Clinical Neurophysiology Practice 4 (2019) 199–211

Contents lists available at ScienceDirect

Clinical Neurophysiology Practice

journal homepage: www.elsevier.com/locate/cnp

Review article

Needle EMG muscle identification: A systematic approach to needle EMG examination ☆

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A R T I C L E I N F O

Article history:
Received 22 April 2019
Received in revised form 31 July 2019
Accepted 23 August 2019
Available online 21 October 2019

Keywords:
Needle electromyography
Muscle sampling
Electrodiagnosis
Waveform analysis
Neuroanatomy

A B S T R A C T

The proper performance of needle electromyography (EMG) requires that the examiner obtain a brief but comprehensive history, perform a directed examination and generate a short differential diagnosis as part of the initial patient encounter. Equally as important is to set reasonable expectations for this study's performance as electronic media do not necessarily portray all of the nuances of an electrodiagnostic study. In addition to these preliminary steps, this minimonograph discusses equipment used in EMG evaluations, EMG examination techniques, muscles commonly sampled, pain reduction techniques, and special considerations that may require study modification such as anticoagulation, lymphedema, obesity and supervening infection. Clinicians performing these studies will maximize useful data collection while minimizing patient discomfort if all of these recommendations are followed.

Contents

☆ Presented as a workshop at the AANEM annual meeting in Phoenix, AZ on September 13, 2017.

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https://doi.org/10.1016/j.cnp.2019.08.003
2467-981X/

1. Introduction

A broad knowledge base is required for performing an electrodiagnostic (EDX) medicine consultation. It includes understanding of anatomy, normal physiology, pathophysiology, EDX medicine techniques, basic principles of electricity, as well as signal processing and analysis. A successful examination requires patient rapport and cooperation. A successful needle examination requires attention to a number of specific issues in a series of steps:

- Clinical evaluation
- Patient preparation
- Muscle selection
- Muscle localization
- Muscle examination
- Special Considerations

2. Clinical evaluation

The referring provider's clinical history and physical examination should be reviewed before beginning the EDX medicine consultation. While not obligatory, it is recommended that verbal informed consent be obtained and documented prior to the performance of any EDX procedure. It is strongly recommended that the examiner establish the salient features of the patient's history along with the performance of a directed examination in order to verify or amend the initial clinical impression. A successful EDX consultation will address the questions posed by the referring provider as well as any new diagnostic possibilities that arise during one's own abbreviated history and physical. Additional historical information may be obtained during the needle examination. This serves an additional purpose of distracting the patient from the discomfort of this portion of the examination.

It is important to include clinically-weak muscles during the needle examination. For example, if an L5 radiculopathy is suspected and the extensor hallucis longus is the only weak muscle, it should be included in the study. You should also review the results of any previous studies to help design selection and order of the muscles to test. One should plan the study to answer the questions as efficiently as possible with the least degree of patient discomfort.

3. Preparing the patient for the study

Most patients will have received information about the needle examination prior to the study and may have a few questions. Nonetheless, it is still helpful to explain that this examination differs from the nerve conduction studies in that no external electrical stimuli are applied. The patient should also be informed that nothing is inserted through the needle or removed from the needle as it will only be used to record muscle activity. One of the authors typically explains needle electromyography (EMG) as a "muscle microphone." You should explain that the needle will be inserted into a number of muscles and that there will be some discomfort, which is unavoidable but generally well-tolerated. You should also explain that needles are discarded after each use. Do not use statements such as, "A fine wire electrode will be placed . . ." Many will be caught unaware seconds later when they feel a needle stick, and the patient will lose confidence in you. The patient will appreciate knowing approximately how long the study will take and how many muscles will be examined. Prepare the skin over each muscle with alcohol or other appropriate agent before needle insertion. Although this has not been shown to reduce infection, many needle EMG videos depict this behavior leading patients to expect that this will be performed. Before each needle insertion, you should inform the patient of the approximate location and alert them to an imminent "stick or poke."

4. Selection of muscles for examination

The groups of muscles to be tested are initially selected on the basis of the clinical hypotheses (e.g., proximal muscles for myopathy, single limb for radiculopathy, widespread for motor neuron disease, etc.) The individual muscles selected for examination should be superficial, easily palpated, and readily identified. They should be located away from major vessels, nerve trunks, and viscera. Select muscles that are less uncomfortable for the patient. For example, the thenar and small foot muscles are often more uncomfortable, and they should only be tested when the information is not available from other muscles. Exceptions to this general guideline would be an evaluation for ulnar neuropathies and median neuropathy at the wrist. The first dorsal interosseous pedis is useful in polyneuropathy examinations and will be described later in this monograph. Since the appearance of motor unit action potentials (MUAPs) can vary greatly between different muscles, the muscles selected should be familiar to the examiner, both in how to test the muscle and the range of normal findings.

5. Anatomical localization of the muscle

A needle EMG examination is inextricably linked to human anatomy. A thorough knowledge of musculoskeletal anatomy is essential to the successful practice of EDX medicine. Most importantly, the practitioner must always be confident of which muscle is being examined. Achieving that certainty is easily accomplished when the EDX medicine consultant is confident of needle placement through a detailed knowledge of the pertinent anatomy (see Appendix A) (Geiringer, 1999; Leis and Schenk, 2012). Knowledge of anatomy is preferable to fixed distances for identifying the optimal point for needle insertion. Estimates of where to insert the needle based upon fixed distances from an anatomical landmark quickly fail in practice. A fixed distance will mean one thing in an infant, another in an obese adult, and quite another in a tall adult. Apparent muscle locations vary with limb and joint position as well as with associated edema and pathological processes that result in atrophy or hypertrophy. It is only through a detailed understanding of the three dimensional relationships that do not vary among patients that allows a practitioner to develop confidence in needle electrode placement. If sufficiently superficial, the muscle to be tested should be palpated during intermittent contraction to localize its borders with the examiner's thumb and index finger before needle insertion in order to define the optimal insertion site. The location of end-plate regions should also be taken into account so that they may be avoided.

6. Performing the EDX medicine consultation

An EDX medicine consultation includes a number of distinct skills that are described in detail below:

- Needle EMG techniques
- Data collection/EMG activity analysis
- Pain minimization

6.1. Needle EMG techniques

The ability to record normal and abnormal electrical activity from muscle is operator dependent. Needle EMG requires a number of skills and knowledge (Appendix E). Needle placement and data recording are absolutely necessary in order to obtain accurate and reliable waveforms. This critical step is generally underemphasized. A few simple guidelines allow this crucial aspect of needle EMG examinations to be performed correctly and efficiently. The following discussion outlines some of the considerations.

6.2. Needle electrodes

There are a variety of needle electrode lengths and types. Needle electrode selection depends on a number of patient and examiner considerations (Appendices B and C). Needle electrodes must be sterile. Disposable, standard electrodes are available at a reasonable cost and should be used for each patient. While more expensive needle electrodes, such as single fiber needle EMG electrodes, may be sterilized and reused, this is not recommended for those employed in routine practice. Such electrodes are typically sharp and undistorted. Rarely, they may not be sharp and will resist insertion. If an electrode penetrates the skin with difficulty, passing it through a sterile cotton ball or sponge may identify snags from bent tips. To determine if a batch of electrodes are not well made, they should be examined under a low power microscope. Needles must be straight. A needle that has been bent should not be straightened for continued use since a small break in the insulation may cause a short circuit and result in needle EMG signal distortion.

