Title: Safety and Pain in EDX Studies

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Abstract:

Discomfort is an unavoidable part of electrodiagnostic (EDX) studies. The most readily modifiable mediator of electromyography (EMG)-associated pain is muscle selection. Interventions that may reduce pain include vapocoolant spray, ibuprofen, and techniques such as slapping or stretching the skin. Needlestick injuries to health care workers carry the risk of transmitting bloodborne illnesses, but other Infectious complications of EDX studies are very rare. EMG probably contributes to asymptomatic hemorrhage in about 1% of patients, but clinically significant bleeding has only been reported a few times. Therapeutic anticoagulation does not significantly increase this risk. With standard procedures, there have been no reports of patients developing cardiac arrhythmia from nerve conduction studies. No special precautions are necessary in patients with implantable cardiac devices or intravenous lines. There is a small risk of pneumothorax associated with EMG of the diaphragm and chest wall muscles. Several techniques have been suggested to improve the safety of diaphragm EMG.

Key words:

Electromyography

Pain

Infection

Arrhythmia

Pneumothorax

Complications

INTRODUCTION

Electrodiagnostic (EDX) studies are useful in the diagnosis and characterization of neuromuscular disorders.[1] Potential complications of EDX studies include discomfort, the transmission of infectious disease, cardiac arrhythmia, hemorrhage, and pneumothorax. By understanding these complications, electrodiagnostic consultants can take appropriate precautions to prevent them.

PAIN

The Importance of EMG-Related Pain

Pain is the most common complication of both nerve conduction studies and needle electromyography (EMG). Some studies suggest that needle EMG is the more painful of the 2 procedures.[2-5] The EDX consultant must study the correct muscles to address the diagnoses in question and study each muscle for sufficient time to identify relevant abnormalities.[6] Pain is often cited as a cause of incomplete or inconclusive EDX studies. In a survey of over 800 EDX consultants, 60.1% reported altering >10% of their needle examinations due to the perception of patient pain.[7] These alterations include avoiding certain muscles, spending less time studying muscles, or even aborting the study prematurely. Altering the studies may protect patients from additional discomfort, but doing so comes at the cost of disregarding the physician's judgment about what constitutes an appropriate and complete study and potentially reduces the diagnostic accuracy of the test.

In an observational study, physicians altered almost one-third of studies because of their perception of patient pain.[8] The greater the physician-estimated level of patient pain, the greater the chance that the study would be altered in some way. Patient-reported pain levels did not correlate with the risk of studies being altered. This suggests that EDX consultants are not good at gauging patient pain levels. Studies are conflicted about whether physicians tend to overestimate or underestimate pain.[8, 9] It is possible that physicians are attending to the limb or the digital display during the procedure, and therefore miss non-verbal indicators of pain severity, such as facial expression. Regardless, it is the physician perception of pain, rather than the actual patient pain, that leads to altered studies.[8] One way to reduce unnecessary alteration of studies is to align physician and patient perceptions of pain by improving communication Having patients rate their pain throughout the study would accomplish this goal. At the same time, the physician should update the patient regarding the relative clinical value of additional diagnostic testing. This empowers patients to request that the study by altered or aborted when doing so would not substantially compromise the diagnostic yield of the EDX study. In this way, increased doctor-patient communication may not only limit pain, but reduce wasted time and low-yield testing.

It is the author's experience that concern about needle-related pain leads some patients to postpone or forego potentially useful EDX testing, but we do not know how often this happens. Fortunately, studies have suggested that needle EMG is less painful than patients expect, and the majority of patients who undergo EDX studies report willingness to have the test performed again.[10] In a survey of children, 66% of subjects reported that needle EMG-related pain was equivalent or less than venipuncture.[11]

Factors Contributing to EMG-Related Pain

The level of pain that patients experience during EDX testing may be related to patient-level factors, physician-level factors, and study-level factors. In 1 analysis, patient characteristics accounted for 47% of the variance in patient pain.[12] Most likely, this is driven by unmeasurable psychosocial factors that are difficult to measure, such as “pain tolerance.” It is known that pre-existing anxiety predicts EMG-related pain.[13, 14] Patients with high levels of baseline pain and disability from their underlying illnesses report more EMG-related pain, as well.[15] Studies are conflicted about whether women experience more EMG-related pain than men.[2, 16] There is a small, but significant correlation between expectation of pain and EMG-related pain.[12] Self-identified Asians may experience more pain than other individuals. Otherwise, age, height, weight, race, ethnicity, and prior history of EMG do not seem to affect pain levels.[12] Physician-level factors, such as years of experience or whether the EDX consultant is a neurologist or physiatrist have very little effect on pain.[12]

