Laryngeal Electromyography: Basic Concepts and Clinical Uses

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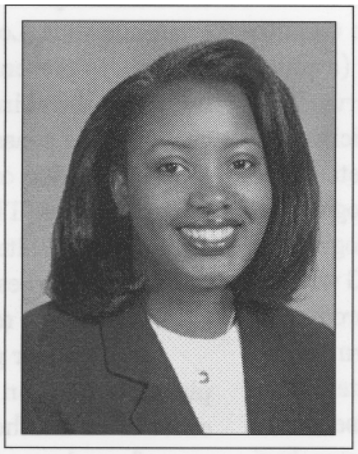

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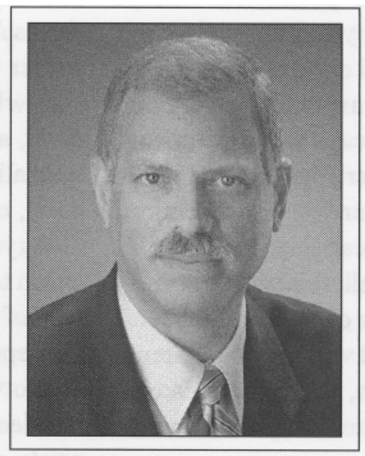

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UNDERSTANDING LEMG

Laryngeal electromyography (LEMG) is a procedure that evaluates the integrity of the muscular and nervous systems of the larynx. This test is performed on patients who have evidence of a movement disorder of the vocal folds. The purpose of the LEMG is to help the physician diagnose and differentiate the causes of these movement disorders. There are several different types of problems that can result in abnormal motions of the vocal folds. These can be classified as disorders in movements of the joints that connect the cartilages of the larynx, primary problems within the muscles themselves, or problems in the nerves that supply the muscles of the larynx. Understanding the exact mechanism of the problem is important in helping the physician understand how to treat the patient's voice problems best and in helping speech-language pathologists and singing teachers select the best exercises to help rehabilitate the voice.

When a person makes a decision to vocalize, the brain initiates the phonation by sending an electrical signal to the brainstem, which then transfers the impulse through the recurrent and superior laryngeal nerves. The superior and recurrent laryngeal nerves are paired, one of each supplying the muscles of the left and right vocal folds. The superior laryngeal nerve innervates the cricothyroid muscle, which is the muscle that lengthens the vocal folds to in-crease pitch. The recurrent laryngeal nerve supplies the thyroarytenoid, interarytenoid, lateral cricoarytenoid, and posterior cricoarytenoid muscles. The thyroarytenoid, interarytenoid, and lateral cricoarytenoid muscles help with vocal fold adduction (closing the vocal folds) during phonation. The posterior cricoarytenoid muscles abduct (open) the vocal folds. As the electrical impulse reaches the end of the nerve, it signals the release of a substance called a neurotransmitter from the tip of the nerve. In the larynx, the predominant neurotransmitter is a chemical called acetylcholine. As this neurotransmitter is released from the end of the nerve, it then binds to its receptor on the muscle. The region that consists of the nerve ending, the muscle receptor for acetylcholine, and the space between the nerve ending and the muscle receptor is of-ten referred to as the neuromuscular junction. When this neurotransmitter binds to its receptor on the mus-

ϑουρναλ οφ Σινγινγ, ϑανυαρψ/Φεβρυαρψ 2002

ςολυμε 58, No. 3, ππ.233 – 238

cle, chemicals are released inside the muscle that signal the muscle to contract. The contraction of the muscle then produces the movements of the vocal folds, resulting in voice production as air is forced from the lungs through the closing vocal folds. Because all of the muscles that are involved in voice production except one (the cricothyroid muscle) attach to the arytenoid cartilage, it is important that the arytenoid is mobile within its joint capsule on the cricoid cartilage. If the cricoarytenoid joint is fixated from scarring or dislocation, the arytenoid cartilage will not be able to move well; this will be seen as limited mobility of the vocal fold and can be confused with a nerve or muscle dysfunction, which can also result in limited mobility of the vocal fold.