The recording surface must be the correct size and shape, as well as absolutely clean. Disposable, sterile needles from the manufacturer may rarely be left with a very thin, poorly conducting film on the surface. This film increases the impedance and may cause a low-voltage, irregular, positive waveform (popping noise). This must be recognized since it may be mistaken for end-plate noise, positive sharp waves, or fibrillation potentials. The film may be dispersed within a few seconds in the muscle. If not, the needle should be replaced. The shaft must be stable in the hub to prevent it from breaking off in a patient. The connections to the cable must be intact. A poor connection can result in intermittent 60 Hz or irregular interference. Electrical impedance should be checked if a break or short is suspected (correct impedance at 60 Hz is 5–20 kΩ).

There is a debate as to whether concentric needles or monopolar needles should be used for the needle EMG examination. While there are some differences, they are relatively minor. Nonetheless, it is important that the examiner use the same type of needle electrode that was used in obtaining the normal values used in his or her laboratory. The authors prefer concentric needles because they do not require a surface reference, the signal is crisper, and the examination may be conducted more rapidly.

6.3. Needle insertion

The muscle to be tested should be palpated during intermittent contraction to localize its borders with the examiner's thumb and index finger. It is helpful to make the skin taut at the site of insertion, particularly where the skin is loose. The taut skin is best pulled a short distance distally over the muscle to reduce bleeding (when released, the skin will pull back over the needle site in the muscle). The needle electrode should be held firmly in the fingers like a pen and inserted smoothly and quickly through the skin into the subcutaneous tissue or superficial layers of the muscle at approximately a 45 degrees angle. This minimizes the force necessary to achieve penetration, and it also may distract the patient prior to skin puncture. Rest the hand holding the needle on the skin in order to make needle movement comfortable and precise. Your opposite hand is located on the boundaries of the muscle for assistance in localization during needle movement. A small flick of the examiner's index finger over the intended insertion site may assist in reducing the patient's perceived discomfort (Boon et al., 2008).

During needle insertion and the study of insertional activity, the study is best served if the patient is not asked to do anything more than relax. There are many pertinent reasons to avoid relying on patient input for your localization of a muscle. No voluntary contractions should be required to confirm needle placement, for the following reasons:

- Some patients are not capable of activating one or any muscle (e.g., with nerve palsy, hemiparesis, coma, upper motor neuron disorders, or non-organic weakness, etc.).
- Some muscles are not palpable from the surface in any patient, (e.g., tibialis posterior).
- Voluntary contractions can be misleading. As an example, if the needle is mistakenly placed in the flexor carpi radialis rather than the targeted pronator teres, testing localization with forearm pronation will not reveal the error, as both muscles subserve this function.
- Patients tend to become less comfortable with needle EMG as time passes. The sequence of palpation, contraction, repalpation, needle insertion, and recontraction takes time, which extends the length of the examination.
- The patient's confidence in you might waiver if you spend as much time searching for each muscle as examining it. Diagnostic ultrasound may be useful for precise placement of the needle electrode into the muscle, especially in patients with a large body mass index. Other uses of ultrasound are summarized later in this monograph.
- Above all, you must be completely confident that you are examining the muscle that you intended to study.

6.4. Needle movement

The muscle is examined by moving the needle along a straight line into the muscle in short steps (0.5–1 mm). Large movements are more painful and end-plate areas may not be recognized. The needle should not be released between movements. The pace of needle movement should not be rushed. A brief pause (1 s or more) between each site is needed to listen and watch for slower onset abnormal activity. The needle is advanced in 5 to 30 such steps depending on muscle diameter. After traversing the diameter, the needle is withdrawn from the muscle, but not from the skin, and then reinserted at a different angle in the same location; 2–4 such passes through the muscle are made until an adequate number of sites within the muscle have been examined. Most texts describe the standard needle EMG examination as requiring 5 sites in each of 4 quadrants be evaluated so that 20 total sites have been sampled per muscle. However, 3 sites in 2–4 quadrants may be sufficient. Significant amounts of spontaneous activity are usually observed with the first few sampling sites.

6.5. Data collection/EMG activity analysis

The muscle should be examined at multiple sites both at rest and during contraction using the methods previously described. Either resting or contracting muscle may be tested initially. Resting muscle is preferred first since it is sometimes more difficult to obtain full relaxation than a contraction. However, if a muscle is already contracting at the desired level on insertion, it should be tested in that position. Do not intermittently relax and contract a muscle at one site. That leads to more local muscle injury, bleeding, and subsequent pain.

6.6. Resting muscle

The resting muscle is tested for spontaneous activity at a gain of 50 μV/cm. When the needle is well within the muscle, it should be left undisturbed for a number of seconds to listen for fasciculations. It is not always easy to obtain muscle relaxation. In tense patients or during a painful examination, relaxation can be enhanced by:

- Carefully positioning the patient at the beginning to provide the best relaxation and save time overall
- Adequately supporting the limb and, at times, passively manipulating the limb
- Contraction of an antagonist
- Distraction with conversation
- Reassurance
- Changing needles

Once you have the needle under the skin, a more gentle movement of the needle can be used to pierce the superficial fascia. As the fascia is approached, listen for the rumbling of "distant" motor units. The muscle might not be relaxed enough to proceed, and pushing the needle into a moderately or strongly contracting muscle may be unnecessarily painful. Give specific directions about how to relax the muscle. For example, "Roll that thigh out toward me." Medical terms such as "dorsiflex your ankle" should be avoided. A similar outcome can be obtained by saying, "Toes up towards your nose." It is not useful to simply request that the patient relax, especially at increasingly higher volumes on your part. The typical responses are, "I thought I was relaxed," or, "I'm as relaxed as I can be with your sticking that needle in me."

Tonic pressure should be kept on the needle hub while studying insertional activity. If you do not, particularly with concentric needle electrodes, there will be a tendency for the electrode to

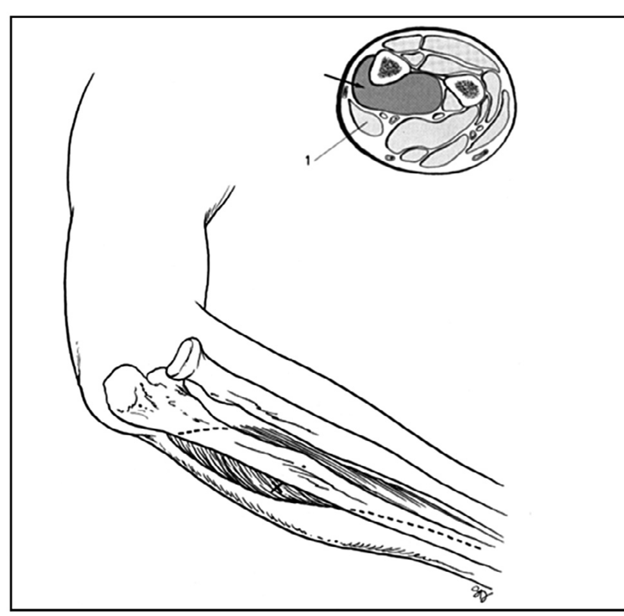

Fig. 1. Flexor carpi ulnaris.

