Electromyography—An Overview

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In Anatomy and Physiology 101, we learned that both nerves and muscles operate electrically. That is, nerves conduct electrical impulses from one point to another, like from the hand to the brain, where they are interpreted as heat, pressure, pain, etc. Likewise, individual nerves conduct the electrical impulses from the brain to the different muscles that allow us to lift our right arm and open our hand. It logically follows from our electronics training that where an electrical impulse exists, it can be measured and recorded. This is the idea behind electromyography, a diagnostic technique where a trained medical professional (a physician specializing in Physical Medicine, a psychiatrist, physical therapist, chiropractor, etc.) inserts small needle electrodes into both motor and sensory nerves as well as muscle tissue to measure and record its electrical activity. The medical device that measures and records electrical activity is called an Electromyograph (EMG) and it presents results both visually on an oscilloscope-like screen and audibly through a speaker. An individual's measurements can be compared with population norms to help determine, for example, the extent of spinal cord injury in a trauma patient. But that is only half of what an EMG does. Muscle groups can be directly stimulated with an electrical impulse to determine where a problem lies—with the nerves connecting the brain to the muscle or within the muscle group itself.

There is normally no electrical activity in resting muscle tissue. In normal muscle tissue, electrical activity increases as the muscle contracts; in disease states, the electrical activity is abnormal either in magnitude or transit time along the nerve. For example, if the initial neurological examination reveals apparent muscle weakness, the EMG will reveal normal magnitude and transit time of impulses through the nerve when the muscle tissue is diseased; such is the case with muscular dystrophies. If the corresponding motor nerve is compromised by disease or injury, either the magnitude or speed of the nerve conduction usually will be slowed. These nerve conduction studies, when performed on sensory nerves, either support or rule out diagnoses of specific maladies such as Myasthenia Gravis, Guillain-Barré Syndrome, and organophosphate poisoning.

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Current Technology

An EMG, in the hands of a skilled operator, detects, processes, and records the electrical activity of particular muscles and the nerves controlling them. The acronym EMG also applies to the printed or stored record of this activity. It takes a very sensitive instrument to measure these relatively miniscule (as small as 0.1 to 5.0 microvolts (µV)) signals across a high-impedance source like a nerve or muscle. The best instrument for this purpose is an oscilloscope and indeed some of the first EMGs were nothing more than custom-made plug-in modules designed to fit a top-brand oscilloscope and the entire package labeled with the EMG manufacturer's name.

The modern EMG has not changed since these legacy units were first sold. They still employ electrodes, amplifiers, a display unit, and a speaker. However they are more likely to use a PC or laptop and custom application software as the core of the unit rather than a large and bulky instrument designed just for this purpose.

To reach the specific nerve or muscle of interest, the physician uses surface, needle, or fine-wire electrodes. The electrode is placed either within or near the muscle or nerve of interest. Surface electrodes are applied to the skin over the muscle of interest and are used when needle electrodes would be too invasive or unnecessary because overall or general measurements are sufficient. Because they do not penetrate the patient's skin, surface electrodes are available in both disposable and reusable forms, normally with a silver-silver chloride (Ag-Ag/Cl) sensor area, and look very similar to electrocardiograph (ECG) electrodes.

Needle and fine wire electrodes are inserted through the skin into the muscle or nerve of interest to make precise measurements on a particular part of the muscle or on just a few muscle fibers. They are usually disposable and come in a variety of types. Most monopolar electrodes resemble a solid, straight, platinum. or stainless steel needle, approximately 27-gauge, with a very sharp tip. Depending on the intended use, the needle will be plain, while the others will have the majority of the shaft covered by an insulating material, like a thin layer of Teflon® or other nonreactive insulating material, leaving the smallest bit of the tip exposed for contact with muscle or nerve tissue. Special purpose electrodes, such as those used in the operating room or for research purposes, terminate a number of ways including a fish hook, a corkscrew, a small ball, or a spring band that slips over fingers. In all cases, electrodes are applied in pairs and referenced to a common electrode applied over an electrically neutral area (over a bony prominence, for example) away from the muscle(s) or nerve(s) being studied.