LEMG takes advantage of the fact that the nerve has an electrical signal that is transferred to a chemical signal at the neuromuscular junction. During the LEMG, electrodes are placed in the muscles of the larynx. These electrodes sense the electrical impulses within the muscle and transpose them to a visual and auditory signal that can be interpreted by the physician or electrophysiologist (a professional who is trained specifically in the interpretation of electrical signals from the body) who is performing the study. The information gained from the LEMG helps in the differentiation and diagnosis of disorders in nerve, muscle, and joint function.

LEMG PROCEDURE DETAILS

LEMG is often performed as a diagnostic procedure, but it also can be performed therapeutically to help guide the placement ofbotulinum toxin. Botulinum toxin, whose trade name is Botox, is a toxin that is produced by the bacteria that cause botulism. Medicinally, it is used to paralyze hyperactive muscles. The procedure of LEMG is the same, regardless of the reason. Some otolaryngologists and laryngologists perform LEMG's themselves, others perform them together with a neurologist (a physician who specializes in nerve disorders), a physiatrist (a physician who specializes in musculoskeletal disorders), or an electrophysiologist. The otolaryngologist's/laryngologist's decision to perform the LEMG with the help of one of these other professionals depends on his/her own level of comfort and expertise in interpreting the electrical signals. Because neurologists, physiatrists, and electrophysiologists perform electromyography (EMG) on other parts of the body on a daily basis, and because their professional training equips them with expertise in interpretation of complex signals, many otolaryngologists/laryngologists prefer to obtain their opinions in the interpretation of diagnostic LEMG's. Because the use of LEMG for botulinum toxin injections into laryngeal muscles requires a level of expertise in laryngeal anatomy, physiology, and LEMG interpretation that most otolaryngologists/laryngologists receive in their professional training, LEMG for hotulinum toxin injections is often performed solely by the otolaryngologist/laryngologist

To perform LEMG, the patient is usually asked to lie down with the neck extended. This position helps to bring the larynx closer to the skin, making it easier to palpate the laryngeal landmarks for insertion of the electrodes into the laryngeal muscles. The neck is cleaned with alcohol to prevent the introduction of any infectious materials on the skin into the larynx. The insertion of the needles through the skin feels like a pinprick; the insertion into the muscles of the larynx produces a small, sharp, stabbing sensation, similar to the sensation experienced while getting a tetanus shot. Local anesthetic can be given to prevent the pinprick sensation on the skin, but it can not be given for the sensations experienced during insertion of the electrodes into the muscles. The presence of the anesthetic will alter the electrical signals of the nerves and the muscles, confounding the results.

A surface or ground electrode is placed either on the forehead or chest or on another part of the body away from the neck to help the EMG machine filter out other electrical signals that the body produces, such as the heartbeat, respirations, or a twitching leg. The electrodes used in LEMG are usually a form of needle electrode or a wire electrode that is inserted with the use of a needle. The muscles of the larynx are relatively small. The electrical activity of the muscles of the larynx is also small, and this requires the electrodes used to be completely surrounded by the muscle that is giving the electrical signal.[1] Needles and wires, which are also small, work well for this purpose.

There are four pairs of muscle groups in the larynx: the thyroarytenoid, the lateral cricoarytenoid, the posterior cricoarytenoid, and the cricothyroid muscles. The interarytenoid muscle sits in the midline of the back of the larynx and is not paired. The thyroarytenoid, lateral cricoarytenoid, posterior cricoarytenoid, and interarytenoid muscles receive innervation from the recurrent laryngeal nerve. The cricothyroid muscle receives innervation from the superior laryngeal nerve. Usually, the thyroarytenoid, the posterior cricoarytenoid, and the cricothyroid muscles are tested on each side. Testing of these three groups of muscles usually gives sufficient information about the integrity of the superior and recurrent laryngeal nerves and the muscles that they innervate.[2] When equivocal results are obtained or when special information is needed, the lateral cricoarytenoid and the interarytenoid muscles maybe tested as well.

