

Overview of Electrodiagnostic Medicine

INTRODUCTION

Electrodiagnostic (EDX) medicine is the medical subspecialty that applies neurophysiologic techniques for the evaluation of patients with potential impairment of the nervous, neuromuscular, and/or muscular systems. The term EMG (electromyography) often has been used to cover the entire spectrum of EDX techniques. However, EMG refers only to the needle electrode recording of the electrical activity of muscles.

When a patient is referred for EDX assessment of a potential neuromuscular problem, the evaluation includes a focused history, a physical examination, and an electrophysiologic evaluation of selected functions of the central nervous system. This includes motor and sensory neurons, nerve roots, peripheral nerves, neuromuscular junctions, and muscles. The results of a properly done EDX evaluation allows the referring physician to develop the best treatment plan.

Electrophysiologic data is generated by a variety of procedures, including motor and sensory nerve conduction studies, needle electrode EMG, repetitive nerve stimulation, reflex latencies, evoked potentials, exercise tests, and autonomic nervous system tests. Many of these procedures are also used for monitoring nerve and muscle function during surgical procedures²⁴ or for assessment of therapeutic treatments.

THE ELECTRODIAGNOSTIC MEDICINE EVALUATION

The general goals of the patient-physician interaction are to: (a) to make a medical diagnosis and (b) to treat the patient. The physician must take a number of steps to achieve these goals. The steps, which are influenced by the physician's knowledge, skill, and experience, include: (1) *definition* of the clinical problem, (2) *selection* of data to be collected, (3) *collection* of data, (4) *interpretation* of that data along with information from the history and physical examination and the *integration* into a final medical diagnosis, and (5) *recommendation* about and *implementation* of a course of action. The EDX evaluation, as described below, is clearly the practice of medicine as defined by these general principles.

EDX medicine is an extension of the neurologic portion of the physical examination and requires detailed knowledge of neuromuscular and musculoskeletal disorders. The range of specific tests available to the EDX physician is extensive, and only a few of those tests are used to collect data on any given patient. Unlike many diagnostic tests, the EDX evaluation is not performed in the same fashion every time but must be specifically designed for each individual patient. Even patients with similar presenting complaints may require different approaches. Throughout the course of the study, the EDX physician continuously monitors and interprets the results of each specific test, in the context of the accumulating data and the patient's clinical problem. It is often necessary to modify the procedure during the examination based on the evolving findings. The evaluation requires continuous problem solving by the physician throughout the course of the study. Only in this way can the appropriate data be collected, unnecessary testing be avoided, and the proper final conclusions be drawn.

Relying on training and experience, the EDX physician interprets the electrophysiologic data and integrates them with other clinical data to make a diagnosis which then allows development of the treatment plan. Improper performance or interpretation of the EDX tests may be misleading to the referring physician and ultimately dangerous to the patient. For example, the exact site and type of surgical operation performed on a patient may be determined in part by the results of the EDX evaluation. Therefore, the physician's knowledge of diseases and their manifestations is necessary to interpret EDX results accurately.

Needle electrode insertion requires a detailed knowledge of anatomy and carries a risk of injury to anatomic structures (e.g., nerves, arteries) that can be reliably identified by a properly trained physician. Appropriate precautions also must be taken to avoid transmitting infectious diseases, such as hepatitis, Creutzfeldt-Jakob disease (CJD), or other blood borne pathogens. Testing risk may increase with examinations near major blood vessels, the abdomen or lung; in the setting of anticoagulants or bleeding disorders; electronic or mechanical cardiac devices, CNS stimulators, or indwelling central venous or

arterial lines. The EDX physician must understand and Assess these risks and take any necessary steps to minimize potential harm to the patient.

QUALIFICATIONS

Electrodiagnostic Medicine Physician

As outlined above, an EDX physician who has special training in the diagnosis and treatment of neuromuscular diseases and is also an expert in the application of the neurophysiologic techniques used to study these disorders. AANEM recommends that EDX physicians have at least 6 months full-time or equivalent supervised training during a neurology or physical medicine and rehabilitation residency or fellowship accredited by the Accreditation Council for Graduate Medical Education (ACGME),¹ American Osteopathic Association (AOA) or the Royal College of Physicians and Surgeons of Canada (RCPSC)^{1,2} and complete at least 200 studies which include adults and children of complexity levels ranging from straightforward to high complexity. To be eligible for the American Board of Electrodiagnostic Medicine (ABEM), physicians must also have at least 1 year of experience following the supervised training period (see www.abemexam.org). For a detailed explanation of training requirements and physician's qualifications, please refer to AANEM's position statement, *Who Is Qualified to Practice Electrodiagnostic Medicine?*²⁵

Laboratory Organization

To help ensure standardization of procedures and normal values, nerve conduction studies (NCSs) and needle EMG should typically be performed in the same EDX laboratory. Although a number of EDX physicians as well as paramedical personnel may work in a laboratory, its activities should be under the direction of a practicing EDX physician who is the laboratory director. Certification by the American Board of Electrodiagnostic Medicine (ABEM) is strongly recommended.