The electrodes detect the minute electrical signals from the muscles and nerves of interest. Muscles tissue at rest is normally electrically inactive, but muscles may produce short bursts of signals while inserting invasive needle electrodes. These signals are significant and are part of the study. After needles are inserted, the muscle should revert back to its resting state, producing no significant electrical signals. When the muscle is contracted, it produces electrical signals of varying duration, frequency, and amplitude. These signals range between 2 and 35,000 Hz and can reach a peak voltage between 50 microvolts (μV) and 30 millivolts (mV) depending on the muscle activity and electrode placement. The examiner will normally take up to 20 readings and calculate their average as the "official" reading.

Because these signals are so small and the electrode lead wires susceptible to outside interference, the lead wires are supplied as a twisted pair and always connected to a differential amplifier to cancel any noise picked up from the environment. Additionally, the lead wires connect to a preamplifier located as close as possible to the patient and utilize capacitive coupling for impedance matching since surface skin impedance varies greatly. To aid in noise reduction, and for diagnostic reasons, many EMGs have filtering networks that can be adjusted to minimize outside extraneous signals and undesired artifact.

Rather than designing an instrument specifically to perform these functions, modern EMGs are built around a personal computer, often a laptop, and custom application software. This provides the added capabilities inherent in PCs such as signal display, data storage, data analysis (averaging multiple readings, calculating amplitude, area, duration, slope, nerve conduction velocity, etc.) of the measured signals, report generation, audio output. Audio output for EMGs is not the luxury one might think since muscle-generated electrical signals are quite complex with numerous signals being generated simultaneously. Collectively, this activity is called motor unit action potential (MUAP) and produces a unique sound when heard through a speaker. Likewise, abnormal muscle functions produce sounds from their MUAP that are different than normal sounds. The examiners have learned to differentiate between normal and abnormal EMG sounds just as they have learned the difference between normal and abnormal heart, lung, and bowel sounds. Visualization of the signals on the computer screen provides more information, especially when combined with the results of the on-board data analysis. Lastly, the PC provides the ability to store the signals and analysis, generate reports, and send the data elsewhere for review, analysis, and archiving.

How to Manage the Device

Like other expensive medical devices, EMGs should be individually managed and their maintenance uniquely assigned and tracked by item using either the device's serial number or a locally assigned asset tracking number. Routine maintenance (preventive maintenance, calibration, and electrical safety testing) must be scheduled around the clinic's patient schedule. Remedial maintenance should be performed on routine priority consistent with the facility's maintenance priorities policy. The in-house maintenance activity should maintain a detailed history of all maintenance actions including the application of periodic software upgrades and software patches. The EMG can be maintained with in-house assets if adequate manufacturer's literature is available. If this is not feasible, based upon their high reliability, billable as-needed services are the next most cost-effective support method if software upgrades can be otherwise obtained. If not, the facility should enter into either a full-service or first-call contract.

Regulations

In the United States, aside from the normal Health Insurance Portability and Accountability Act (HIPAA) of 1996 concerns regarding personal medical information that may be stored in the computer portion of the analyzer, there are no specific regulations covering EMGs. The needles are under the purview of the Food and Drug Administration (FDA).

Risk Management Issues

Obtaining an EMG is a mildly invasive procedure. But there is always a risk to be addressed in any medical procedure no matter how minimally invasive it is. Some patients experience irritation from the adhesive used on surface electrodes. Reusable needle and wire electrodes must be terminally sterilized, cleaned, and sterilized before use on the next patient. Otherwise there is a greater

It All Started With a Frog

Jan Swammerdam, a Dutch anatomist and biologist, discovered that stroking the innervating nerve of a frog generated a contraction. There is strong evidence he conducted the first electrical stimulation experiments 134 years before Luigi Galvani, but there is no absolute proof. Therefore, Luigi Galvani is popularly credited as the father of neurophysiology for his work with frogs' legs around 1791. Unfortunately, it took another 40 years to develop instrumentation sensitive enough for Galvani's work to be accepted by his peers.