Of course, factors related to the demographics of the patient and physician may not be relevant, because they cannot be controlled or modified. A prospective study of 227 patients suggest that needle examination of the abductor pollicis brevis was more painful than the first dorsal interosseous of the hand.[16] Among study-level factors that the EDX consultant can control, the choice of muscles has the greatest impact on pain. In another study, 304 patients rated their pain on a visual analog scale after each muscle was studied. Among the 1781 muscles studied, the choice of muscle accounted for nearly 50% of the variance in pain.[12] The authors of this study calculated adjusted pain scores for every muscle examined, correcting for the amount of time in each muscle, whether endplate noise was detected, the order the muscle was studied, and patient-level characteristics. These scores represent the adjusted marginal pain on a 100 mm visual analog scale. The most painful muscles were the rectus femoris, extensor digitorum brevis, abductor hallucis, extensor hallucis longus, abductor pollicis brevis, opponens pollicis, vastus lateralis, medial gastrocnemius, and thoracic paraspinal muscles. The least painful muscles were the deltoid and gluteus medius.

One possible application of these scores would be in screening for radiculopathy. It has been recommended that needle examination should include 5 limb muscles and a paraspinal muscle when screening for cervical or lumbar radiculopathy.[17, 18] The authors suggested various protocols, each of which had a similar sensitivity for the diagnosis of radiculopathy. It is possible to summate the average marginal pain scores associated with all of the muscles in each of these protocols to identify the least painful cervical and lumbar root screens. Using this method, the recommended cervical root screen includes the deltoid, triceps, extensor digitorum, first dorsal interosseous of the hand, flexor carpi ulnaris, and a cervical paraspinal muscle. The least painful lumbar root screen includes the tensor fascia latae, posterior tibialis, anterior tibialis, vastus medialis, lateral gastrocnemius, and a lumbar paraspinal muscle.

The type of needle electrode used may also affect pain severity. Earlier studies suggested that monopolar needles, which are thinner and cause less tissue damage are less painful than concentric needles.[19] [20] More recent studies showed no significant difference between the 2 types of needle electrodes.[9, 21] The order in which muscles are studied and the amount of time spent with the needle in each muscle do not have meaningful effects on patient pain levels.[12]

Insertion of the needle electrode into the motor endplate region of the muscle leads to greater levels of pain. Pain at the endplate region was insignificantly greater than the pain associated with skin penetration. The quality of the pain was no different in the endplate region than in electrically silent muscle. This is another study-level characteristic, but the EDX consultant has little control over it. The etiology of increased pain at the motor endplate is unknown, but one proposed theory is that pain fibers are more densely situated in this region. Another possibility is that the needle provokes enough depletion of acetylcholine from the presynaptic membrane to generate an axon potential. This causes the muscle to contract, and the movement of the fiber irritates the nearby pain fibers.[22]

Interventions to Reduce Pain

Investigators have proposed a number of interventions to reduce EMG-related pain. One study compared vapocoolant spray (ethyl chloride, or a similar substance that acts as a skin refrigerant), EMLA cream (eutectic mixture of local anesthetics), and placebo in needle examination of the medial gastrocnemius.[23] The vapocoolant spray was significantly better than placebo in reducing EMG-related pain. The EMLA cream was no different from placebo. It is unclear if cooling the skin in this manner affects the interpretation of the needle examination. If the vapocoolant spray indirectly cooled the muscle, it could, increase the amplitude, duration, and phases of motor unit action potentials.[24]

A crossover study compared the analgesic effects of ibuprofen to placebo in subjects who were to undergo needle examination of a proximal and distal muscle in the upper and lower extremity. The subjects who took 400 mg of ibuprofen 2 hours before the EMG reported less pain on immediate recall, but there was no difference in the delayed recall of pain or residual pain. Subgroup analysis showed a greater effect in women than men, but there were only 7 women in the study.[25]

In a crossover study of 44 healthy volunteers, pain immediately after needle EMG was significantly less in patients who took paracetamol (acetaminophen) 325 mg/tramadol 37.5 mg than those in the placebo group. Two hours after the EMG, men in the treatment arm continued to report significantly less pain than those in the placebo arm, but there was no difference between women in the treatment and control groups.[26] While these results were encouraging, the incidence of adverse effects was much higher in the treatment group than the placebo group. In addition to many subjects in this small study who reported minor adverse events, 1 subject had a syncopal episode after taking acetaminophen/tramadol, and another developed severe vertigo requiring hospitalization. The incidence and severity of adverse events is probably too high to justify routine use of this medication combination without further study.