To test the muscles, the needles are inserted through the skin and into the laryngeal muscle. The physician feels the position of the thyroid and cricoid cartilages and positions the needles in the direction of the muscle of interest. When the physician feels as though he/she has the needle positioned correctly, the patient is asked to perform laryngeal maneuvers (phonating, sniffing, breathing, or swallowing) that require contraction of the muscle of interest and relative relaxation of other muscles of the larynx.[2] For the cricothyroid muscle, this involves sliding from a low-pitched sound to a high-pitched sound. For the posterior cricoarytenoid muscle, this involves performing a forceful sniff. For the thyroarytenoid, the interarytenoid, and the lateral cricoarytenoid muscles, this involves saying the sound /1/. The distinction between these three muscles is that the thyroarytenoid muscle sits higher and more towards the middle of the larynx than does the lateral cricoarytenoid muscle, and the interarytenoid muscle sits between the arytenoids and more posterior in the larynx than do the lateral cricoarytenoid and thyroarytenoid muscles. Knowledge of the correct position of the electrode in distinguishing these muscles comes from experience. When the needle is in the correct position, the electrical signal seen on the monitor and the auditory signal heard through the speaker will be increased with the appropriate maneuver. If botulinum toxin is to be injected, it is injected through the EMG needle at this time.

If there is evidence of weakness, repetitive stimulation studies and possibly Tensilon testing may be per-formed)· Repetitive stimulation involves stimulating the nerve with electrical shocks and recording the neuromuscular response by EMG. The nerve stimulated is often the spinal accessory nerve, which moves the trapezius muscle, one of the large muscles of the shoulder. This nerve is chosen because it lies just beneath the skin in the neck and is easy to locate for stimulation. Many people describe the sensation experienced during repetitive stimulation studies as being similar to the sensation of an electrical shock going from the shoulder through the arm. Repetitive stimulation gives information regarding the integrity of the neuromuscular junction. If this test is abnormal or if there are other abnormalities seen on the LEMG, Tensilon testing may be performed. With Tensilon testing, edrophonium, whose trade name is Tensilon, is injected into a vein and the LEMG is repeated. Tensilon testing helps to determine whether the site of the problem is in the neuromuscular junction. When Tensilon is injected into the vein, a needle prick is felt, otherwise there are no other abnormal sensations. The sensations experienced during the LEMG for Tensilon testing are simi lar to the sensations experienced during the first LEMG.

INTERPRETING LEMG RESULTS

The physician/electrophysiologist interpreting the LEMG results assesses four main characteristics of the EMG signal: the insertional activity, spontaneous activity, recruitment, and waveform morphology.'-[3] The results of the LEMG alone are not sufficient to establish a specific diagnosis. The LEMG gives general information about the integrity of the motor units, the muscle, the nerve, and the neuromuscular junction. Several different disease processes can produce damage to any of these structures. The LEMG simply indicates whether they are functioning properly and sometimes can give an indication of the chronicity of abnormal function. The etiology of the dysfunction is established on the basis of all of the information learned from the history of the voice problem, the physical examination, the LEMG, imaging studies, laboratory studies, and biopsies, as indicated by the specific disease process.

Insertional Activity

The insertional activity is the electrical signal that is produced as the needle is introduced into the muscle. Normally, insertion of the needle causes bursts of electrical activity. These should not last more than several hundred milliseconds.[1,2] This burst of electrical activity results from the fact that the needle itself has some electrical energy that, when placed near the muscle membrane, causes a relative change in the surrounding electrical energy. If the electrical charges surrounding the muscle membrane are unstable, such as occurs during early nerve and muscle injuries, the insertional activity will be increased.[1>2] With late nerve and muscle injuries, healing sometimes results in replacement of normal muscle with scar tissue or with fat, which insulate the remaining muscle fibers and cause a decrease in the insertional activity.

Spontaneous Activity

Spontaneous activity refers to the presence of electrical activity in the muscle when it is at rest. Under normal conditions, there should be no spontaneous electrical activity at rest.[1>2] Electrical activity arises from neural impulses that signal the muscle to contract.

Spontaneous electrical activity occurs in a severely denervated muscle with unstable electrical charges. The presence of spontaneous activity implies that the muscle is degenerating and/or that the nerve has been injured and that the process that caused the injury is ongoing.[1-3] Spontaneous activity usually begins two to three weeks after denervation has occurred, because it takes a while for the nerve to degenerate to a degree that results in absence of electrical impulses from the nerve to the muscle.[2] This degree of denervation occurs only with severe nerve injury, and the presence of spontaneous activity indicates a worse prognosis for recovery. Once regeneration begins, the muscle begins to receive electrical impulses from the regenerating nerve, and the spontaneous activity ceases.

