Workshop handouts are prepared as background didactic material to complement a hands-on workshop session. This workshop handout was originally prepared in September 2005. The ideas and opinions in this publication are solely those of the author(s) and do not necessarily represent those of the AANEM.
Pelvic floor disorders affect millions of American women. One out of nine women in this country will undergo surgery for incontinence or prolapse in her lifetime with 30% of those women requiring additional surgery. Reports estimate that 135,000 women have surgery for incontinence and 200,000 for prolapse annually. The societal cost of incontinence in 1995 for persons over the age of 65 was estimated at $26.3 billion. Using 1995 cost estimates, the direct annual cost of urinary incontinence in women was estimated to be $12.4 billion. Given the demographic distribution of United States population and the increasing prevalence of pelvic floor dysfunction with age, it is expected that the demand for treatment of pelvic floor disorders will increase by at least 45% over the next 30 years.

Electrodiagnostic (EDX) testing of the pelvic floor is becoming increasingly common in clinical pelvic medicine and pelvic floor research. Clinically, it can be used with history, physical examination, and urodynamic testing to aid in the diagnosis of certain pelvic floor disorders and to determine if a central or peripheral neurologic problem exists. Electrodiagnostic testing is also emerging in studies investigating the etiology of pelvic floor disorders. A basic understanding of the principles and techniques used in EDX medicine are essential for reconstructive pelvic surgeons. However, most pelvic surgeons will never have the skills or expertise to perform pelvic floor neurophysiologic testing. Multidisciplinary teams including urogynecologic, urologic, and colorectal surgeons, physiatrists, neurologists, and physical therapists are imperative if we are going to improve our understanding of pelvic floor disorders and improve treatment outcomes.

The aim of this handout is twofold:

1. To introduce reconstructive pelvic surgeons (urogynecologists, urologists, and colorectal surgeons) to the principles of neurophysiologic testing.
2. To introduce EDX physicians to specific pelvic floor neurophysiologic studies.

The goal is also to allow pelvic surgeons and EDX physicians to improve their understanding of pelvic floor disorders and the role of EDX testing in caring for women with these disorders. Hopefully, it will aid clinicians with differing expertise to collaborate as members of a multidisciplinary team. This handout introduces the most common EDX techniques used in women with pelvic floor disorders, including pudendal and perineal nerve conduction studies (NCSs), sacral reflex testing, and surface and concentric needle electromyography (EMG). It describes the technique, advantages and disadvantages of the technique, and how the technique can be applied clinically. A brief review of neurophysiology is presented to provide a basis for understanding the pathophysiology that leads to nerve and muscle disorders and how the EDX studies work.

NEUROPHYSIOLOGY

Understanding membrane physiology at the cellular level is the basis for performing and troubleshooting neurophysiologic testing in the clinical arena. The nerve cell membrane and its
processes are semipermeable, lipoprotein bilayers, which create a border between the intracellular and extracellular fluids. Both contain approximately equal concentrations of ions; however, an electrical potential exists across the cell membrane, the transmembrane potential. The inside of the cell is more negative than the outside with the average resting membrane potential in human skeletal muscle being –90 mV. The intracellular fluid has a higher concentration of potassium (K\(^+\)) and lower concentrations of sodium (Na\(^+\)) and chloride (Cl\(^-\)) than the extracellular fluid. In the resting state, K\(^+\) ions move freely across the membrane, while Na\(^+\) ions are static. When the membrane is depolarized to a critical threshold level, membrane channels to Na\(^+\) open, allowing Na\(^+\) to enter the cell and an action potential is generated. This intrinsic property of nerve and muscle underlies an "all or none" phenomenon. As long as any portion of the cell membrane reaches the threshold level, an action potential will result, independent of the initiating stimulus' magnitude above the critical level. After a 1ms delay, permeability to K\(^+\) also increases, while permeability to Na\(^+\) reverses allowing for a rapid recovery of cell membrane potential. These differences in cell membrane potential (action potentials) can be recorded electrically during EDX testing.