Another crossover study found evidence to support slapping the patient's skin at the time of needle insertion.[27] This finger-slapping technique has been used by Korean nurses to reduce the pain associated with venipuncture.[28] It is based on the gate control theory of pain, that afferent impulses in large mechanoreceptor nerve fibers inhibit impulses from smaller nociceptive nerve fibers. Stretching the skin prior to needle insertion may also decrease the pain of needle EMG.[29]

A minimal insertion technique appears to reduce pain, as well.[9] This entails a needle movement of 0.5-1 mm per insertion, causing less than 200 milliseconds of insertional activity.

A number of other interventions to reduce pain have been touted, including lidocaine iontophoresis, hypnosis, acupuncture, behavioral modification and relaxation techniques, providing patients with written material describing the procedure ahead of time, and having patients listen to music on headphones.[3, 30-35] Most of these are smaller studies with underwhelming results, and many of the interventions require special expertise or are too time-consuming to use in routine practice.

Pain Associated with Nerve Conduction Studies

Other studies have suggested that there may be more pain associated with nerve conduction studies than with needle EMG.[4] This appears to be a larger effect among older patients and those with a greater body mass index.[5] No studies have been done on interventions to reduce the pain associated with nerve conduction studies.

INFECTION

Skin infections and EMG needles

Skin infections are a very rare medical complication of needle EMG. A series of 6 patients were reported who developed *Mycobaterium fortuitum* skin infection following EMG. However, this was in the setting of reusable needles cleaned with glutaraldehyde and rinsed with tap water.[36] There is a single reported case of *Staphylococcus epidermidis* cellulitis following EMG.[37] It is unknown whether the skin was prepared with alcohol, or what type of needle was used. This case was reported in 1986, at a time when reusable needles were more commonly employed. It is unlikely that standard EDX procedures with single-use needles present a significant risk factor for skin infections in the general population. Reusable needles, such as those used for single-fiber EMG, must be sterilized between patients according to Joint Commission Accreditation Healthcare Organizations (JCAHO) standards.

Many EDX consultants employ what has been referred to as “clean technique” during EMG. This means that they wash their hands before each study, wear gloves, and clean the patient’s skin with an alcohol preparation immediately prior to needle insertion. This practice most likely reduces the number of microorganisms on the skin, but there is no evidence that it prevents iatrogenic skin infection. Uncleaned skin has approximately 2.0×10^4 colony-forming units of *Staphlococcus aureus*. It takes 7.5×10^6 colony-forming units of *S. aureus* injected intradermally to cause an abscess.[38]

Although there is a lack of data pertaining specifically to the benefits of skin preparation in electrodiagnosis, it is reasonable to equate EMG with subcutaneous insulin injections. In a small prospective study, patients who injected themselves with insulin and did not prepare the skin with alcohol showed no signs of local or systemic infection.[39] In a large retrospective cohort of diabetic subjects who gave themselves an estimated 10 million insulin injections, the incidence of cellulitis was actually greater in subjects who wiped their skin with isopropyl alcohol than those who did not.[40]

Based on these findings, the practice of preparing skin with an alcohol wipe prior to needle EMG is superfluous. Of course, if skin is visibly infected, it is prudent to clean the skin or avoid needle insertion through the site of infection altogether.

Precautions to prevent transmission of disease between healthcare workers and patients

Human immunodeficiency virus, hepatitis B virus, and other bloodborne pathogens may be transmitted through contact with open wounds, mucus membranes, or body fluids such as blood. Needle EMG, like any procedure that involves sharps, carries some risk of bloodborne infection. It is important to take appropriate measures to reduce the risk of transmitting bloodborne pathogens from patients to EDX consultants and staff, from EDX consultants and staff to patients, and from EDX equipment to either party.

In 1983, the Centers for Disease Control and Prevention (CDC) issued its first guideline calling for blood and body fluid precautions when dealing with patients known to be infected with bloodborne pathogens. In 1987, the CDC updated these recommendations to include all patients. These universal precautions, now called standard precautions, are mandated by the Occupational Safety and Health Administration and are among the most effective ways health care workers can protect themselves and their patients against exposures.[41, 42]

Health care workers should wear gloves to prevent transmission of bloodborne pathogens.[43-45] Following needlestick with a solid-bore needle, gloves reduce the risk of disease transmission by 46-86%.[46] Latex and nitrile gloves are more effective than vinyl gloves.[47-49] The American Association of Neuromuscular and EDX Medicine (AANEM) recommends that gloves be worn when the possibility of contact with blood and other potentially infectious materials exists during needle EMG.[50] However, not all EDX consultants follow this recommendation. In a 2008 survey of AANEM members, 73% of respondents reported that they always wore gloves, and 11% reported that they never wore gloves.[51] It is unknown if the rate of glove-wearing has changed in the years since this survey.

