEMG in Pediatric Otolaryngology

LEMG is not used as widely in pediatric otolaryngology as in adults and has not been as thoroughly investigated. There continues to be a lack of specific indications for use of LEMG in children, and there are no established norms for standardization of technique [19, 20•]. The use of LEMG in unsedated children versus sedated or intraoperative LEMG also varies between studies, whereas most adult studies have been performed in unsedated patients. Jacobs and Finkel verified the utility of LEMG as a diagnostic tool to distinguish paralysis from cricoarytenoid joint fixation in children, particularly in patients with diffuse laryngeal scarring [21]. This was done during microlaryngoscopy under light sedation with spontaneous respiration. Another study by Ysunza done on unsedated children concluded that LEMG was

useful in differentiation of paralysis from arytenoid dislocation, and also provided information regarding the innervation status of the vocal fold [22]. The authors suggested that serial LEMG might be useful for monitoring recovery and providing prognostic insight. Others have evaluated the role of intraoperative LEMG in pediatric VFP. Maturo et al. [20•] found that intraoperative LEMG is a viable method for assessing the likelihood of nerve function return in children that have suffered RLN injury secondary to patent ductus arteriosus ligation, centrally correctable lesions, and in idiopathic VFP. Alqudehy's et al. [19] interesting 2012 study developed a grading system that used the amplitude and timing of action potentials in relationship to patients' respiratory cycles to evaluate injury severity. This grading system showed a significant ability to predict long-term tracheostomy requirement in children and demonstrated the potential for standardization of pediatric LEMG interpretation and prognostic value in children with UVFP.

Setlur and Hartnick's [23•] review further discussed the use of LEMG in surgical decision making for unilateral UVFP in the pediatric population. All patients are observed for a period of time to allow for potential spontaneous return of function in their practice. Infants are referred for injection laryngoplasty while more mature adolescents are generally referred for medialization thyroplasty. They recommend use of LEMG to guide decision making in older children and adolescents. They reserve laryngeal reinnervation for older children, with the goal of restoring tone to the vocal cord and adequate medicalization for glottic closure. The reinnervation procedure prevents any chance of spontaneous nerve function recovery and they therefore recommend the use of LEMG preoperatively for detection of any nerve activity, which might therefore suggest that temporary medialization may be preferable [23•].

Laryngeal Surface Electromyography

Most studies of LEMG utilize percutaneous needle or hooked-wire electromyography. Surface LEMG utilizing electrodes placed on the skin surface provide for a much less invasive technique. Tracing resolution can be limited by the tissues separating the recorded muscle from the electrode and for this reason deeper muscles are usually recorded intramuscularly to provide greater spatial and temporal resolution in the LEMG signal [24•]. Extrinsic laryngeal muscles can therefore often be recorded with surface EMG while intrinsic laryngeal muscles are typically recorded with needle or hooked-wire electrodes. Prior work by Loucks [25] showed that surface LEMG recordings did not adequately demonstrate cricothyroid muscle activation and they recommended intramuscular recording for the cricothyroid muscles. Balata recently re-evaluated this and attempted to

normalize the surface LEMG signal from the extrinsic laryngeal muscles by investigating the effect of muscular maneuvers (tongue retraction or incomplete swallowing) on the magnitude of electrical activity recorded with some success [26]. A tutorial was published in 2012 by Stepp presenting practical guidelines for the recording and interpretation of surface LEMG tracings [24•]. The small size of the recorded muscle compared to the detection volume of the surface LEMG as well as the lack of knowledge of precise innervation zones posed as a challenges to surface LEMG application. Despite its limitations, the authors predict that surface LEMG will play a larger role in the evaluation of speech and swallowing disorders as technique improves.