"bounce" back out of the muscle at the same distance that you just moved it inward. Insertions should be smooth, firm, and with small amplitude forward movements of 0.5 mm or so. There is no advantage in using hard jabbing motions as they may cause pain.

6.7. Contracting muscle

The contracting muscle is examined using the same needle methods as for resting muscle. The contracting muscle is best examined with the muscle held at a level of contraction that activates a few motor units (low-to-moderate effort). Selective activation of the muscle of interest and adjacent muscles is needed to determine needle position when examining deep muscles, muscles that are difficult to palpate, or small muscles. Steps in testing a contracting muscle include:

- Withdrawing the needle to a subcutaneous position before asking for muscle contraction.
- Positioning the limb and muscle and initiating contraction before moving the needle into the muscle. Advance the needle until you encounter MUAPs with a rapid rise time and a sharp, clicking sound.
- Proper limb positioning such that the activity of synergistic and adjacent muscles is limited.
- Asking the patient to perform a movement that only requires activation of the muscle being examined.
- Palpating the contracting muscle in order to help guide the needle movement.

6.8. Other considerations

Small muscles are best tested with an oblique needle course through the muscle to lengthen the needle's path. Deep muscles and obese patients require a needle of adequate length. If the needle were to break off, it would likely do so at its hub, which is its weakest point. If a needle were to be inserted to a depth greater than its length and it broke, it would be difficult to remove. Some muscles, such as the deep paraspinal muscles, may be difficult to reach without a long needle, even in average-sized patients. Needles of up to 120 mm length should be available and should be used in such circumstances.

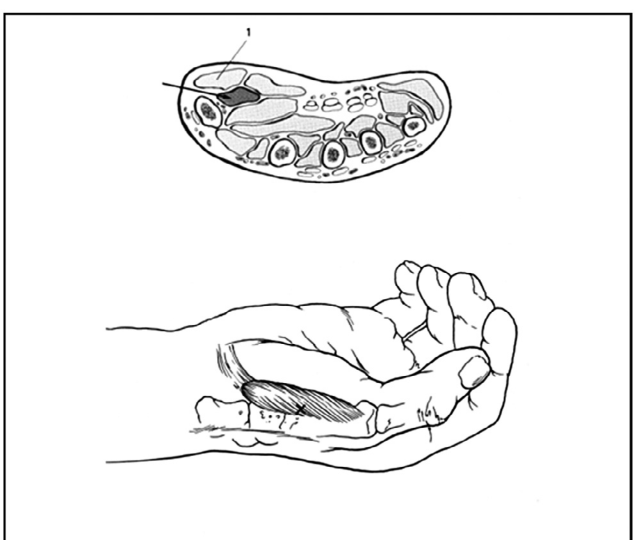

Fig. 2. Opponens pollicis.

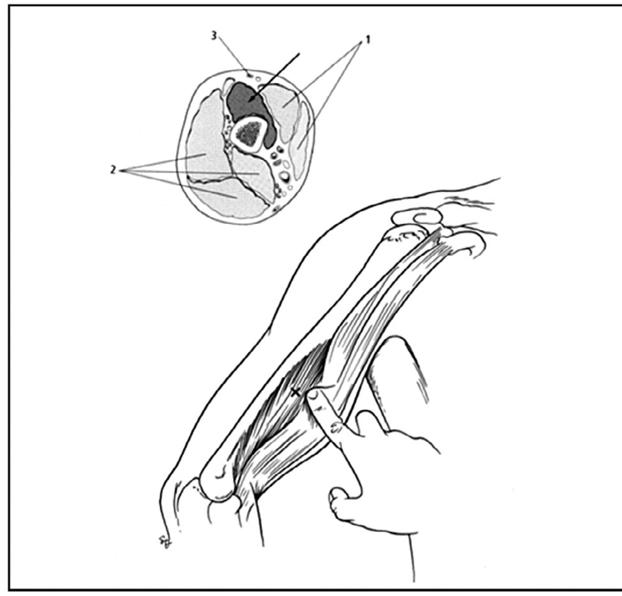

Fig. 3. Brachialis.

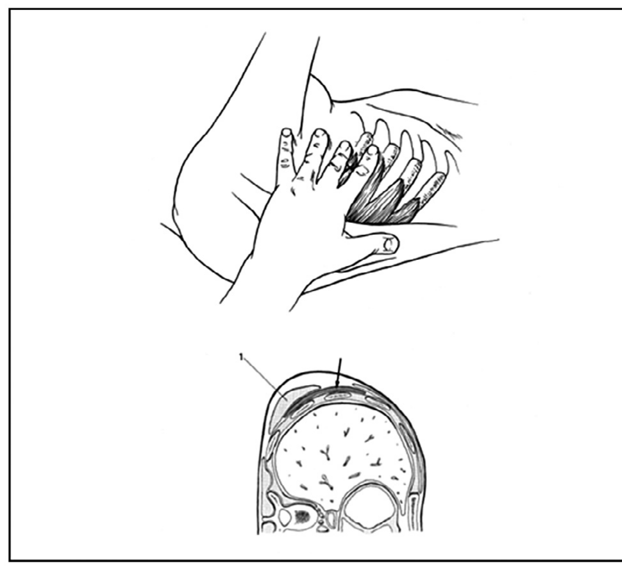

Fig. 4. Serratus anterior.

6.9. Pain control/minimization

Most patients are able to tolerate the discomfort of the needle examination without difficulty, but a few need special approaches. A review article on safety and pain in EDX studies summarizes the salient features of needle EMG associated pain (Boon et al., 2008).

Pain minimization requires attention to all interactions with the patient, in particular the techniques of the needle examination itself. Approaches that can be helpful in all patients are described in Appendix C.

6.10. Overview of adjunctive ultrasound

Ultrasound has been evolving as an adjunctive electrodiagnostic methodology based on its ability to assess normal and pathological anatomy (Boon et al. 2012a, 2012b). A complete discussion of neuromuscular ultrasound is beyond the scope of this discuss save for a brief description of using this technique for needle EMG guidance. However, it can be summarized as allowing the examiner to sample muscles in patients with atypical surface anatomy, significant body mass index, deep muscles, denervated muscles and muscles often not routinely examined such as the diaphragm (Boon et al., 2008). Ultrasound was also demonstrated to improve sampling accuracy in a cadaveric model, especially in less experienced examiners (Boon et al., 2011). In summary, ultrasound guidance should be considered in situations wherein the examiner has a concern about accurate needle placement.