During needle EMG, the EDX consultant should avoid touching anything other than the patient and the EDX equipment. If visible blood gets on equipment, it should be disinfected between patients. It may be necessary to change gloves in the midst of a single encounter if the patient interaction involves touching mobile computer keyboards or other mobile equipment that is taken from room to room.[52] Gauze with blood on it should be placed in disposal containers that meet Occupational Safety and Health Administration (OSHA) standards. Physicians and staff should dispose of all waste in accordance with all federal, state, and institutional regulations. Personal protective equipment such as gloves should be removed prior to leaving the examination room and placed in an appropriately designated container for disposal.

Needlestick Injuries

In a survey of AANEM members, 64% of responders reported a personal history of at least 1 needlestick injury.[51] Most needlesticks reported by EDX consultants occurred in the course of routine procedures, but patient movement and recapping were cited as common causes. Recapping needles with a one-handed technique rather than holding the cap in 1 hand during recapping may reduce needlestick injuries.

More concerning is that 33% of those surveyed were not aware of their lab's or institution's policies for dealing with needlesticks, 56% had never had a needle safety component of their EDX medicine training, and 44% did not report their injury to official hospital health centers.[51]

Needlestick injuries have been implicated in transmission of bloodborne infections such as hepatitis and HIV from patients to healthcare personnel.[53] Fortunately for EDX consultants, the risk of transmission is much lower with solid-bore needles such as those used in EMG than hollow-bore needles.[54] Taking appropriate action following a needlestick injury can further reduce the risk of infectious transmission. Health care workers should immediately remove protective gloves and wash the injured area thoroughly with soap and water. Every institution should have a process in place for reporting the incident, and testing the patient for HIV, hepatitis C antibody, and hepatitis B surface antigen. The turnaround time for these tests is usually a day or less.[55, 56]

At-Risk Patient Populations

Some populations of patients may be at special risk for contracting infections. Patients with breast cancer, pelvic cancer, or melanoma may develop lymphedema following diagnostic or therapeutic lymph node dissection. Historically, patients are cautioned against having venipuncture in the affected limb to avoid development or worsening of lymphedema or cellulitis. The theoretical concern is that needlesticks in the affected limb could cause an inflammatory reaction that could overburden an already compromised lymphatic drainage route. The evidence to support the practice of avoiding venipuncture is controversial. In a study of 691 referrals to a lymphedema service, 10 patients (1.5%) cited venipuncture as a significant event in the history of their swelling.[57] In a prospective observational study of 188 lymphedema patients, 44% of those who were subjected to needle sticks developed lymphedema as compared to 18% of those without needle sticks.[58] Other authors suggest that there is no reason to avoid needlesticks, citing other studies that showed few, if any, patients with lymphedema developed increased swelling following venipuncture.[59, 60] These studies are challenging to interpret in their intended clinical contexts, and even more challenging in the context of needle EMG. There are no reported cases of cellulitis or increased swelling following EDX studies in this population. A reasonable approach is first to attempt to address the EDX questions by studying a limb that is not affected by lymph node dissection. If that is not feasible, the EDX consultant and patient should weigh the relative diagnostic value of the study against the small theoretical risk of developing lymphedema.

EDX patients with diabetes may have poor wound healing and a greater risk of infectious complications. While diabetic patients have been known to develop foot ulcers following needle-induced trauma, it is unknown if needle EMG poses a risk to diabetic patients.[61] It is reasonable to exercise caution and avoid needle examination of intrinsic foot muscles in patients with severe diabetes.

Patients with a history of valvular heart disease do not require prophylactic antibiotics before needle EMG. While there is a theoretical risk that patients with prosthetic joints may develop joint infection from hematogenous spread, there are no reported cases of this occurring as a result of needle EMG. Again, prophylactic antibiotics are not recommended.[62]

BLEEDING

Bleeding complications secondary to needle EMG are very rare among patients with no history of medically-induced anticoagulation. There are 2 case reports of patients who developed compartment syndrome in a limb following EMG.[63] [64] One of the hematomas was traced to unintentional laceration of the ulnar artery, and the other was suspected to be caused by damage to a perforating vessel from the posterior tibial artery.