In unmyelinated axons, action potential propagation occurs by each small area of nerve undergoing depolarization activating its neighbor in a continuous fashion. Many nerve cell axons are covered myelin, which improves impulse conduction by increasing speed of current movement down the inside of the membrane. The myelinated axon is surrounded by myelin except at small intervals called nodes of Ranvier, which contain voltage-gated Na\(^+\) channels. The axonal membrane beneath the myelin does not contain any Na\(^+\) channels. The myelin acts as an insulator, allowing the action potential generated at one node to "jump" to the next node significantly increasing the velocity of action potential propagation. The amount of myelin surrounding a nerve and the distance between nodes of Ranvier are directly proportional to the nerves diameter and conduction velocity (CV). A large myelinated nerve will conduct more quickly than small unmyelinated nerves. Axonal and demyelinating neuropathies can decrease the distance between nodes and slow nerve CV, which can be recorded clinically during EDX testing. Table 1 shows nerve fiber classifications.

Skeletal muscles are activated by electrical impulses (action potentials). Large, myelinated motor axons conduct action potentials, and then branch out into a few terminal branches, which attach to a single muscle fiber. The area of attachment is referred to as the neuromuscular junction or endplate. When an action potential reaches terminal axon, Na\(^+\) channels open as expected. Calcium (Ca\(^+\)) channels also open and Ca\(^+\) enters the terminal portion of the axon. Calcium is essential to the process of neuromuscular transmission. Vesicles containing acetylcholine are released into the space between the axon and muscle fiber. The acetylcholine diffuses across the synaptic cleft to bind acetylcholine receptors, which creates conformational changes in the Na\(^+\) channels. Sodium enters the cell and depolarizes the adjacent muscle fiber membrane.

### ELECTRODIAGNOSTIC TESTING

#### Nerve Conduction Studies

A NCS is the introduction of an action potential in the peripheral nervous system and the subsequent recording of the neural impulse at some location distant to the site of stimulation. Nerve conduction studies measure the velocity of action potential propagation and the magnitude of the response, thereby allowing one to make clinical judgments about the health of a particular nerve. One can measure three different types of responses depending on the type of nerve stimulated and where the recording electrodes are placed. Pure sensory nerve action

<table>
<thead>
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<th>Table 1 - Classification of Nerve Fibers</th>
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<tr>
<td><strong>Sensory &amp; Motor Fibers</strong></td>
</tr>
<tr>
<td>A(\alpha)</td>
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<td>A(\alpha)</td>
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<td>A(\beta)</td>
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<td>A(\gamma)</td>
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Pelvic Floor Neurophysiology AANEM Workshop
potentials compound nerve action potentials from mixed sensory and motor nerves, and pure motor nerve evaluations by measuring compound muscle action potentials (CMAP).

Compound muscle action potentials have been traditionally used to evaluate neuropathies in women with pelvic floor disorders. Nerve conduction studies allow one to identify precise neural injuries or more generalized neuropathic injuries along portions of the peripheral nervous system. As with all electrodiagnostic tests, it is important to have a thorough understanding of peripheral neuromuscular anatomy prior to performing nerve conduction studies.

**Stimulating**

When performing NCSs, a stimulus is given at a predefined site using a surface or monopolar needle electrode. Most pelvic floor EDX physicians use surface electrodes to stimulate, reserving needle electrodes for nerves that are hard to stimulate with surface electrodes because of excess fat or edema. The magnitude of stimulus used in routine NCSs is referred to as the supramaximal stimulus. The supramaximal stimulus is approximately 20-30% above the stimulus, which does not produce any further increase in CMAP response because all the nerve fibers to the muscle are being depolarized. The larger, myelinated axons are depolarized first, and then at supramaximal stimulation, the smaller, myelinated axons are depolarized. The pulse width is the duration over which the stimulus is delivered and typically ranges from 0.05 to 1 ms.

