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Review article

Potential risks of iatrogenic complications of nerve conduction studies (NCS) and electromyography (EMG)

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ABSTRACT

Nerve conduction and electromyography studies are generally well tolerated and pose little risk to patients of serious adverse events in the hands of a well-trained competent practitioner. However, some patients and certain examinations do carry a higher risk of potential complications. It is good medical practice to inform patients of any risks, their potential severity and relative frequency. In order to obtain informed consent a dialogue should take place about the nature, purpose and effects of the studies, so patients can decide if they wish to undergo the proposed investigation. In this educational review we identify those procedures and patients at risk, and provide pragmatic practice recommendations for managing these material risks.

Contents

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In modern medicine it is best practice to explain the investigative and therapeutic options available to patients, so that they can take an active role in decisions about their management along with health professionals. Ideally a practitioner should explain the potential benefits and risks associated with these, including the option of either doing nothing or suggesting any alternatives. Patients should be informed of all serious risks, however infrequent, so that they can weigh up the potential benefits against the material risks for themselves. The purpose of this review, which includes our pragmatic practice *recommendations*, is to outline the known risks or complications of nerve conduction studies (NCS) and needle electromyography (EMG), along with their estimated frequency and severity (see Tables 1 and 2) with reference to evidence-based information where currently available. Unfortunately there is in fact surprisingly little evidence from prospective studies, and we have therefore based our observations on the relatively small number of review articles and case reports available, as well as the collective experience and opinion of the authors. The guidelines of the local Health Provider's Policies on hand washing, health and safety (including electrical safety), infection control and control of hazardous substances to health, should be observed where applicable for electrodiagnostic assessment, and our *recommendations* should not supersede the regulations of an employing Institution. Furthermore it is essential to have equipment properly maintained and safety tested, to prevent electric shock hazard. Equally practitioners should be appropriately trained and proven competent to undertake electrodiagnostic studies as potential misinterpretation can lead to over- or under-diagnosis and misprognosis, which in themselves carry significant risks for patients, although this subject is outside the remit of our review.

1. Basic considerations

It is widely recognized in the literature that electrodiagnostic studies are generally well tolerated (Dumitru et al., 2002; Preston and Shapiro, 2013,). On the other hand transient mild procedural pain and discomfort are very common, and in fact the most frequent "undesired effect" that patients will experience. The discomfort, or mild pain experienced by some patients, following the application of electrical stimulation during nerve conduction studies (NCS) is transient and self-limiting and will not initiate or aggravate pre-existing symptoms beyond the duration of the actual investigation. Adverse events such as self-limiting mild tenderness and/or bruising commonly follow an 'uncomplicated' needle electromyography (EMG) examination. Some patients might be unable to cooperate with or even tolerate supramaximal electrical stimulation or needle examination, especially when patients have been sensitized previously. In the context of consent patients need to be advised that this might limit the diagnostic yield and sensitivity of the investigation, but could be informed about potential alternative diagnostic tests (e.g. Magnetic Resonance Imaging in the investigation of radiculopathy). We *recommend* documenting this in the final report. Presyncope and even syncope are well known to Electromyographers, albeit relatively uncommon (<1/100).

Table 1
Classification of the frequency of adverse events.

Very common	$\geqslant$1/10
Common (frequent)	<1/10 and $\geqslant$1/100
Uncommon (infrequent)	<1/100 and $\geqslant$1/1000
Rare	<1/1000 and $\geqslant$10,000
Very rare	<1/10,000

CIOMS -Council of International Organizations of Medical Sciences.

Table 2
Severity of adverse events.

Grade 1 Mild	Asymptomatic or mild symptoms; clinical or diagnostic observations only; intervention not indicated
Grade 2 Moderate	Minimal, local or noninvasive intervention indicated; limiting age-appropriate instrumental ADL (preparing meals, shopping for groceries or clothes, using the telephone, managing money, etc.)
Grade 3 Severe	Medically significant but not immediately life-threatening; hospitalization or prolongation of hospitalization indicated; disabling; limiting self-care ADL (bathing, dressing and undressing, feeding self, using the toilet, taking medications, and not bedridden)
Grade 4 Life-threatening	Urgent medical intervention indicated
Grade 5 Death	

Common Terminology Criteria for Adverse Events (CTCAE) Version 4.0.