The laboratory director should have control over the selection of all laboratory personnel, including other medical staff and technologists, and control over the selection of equipment, designation of normal values, and the procedures offered. AANEM has developed a laboratory accreditation program. The Electrodiagnostic Laboratory Accreditation Program is a voluntary, peer review process that identifies and acknowledges EDX laboratories for achieving and

maintaining the highest level of quality, performance, and integrity based on professional standards. Accreditation provides laboratories specializing in

EDX medicine with a structured mechanism to assess, evaluate, and improve the quality of care provided to their patients. More information can be found at www.aanem.org/accreditation.

EDX laboratory medical personnel might include the laboratory director, other EDX physicians, physician trainees (residents and fellows), and allied health support such as technologists.

Technologists

Many clinical neurophysiology laboratories utilize technologists to enhance operational efficiency. A technologist must always work under the supervision of an EDX physician as outlined in the *Who is Qualified to Practice Electrodiagnostic Medicine?*²⁵ position statement. The EDX physician should be responsible for the planning and interpretation of EDX studies, but a technologist may perform a variety of functions and tests in the laboratory depending on the technologist's level of training and experience. To ensure an appropriate level of training, it is recommended that technologists obtain certification, such as CNCT (Certified Nerve Conduction Technologist) granted by ABEM or R.NCS.T. (Registered Nerve Conduction Study Technologist) granted by American Association of Electrodiagnostic Technologists (AAET). For more detailed information on technologists' roles and training, refer to *Responsibilities for an Electrodiagnostic Technologist*²⁶ and *Job Descriptions for Electrodiagnostic Technologists*.²⁷

A technologist should be able to establish good rapport with patients and staff and be able to work effectively and safely deal with sick patients. The technologist should be able to instruct the patient about the tests to be performed, prepare the patient, apply surface electrodes, make accurate measurements, keep the equipment in good condition, and maintain reports.

With appropriate training, the technologist may perform a variety of NCSs, reflex studies, repetitive stimulations, and evoked potential tests. The test results must be recorded adequately for review by the EDX physician. The EDX physician must be immediately available and present in the office suite to

review any problems that develop during the NCSs. The physician need not be physically present in the room when the NCSs are performed though. The EDX physician should be alerted during the testing if any results appear to be unusual or unexpected, so there is opportunity to reassess the results and modify the testing strategies.

The patient should remain in the examination room until the supervising EDX physician has reviewed the NCS results and determined whether more studies are needed. It is recommended, that the patient's NCSs and needle EMG examination be performed on the same day by the same EDX physician, to ensure continuity of care and consistency in reporting.

Senior technologists may have responsibility for laboratory work assignments, in-service training, and instruction of junior personnel. Their knowledge and skills should be demonstrated through a structured examination. Such examinations are provided by the ABEM and AAET.

Performing the Electrodiagnostic Medicine Evaluation

The EDX physician must be involved in the pretest evaluation of the patient and in planning the EDX studies. The physician should perform only those tests that are medically indicated. While it is permissible for a technologist or a physician trainee to assist an EDX physician by performing NCSs, the physician has the ultimate responsibility for these tests.

All needle EMG examinations should be performed by a qualified EDX physician as described in *Who is Qualified to Practice Electrodiagnostic Medicine?*²⁵ In the case of residents or fellows, needle EMG studies should be performed under the supervision of a qualified EDX physician. Under no circumstances should a technologist, regardless of qualifications or experience, perform needle EMG examinations. This position is endorsed by the American Medical Association,⁵ the American Academy of Neurology,² the American Neurological Association, the American Academy of Physical Medicine and Rehabilitation,³ and the Department of Veterans Affairs (Veterans Administration),²³ as well as many state medical examining boards. There have also been court decisions upholding this principle.⁷

Somatosensory evoked potential (SEP) testing requires direct supervision by, but not the constant physical presence of, an EDX physician. The EDX physician supervising the SEP study should be immediately available to see the patient, review the SEP results, or review the set-up of the electrodes. When SEP testing is performed during surgery, the EDX physician must be immediately available during those critical portions of the surgical procedure that require immediate interpretation of results. The patient should remain in the examination room until the supervising EDX physician has reviewed the SEP results. This will help to minimize the number of cases in which further SEPs need to be performed based on the results of the initial SEP examination.