Waveform Morphology

Waveform morphology refers to the shape, amplitude, and duration of the motor unit potentials, which are the electrical signals captured by EMG. The normal motor unit potential is biphasic; that is, it has an upward positive spike and a downward negative spike, like an electrocardiogram (EKG) signal of the heart's electrical conduction system.[1>2] It also has an amplitude of 200 to 500 microvolts and has a duration of five to six milliseconds.[2] The amplitude of the motor unit potential reflects the number and the strength of the muscle fibers innervated by one nerve ending. The duration of the motor unit potential reflects the velocity of the neural input, which is influenced by the insulation of the nerve. Nerves that are well insulated and have an intact and functioning sheath (insulating cover) are able to transmit electrical impulses faster than those that are not, similar to the way insulation of a telephone or electrical wire helps to increase the velocity of transmission of their respective signals. The shape of the motor unit potential reflects changes in the electrical activity of the muscle membrane. Under normal circumstances, this is biphasic.

The waveform morphology of the motor unit potential gives information regarding likelihood of recovery. After injury, the nerve goes through a process of denervation followed by regeneration. The length of time that denervation and regeneration occur can vary from one situation to another and can last for periods of weeks to months each. It is unknown what determines how much any one nerve will denervate or regenerate. During denervation, there is no neural input into the muscle and, thus, no abnormal waveforms are produced. Abnormal motor unit potential morphologies are produced during the period of regeneration.

During the early phases of regeneration, tiny nerves begin to course back into the muscles that have undergone atrophy (wasting) during the period of time that they were denervated. Early in regrowth, the insulation of the nerve is decreased. The combination of the tiny, minimally insulated nerves and the weak muscle fibers produces electrical signals on the LEMG that are seen as motor unit potentials that have small amplitudes, long durations, and polyphasic shapes.[2>3] These waveforms are sometimes referred to as nascent units; they imply the presence of a recent nerve injury.

As the regeneration progresses, the nerves become healthier and better insulated through regrowth of their sheaths, and the muscle fibers become stronger and gain more mass. Not all of the nerve fibers regenerate. Those that do regenerate branch more so than before the injury to innervate as many muscle fibers that lack innervation as possible. The motor unit potentials that are produced as a result of this ongoing regeneration have greater amplitudes than normal, are polyphasic, and have a prolonged duration. These motor unit potentials are usually described as being polyphasic or as giant polyphasic potentials; their presence implies an old nerve injury.[2>3]

If the nerve is uninjured, and the muscle is damaged, the morphology of the motor unit potential is different. The nerve is intact and functioning well, so the duration of the motor unit potential is normal. The electrical charges in the muscle membrane are abnormal, resulting in a polyphasic shape. The amplitude, which reflects the decreased muscle mass and force of contraction, is decreased.)

Recruitment

Recruitment refers to the serial activation of motor units during increased voluntary muscle contraction. One motor unit consists of a nerve fiber and the muscle fibers that it innervates. Typically, one nerve fiber innervates several muscle fibers. Normally, as the intensity of the muscle contraction increases, the motor units have increased activity and new motor units are "recruited" to maintain the strength of the contraction. This is seen on LEMG as an increase in the number and density of motor unit potentials.[2] This density of motor unit potentials is the recruitment. Thus, recruitment reflects the degree of innervation, which is a reflection of the number of active nerve fibers of a given muscle. With normal innervation, there are so many motor unit potentials that they blend together on the LEMG. When there is a loss of nerve fibers, the recruitment is decreased.

When the nerves are normal but the muscle is abnormal, recruitment occurs earlier than normal, with a similar density of motor unit potentials but with decreased amplitude. The decreased amplitude reflects the weakness of the muscle contraction. The early recruitment reflects the nerves' attempts to increase the force of the contraction in response to the weak muscle.

Cricoarytenoid Joint Fixation

If the nerve and muscle are normal, and fixation of the cricoarytenoid joint is the cause of vocal fold hypomobility, the LEMG recruitment, waveform morphology, spontaneous activity, and insertional activity will be normal. Mobility of the cricoartyenoid joint is independent of nerve and muscle function. The LEMG is only able to assess the integrity of the neuromotor system.