2. Infections

Historically soft tissue infections secondary to needle EMG have been reported sporadically but are probably very rare (<1/10,000). Infectious pathogens that have been identified include *Staphylococcus epidermidis* (Burris and Fairchild, 1986) and an outbreak of *Mycobacterium fortuitum* occurred with re-usable needles (Nolan et al., 1991), but these were mild and self-limiting. Indeed re-usable needles are now largely outmoded, since the demonstration that single-fibre EMG can be effectively performed with disposable fine concentric needle electrodes using a restricted bandpass for jitter studies. A single disposable needle electrode is typically used to make multiple insertions in several muscles in the same patient during needle EMG testing, but there is no evidence to suggest that multiple insertions into the same patient with a single needle electrode increases the risk of infection. Whether treatment of the skin with disinfection agents prior to needle insertion reduces the risk of infection is not known. Infection risk and the role of prophylactic antibiotics in immune compromised patients and endocarditis risk in vulnerable patients are largely unknown, but we are not aware of any incidences of procedure related infection. Vigorous dermabrasion and adhesive electrodes can injure the skin, particularly in very young, elderly or vulnerable patients, and theoretically lead to either local skin infection and/or act as a portal of entry in a susceptible patient. When very sticky self-adhesive surface electrodes are applied to vulnerable skin (e.g. after corticosteroid treatment) their subsequent removal can lift off skin. It is *advisable* that broken and potentially infected skin (e.g. decubitus ulcer) is avoided.

Urticaria changing into vitiligo has been reported in an early study (Walpin and Reiss, 1966), but not described since to our knowledge, and may therefore have been co-incidental.

3. Lymphoedema

It has been speculated that performing needle EMG in limbs with significant lymphoedema might theoretically carry an increased risk of infection (Dumitru et al., 2002). In patients with gross oedema anywhere on the body skin puncture by needle electrodes may result in weeping of serous fluid. However, no published report of cellulitis, infection, or other complications related to EMG performed in the setting of lymphoedema or after regional lymph node resection were found (AANEM, 2014). None the less it is perhaps *advisable* to avoid needle insertion in lymphoedematous regions to avoid potential complications (Al-Shekhlee et al., 2003) and any distressing exudate. Indeed patients

with oedema following lymph node resections and/or radiotherapy often request that needle examination not be performed in the affected limb.

4. Prosthetic joints and metal osteosynthesises

Based upon current published literature no reports of complications related to needle EMG in patients with prosthetic joints were found (AANEM, 2014). It is uncertain whether the electrical NCSs stimulation near metal osteosynthesis after bone fractures would present a potential risk of electrical injury. Theoretically the risk might increase in patients with external fixation apparatus (e.g. Ilizarov), but at present this should not be a contraindication to NCS/EMG.

5. Bleeding, haematoma and compartment syndromes

Inserting EMG needles into skeletal muscles is generally well tolerated with minimal or no discernable bleeding. Amongst the wide range of coexisting medical conditions thrombocytopenia (platelets below 50,000/mm^3), chronic renal failure and coagulopathies (either acquired or inherited) are more frequently associated with an increased risk of bleeding during invasive procedures. Similarly it is possible for individuals on anticoagulation, anti-platelets agents and some other drugs (e.g. non-steroidal anti-inflammatory drugs and 'over the counter' herbal medications) to bleed significantly following a needle study (Preston and Shapiro, 2013).

There are a few very rare case reports in the literature (probably < 1/10,000) of medically significant haematomas and resultant potentially severe compartment syndromes, the majority in patients with known bleeding disorders, either medically induced or acquired (Al-Shekhlee et al., 2003; Baba et al., 2005; Butler and Dewan, 1984; Hough et al., 2003; Vaienti et al., 2005). The frequently cited study by Caress et al. (1996) found subclinical haematomas in paraspinal muscles after needle EMG in 5 of 17 patients, on retrospective review of Magnetic Resonance Imaging (MRI). However, a later retrospective study of 370 patients did not find evidence of any EMG-related MRI-evident paraspinal haematomas, including 161 patients who were on medications know to affect coagulation (Gertken et al., 2011). However, in a prospective study of anticoagulated patients (on warfarin, aspirin or clopidogrel) subclinical haematomas were visualized by ultrasonography in 3 out of 158 patients, compared with none of 51 control patients not on these agents (Lynch et al., 2008). The same group in a later study prospectively examined over 300 muscles with ultrasound after EMG and showed no statistical difference in the incidence of haematoma between anticoagulated patients and case control patients without blood thinning medication; although two subclinical haematomas were detected in the anticoagulated group confirming the higher theoretical risk of possible progression to significant haematomas (Boon et al., 2012). Taken together the available evidence indicates that subclinical or asymptomatic haematomas occur with an incidence of about 1 to 2/100 examined muscles; and given that generally multiple muscles are examined the risk for an individual patient is therefore in fact common. However, clinically significant haematomas are likely to be uncommon, although in a survey of 47 electrodiagnostic laboratories 4 retrospectively reported at least one case of bleeding in anticoagulated patients, requiring medical or surgical intervention (Gruis et al., 2006).