At the conclusion of the study, the report should be prepared by the EDX physician or by a resident or fellow under the supervision of the EDX physician.

PATIENT COMFORT AND PREPARATION

Electrodiagnostic testing can cause the patient^{6,11,14,15,17,21} discomfort and anxiety. NCS results can be complicated by patient movement artifact. Interpretation of needle EMG can be compromised if the patient is unwilling or unable to properly voluntarily activate the muscle being examined. In some cases, the EDX evaluation cannot be completed. This determination can be based on patient request or judgment of the EDX physician.

Patients with high levels of pretest pain and anxiety report the most pain during a needle EMG. The EDX physician should be able to recognize patients at risk to have extreme pain or anxiety during the test since physicians' and patients' ratings of patient pain and anxiety are concordant.^{11,15} In order to assist patients with anxiety issues, EDX physicians may use analgesics or anxiolytics (e.g. oral benzodiazepines) in consultation with the referring physician, if needed.¹⁷ Chaperones in the testing room may also be helpful in certain circumstances.

Most EDX evaluations can be performed without sedation. If studies are performed under moderate or deep sedation, the AANEM recommends the EDX evaluation be performed in a hospital/surgery center or outpatient setting where appropriate equipment and support personnel are immediately available to handle emergency situations arising from sedation. Use of drugs to assist patients with anxiety issues are not

considered moderate or deep sedation (e.g. oral benzodiazepines). The AANEM recommends EDX physicians using sedation follow the guidelines that

have been established at their hospital or outpatient clinic or those established by the American Society of Anesthesiologists (Practice Guidelines for Sedation and Analgesia by Non-Anesthesiologists). For pediatric patients, physicians should follow the American Academy of Pediatrics *Guidelines For Monitoring and Management of Pediatric Patients During and After Sedation for Diagnostic and Therapeutic Procedures*⁴ which contains detailed recommendations on this topic. In addition to the above, United States EDX laboratories must comply with the provisions of the Americans with Disabilities Act.

QUALITY ASSURANCE PROGRAMS

The goal of a quality assurance program is to improve patient care and the satisfaction of patients and referring providers by using ongoing monitoring and evaluation strategies. It is the responsibility of EDX physicians to establish processes by which this goal is achieved.

A quality assurance program should include effective mechanisms for reviewing and evaluating cases. Patient and referring provider questionnaires are an excellent method to assess this aspect of EDX practice. The program should also provide for effective responses to enhance patient and referring provider satisfaction.

Examples of the parameters of EDX medicine that could be monitored and evaluated, as well as guidelines for some of the aspects of quality assurance can be found on the AANEM website at <http://www.aanem.org/Practice.aspx>. AANEM has also developed Performance in Practice modules to assist physicians to work on quality improvement initiatives.

REPORTS AND RECORDS

Reports

Following the examination, a written report should promptly be prepared. The report should include the following components:

1. Description of Patient Data and the Clinical Problem Section
 - a. Patient demographic information
 - b. The reasons for referral, brief relevant symptom history, and physical examination findings.
2. Nerve Conduction Studies Section
 - a. List of the nerves studied
 - b. Numerical values for the results of each NCS
 - c. Reference laboratory values or statement of abnormal findings
 - d. Limb temperature
3. Needle Electromyography Section
 - a. Confirmation that needle EMG was performed.
 - b. Muscles tested
 - c. Description of the insertional, spontaneous, and voluntary activity for each muscle tested as normal or abnormal.
 - d. Listing of the specific abnormalities
4. Summary of Results Section
5. Diagnostic Interpretation Section
 - a. Statement of the normality or abnormality of the study
 - b. Probable electrophysiological diagnosis
 - c. Description of any limitations on the interpretation of results
 - d. Description of any interval changes and the nature of the change in the NCS and needle EMG compared to previous study (if applicable)
 - e. Optionally, a differential diagnosis and recommendation for future testing may be included.

The statement of the problem should include at least a brief description of symptoms and clinical signs, as well as the clinical diagnosis and problem that was elucidated by the study.