In 1996, Caress et al reviewed spine MRI scans of patients who had undergone paraspinal EMG within the prior week.[65] Five of the 17 patients in this series were found to have asymptomatic hematomas in or around the sampled paraspinal muscles. Follow-up studies, however, have not reproduced this finding. In a retrospective review of 431 patients who underwent spine MRI within a week of EMG, no hematomas were noted.[66] In another study, a blinded radiologist compared the MRI scans of 29 patients who underwent recent extensive paraspinal EMG using the paraspinal mapping technique to the MRI scans of 26 control patients who had not had a recent EMG. In both the study and control groups, there were a similar number of “possible” hematomas, in which lesions lacked a hemosiderin ring and were behind or immediately contiguous to facet joints. The radiologist could not determine whether these represented small hematomas or synovial cysts arising from degenerative facet joints. Surprisingly, the only 2 definite hematomas identified were in the paraspinal muscles of control subjects. None of the definite or possible hematomas were larger than 10 mm, and none were near any neural structures.[67]

Most of the patients in the aforementioned studies were not taking medications that could increase the risk for bleeding following instrumentation. In 1999, the AANEM issued a position statement which recommended exercising caution when deciding whether to perform needle EMG on patients with platelet counts less than 50,000/µL, an international normalized ratio (INR) >1.5-2.0, or prothrombin time >1.5-2.0 seconds.[50] The position statement also recommended a number of practice modifications to reduce the risk of hemorrhage if the EDX consultant chose to perform an EMG on one of these patients.

These recommendations were not based on any controlled studies and did not take into account many of the other medications known to affect coagulation. This includes the newer oral agents (dabigatran, apixaban, rivaroxaban), intravenous and subcutaneous anticoagulants (heparin, dalteparin, enoxaparin), antiplatelet agents (aspirin, aspirin/dipyridamole, clopidogrel), and non-steroidal anti-inflammatory drugs (NSAIDs). Despite the widespread use of these medications, there have been very few reported cases of clinically significant EMG-induced bleeding complications in this population. One patient who was taking chronic warfarin therapy developed anemia and ecchymosis on his flank following an EMG. Complicating this case was the observation that the subject had fallen on the same side of his body 2 days previously.[68] Similarly, a patient who had suffered from a recent back injury and was receiving heparin and aspirin developed paraspinal and iliopsoas hematomas following EMG.[69] In both of these cases, it is not clear if there was truly a causal effect between the EDX study and the hemorrhagic complications. The third reported case was a patient on warfarin with an INR of 2.5 who developed a posterior tibial pseudoaneurysm which was managed conservatively.[70] The final reported case was a patient taking aspirin and subcutaneous heparin who developed a large gluteal hematoma.[71] This patient was also found to have hematomas in other locations and limbs that had not been examined during the EDX study.

The actual incidence of symptomatic EMG-induced hemorrhage in anticoagulated patients is unknown, but in a survey of 60 EDX laboratories, 4 of 47 responders (9%) reported a history of at least 1 clinically significant bleeding complication from performing EMG in this population.[72] A majority of responders noted that they altered their practices to account for the risk of anticoagulation: 72% avoided EMG of paraspinal muscles; 34% avoided certain limb muscles; and 13% required patients to withhold anticoagulation therapy in anticipation of the study. Even though none of the responders reported hemorrhagic complications with antiplatelet medications, 19% altered their studies in some way in patients taking these medications.

In 2008, investigators used ultrasound to screen for hematomas in 209 patients who had just undergone needle EMG of the tibialis anterior. The overall incidence of ultrasound-proven hematoma was 1.45%, and there was no significant difference between patients taking oral anticoagulants, patients taking anti-platelet medications, and control patients.[73] None of these patients reported symptoms during the examination, and no mention of symptomatic hematoma was found on chart review 3-15 months later.

A follow-up study used ultrasound to screen for post-EMG hematoma in 323 “high-risk” muscles, including the paraspinal muscles, the tibialis posterior, the flexor digitorum longus, the flexor pollicis longus, and the iliopsoas. The overall incidence of hematoma among all muscles studied was 0.62%.[74] One small hematoma was noted in 1 of the 107 patients taking warfarin, and in 1 of 116 patients taking anti-platelet therapy, while no hematomas were noted in 100 control patients. Again, this was not a statistically significant difference, and none of the subjects reported symptoms.