7. Special considerations

A number of special issues presented by a few patients must be considered before initiating the needle examination. As the article by London (2017) addresses many of these items, only a brief summary will be listed in Appendix D and includes:

- Anticoagulants and bleeding disorders
- Infection
- Cardiac valvular disease
- Obesity
- Skin conditions

8. After the study

Before leaving the room, check to be sure that all puncture sites are dry and that no bruising is evident. If bleeding is still present, 1–2 min of firm pressure applied by either the EDX examiner or the patient will usually stop it. An ice pack is useful to minimize additional bleeding if a small hematoma has formed. Ensure that the patient can get dressed unassisted, or be sure they have help. Some patients ask about persisting discomfort after the examination. They can be advised that their muscles may ache for a few hours, but this will usually disappear overnight. If necessary, mild analgesics such as non-steroidal anti-inflammatory agents may be used, (e.g., acetaminophen).

Acknowledgements

The author would like to thank Jasper R. Daube, MD and Steve R. Geiringer, MD, who authored the previous version of this manuscript as published by the American Association of Neuromuscular and Electrodiagnostic Medicine [AANEM] formerly known as the American Association of Electrodiagnostic Medicine [AAEM]. This version has been updated with that organization's express written permission.

Conflict of interest

I confirm that I have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

Daniel L. Menkes, M.D. has received travel expenses from Neurotron, Inc.

Appendix A: Testing specific muscles

Note: In the arm, "lateral" refers to the thumb side of the arm, while "medial" refers to the ulnar side of the arm.

Innervation: Ulnar nerve; medial cord; lower trunk; C8-T1

Utility: Abnormalities localize pathology in the ulnar nerve territory proximal to the wrist. It is also useful for assessing lower trunk brachial plexopathies and C8-T1 radiculopathies.

Comments: Spontaneous activity detected in this muscle localizes the lesion proximal to Guyon's canal, the site of ulnar neuropathy at the wrist.

Localization: Insert the needle 5–8 cm distal to the medial epicondyle along an imaginary line from the medial epicondyle to the pisiform bone as depicted in Fig. 1.

Activation: Abduction of the little finger away from the hand.

Innervation: Median nerve; lateral cord; lower trunk; C8-T1

Utility: Abnormalities confirm pathology in the median nerve distribution distal to the carpal tunnel. It is also useful for assessing lower trunk brachial plexopathies and C8-T1 radiculopathies.

Comments: Examining this muscle usually results in less discomfort to the patient than when the abductor pollicis brevis is examined.

Localization: At the midpoint of the first metacarpal shaft, in the groove between the metacarpal bone and abductor pollicis brevis (see the top cross section in Fig. 2). The muscle is studied where it attaches to the medial side of the bone. In most patients, no other muscle overlies the opponens at this point.

Activation: Opposition of thumb across the palm.

Innervation: Musculocutaneous nerve; lateral cord; upper trunk; C5-C6

Utility: Diagnose lesions of the musculocutaneous nerve, upper trunk brachial plexopathy, or C5-C6 radiculopathy.

Comments: Examining this muscle usually results in less discomfort to the patient than when the biceps brachii is examined.

Localization: In the distal one-third of the arm, push the biceps (see the axial cross section in Fig. 3) medially and insert the electrode in the groove between biceps and triceps (see the longitudinal section in Fig. 3). Direct it down and medially, toward the anterior aspect of the humeral shaft.

Activation: Elbow flexion; the degree of forearm pronation–supination is irrelevant.

Innervation: Long thoracic nerve; C5, C6, C7

Utility: Often affected in acute brachial neuritis along with muscles supplied by the anterior interosseous nerve (flexor pollicis longus, median nerve portion of the flexor digitorum profundus, and the pronator quadratus). It is also a "root collateral" that may be abnormal with a cervical radiculopathy.

Comments: A "root collateral" indicates a muscle innervated by a nerve that originates proximal to a plexus such that its involvement favors root level pathology. Cervical root collateral muscles should be sampled if there has been previous cervical spine sur-

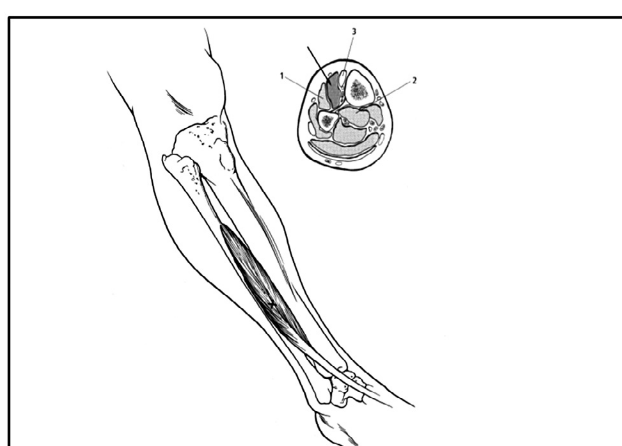

Fig. 5. Lower extremity muscles. Extensor hallucis longus.

gery from a posterior approach. Another example of a root collateral is the rhomboid, which is described in the next section.

Localization: In the mid or anterior axillary line, isolate 1 rib by placing 2 fingers in the adjacent interspaces, anterior to the bulk of the latissimus dorsi (see the top cross section in Fig. 4), but posterior to the breast tissue in a woman. Needle electrode insertion is directly between your fingers, as serratus anterior is the only muscle between the skin and the rib.

Activation: Elevation and reaching forward with the arm, (i.e., scapular protraction). Providing resistance is sometimes necessary.

Rhomboid

Innervation: Dorsal scapular nerve; C4, C5

Utility: Often affected in acute brachial neuritis. A "root collateral" that may be abnormal with a C5 radiculopathy. Useful in differentiating a C5 radiculopathy from an upper trunk brachial plexopathy.

Comments: Spontaneous activity detected in this muscle will help to substantiate a C5 radiculopathy.

Localization: Beneath the trapezius. Origin from lateral mass of upper thoracic vertebrae. Insertion on lower third of medial scapular border. Can be palpated during activation in some muscular patients.

Activation: Hand in the small of the back with palm pushing posterior against the examiner. Posterior (dorsal) pressure against resistance of the elbow on the hip can be used in patients unable to make this first maneuver. Caution is required since penetration too deeply could enter the pleural cavity.

Pronator teres

Innervation: Median nerve; lateral cord; upper and middle trunk; C6-C7

Utility: Useful for determining the presence of a C6-C7 radiculopathy, upper/middle trunk brachial plexopathy, or a proximal median neuropathy.

Comments: The most proximal muscle innervated by the median nerve. It should be unaffected in pronator syndrome. Spontaneous activity in this muscle may help to confirm a C6 or C7 radiculopathy when similar abnormalities are identified in radial nerve-innervated muscles innervated by the same nerve root.

Localization: Insert the needle 2–3 cm distal and 1 cm medial to the biceps brachii tendon (the edge of the muscle may be palpated in this location).

Activation: Have the patient flex the elbow, which is a secondary action of the muscle. This is less uncomfortable than having the patient pronate, which may bend the needle.

Extensor indicis

Innervation: Posterior interosseous branch of the radial nerve; posterior cord; lower and middle trunks; C7-C8

Utility: Useful for determining the presence of a C7-C8 radiculopathy, middle/lower trunk brachial plexopathy, radial neuropathy, or posterior interosseous neuropathy.