In 1838 Carlo Matteucci used a galvanometer to show that there was a definite connection between bioelectricity and muscular contraction, and in 1842 demonstrated the existence of the action potential accompanying a frog's muscle. In 1850, Guillaume Duchenne, using external handheld electrodes, applied electrical stimulation to intact skeletal muscles, causing muscle contractions and facial movements. He showed that by stimulating various places on the face, one could be made to involuntarily smile, frown, and make some quite scary facial expressions. Finally, in 1890, Etienne Marey made the first actual recording of muscle contraction electrical activity and coined the term "electromyography."

From then on, knowledge of electromyography developed as fast as technology would allow. In 1922, researchers showed electrical signals from muscles on an oscilloscope, but because of the apparent randomness of these signals, only rough assessments were possible. As early as 1929, concentric needle electrodes were developed and used in basic research of motor control and muscle schemes, thus enabling signal detection in individual and small groups of muscle fibers. Over the next 20 years, detection of electromyographic signals improved as electrode designs were refined and research continued. One highlight in the 1940s was the development of the first true electromyograph by Herbert Jasper and its use in groundbreaking work in the field of neurology.

In 1953, the American Association of Electrodiagnostic Medicine was founded and held its first meeting in Chicago. Shortly thereafter, a number of universities established electromyographic and neurophysiological laboratories and electromyography began to become a field of its own. Clinical use of surface electromyography for the diagnosis of specific maladies began in the 1960s and its use increased.

By the mid-1980s, research resulted in a better understanding of the properties of surface EMG recordings. Around this same time, first-generation EMGs were developed and marketed, followed 10 years later by second-generation instruments that were little more than a top quality triggered-sweep oscilloscope housing with custom-designed plug-in amplifier and sweep modules. These were eventually replaced by the current generation of personal computer-based instruments.

risk of infection in the procedure. Even disposable needle electrodes must be handled carefully to maintain sterility. Proper grounding of the EMG is necessary.

Common Problems and Solutions

Most of the common problems with EMGs can and should be resolved by the technician or physician. Problems like broken electrode wires, electrode integrity, poor electrode cleaning (of reusable electrodes), poor electrode contact with the patient's skin, static electricity, and even unwanted patient movement can and will appear as artifact in the EMG. EMG electrode wires, even when they are twisted to cancel interference, will pick up electrical interference from fluorescent lights, diathermy, and electrosurgical units and display it as artifact. There are cases on record where radio frequency (RF) interference completely overwhelmed the patient's muscle signals, so steps must be taken to minimize potential RF interference. Occasionally, the physician may change filter settings during the procedure, changing the apparent amplitude and duration of the averaged waveforms. This would falsely indicate a change in the condition being evaluated, and would adversely affect the diagnostic integrity of the procedure.

Servicing Electromyographs

Normal handtools and test equipment (such as an oscilloscope and standard pulse generator) are required to service EMGs. Fortunately, due to the stability of the computer platform that most modern units are based on, hard failures of the devices are quite rare. The biomedical technician should have the necessary passwords and rights to reload operating software and patches as well as application software and upgrades when necessary. Knowledge of basic computer repair is certainly a plus; almost a requirement considering how many medical devices now utilize a PC or laptop as their platform. Lastly, if it is available, manufacturers' literature and training would be a plus, since most facilities do not have the necessary equipment density to make this training cost-effective.

Future Development of Electromyographs

The electronics of modern EMGs are considered mature technology. Future improvements will be in the areas of software that will increase the power of menu-driven controls and measurements. The addition of telemetric capabilities will make it an important tool for clinical research and make EMGs an even more important diagnostic tool. The addition of expert systems to assist in waveform analysis, an ever improving on-board database of normative data, and storage for an operator-generated database are all seen as future improvements. ■

For More Information

ECRI Healthcare Product Comparison System for Recorders, Graphic, Evoked-Potential; Electromyographs; Electronystagmographs; Videonystagmographs.

American Academy of Neurology. 1080 Montreal Ave., St. Paul, MN 55116. (651) 695-1940, www.aan.com.

American Association of Electrodiagnostic Medicine. 421 First Ave. SW, Suite 300, East Rochester, MN 55902. (507) 288-0100, www.aaem.net.

American Society of Electroneurodiagnostic Technologists. 204 West Seventh St., Carroll, IA 51401-2317. (712) 792-2978, www.aset.org.