The report of the findings should contain a description of the NCSs and evoked potential tests conducted, including the limb temperature, sites of stimulation and recording, amplitudes of responses, configuration, latencies, and distances or conduction velocities. The AANEM recommends that this data be provided in a tabular format. For late responses, limb length or body height should be measured. For repetitive stimulation tests, the amount of decrement of response amplitude

or area should be described.^{10,16,18} The method of measuring, for example, peak to-peak or baseline-to-negative peak, should be mentioned. Technical issues,

such as local edema or deformity, should be recorded. In reporting needle EMG studies, the type of needle electrode should be specified, and the data should be quantified according to currently accepted standards.⁸ Insertional activity, spontaneous activity, and parameters of motor unit action potentials (MUAPs), such as, amplitudes, durations, configuration, and recruitment pattern, should be recorded and quantified when indicated. For single fiber EMG (SFEMG), accepted methods of description should be used.²⁰ Including generated waveforms in the EDX report can be helpful for subsequent review but should not be required for reimbursement.

A statement regarding the normality or abnormality of the findings should be included and be as succinct as possible. It should include a statement regarding the degree and significance of the abnormalities. Providers should include reference laboratory values for NCS data in their reports to permit independent review of NCS data by an outside reviewer. It is recommended laboratories use normative values that are based on high-quality scientific literature, such as the AANEM normative values,³⁰ to promote accuracy and consistency of care. The use of any published norms may be judiciously adjusted based on the physician's own experience and the characteristics of their patient population.

The final conclusion should attempt to explain how the findings of the EDX studies fit, or do not fit, the clinical problem which prompted the referral. In many instances, the EDX evaluation can be diagnostic of a definite anatomic or physiologic abnormality but not of a definite clinical disease. In such cases, a differential diagnosis should be offered. When the referring diagnosis is at odds with the EDX findings, possible reasons for the discrepancy should be mentioned, including clinical findings elicited by the

EDX physician. More detailed information is available in the AANEM practice topic, *Reporting the Results of Needle EMG and Nerve Conduction Studies: An Educational Report*,²⁹ at <http://aanem.org/clinical-practice-resources/position-statements>. Also available on the AANEM website is a sample report and a report checklist.

Records

Records should be maintained in a Health Insurance Portability and Accountability Act (HIPAA)-compliant electronic or paper system.

Referring physicians have the right, and may delegate the right, to examine any records of EDX consultations pertaining to their own patients. In addition, patients' written requests that reports be sent to appropriate outside physicians and other parties, including attorneys and insurance companies, should be promptly honored if the request is in accordance with state law.

EQUIPMENT

The equipment used for EDX testing (typically called EMG instrument) must fulfill two requirements. It must be: (1) accurate in making required measurements and (2) safe.¹² The electrical activity recorded in a standard EDX evaluation varies widely in several important characteristics, and the EMG system must be capable of accurately reproducing this activity in all circumstances.

The EDX evaluation typically consists of measurements of motor and sensory nerve conduction and recording of spontaneous and voluntary activity from muscles. Specialized techniques in common use include signal averaging of evoked responses generated from central structures to peripheral stimulation and SFEMG. Each technique requires different stimulating and recording characteristics.

The EMG instrument must be capable of recording and accurately reproducing electric signals that range from submicrovolt levels to greater than 10 mV. Gain settings should be available to make recordings over this 10,000 fold range. The frequency spectrum of bioelectric signals may vary over a range from 2 Hz to 20 kHz, and specific applications may emphasize particular frequency bands. The instrument should have either adjustable low-and-high-frequency cutoffs or fixed filter settings that are appropriate for the types of electric activities being studied. An important component of any EMG instrument is a volume-controlled loudspeaker for auditory monitoring of bioelectric activity.

Since the measurement of the time of occurrence of specific electric events is crucial for accurate



bioelectric signal recording, the instrument should be equipped with an accurate time-base generator. The instrument must be able to measure latencies and amplitudes of the signals being assessed.

A nerve stimulator should be an integral component of the EMG system. The stimulator should have the

capability of delivering either single or repetitive stimuli of variable intensity and duration and should have separate controls for each of these parameters. Stimulators are available that deliver either constant current or constant voltage stimuli; there is no consensus among EDX physicians as to the preferred type.

Lead wires which connect the patient to the EMG instrument's amplifier should be of the female safety connector type. Older systems which may still use the 2mm male amplifier connectors must use a male to female convertor for lead wire connections between the patient and amplifier.

Electrical equipment used in the examination of human subjects should fulfill minimum electric specifications. Underwriters Laboratories has set standards for the amount of allowable leakage current for medical equipment.²²

Any equipment used in an EDX laboratory should conform to these standards and be regularly checked to maintain electrical safety. The EDX physician is responsible for ensuring that electrodiagnostic equipment is not used in an electrically hazardous manner. Ungrounded devices should not be used in a patient area, and liquid spillage near any instrument should be promptly removed to avoid high-leakage current flow.

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