**Recording**

After stimulating the nerve, it is necessary to record the response. Surface or monopolar needle electrodes can be used. When recording a muscle response, three electrodes are necessary – an active, a reference, and a ground. The active electrode should be placed directly over the muscle being studied, and the reference electrode should be placed some distance from the muscle. The responses recorded from the active and reference electrodes undergo differential amplification resulting in the CMAP displayed on the EDX instrument. The ground electrode should ideally be placed between the active and reference electrodes. This is frequently not possible in pelvic floor NCSs and the ground electrode can be placed on the inner thigh. To decrease impedance from the skin and improve the recorded response, the skin under the electrodes should be gently abraded with fine sandpaper prior to placing the electrodes with a small amount of electrode gel.

**Compound Muscle Action Potential**

A CMAP is the biphasic waveform obtained from stimulating a nerve proximal to a muscle and recording the potential directly over the muscle. A CMAP, or M response, is a summation of all the muscle fibers, which are depolarized by a single stimulated nerve. Several parameters recorded from the CMAP are useful in EDX testing (Figure 1). Onset latency is the time from nerve stimulation to the initial upward deflection of the CMAP. Onset latency reflects neural activation at the cathode, propagation of the action potential along the nerve, and transmission at the neuromuscular junction. Therefore, an abnormality at any of these sites can result in prolonged latency. Latency measures only the large, heavily myelinated, fastest conducting axons in a nerve. If a nerve has lost many axons, but a few myelinated axons remain intact the onset latency will be normal. When the latency is prolonged, one can assume significant loss of neuromuscular function. However, if only a few axons conduct the nerve impulse at a normal velocity, the latency can be normal despite significant neural injury. Therefore, latency is not a sensitive measure of nerve injury. Amplitude is measured from baseline to the maximum point of the waveform. Amplitude reflects the total number of axons and muscle fibers being tested and provides an estimate of the amount of functioning tissue. It is less reliable than latency because the distance between the electrode and muscle influences it. Area is the space under the portion of the waveform above baseline and provides the most direct estimate of functioning tissue. Compound muscle action potential duration is typically measured from the onset latency to where it crosses the baseline. Duration and shape of the waveform measure the temporal dispersion of all the individual fibers. Nerve CV is the rate an action potential propagates along the stimulated nerve. It is calculated by dividing the length of nerve over which the action potential travels by the time.

![Figure 1](https://example.com/figure1.png)
required to travel the distance. However, in motor NCSs the latencies between two different sites of stimulation are subtracted from one another to account for the delay at the neuromuscular junction. Nerve CVs are difficult to obtain on the pudendal nerve due to the nerve's anatomic course and the inability to stimulate at two well-defined sites.

If the anticipated CMAP response is not obtained, the EDX physicians should not assume it is absent before troubleshooting and trying to elicit a response. Make sure stimulation is supramaximal. Also, check to ensure proper placement of both the active and reference electrodes. Verify continuity of the electrode leads and that the preamplifier is turned on. If the expected response is small, most electrodiagnostic instruments have programs to distinguish the waveform from baseline noise.

Nerve CVs are affected by the diameter of the nerve (large nerves conduct more quickly), temperature (cooler temperatures increase latency and amplitude), and age (age greater than 60 years decreases nerve CV and amplitude). Therefore, delayed nerve CVs in these instances may not be abnormal.

PELVIC FLOOR ELECTRODIAGNOSTIC TESTING

Pudendal Nerve Conduction Studies

The pudendal nerve branches after exiting Alcock's canal to form three terminal branches — the inferior hemorrhoidal, the perineal, and the dorsal nerve to the clitoris. The inferior hemorrhoidal and perineal branches contain efferent fibers to the external anal sphincter and urethral sphincter, respectively, which can be measured using nerve conduction techniques.

Pudendal NCSs are the most commonly reported EDX tests done on the pelvic floor. First described by Kiff and Swash in 1984 to study patients with fecal incontinence, they have been used to investigate the role of pudendal neuropathy in stress urinary incontinence and pelvic organ prolapse. A St. Mark's electrode (Figure 2) consists of a stimulating cathode and anode and two recording electrodes, which can be attached to a gloved index finger. The stimulating electrodes are located at the tip of the index finger and the recording electrodes at the base. The pudendal nerve is then stimulated at the level of the ischial spine. If stimulation is applied transrectally, the recording electrodes are located at the external anal sphincter. The CMAP latencies recorded with this technique have good reproducibility; however, CMAP amplitudes vary with the size of the examiner's index finger. In women, it is preferable to stimulate the pudendal nerve using a transvaginal approach with surface electrodes placed over the external anal sphincter at the 3 and 9 o’clock positions with the patient in dorsal lithotomy. Normative data using this technique in 42 continent women have been established (Table 2). Older age, more vaginal deliveries, and a wide genital hiatus were associated with longer pudendal and perineal nerve terminal motor latencies. This data is consistent with normative data determined in other EDX laboratories.