Localization: Originates at the posterior surface of the lower half of the ulnar shaft and adjacent interosseous membrane. Insert the needle 5–7 cm proximal to the ulnar styloid just radial to the shaft of the ulna.

Activation: Extend the index finger.

Extensor digitorum [formerly the extensor digitorum communis]

Innervation: Radial nerve; posterior interosseous nerve; posterior cord; middle and lower trunks; C7, C8

Utility: Useful for determining the presence of a C7-C8 radiculopathy, radial neuropathy, or posterior interosseous neuropathy.

Localization: Superficial, readily palpable muscle that is bordered laterally by muscles innervated directly from the radial nerve, rather than from the posterior interosseous. Localization is best obtained by palpation of the active muscle in the center of the proximal third of the forearm dorsum, during selective extension of the middle finger. It is important to distinguish the radial-innervated wrist extensors supplied by the posterior interosseous nerve from the extensor digitorum, formerly designated the extensor digitorum communis (EDC). These groups are easily separable by a groove between them and the EDC. The radial-innervated wrist extensors are just lateral to the groove, whereas the EDC is just medial to it. The muscles lateral to the groove are easily movable (anatomists label them the "movable wad"). The EDC and the extensor carpi ulnaris just medial to it are fixed to the underlying tissues.

Activation: Extension of middle finger.

Innervation: Deep branch of fibular (formerly peroneal) nerve; fibular division of sciatic nerve; lumbosacral plexus; L5, S1

Utility: Useful for determining the presence of a deep fibular (deep peroneal) neuropathy, sciatic neuropathy, or L5 radiculopathy.

Localization: At the junction of the middle and lower thirds of the leg, one-third of the distance from the tibial shaft to the lateral border of the leg. The electrode is directed deep and medially. The tibialis anterior is just lateral to the shaft of the tibia. Insert the electrode one-third the distance laterally around that quadrant to avoid piercing the thick tibialis anterior tendon. Angle the needle from lateral to medial, rather than aiming it straight down, because the belly of the extensor hallucis longus is thin and vertically oriented (see cross section in Fig. 5).

Activation: Great toe extension; be certain the needle is pulled back into the subcutaneous tissue before the patient contracts this muscle.

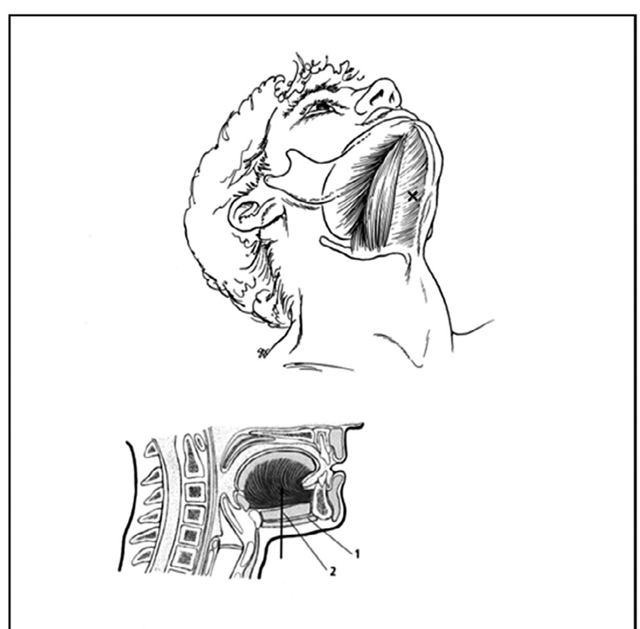

Fig. 6. Cranial muscles. Tongue (genioglossus).

Gluteus medius

Innervation: Superior gluteal nerve; lumbosacral plexus; L4-L5-S1

Utility: Useful for differentiating a sciatic neuropathy from an L5 radiculopathy or lower lumbar plexopathy, as it is not innervated by the sciatic nerve. (Note: The gluteal muscles should be examined if the patient is being evaluated for a radiculopathy and the patient has undergone lumbar spine surgery in the past. Their involvement favors a diagnosis of radiculopathy.)

Localization: The anterior border of gluteus medius is defined by the line joining the anterior superior iliac spine (ASIS) and greater trochanter. The electrode is inserted parallel to this line, at its midpoint and just posterior to it.

Activation: Internal rotation of the thigh. Needle insertion as described above places it in the anterior fibers of gluteus medius, allowing internal rotation to be used for activation. If more posterior locations are needed, the gluteus medius can be readily activated with the patient lying on the contralateral side and the foot resting on the bed while the knee is gently raised toward the ceiling.

Adductor longus

Innervation: Obturator nerve; lumbar plexus; L2, L3

Utility: Abnormalities confirm obturator nerve distribution involvement. This muscle helps to differentiate femoral neuropathy from upper lumbar plexopathy/radiculopathy.

Localization: Both borders are readily palpable for needle placement in the proximal 20% of the medial thigh with the knee flexed to 90 degrees and abducted. If the needle is placed too distal, approaching the adductor canal of Hunter, it could easily enter the adductor magnus, which is also supplied by the sciatic nerve. Investigation of a possible obturator neuropathy could thereby be compromised.

Activation: With the patient lying on the back with the knee flexed and externally rotated, minimal elevation of the knee readily activates a number of motor unit potentials without the examiner needing to resist the motion.

Biceps femoris short head

Innervation: Fibular division of sciatic nerve; lumbosacral plexus; L5-S1

Utility: Abnormalities confirm that the pathological site is proximal to the common fibular (common peroneal) nerve.

Localization: The needle is inserted just lateral or just medial to the lateral hamstring tendon, at the proximal popliteal crease, then directed to underneath the tendon. If the muscle is studied more proximally, the short and long heads cannot be distinguished. At the more distal point only short head muscle fibers will be encountered, to help exclude proximal damage to the fibular division of the sciatic nerve.

Activation: Partial knee flexion.

Fibularis longus (Peroneus longus)

Innervation: Superficial fibular nerve; fibular nerve; fibular division of sciatic nerve; lumbosacral plexus; L5-S1

Utility: Abnormalities confirm pathology in the distribution of the superficial fibular (peroneal) nerve.

Localization: Readily palpable, immediately lateral to the anterior tibial muscle, in the proximal third of the leg.

Activation: Plantar flexion of the foot with a minimum of eversion.

Flexor digitorum longus

Innervation: Tibial nerve; sciatic nerve; lumbosacral plexus; L5-S1

Utility: Abnormalities confirm pathology outside the distribution of the fibular (peroneal) nerve.

Localization: Distal third of the leg, immediately posterior to the tibia at a depth of 2–3 cm. Needle insertion just behind the ventral (posterior) surface of the tibia usually passes through some of the soleus, which can be distinguished by selective activation. Occasionally, the tibialis posterior is entered first. (Note: Both are innervated by the tibial nerve such that needle EMG abnormalities in one or the other have virtually the same diagnostic significance.)

Activation: Toe flexion with the ankle slightly dorsiflexed. The tibialis posterior can be distinguished by slight plantar flexion.