Based on the available literature the requirement of patients to discontinue warfarin or aspirin before undergoing EMG is somewhat controversial, given that the risk of discontinuing antithrombotic medications can cause thromboembolic complications. The recommendation of a subcommittee of the American Academy of Neurology is that warfarin and aspirin "might be associated with no increased clinically important bleeding with EMG" (Armstrong et al., 2013). Furthermore, there is evidence that 'bridging' patients in atrial fibrillation on Warfarin with heparin for surgical procedures did not reduce embolic complications, but did lead to an increased risk of major bleeding (Douketis et al., 2015). Moreover, a study on over 200 patients undergoing implantation of a cardiac rhythm management device compared patients with uninterrupted warfarin therapy, or in whom warfarin was paused for 2 days, and found no increase of peri-procedural bleeding complications (Airaksinen et al., 2013). However, it is currently unclear whether these results from surgical procedures with visual inspection and accurate haemostasis can be extrapolated to blind needle exploration of a muscle.

We *recommend* that a recent (within 48 h) International Normalized Ratio (INR) is measured in patients taking a stable dose of Warfarin and that certain measures, such as examination of superficial muscles with a fine gauge needle, may reduce the risk of clinically significant bleeding. It is probably wise to avoid needle EMG examination in patients' whose INR lies outside the therapeutic range. If the INR is unknown the urgency of the clinical question that is being addressed should be determined, along with the patients' expectations, to assess whether the examination should be deferred to a later date.

Further studies are clearly needed to evaluate the relative risk frequency of clinically relevant haematomas. Little is known whether the experience of the examiner, anatomical site of the muscle examined (i.e. limb versus paraspinal) or gauge of needle used has any influence on the bleeding risk; or whether the knowledge of the examiner of the compromised coagulation status of a patient has any impact. Most available evidence examined patients taking Warfarin and less is known about the new oral anticoagulant agents such as Xa inhibitors (e.g. rivaroxaban).

6. Electrodiagnostic assessment of pregnant women

No known contraindications exist for performing NCS and needle EMG in pregnant patients. In addition, no complications from these procedures have been reported in the recent neurophysiology literature. Evoked response testing, likewise, has not been reported to cause any problems when performed during pregnancy (AANEM, 2014).

7. Pneumothorax, peritonitis and local nerve injury

Several reports document that it is possible to cause pneumothorax, the most potentially serious (i.e. life threatening) iatrogenic complication of needle EMG, when attempting to examine certain "high risk" muscles such as the diaphragm, serratus anterior, supraspinatus, rhomboids, cervical or thoracic paraspinal muscles (Honet et al., 1986; Honet, 1988; Miller, 1990; Reinstein et al., 1987). In the most recent paper Kassardjian et al. (2016) retrospectively found over an 18 year period a symptomatic pneumothorax caused by EMG examination in 7 patients out of 64,490 patients, who had undergone EMG evaluation of 71,782 high risk muscles. Pneumothorax became apparent within 1 h in 6/7 patients and in 1 patient after 24 h. Overall the complication frequency is therefore rare (<1/1000) but dependent up on the target muscle. The highest risk was for the serratus anterior muscle with about 1/200 examinations and less than 1/500 for the diaphragm (i.e. uncommon). These figures are in agreement with previous assessments of fewer patients (Bolton, 1993; Saadeh et al., 1993; Sander et al., 1997).

A potentially hazardous penetration of the peritoneum during chest wall or abdominal musculature by needle EMG examination

might theoretically lead to peritonitis, although we are not aware of any reported cases.

It is feasible that an EMG needle may also injure a nerve by direct intraneural puncture during near nerve stimulation or if a nerve travels near or through the muscle of interest. Although there are no reported cases of routine EMG needle-induced nerve trauma, there are reports of nerve trauma from other types of needles (Davison et al., 1996; Horowitz, 1994), including deliberate insertion of small needles into nerves in microneurography (Eckberg et al., 1989).

8. Electrically sensitive patients

8.1. Studies in the critical care unit

The most common ways a critically ill patient can become electrically sensitive are: (a) when the normal protective function of the skin is breached by intra-venous and intra-arterial catheters with leakage and spills around the catheter site, and (b) when the large volume of 'protective' soft tissue which surrounds the heart (i.e. the trunk) is bypassed by intra-cardiac catheters and external pacing wires such that small, otherwise harmless currents, become potentially lethal by direct conduction to the heart (''microshock'') (Al-Shekhlee et al., 2003). A small study on 20 patients suggested that there was no risk of cardiac conduction abnormalities or malfunction of implanted cardiac pacemakers or cardiac defibrillators, if routine NCS were performed when short saline filled cannulae were placed in the antecubital fossa or at the wrist (Mellion et al., 2010).