Taken together, 10 definite hematomas have been reported in 1037 muscles that have been imaged after EMG, with an absolute risk of less than 1%. The risk was slightly higher (1.35%) in therapeutically anticoagulated patients and slightly lower (0.61%) among patients on anti-platelet medications.[75] Overall, the risk of asymptomatic bleeding is very low in all groups, and the risk of symptomatic bleeding is so rare that it has only been reported a few of times in the many decades of collective clinical experience with EMG. The author's recommendation is to do complete and appropriate EDX evaluations on patients receiving antiplatelet medications or those taking warfarin with an INR < 3.0. Patients should not be asked to withhold therapeutic anticoagulation prior to EDX studies. In patients with an INR >3.0, the study may be completed at the discretion of the EDX consultant. If the managing physician intends to lower the warfarin dose, it may be reasonable to postpone the study until the INR is in the therapeutic range.

No data exist to guide our practice in patients receiving therapeutic doses of heparin or oral anticoagulants other than warfarin. It is likely that patients on therapeutic doses of these treatments will have a similarly low incidence of EMG-induced hemorrhage, but the actual risk is unknown. Likewise, little is known about the bleeding risks associated with herbal supplements, but it is unlikely that they pose a greater risk than pharmaceutical anticoagulants.

<u>ELECTRICAL COMPLICATIONS OF NERVE CONDUCTION STUDIES</u>

The electrical currents used in nerve conduction studies are too small to directly damage tissues, but the heart is an electrically-sensitive organ. Two hundred µA of current applied directly to the myocardium is enough to induce ventricular tachycardia.[76], and yet, a current 5 times as large, 1 mA, is barely perceptible on the skin, and certainly not dangerous.

There are theoretical mechanisms by which otherwise harmless electrical currents may reach the heart. The first pertains to the concept of leakage currents. When electrical devices are attached to a patient, a small amount of current may leak from the internal electronics. Stray voltages can also build up on power cords. The magnitude of these voltages correlates directly with the length of the cord. Extension cords, for instance, may accumulate very high leakage currents which can find their way to the patient.[77] The third prong on a standard electrical plug serves as a ground, allowing stray currents to dissipate safely. One scenario in which this system can fail is if a patient is attached to electrical devices on both sides of the body, and 1 of the grounds fails due to a frayed, loose, or wet cord. Now the leakage current from the device with the malfunctioning ground has nowhere to go except across the patient's body to the contralateral ground. If the leakage current in this scenario is sufficiently great, it could, in theory, be enough to induce arrhythmia.

Critically ill patients in an intensive care unit are the most electrically susceptible, because they are often connected to a number of electrical devices simultaneously. To minimize the potential risk of leakage current, EDX consultants should ensure that their equipment is appropriately grounded on the same side as the stimulation. Extension cords should not be used, and patients should be disconnected from all non-essential electrical equipment prior to EDX studies. Machines should be turned on before attaching electrodes to patients and turned off after removing the electrodes from the patient to minimize the risk of power surges. Biannual inspection of EDX equipment by a biomedical engineer to measure leakage current and ensure proper grounding is prudent, as well.

Skin resistance is the body's greatest defense against all electrical injury. Intact skin confers several million Ohms of resistance. Patients with a transcutaneous pacer wire, on the other hand, have a direct electrical conduit from the surface of the skin to the heart. These patients are extraordinarily sensitive to electricity. Nerve conduction studies should be avoided altogether in this population.[78]

Peripheral intravenous access does not compromise the protective effects of skin. One study found no deleterious effects of performing nerve conduction studies on patients with peripheral intravenous lines in a distal limb. It did not matter whether fluids were running through the line or the line was clamped.[79]

Until recently, performance of nerve conduction studies in patients with central venous catheters in the internal jugular or subclavian veins was controversial. These lines create a larger skin breach than peripheral intravenous lines in the distal limb. They also extend towards the heart, bypassing the electrical sink provided by the soft tissues of the torso. Some authors have suggested ipsilateral or proximal nerve conduction studies be avoided in patients with central lines. [62] There is evidence that these precautions are probably unnecessary. In an unpublished study by the author, 10 patients with and 10 patients without central lines underwent nerve conduction studies on both upper extremities, including proximal and distal stimulations, high and low amplitude stimulations, and 2 Hz repetitive stimulations. Subjects underwent electrocardiographic (EKG) monitoring throughout the nerve conduction studies. No significant arrhythmias or conduction abnormalities were noted in either the control subjects or the subjects with central lines.