Tensor fascia lata

Innervation: Superior gluteal nerve; lumbosacral plexus; (L4), L5

Utility: A truncal or proximal muscle such that it is useful in differentiating a sciatic neuropathy from an L5 radiculopathy or lower lumbar plexopathy. (Note: Similar function to the gluteus medius, which has the same innervation.)

Localization: One-half the distance between the anterior iliac spine and the greater trochanter. Vertical entry is needed, since the muscle is often deep.

Activation: Most patients can provide excellent MUAP control with gentle internal hip rotation, and full relaxation with external rotation.

First dorsal interosseous, pedis

Innervation: Deep branch of the fibular (peroneal) nerve; sciatic nerve; lumbosacral plexus; L5, S1

Utility: One of the first muscles involved with a distal symmetric axonal polyneuropathy.

Localization: The index finger of one hand is placed in the notch between metatarsal heads I and II. The needle is inserted just distal to your finger, and directed slightly toward the index finger upon which this muscle acts. This muscle is less painful, is less subject to trauma than other intrinsic foot muscles, and is the most distal muscle in the body. This muscle is therefore very sensitive to even mild, distal motor axon loss.

Activation: Plantar flexion of the toes against resistance.

Innervation: Hypoglossal nerve; cranial nerve XII

Utility: Confirms pathology rostral to the foramen magnum in persons undergoing needle EMG for a presumed diagnosis of motor neuron disease.

Localization: Midpoint between tip of the chin and the angle of the jaw, medial to the mandible. The tongue is found deep here, after the electrode passes through mylohyoid (see Fig. 6 with the skin reflected and geniohyoid (see the sagittal section in Fig. 6) muscles.

Activation: Protrusion of the tongue. Ask the patient to stick out the tongue.

Masseter

Innervation: Motor nucleus of the third division of the trigeminal nerve (mandibular division); cranial nerve V

Utility: Will be normal in cases of infranuclear facial nerve lesions.

Localization: Insert the needle 2–3 cm distal to the angle of the jaw and 2 cm cephalad to the lower edge of the mandible with the jaw open. (Note: The muscle belly is easily palpated when the patient is asked to clench the teeth.)

Activation: Jaw closure.

Appendix B. Reducing the discomfort of the needle examination

Needle handling techniques

A description of the procedure, patient engagement, setting expectations, and using short, gentle needle movements should minimize the discomfort experienced during needle EMG. However, there will be patients who are unwilling or unable to tolerate this examination.

Here are some recommendations that will help improve patient tolerance of the discomfort that does occur.

- Tell the patient that some areas of the muscle may be uncomfortable (near small nerves).
- Tell the patient that you will move away from such areas if they tell you about the pain.
- Quickly move a short distance away from an area where the patient has increased pain.
- Penetrate through dorsal rather than ventral skin if possible (e.g., opponens rather than abductor pollicis brevis, and brachialis rather than biceps brachii).
- Whenever feasible, direct the needle to follow a path nearly parallel to the muscle fibers, rather than perpendicular to them. While there will be no difference in the appearance of the wave forms observed, normal or abnormal, the tangential approach is less painful.
- Use a secondary muscle function for contraction (e.g. the pronation of the pronator teres can be quite painful as the muscle torques around the electrode). The secondary function of elbow flexion pulls the needle along in a linear path that is generally much more easily tolerated.
- Use a 1-joint muscle if possible. For example, the gastrocnemius is an extremely strong muscle and obtaining its contraction using pressure against your hand can be difficult if not impossible. The soleus has the same S1 innervation, and can be much more readily activated by plantar flexion.
- Select muscle testing in which nothing of importance lies between the skin and the targeted muscle except perhaps subcutaneous tissue. Some muscle approaches require piercing other structures first, which may add discomfort, greater risk, and uncertainty about needle location. Examples include: (1) the distal approaches to the flexor pollicis longus, flexor digitorum longus, and extensor indicis; (2) the medial approaches to the flexor digitorum profundus and the pronator quadratus; and (3) the lateral chest approach to the serratus anterior.

Pain is most common if the needle is in the end-plate region. As the needle is moved through the muscle, end-plate noise will be recognized as the needle tip approaches. When this is apparent from the presence of end-plate noise or spikes, the needle should be quickly moved to another area. Sometimes, movement in every direction is plagued by end-plate activity. In this situation, the needle should be completely withdrawn and reinserted a short distance away. Localized burning pain occurs if the needle is inserted in the immediate region of pain nerve terminals in the skin, and also requires withdrawing and reinserting the needle through the skin.

A number of methods can help a patient tolerate a full evaluation:

- Reassure the patient that everyone experiences some discomfort during the test, but almost all are able to tolerate it.
- Continue reassurance and verbal sympathy for the patient throughout the study.
- Reassure the patient that the discomfort of the test is not long lasting.
- Move the needle gently and slowly.
- Begin with the most important muscle (e.g., paraspinal muscles in suspected radiculopathy).
- Avoid hyperventilation.
- Inform patients that they can take analgesics prior to the test if they are concerned about the pain.
- Change needles if there is increased resistance to needle movement.
- Rarely, but if all else fails, it may be necessary to use a narcotic such as fentanyl by injection at the start of the test.

Under most circumstances, thorough explanation of the procedure and a kind, understanding, and sympathetic manner with adult patients will be sufficient to complete the needle examination. Some patients inquire if they can take acetaminophen with codeine before the examination. While this is quite acceptable, it is probably of limited benefit. On rare occasions, it may be necessary to use a short-term parenteral analgesic such as fentanyl. Chloral hydrate may be helpful in children. Some institutions now require conscious sedation by a qualified professional (e.g., anesthesiologist).

Patient interactions to optimize cooperation on clinical needle EMG

Introductions in the examining room:

- Greet patient, introducing yourself
- Confirm patient's name and test
- Confirm clinical problem requiring needle EMG
- Briefly describe purpose of test
- Briefly describe test components and length of time
- Reassure patient about test
- Ask about possible contraindications or confounding factors such as:
  - Medications such as anticoagulants, and acetylcholinesterase inhibitors
  - Allergies and reactions such as alcohol or iodine
  - Pertinent medical problems such as sub-acute bacterial endocarditis
- Reassure patient about absence of significant risk

Discussion of the discomfort of test by physician:

- Review specific components of test
- Provide understanding of need for discomfort
  - Describe options for dealing with discomfort:
  - Patient choice on how to proceed
  - Tolerate as best as possible
  - Move needle or stimulating electrodes to different sites
  - Change needle type
  - IM medication if needed
- Discontinue individual muscle or entire test if necessary

During needle EMG:

- Describe nature and purpose of needle examination
- Explain cleansing with alcohol and use of gloves
- Describe use of disposable electrodes
- Describe need to record at rest and with voluntary contraction
- Use as small needle movements as possible (0.5 mm)
- Do not change level of voluntary contraction with needle in muscle