Repetitive Stimulation Testing

Repetitive stimulation testing is performed if there is evidence of decreased recruitment. Repetitive stimulation involves stimulating the nerve with electrical shocks and recording neuromuscular response by EMG. With a normal neuromuscular system, recruitment remains normal during this repetitive stimulation.

If the stimulation causes a progressively decreasing recruitment response, an abnormality in the neuromuscular junction is suspected.[i] A decrease in the recruitment response implies that motor units that were previously recruited are unable to be actively and continually recruited during repetitive stimulation. The fact that they were able to be recruited initially and give normal waveform morphology implies that the nerve fibers themselves are intact and that the muscles are able to respond to an impulse signal. The fact that the motor units are unable to keep up with the repetitive stimulation implies that there is an abnormality in the transfer of information across the neuromuscular junction that is only apparent when the system is stressed.

Tensilon Testing

The use of the Tensilon test helps to further isolate the problem to the neuromuscular junction. The Tensilon test is performed if there are decreasing recruitment responses to repetitive stimulation or if there are fluctuating recruitment responses during the LEMG. Tensilon is a drug that inhibits the breakdown of acetylcholine in the neuromuscular junction, resulting in increased exposure of the muscle receptors to acetylcholine during neural stimulation. In normal muscles, this has very little effect on muscle activity. Increased muscle contraction from the prolonged exposure to acetylcholine occurs in muscles with decreased numbers of receptors for acetylcholine, such as occurs with myasthenia gravis, and the recruitment pattern reverts to a more normal pattern with voluntary contraction and with repetitive stimulation.) This positive response to Tensilon further isolates the problem to the neuromuscular junction.

Use of LEMG Data

At the completion of the LEMG, the physician has valuable information that will help to guide his/her diagnosis of the laryngeal mobility problems. Each of the factors investigated with the LEMG helps to give the physician an indication of the chronology, the site of pathology, and the prognosis for recovery. Sometimes, serial LEMGs are needed to follow changes in nerve recovery or degeneration over time, which may help to give a better indication of the prognosis. In patients with paresis and/or paralysis, the results of the LEMG may also help to guide subsequent therapy. If paresis is found, the patient can undergo voice therapy that is specifically aimed at increasing the strength of the weak muscle. In patients with abnormalities in vocal fold mobility who may benefit from surgical procedures to enhance their vocal fold function, the LEMG can help to determine the nature and timing of the surgical procedure. If there is evidence of an ongoing degenerative process, surgery may be delayed until degeneration is complete. Similarly, if there is evidence of regeneration, surgery maybe delayed until maximal recovery has been achieved.

CONCLUSION

LEMG is a procedure that evaluates the integrity of the neuromotor systems of the larynx. It is particularly useful in evaluating disorders affecting the nerves, the neuromuscular junctions, and the muscles of the larynx. The LEMG should be considered as an extension of the physical examination, not as an isolated laboratory procedure. LEMG abnormalities are interpreted within the context of the clinical impression and are used to guide diagnosis and treatment of vocal fold mobility disorders. Readers interested in additional knowledge are encouraged to consult other literature. 4-6

NOTES

1. S. Mandel et al., "Laryngeal EMG: Electromyographic Evaluation of Vocal Fold Disorders,"Journal *of Singing* 55, no. 2 (Nov/Dec 1995): 43- 48.

2. J. A Koufman and F. O. Walker, "Laryngeal Electromyography in Clinical Practice: Indications, Techniques, and Interpretations," *Phonoscope* 1 (1998): 57-70.

3. C. Sittel et al., "Prognostic Value of Laryngeal Electromyography in Vocal Fold Paralysis," *Archives of Otolaryngology—Head and Neck Surgery* 127 (2001), 155-160.

4. R. Manon-Espaillat, S. Mandel, and R. T. Sataloff, "Laryngeal Electromyography," in R. T. Sataloff, *Professional Voice: The Science and Art of Clinical Care,* 2nd ed. (San Diego, CA: Singular Publishing Group, 1997), 245-255.

5. R. T. Sataloff et al., "Laryngeal Electromyography," *Current Opinion in Otolaryngology—Head and Neck Surgery 8* (2000): 524-529.

6. R. Manon-Espaillat et al., *Laryngeal Electromyography* (San Diego, CA: Singular Publishing Group, 2002 [in press]).

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