Surface LEMG has also recently been proposed in evaluation of laryngeal sensation via testing of superior laryngeal nerve function by Bock et al. [27]. The authors describe a new technique in which they apply cathodal stimulation at the skin surface below the mastoid tip behind the sternocleidomastoid muscle with reference surface electrodes placed over the cricothyroid membrane. This simulates peripheral sensory nerve testing for such disorders as diabetic neuropathy. They describe a Surface Evoked Laryngeal Sensory Action Potential, or SELSAP waveform, which is a compound sensory action potential that they hypothesize may be generated by electrical conduction along the internal branch of the superior laryngeal nerve. Patients with known RLN or SLN neuropathy were found in their study to have significantly decreased SELSAP baseline-to-peak amplitudes, conduction velocities, and side-to-side amplitude ratios. Further studies are proposed to evaluate the efficacy of this method and compare it with existing techniques for laryngeal sensory evaluation.

LEMG in Dysphagia Evaluation

Dysphagia is a common symptom of recurrent laryngeal nerve damage and pharyngeal palsy, and the use of LEMG for the evaluation of swallowing disorders was well established by the 1990's [28]. Recent studies have evaluated the role of LEMG in the work-up of post-operative dysphagia [29, 30] as well as swallowing disorders in neurologic disorders such as Parkinson's disease [31•]. Ryu's et al [29] study, for example, demonstrates the use of LEMG to evaluate dysphagia after anterior-approach cervical spine surgery. LEMG findings correlated with presence of laryngeal neuropathy that manifested as post-operative dysphagia. Lombardi further demonstrated that LEMG can be used to document the absence of RLN injury in patients with post-thyroidectomy voice and swallowing symptoms [30]. Patients were found to have dysphonia and/or dysphagia despite normal LEMG tracings, thereby showing that LEMG can be used to differentiate

“functional” post-operative symptoms (i.e. from pain or scar) from subtle RLN or SLN injuries.

A number of past studies have used surface electromyography of the suprahyoid muscles to assess oropharyngeal dysfunction in dysphagia [24•, 32–35]. Tawadros et al. [31•] conducted an innovative study in 2012 investigating the effect of levodopa on swallowing function in patients with Parkinson's disease. They compared surface EMG recordings from the submental and infrahyoid cervical muscles in patients prior to and after levodopa administration. Patients with Parkinson's disease demonstrated increased swallowing duration, and increased latency between submental and laryngeal bursts when compared to controls. After levodopa administration, the latency between submental and laryngeal bursts was shortened in patients with Parkinson's disease. This study not only demonstrates the role of laryngeal and oropharyngeal surface EMG as a non-invasive means of swallowing evaluation but also provides neurophysiologic data supporting the use of medications like levodopa to improve swallowing function in patients with Parkinson's disease. It is likely that further studies such as this will continue to investigate the role of LEMG in the screening and evaluation of patients with oropharyngeal dysphagia.

Intraoperative and Perioperative Use of LEMG

The use of RLN monitoring during thyroid and parathyroid surgery is a widely used practice and has been a long-standing topic of debate. This approach to monitoring RLN function during surgery is a type of surface EMG wherein the surface electrodes are built into an EMG-enabled endotracheal tube. This is generally not as precise as traditional needle EMG, but does allow for continuous monitoring of TA activation due to RLN stimulation during surgery. It has quickly become part of the standard repertoire of care for thyroid procedures for the otolaryngologist. Randolph et al. [36••] published an international guideline statement in 2011 regarding RLN monitoring during thyroid and parathyroid surgery. In this work, they recommend pre and post-op laryngoscopy for all thyroidectomy patients, as well as standardized use of intraoperative nerve monitoring for all patients undergoing this surgery. They discuss their recommended protocols for tube placement, testing of function, securing the LEMG tube, and anesthetic considerations in this guideline statement.

A number of additional recent studies have further investigated the utility of intraoperative nerve monitoring with LEMG and intraoperative nerve stimulation for preservation of RLN function during thyroid surgery [36••, 37–39, 40•]. Singer et al. published a survey in 2012 evaluating the use of intraoperative RLN monitoring

during thyroid surgery. They concluded that no consensus currently exists among thyroid surgeons regarding laryngeal nerve monitoring during thyroid and parathyroid surgery despite increasing use of the technology. Singer's survey revealed that 43 % of otolaryngologists vs. 17 % of general surgeons "always" use laryngeal nerve monitoring; 27 % of otolaryngologists vs. 47 % of general surgeons "never" use monitoring [41]. Ho published a similar survey in 2013 and found that the vast majority of otolaryngology training programs regularly used intraoperative nerve monitoring in thyroid and parathyroid surgery in contrast to less than half of general surgery programs [42]. Surgeons with increased thyroid surgery case volumes also tended to use intraoperative nerve monitoring more often regardless of specialty.