Perineal Nerve Conduction Studies

The amplitude and latency of fibers to the urethral sphincter can be measured at the same time pudendal NCSs are being done. Ring electrodes consisting of two pieces of platinum wire wound onto a small cylinder are available, which slip onto the end of a Foley catheter (Figure 3). When the electrode is placed 1 cm distal to the Foley balloon and the balloon is secured at the

Figure 2 St. Mark’s Electrode

Figure 3 Urethreal Ring Electrode
level of the urethrovesical junction, the electrode can record neuromuscular activity from the striated urethral sphincter. Stimulating the pudendal nerve at the ischial spine and recording from the urethral sphincter and external anal sphincter simultaneously allows one to record CMAP from the pudendal (inferior hemorrhoidal) and perineal branches. Normal values for perineal latencies and amplitudes are located in Table 2. Figure 4 shows typical waveforms from pudendal and perineal NCSs from a vaginally parous woman with stress incontinence.

In some women, the urethral sphincter is not innervated by the perineal branch of the pudendal nerve, but is supplied by separate sacral nerves similar to the nerve to the levator ani, which supplies the levator muscles. The perineal CMAP in these women demonstrates an initial positive deflection due to volume conduction from nearby pelvic floor muscles (Figure 5).

Clinical applications:

Pudendal and perineal NCSs established the link between pudendal neuropathy and stress urinary incontinence and fecal incontinence. Prolonged terminal motor latencies have also been shown after vaginal incontinence and prolapse surgery, suggesting that some anterior vaginal wall dissection leads to distal pudendal nerve injury.

Pudendal nerve terminal motor latencies are most frequently reported in case-series of women undergoing anal sphincteroplasty. Authors have attempted to predict surgical outcomes based on normal verses abnormal pudendal nerve function with varying results. One-hundred subjects underwent anterior overlapping anal sphincteroplasty after pudendal nerve testing. Sixty-two percent of subjects with normal pudendal nerve terminal motor latencies had "successful" outcomes versus only

<table>
<thead>
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<th>Latency (msec)</th>
<th>Amplitude (μV)</th>
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<tr>
<td>Pudendal</td>
<td>1.94 (1.55-2.54)</td>
</tr>
<tr>
<td>Perineal</td>
<td>2.18 (1.84-3.33)</td>
</tr>
</tbody>
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* Olsen AL, 2003
17% of subjects with unilateral or bilateral pudendal nerve terminal motor latencies. Other authors have reported good post-operative success in patients with prolonged pudendal nerve terminal motor latencies.

The clinical usefulness of pudendal and perineal nerve terminal motor latencies is hotly debated. They should not be used in isolation from other EDX tests when evaluating pelvic floor injuries. Generally, EMG follows NCSs since EMG is more sensitive for detecting neuropathic injury.

Sacral Reflex Testing

Stimulation of certain pelvic floor structures results in reflex contractions of pelvic floor skeletal muscles. Techniques to test these reflexes in the pelvic floor are used to measure efferent and afferent nerve activity, as well as neurotransmission through the pelvic plexus and sacral nerve routes. Reflexes from the urethra and bladder travel through visceral afferent pathways.