Pacemakers and defibrillators are implanted below the skin and therefore do not impact skin resistance. The concern is that pacemakers have electrical sensors that regulate their control of the heart rhythm. Likewise, defibrillators have sensors that are intended to recognize malignant arrhythmias and discharge a large shock to reset the heart rhythm. There is a potential danger if these devices were to discharge inappropriately. There are no reported cases of patients developing failure of implantable cardiac devices during routing EDX studies, but there are reports of compromised pacemaker function in dissimilar and unusual scenarios. One case of pacemaker failure was in the setting of an implanted phrenic nerve stimulator and the other with a portable nerve stimulator in the operating room.[80, 81]

Three studies between 1988 and 2010 found that pacemakers or automatic implantable cardioverter-defibrillator (AICD) devices in a total of 40 patients failed to sense nerve conduction stimulations.[79, 82, 83] In another study, subjects under general anesthesia for device implantation or revision were given 2 Hz and 50 Hz repetitive stimulation of the median, axillary, and spinal accessory nerves.[84] The 10 AICD devices in this study did not sense the exogenous currents. In the subjects with pacemakers, the findings depended on whether the device was set to a unipolar or a bipolar configuration. The unipolar configuration is an outdated modality in which the reference electrode is placed on the chest wall instead of in the heart. The larger distance between the 2 electrodes makes the device more sensitive to far field potentials. Modern pacemakers may be configured this way, but it has not been the industry standard for >25 years. In this study, pacemakers set to the standard bipolar configuration did not sense the nerve conduction stimulations. A subset of the pacemakers set to the unipolar configuration sensed some of the stimulations enough to alter the pacing of the heart for the duration of the impulse. This finding does not portend a realistic risk to patients. Perhaps it is possible that a high amplitude proximal repetitive stimulation in a patient with a very old pacemaker could alter pacing for 2-3 seconds. Even in this very rare scenario, most patients would be asymptomatic or, at worst, develop 2 to 3 seconds of lightheadedness.

Some pacemaker or AICD companies require EDX consultants to place a “magnet” on the devices and monitor heart rhythm during nerve conduction studies. A magnet is thought to counteract the electromagnetic interference from nerve conduction studies and eliminate the sensing component of the device.[85] Ohira et al performed nerve conduction studies in 30 patients after magnet placement and 47 patients without magnet placement. None of the stimulations were detected in either group, but the subjects who had the magnet placed were 11 times more likely to report symptoms such as scapular pain, chest pain, paresthesias, or lightheadedness. Based on these data, magnet placement is not recommended for EDX testing in patients with implantable cardiac devices.[86]

Deep brain stimulators (DBS) are used in patients with Parkinson disease and other movement disorders. They are implanted in the chest wall, on either side of the pectoralis muscle, and have leads that travel rostrally through the neck and skull to reach the deep nuclei of the brain. There is no FDA labeling for the combination of nerve conduction studies and DBS, but it is unlikely that there would be any interaction between them. DBS devices are not programmed to sense electrical impulses the way pacemakers do, so it is not possible to measure if these devices detect nerve conduction stimuli.

A summary of recommendations for avoiding infectious, hemorrhagic, and electrical complications of EDX studies can be found in Table 1.

PNEUMOTHORAX

Pneumothorax is a rare but serious complication of needle EMG of the diaphragm, supraspinatus, rhomboids, and cervical paraspinal muscles.[87-92] A telephone survey of 1000 patients who had undergone EMG of the diaphragm identified 2 with symptomatic pneumothorax, both of whom were inpatients receiving mechanical ventilation at the time of the complication.

A large retrospective study of 64,490 patients identified 7 cases of pneumothorax associated with EMG.[93] Another 22 patients in this series were found to have a pneumothorax that was temporally associated with the EMG study, but it was felt to be attributable to a different cause, such as a recent lung biopsy or thoracentesis. The highest frequency of EMG-induced pneumothorax in this series was among patients who had undergone EMG of the serratus anterior (0.445%) and the diaphragm (0.149%). All of the patients who were found to have pneumothorax were symptomatic and presented within 24 hours.

A simple way to prevent these complications is to avoid EMG of these muscles, but the diagnostic utility of the study may outweigh the risk. [94-96] In the critically ill population, nearly 60% of neuromuscular diseases may be identified with EMG of limb muscles alone, but an additional 30% remain undetected unless respiratory muscles are examined.[97] [98]

Various techniques have been proposed to reduce the risk of pneumothorax secondary to EMG of the diaphragm. Bolton proposed what has been called the "trans-intercostal method." The EDX consultant palpates the lower costal margin and inserts a monopolar needle just above this margin at the most distal palpable intercostal space between the anterior axillary and medial clavicular lines. No pneumothorax was identified in 49 consecutive patients, including 32 in the critical care unit.[99] [100] Another author noted anecdotally that using a concentric needle with a variant of this method led to no pneumothoraces in 53 consecutive pediatric cases.[101]