8.2. Implanted pacemakers and cardiac defibrillators

Implanted Cardiac Pacemakers (ICPs) and Implanted Cardiac Defibrillators (ICDs) both have an electronic sensing as well as stimulation function. In theory stimulation during NCSs might be mistaken as an abnormal cardiac rhythm (Almeida and Buckingham, 1993; Bardy et al., 1989; Grimm et al., 1993; LaBan et al., 1988; Preston and Shapiro, 2013; Romano et al., 1993) that may cause anti-tachycardia pacers to deliver a countershock. It is known that transcutaneous electrical nerve stimulation (TENS), with stimulus frequency, pulse duration and current parameters comparable to those used in neurophysiological investigation, can interfere with ICD function (Holmgren et al., 2008). The most recent study has shown that this situation is, however, very unlikely to occur in routine electrodiagnostic testing, as evidenced by the lack of significant ECG change during nerve stimulation in a study of 77 patients (Ohira et al., 2013). When the pacemaker was deliberately inhibited in 30 of these patients there were minor symptoms including lightheadedness, heart palpitations and tingling of the fingers accompanied by heart rate changes. This contrasted with the symptom free 'control group' of 47 patients whose implanted cardiac devices were not inhibited by a magnet. Based on this small study the authors advised not to inactivate the device (Ohira et al., 2013). Similar observations showed that there is no demonstrable risk of peripheral NCSs, even at the left supraclavicular fossa, interfering with an ICP or ICD using a bipolar sensing configuration (Schoeck et al., 2007). Early devices with unipolar pacing circuitry have an increased signal pick-up area and make it theoretically possible to detect volume conducted potentials from NCS. There is a case report of an 89 year old man with a unipolar ICP whose cardiac output was lost during facial nerve stimulation, but returned after cessation of nerve stimulation (Schoeck et al., 2007).

Incidentally a reported implantable pacemaker failure, thought to be related to phrenic nerve stimulation (Wicks et al., 1978), represents a rather different situation than occurs in NCS and is more akin to the interference that may occur from powerful external electromagnetic devices, such as magnetic resonance imaging or a magnet placed over the pulse generator. However, complete inhibition of a unipolar cardiac pacemaker in conjunction with an interscalene nerve stimulator (utilized for regional anesthesia) has been reported (Engelhardt et al., 2007).

A study of fourteen patients undergoing insertion of 10 ICDs and 4 ICPs under general anaesthesia received Repetitive nerve stimulation of the median, axillary, and spinal accessory nerves at 2 Hz and 50 Hz. Noise due to electromagnetic interference was visible in 2 ICDs, but only with stimulation at neck and supraclavicular sites and without spurious tachyarrhythmia. With 4 pacemakers electromagnetic interference led to pacing inhibition with 3 and a pause in 2, both of which were then programmed to a unipolar sensing configuration. (Cronin et al., 2013).

In general terms, routine NCS appear to be safe in patients with modern bipolar implanted cardiac devices. However, we *recommend* that NCS should not be performed in patients with external pacing wires or intracardiac catheters. As regards pacemakers with unipolar sensing and implanted cardiac defibrillators there are limited data and knowledge gaps, such that we *recommend* a dialogue with the patient and their cardiologist about the theoretical risks. Some device manufacturers and cardiologists advise that the devices should be deactivated, and in the spirit of engagement we feel patients should be offered this, as it is quite easy to undertake whilst monitoring the ECG.

8.3. Implanted deep brain stimulators (DBS) and Vagal nerve stimulators (VNS)

Implanted DBS and VNS are rarely known to interfere with EMG recording (Bejanishvili et al., 2005; Nandedkar et al., 2013). These artifacts could render findings un-interpretable and potential problems in performing the studies (St John Edward Barker et al., 2010). Prior arrangement with patients and their specialist nurses is required to switch the device off during EMG studies.

9. Conclusion

Ultimately a clinical discussion in each individual case with the patient, and where relevant their primary Physician, should assess whether the risk of complications is greater than the diagnostic and prognostic benefit of the information to be obtained from an electrodiagnostic test. We have provided pragmatic recommendations based on the information available in the limited literature, and our clinical experience, about the level and severity of risks. We have outlined situations where the evidence suggests that NCS and EMG are safe, but where a patient themselves may have misgivings. Both NCS and EMG very commonly cause procedural discomfort, whilst needle EMG commonly causes bruising and asymptomatic haematoma, but clinically significant haematoma and their sequelae are uncommon. The most serious complication of needle EMG is pneumothorax, depending on the muscle examined, but overall this is rare, and clinically significant infection is very rare.

Authors contribution

All authors have contributed to the writing and researching material relevant to this educational review and have reached consensus on the recommendations there in.

Conflict of interest

None.

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