- Do not move the joint with needle in muscle
- Move needle only in straight lines through muscle
- Redirect needle only in subcutaneous tissue
- Ask patient frequently how they are doing
- Respond to each clue that they are having discomfort by a change in technique
- Warn before each new needle insertion
- Describe need for and nature of any unusual or particularly uncomfortable recordings
- Reassure patient about quality of cooperation and recordings frequently
- Maintain local pressure on each site to stop all bleeding after testing
- Ask for a chaperone when examining intimate areas irrespective of stated gender
- Keep patient covered at all times everywhere except the area being tested

After the test:

- Reassure patient about their cooperation
- Sympathize with their discomfort
- Indicate that useful data was recorded
- Describe results to the extent appropriate
- Ask if they have questions or concerns before they leave

Appendix C: Needle electrode types

	Concentric Needles	Monopolar Needles
Recording area	Smaller (stable)	Larger (variable)
Recording properties	Stable	Variable; may polarize
Background	Less noise (better common mode rejection)	Noise from surrounding muscles
Reference electrodes	Needle shaft	Separate surface electrode
Motor unit potentials	Smaller	Larger
Motor unit quantitation	More reliable	Less reliable
Discomfort	No difference, if disposable	Less than non-disposable
Cost	More expensive	Less expensive

Concentric needle electrodes

Concentric needle electrodes (CNEs) are made of a bare needle shaft (reference electrode) and a central platinum wire (active electrode) insulated from the shaft. All standard CNEs are beveled to a fine tip with an exposed central core 125 by 500 μm. There are 4 common sizes of needles available: 25 mm (30 gauge), 37 mm (26 gauge), 50 mm (26 gauge), and 75 mm (20 gauge). The needle is a detachable electrode connected to the preamplifier by a cable. Because of the narrow gauge electrodes are particularly delicate and need careful handling. CNEs are most fragile at the junction of the shaft and the hub, and they may bend or break at that location. The beveled cutting edge of the concentric needle electrodes may be more likely to induce bleeding than monopolar needle electrodes, which are cone-shaped.

Monopolar electrodes

Monopolar needle electrodes are Teflon™ coated fine needle electrodes, usually made of stainless steel, and can have a very fine gauge and an extremely sharp point. The recording surface is usually somewhat larger than a standard CNE, resulting in different characteristics of the recorded potentials. The area of the exposed surface may change as the Teflon™ insulation near the tip is damaged or pulled back from repeated needle insertions. In the past, these needles were reused. This is no longer recommended, as disposable needles have become the standard of care.

Single-fiber electrodes

Single-fiber EMG is being performed with decreasing frequency in favor of using disposable CNEs, which can assess jitter but not fiber density. Single-fiber electrodes have a fine 25 wire exposed on the lateral surface of the shaft of a needle as the active electrode. These electrodes may also develop barbs or bent tips, but can be readily sharpened without damage to the active electrode. Microscopic examination is needed, since a damaged tip will result in damage to muscle fibers, and prevent reliable recording from single fibers. They should be examined after every use. The impedance of the small surface of a single-fiber electrode is much higher than that of a monopolar or a standard CNE and cannot be reduced by cleaning or etching. These electrodes should be examined at regular intervals for pitting or local damage to the surface of the active electrode which, if present, are best corrected by sanding with fine emery paper. These electrodes are much more susceptible to noise if the electrode surface is dirty (high impedance) or if improperly seated in the connecting cable.

Appendix D: Special problems to consider prior to needle EMG

Anticoagulants and bleeding disorders

Patients with a variety of bleeding disorders may be referred for an EDX medicine consultation. The EDX medicine consultant must examine each case individually, carefully weighing the potential risks and benefits. Regarding antiplatelet agents, neither aspirin nor clopidogrel pose a significant bleeding risk. Needle EMG may proceed as usual, although additional direct pressure to the sites sampled may be required on a case-by-case basis.

Warfarin therapy does not pose a significant risk with an INR < 3.0 (Boon et al., 2012b). A greater degree of anticoagulation is not an absolute contraindication, but caution should be exercised. Notwithstanding, hematoma formation from needle EMG is rare even in high risk muscles such as the paraspinals (Geiringer, 1999). Therefore, needle EMG need not be deferred simply because the patient is anticoagulated. While these data cannot be definitively extrapolated to dabigatran or other anticoagulants, the risk is likely low as well. Nonetheless, it is prudent to perform a risk/benefit assessment in such instances. If the needle EMG is performed, it is prudent to examine the minimum number of muscles, especially deep muscles, to study each muscle briefly, and to avoid tight fascial spaces, if possible. After each muscle is examined, place firm pressure on the needle puncture site for 1–5 min to stop bleeding or bruising. It is often possible to proceed to another muscle while maintaining local pressure on the previous puncture site.

Thrombocytopenia may be encountered in some patients. If the platelet count is above 30,000/mm2, the study can usually be performed. Needle EMG should be avoided in patients with hemophilia who have inhibitors. For these and more uncommon bleeding diatheses, it may be necessary to consult with a hematologist before proceeding.

Infection

Special precautions are needed in the use of needle electrodes in patients who are demented and those who have a history of viral hepatitis, acquired immune deficiency syndrome (AIDS), and other potentially transmittable diseases. The author treats all patients as potentially infectious and recommends that universal precautions be observed at all times. Thus, these needles should always be discarded after use in specially-designed containers. The use of gloves by the physician is strongly recommended when performing the needle examination, not only for patients who have a potentially transmittable disease, but to protect the EDX medicine consultant from unrecognized agents.

Cardiac valvular disease

Patients with rheumatic or other types of valvular disease and patients with prosthetic valves are at risk of developing endocarditis as a result of transient bacteremias. However, the risk from needle EMG is similar to the risk from repeated venipunctures in which prophylactic antibiotics are not used. Therefore, prophylactic antibiotics for such patients undergoing an EDX medicine consultation are not required.

Obesity

Patients with a large body mass index present problems of locating and palpating muscles that need to be studied. For example, it may be difficult to palpate the spinous processes used as a landmark for paraspinal muscle insertion. Diagnostic ultrasound may prove valuable in this situation (O'Neill, 2008). With extra palpation and manipulation, landmarks can often be distinguished. If landmarks cannot be appreciated, muscles that are near the pleural cavity, viscera, or neurovascular bundles may have to be eliminated from the study (e.g., serratus anterior). For obese patients, the standard 50 mm needle will not be long enough to reach some muscles. A 75 or 120 mm needle should be chosen at the start of the study.

Skin considerations

Inspect the skin over the muscle to be examined before inserting the needle to avoid superficial veins or varicosities. Tortuous arteries or anomalous vessels can be detected by palpation. Avoid areas of infection, ulceration, dermatitis, and venous stasis. Scars should also be avoided since there may have been associated damage to the underlying muscle. If the lower extremity is ischemic, the small foot muscles or even leg muscles may need to be avoided. Foot intrinsic muscle sampling should be performed with caution in patients with severe diabetes mellitus. Severely swollen lower extremities will make the examination difficult, as edema fluid may leak after the needle puncture. If the edematous limb has macerated or has very thin skin, a judgment will have to be made about the safety of the needle EMG. On general principle, a risk benefit analysis should be conducted, discussed with the patient, and documented.