Urethral Anal Reflex

Urethral anal reflexes were first described by Bradley and use the ring electrode mounted on a Foley catheter to stimulate while recording from electrodes over the anal sphincter (3 and 9 o’clock – dorsal lithotomy). A nonrecurrent, paired stimulus with an interstimulus interval of 5 ms and a stimulation of 0.1 ms is used to stimulate at the urethra using a ring electrode mounted on a Foley catheter. Recordings are made from surface electrodes over the external anal sphincter at 3 and 9 o’clock. The level of stimulation is slowly increased until the patient perceives the stimulus (sensory threshold). The stimulation level is increased to 3-4 times the sensory threshold and 4 stimuli are given. The four responses are superimposed and the latency is measured as the takeoff of the consistently obtained response (Figure 6). Responses with latencies greater than 100 ms are voluntary and not considered reflex responses. Amplitudes of the responses are not used clinically, but are currently being assessed in research protocols. Normal values for women can be found in Table 3.

This reflex involves afferent fibers from the urethra, which synapse in the conus medullaris and travel through pudendal efferents to the external anal sphincter. Injuries to the pelvic plexus or cauda equina frequently result in absence of the urethral anal reflex. If the patient is unable to sense the stimulus, but the reflex is intact, she likely has an injury in the sensory cortex or ascending spinal cord.

Figure 6  Left and Right Urethral Anal Reflexes. 4 responses superimposed

<table>
<thead>
<tr>
<th>Reflex</th>
<th>Sensory Threshold (mA)</th>
<th>Latency (ms)</th>
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<tbody>
<tr>
<td>Urethral Anal</td>
<td>8</td>
<td>82</td>
</tr>
<tr>
<td>Bladder Anal</td>
<td>37</td>
<td>85</td>
</tr>
<tr>
<td>Clitoral Anal</td>
<td>9</td>
<td>55</td>
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BLADDER ANAL REFLEX

The ring electrode mounted on the Foley catheter is used to apply the stimulus in the bladder anal reflex. The bladder is deflated and the impedance measured between the bladder wall and the stimulating electrode. Impedance should be less than 10 KOhms. Stimuli are applied to determine the sensory threshold, the stimulation is increased 3-4 times, and the latency measured.
CLITORAL ANAL REFLEX

Surface electrodes are placed paraclitorally to stimulate while recording is done at the surface electrodes placed over the external anal sphincter. This reflex passes through the pudendal afferents to the spinal cord back through pudendal efferent fibers to the anal sphincter. These roots are often affected in cauda equina disease and will not be affected in conditions that disrupt the pelvic plexus.

Clinical Applications

Anything that affects the pelvic plexus can potentially disrupt the urethral and bladder anal reflexes. This can be seen in peripheral neuropathies with significant autonomic components and after radical pelvic surgery or radiation. The clitoral anal reflex should be preserved because the course of this branch is not involved.

Pudendal neuropathy typically results in prolonged or absent clitoral anal reflex with preservation of the urethral and bladder anal reflexes. The afferent limb of the pathway through the pelvic plexus is less affected and is a temporally longer portion of the pathway. Lesions in the conus medullaris and cauda equina frequently produce abnormalities in all sacral reflexes.

Suppression of the urethral anal reflex by actively trying to void is a measure of upper motor neuron function. If a patient is unable to suppress the response during voiding, she may have a lesion in the suprasacral spinal cord.

ELECTROMYOGRAPHY

Electromyography is the recording and study of electrical activity from striated muscles and can be used to distinguish between normal, denervated, denervated and reinnervated, and myopathic muscle. The electrical activity can be recorded using surface or needle electrodes and then displayed on the oscilloscope screen of an EDX instrument. Voluntary electrical activity is recorded as motor unit action potentials (MUAP), which represent the summation of activity from multiple motor units. Motor units are comprised of a single anterior horn cell, its axon, and all the skeletal muscle fibers it serves.

A variety of electrode types is used for EMG. Each has different properties and capabilities. The most common electrodes used in the pelvic floor are surface and concentric needle (CNE).

SURFACE ELECTRODES

Surface electrodes are placed on the skin over the muscle being evaluated and can be used to evaluate patterns of muscle activity. Surface electrodes record a summation of electrical activity from the muscle, but cannot distinguish individual MUAPs; and therefore, cannot be used to diagnose or quantify neuropathy or myopathy. They are easier to use and less painful than needle electrodes, but provide less reliable information due to signal distortion by intervening skin, subcutaneous tissue, and volume conduction from other muscles.