Saadeh et al proposed an alternative technique, in which the abdomen is depressed with the examiner's non-dominant hand to delineate the costal margin. A 50 mm needle is inserted under and behind the 9th rib cartilage, parallel to the long axis of the body and closely hugging the posterior aspect of the chest wall. The needle is advanced to about 3.0-3.5 cm of depth to costal insertion of the diaphragm. Eighty-nine patients and 108 hemidiaphragms were studied without any complications.[102] In a letter to the editor many years later, the authors reported anecdotally that they have used this technique on thousands of subsequent diaphragms without a complication.[103]

A study of cadavers suggested that the best combination of safety and accuracy could be achieved by inserting the needle perpendicular to the chest wall directly above the eighth rib.[104] The side of needle placement made no difference in accuracy, but the left side appeared to be safer.

The use of ultrasound has increased our understanding of anatomic localization. Using this modality, Shahgholi et al demonstrated that the location of diaphragm below the surface of the skin varied between 0.78 and 4.91 cm. The authors provided reference values to allow EDX consultants to predict the depth of the diaphragm based on the patient's body mass index.[105]

In the hands of an experienced examiner, ultrasound can be used to effectively identify the diaphragm and guide the EMG needle away from nearby viscera.[106] Amirjani et al used ultrasound visualization of the relevant landmarks in 20 healthy, non-obese, subjects and found that the lungs were less likely to expand into the distal intercostal space at the anterior axillary line than at the mid-clavicular line.[107] The only scenario with 100% safety in this study was the right distal intercostal space at the anterior axillary line in women who were supine and not breathing deeply. The authors estimated that performing this same procedure in men would lead to a 10-20% risk of lung tissue intervention. In response to finding, Podnar et al performed ultrasound on 10 healthy men. They found that the distance between the standard insertion site recommended by Bolton et al and the lung margin was between 7.5 and 17 cm.[108] This study provided evidence that the trans-intercostal method is likely to be safe in healthy subjects. It is unknown if pre-existing respiratory disorders, such as chronic obstructive pulmonary disease, increase the risk of pneumothorax.

Conclusions

By far the most common complication of EDX studies is pain. Limiting EMG-related pain has the potential to enhance the diagnostic utility of the EDX examination. Among factors within the control of the EDX consultant, the choice of muscles to study has the largest effect on pain. Interventions such as vapocoolant spray or pre-examination ibuprofen, and techniques such as finger-slapping, skin-stretching, and minimal insertion may play a role in further reducing pain. It is unclear how well these interventions translate to real-world situations.

EDX consultants should be familiar with the rare medical complications of needle EMG and nerve conduction studies. With proper technique and appropriate precautions, EDX studies are safe in the general population. Certain patient populations may be at a greater risk of bleeding, infection, or cardiac arrhythmia. It is important to recognize these patients and ensure that the benefits of EDX testing outweigh the risks prior to proceeding.

Table 1: Populations at risk for complications of EDX studies

Potential Complications	**Recommendations**
Infectious	
History of lymph node dissection	Consider avoiding needle examination in affected limb
Severe diabetes mellitus	Consider avoiding needle examination of intrinsic foot muscles
Valvular heart disease	No precautions necessary
Prosthetic joints	No precautions necessary
Bleeding	
On anti-platelet therapy	No precautions necessary
On warfarin therapy	If INR < 3.0, no precautions other than close surveillance during and immediately after needle EMG. If INR > 3.0, exercise caution.
On heparin or other oral anticoagulant	No precautions are likely to be necessary at therapeutic doses, but risks are unknown.
Electrical	
Transcutaneous pacemaker	Do not perform nerve conduction studies
Peripheral or central intravenous line	No precautions necessary
Patient in critical care unit	Properly ground equipment on the side of the study

	Do not use extension cords
Implanted pacemaker or defibrillator	No precautions necessary
Deep brain stimulator	No precautions necessary

EMG – electromyography

INR – international normalized ratio

JCAHO – Joint Commission Accreditation Healthcare Organizations

Abbreviations:

AANEM - The American Association of Neuromuscular and EDX Medicine

AICD - Automatic implantable cardioverter-defibrillator

CDC – The Centers for Disease Control and Prevention

CI – confidence interval

DBS – Deep brain stimulators

EDX - EDX

EMLA - Eutectic mixture of local anesthetics

EMG – Electromyography

INR – International normalized ratio

JCAHO – Joint Commission Accreditation Healthcare Organizations

OSHA - Occupational Safety and Health Administration

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