A. Clinical evaluation

1. Review clinical history and examination from record. Perform a focused (yet thorough) neuromuscular history and examination.
2. Define the question/hypothesis: What is the differential diagnosis?

B. Plan the study

1. Review nerve conduction studies. Do they support the hypothesis or suggest a different etiology?
2. Decide which muscle to test.
a. Test most likely involved muscles. If normal, test other muscles with similar supply or distribution. If abnormal, confirm in another muscle.
b. Superficial muscles are preferable to deep muscles.
c. Palpable muscles are preferable to those that cannot be palpated.
d. Familiar muscles are preferable. One should attempt to become familiar with as many muscles as possible.
e. Stay away from dangerous areas (pleura, arteries).
f. Have a reason for each muscle examined. If you think about examining a muscle, then you probably should.
g. Other considerations:
i. Myopathy, unilateral study recommended (one side should be preserved for biopsy).
ii. Paraspinal muscles, if abnormal, consider sampling the other side.
iii. Define the rostral/caudal limits of paraspinal muscle abnormalities.

C. Prepare the patient

1. Greet patient; identify yourself.
2. Confirm understanding of their problem.
3. Explain the purpose of the study; identify disease process and severity.
4. Explain the test (e.g., muscle recording, test muscles, no shocks or electricity).
5. Advise that there is some discomfort, but minimized (pain averages a 3 on a scale of 1–10).
6. Inform that the test will not be performed without their consent, and that the study will be discontinued on request.

D. Needle EMG technique

1. Identify muscle by palpation of selective activation.
2. Wipe muscle with alcohol.
3. Retract the skin.
4. Set parameters (50 μV/div for spontaneous activity, 200 μv/div for voluntary activity). On many machines, sweep speeds can be varied.
   a. Upper or left screen
      i. Sweep can be set at half (10 divisions) or full screen (20 divisions).
      ii. Sweep speed can be varied:
         10 ms/div reproduces what is seen on oscilloscope with a 100 ms (half) or 200 ms (full) sweep time.
         50 ms/div at full screen width.
         Full 1 s sweep, easier analysis of firing frequency and pattern.
         Evaluation of duration of insertional activity.
         Evaluation of slow initial and terminal component long duration waveforms.

   b. Right or lower screen
      i. Superimposition or rastering of multiple traces of the same triggered MUAP. (The standard number of traces is 5.)
      ii. Sweep speed can be varied (5 ms/div is standard).
      iii. Filters: Low frequency filter (LFF): 30 Hz; High frequency filter (HFF): 20 kHz

5. If quantification of MUAPS is performed, the technique should be identical to a standard reference.
6. Support muscle by hand.
7. Warn patient.
8. Pull skin taut, quick stick through skin. Hold needle like pen and insert needle at an angle. Brace hand on muscle.

E. Evaluating insertional and spontaneous activity

1. Move needle in short steps (0.5–1 mm); large movements are more painful.
2. Move in straight line from insertion through muscle.
3. Don't release between steps.
4. Pause at least 1–2 s to listen for slow fibrillations.
5. Rest hand on muscle; brace for stability.
6. Make 3–4 passes of 5–10 steps in a straight line through muscle.
   a. Explore different areas of muscle with each pass.
   b. Move obliquely through muscle with each pass.
   c. Withdraw needle from muscle, but not skin, between passes. It may be necessary to look at completely different areas of the same muscle (e.g., inflammatory myopathies) Ultrasound may be of additional value in localizing areas that of greater abnormality.
7. Don't contract muscle with needle in muscle (painful, lacerates muscle, and bends needle).
8. Remember: Careful positioning of the patient at the beginning, adequate support and passive manipulation of the limb, contraction of antagonist muscles, distraction with conversation, and reassurance are all methods to improve relaxation during evaluation of spontaneous activity.

F. Evaluating voluntary activity

1. Same needle methods as for resting muscle.
2. Withdraw needle to a subcutaneous position before initiating muscle contraction.
3. Best examined with weak muscle contraction, with only 1–3 motor units firing at a time. Too strong of a contraction will activate too many MUAPs at once, making it more difficult to analyze.
4. Advance needle until you reach MUAPs with a rapid rise time (0.5 ms) and sharp clicking sound. Only assess MUAPs with short rise time.
5. Know duration of MUAPs for various muscles. Units in some muscles always look long and large.
6. Avoid MUAPs at edge of muscle.
7. Move from one site to another site quickly. Look at units in one site, evaluate their characteristics, and then move to another site. "Spend a little time looking at a lot of units."
8. Be objective. Avoid seeing what you expect to see. Specificity is more important than sensitivity.

G. Special considerations

1. Anticoagulants and bleeding disorders.
   a. Examine each case individually, weighing risks and benefits with the understanding that the current literature indicates that there is minimal risk in performing needle EMG in patients taking Coumadin for anticoagulation when the INR is < 3.
   b. If needle EMG is performed, minimize the number of deep muscles examined (e.g., paraspinals), avoid tight fascial spaces if possible (e.g. tibialis anterior–anterior compartment), and apply direct pressure over the puncture site for 1–2 min after the examination.
   c. In patients with thrombocytopenia, if the platelet count is above 30,000/mm2, the study can be performed safely. For uncommon bleeding disorders, consult a hematologist.
2. Infection precautions.
   a. All patients should be considered infectious such that universal precautions should be practiced.
   b. Special precautions should be taken in patients with dementia or a history of viral hepatitis, AIDS, and other potentially transmittable diseases.
   c. Always discard needles in specially designed containers.
   d. Always use gloves (for any patient).
3. Cardiac valvular disease.
   a. Risk of needle EMG in patients with rheumatic or other type of valvular disease or with prosthetic valves is similar to that of repeated venipuncture. Prophylactic antibiotics are not necessary.
4. Obesity
   a. May present problems of locating and palpating muscle. If landmarks cannot be appreciated, certain muscles may need to be eliminated from the study (e.g., serratus anterior, diaphragm). Diagnostic ultrasound may be useful for precise localization within the muscle to be examined.
   b. Standard 50-mm needle may not be long enough. Use a 75- or 120-mm needle.
5. Skin considerations.
   a. Examine skin over the muscle before inserting needle.
   b. Avoid superficial veins or varicosities.
   c. Avoid areas of infection (cellulitis), dermatitis, and venous stasis.
   d. Avoid areas of lymphedema (persistent leak of fluid, risk of development of infection).
   e. Use special care with thin brittle skin (e.g., patients on steroids).

H. Reducing the discomfort of the needle EMG

1. Use proper needle handling techniques.
2. Make only short movements.
3. Tell patients that some areas of the muscle may be more uncomfortable).
4. Tell them that you will move away from them if they tell you about the pain.
5. Watch/listen for end-plate activity and move away from it.
6. Develop patient rapport:
   a. Reassure the patient that everyone experiences some discomfort.
   b. Continue reassurance and verbal sympathy throughout the study.
   c. Reassure the patient that the discomfort is not long lasting.
   d. Move the needle gently and slowly.
   e. Begin with most important muscles.
   f. Inform patients that they can take analgesics prior to the test.
   g. Change needles when increased resistance is encountered.

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