Laryngeal EMG has also been used to evaluate laryngeal nerve function in the postoperative window following other procedures known to put the RLN at risk [20•, 29, 43–45]. Ryu used LEMG to RLN function in patients that underwent cervical spine surgery and associated the highest levels of dysphagia with the presence of laryngeal neuropathy. Maturo et al. [20•] published a novel multi-center longitudinal study using intraoperative LEMG in pediatric patients undergoing ligation of a patent ductus arteriosus. They once again demonstrated the negative predictive value of LEMG, showing that if LEMG testing 6 months post-op demonstrated no activity, nerve function was unlikely to return. They further discussed the ability of LEMG to assess the likelihood of recovery of RLN function in children undergoing other procedures such as brain surgery for tumors, as well as children with idiopathic vocal fold immobility. Other groups have recently evaluated the role of LEMG in workup of vocal cord immobility after endotracheal intubation with suspected arytenoid dislocation [43]. The aim of this study was to investigate clinical and LEMG characteristics and outcome of closed reduction of arytenoid dislocation after endotracheal intubation. Closed reduction of arytenoid dislocation was performed in 54 of 60 patients with post-intubation vocal fold immobility. Of these patients, 45 underwent LEMG evaluation—16 of these patients demonstrated abnormal results on the affected side. Although less than half of patients showed abnormal LEMG findings, all 54 patients that underwent reduction recovered vocal fold function in their series. This study would suggest a strong role for LEMG in the immediate evaluation of a patient with this rare disorder.

Vocology Research and LEMG

A number of studies using LEMG to study the physiology of phonation and singing have been conducted since the

1970s [4, 46, 47]. An interesting 2012 study by Kochis-Jennings et al. [48•] evaluated our current understanding of the neurophysiologic laryngeal identities of the three different vocal registers (chest, falsetto, glottal fry). Despite many years of research, little is known about the actual physiology of falsetto voice production. This study used hook-wire LEMG to test the hypothesis that singers produce chest register by maintaining or increasing vocal process adduction and by engaging the thyroarytenoid muscle to a greater extent than in the production of head register. While maintaining the same pitch phonation, subjects were found to increase thyroarytenoid muscle activity and vocal process adduction when shifting down from head to chest registers, and were able to change register on the same pitch by increasing TA activation. Cricothyroid muscle activity was more directly related to pitch than to vocal register. Kochis-Jennings's et al. study provides greater understanding of human vocal physiology and recommends that further studies feature subglottic pressure measurements in combination with LEMG to investigate subglottic air pressure's potential influence in pitch and register control. This type of study demonstrates the power of LEMG to demonstrate subtle changes in muscle firing patterns with different vocal registers, and provides a basis for the future incorporation of this type of LEMG study in vocology research.

Conclusion

The use of LEMG in evaluation of voice and swallowing disorders continues to evolve at a rapid pace. Progress has been made in the areas of novel recording and analysis techniques, evaluation of laryngeal sensation, and application toward new clinical entities. Recent recommendations from large combined physician groups like the European Laryngological Association have brought us closer to a common approach to use of LEMG [7•]. Multi-institutional prospective trial data is lacking and many issues exist with uniformity of interpretation of LEMG results between investigators and institutions. Recent meta-analysis studies have provided significant data to support the negative predictive value of LEMG in the patient with UVFP, and may provide a rationale for earlier definitive intervention in these patients. Further studies are needed to explore and refine the applications of LEMG in the otolaryngology clinic. The common goals of standardization of technique and uniform data interpretation will likely influence and increase the validity of future studies investigating the clinical use of LEMG.

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