Surface electrodes are commonly used during urodynamic studies to assess striated urethral sphincter activity. Electrodes are places on either side of the perineal body or anal sphincter and neuromuscular activity is recorded during the cystometry and voiding portions of the study. An increase in activity is normally seen during filling with an absence activity during voiding or episodes of detrusor overactivity. This set up records neuromuscular activity of multiple pelvic floor muscles not just the striated urethral sphincter, making it difficult to differentiate which muscle is contributing to the signal. A recent study comparing perineal surface to urethral CNE during urodynamics demonstrated that needle tracings were consistently more interpretable than surface recordings. Needle tracings demonstrated urethral relaxation with voiding 79% of the time, while surface recordings only demonstrated urethral relations 28% of the time.

CONCENTRIC NEEDLE ELECTRODES

Electrodiagnostic physicians consider EMG the gold standard for studying peripheral striated neuromuscular disease. Needle electrodes are inserted directly into the muscle allowing an accurate portrayal the electrical signals to diagnose neuropathy or myopathy. A variety of needle electrodes are available – monopolar, single fiber, and concentric – each with unique recording properties.

Concentric needle electrodes are hollow, 24-26 gauge needles with a fine wire electrode down the center and a beveled tip. The small recording area at the beveled tip differentiates activity from approximately 20 nearby muscle fibers. The wire or active electrode is referenced to the needle shaft, reducing the activity recorded from nearby muscles. Concentric needle electrodes have the advantages of being able to record EMG activity with little interference from other muscles, a predictable recording surface, and the absence of a separate reference electrode.

Three types of activity can be recorded with CNE – insertional, spontaneous, and MUAPs.

Insertional activity is the electrical activity detected by the CNE as it passes through the muscle at rest. When the electrode is in healthy muscle, the insertional activity will return to baseline in 300 ms. Decreased insertional activity indicates that the electrode is not in muscle or the muscle has undergone severe atrophy and replacement by electrically inactive tissue. This is
commonly seen in the anal sphincter at the 12 o’clock position in women with long-standing anal sphincter disruptions.

Spontaneous activity is persistent electrical activity after the CNE is inserted and results from marked membrane instability of the muscle or neuron innervating it. Unlike most skeletal muscles, which are electrically silent at rest, the pelvic floor muscles have baseline tonic electrical activity making it more difficult to detect spontaneous activity. The most common form of spontaneous activity is the presence of positive sharp waves or fibrillation potentials. Fibrillation potentials are action potentials of single muscle fibers that have been denervated. The density of the fibrillation potentials is a rough estimate of the number of denervated muscle fibers. Fibrillation potentials develop within 1-3 weeks of after the loss of innervation. The final type of spontaneous activity reported in pelvic floor muscles is complex repetitive discharges (CRD). Complex repetitive discharges are high frequency, abrupt onset and offset waveforms associated with neuropathy and voiding dysfunction in women. Fowler’s syndrome, first described in 1985, is the triad of urinary retention, urethral CRDs, and polycystic ovaries in young women. Retention in this group of patients is thought to be due to "overactivity" of the striated urethral sphincter due to direct spread of electrical excitation from muscle fibers to muscle fiber.

Motor unit action potential analysis in the sphincters can be done at rest and with voluntary activity. Figure 7 shows a normal MUAP. Nerve injury results in characteristic changes in MUAP parameters of duration, amplitude, and polyphasia. After nerve injury, a muscle fiber can be reinnervated by regrowth of the original axon or a nearby axon. If a nearby axon reaches the denervated muscle fiber, it will supply more muscle fibers creating a more complex MUAP. The new complex waveform tends to be polyphasic (number of times a MUAP crosses the baseline). New axons are initially not well myelinated and conduct impulses more slowly; as a result, newly reinnervated muscle has long duration MUAPs. The MUAPs have larger amplitudes since one motor unit is supplying more muscle fibers.

Motor unit action potential analysis can be done using one of three techniques – manual MUAP, individual MUAP, and computerized multi-MUAP programs. A study comparing the techniques in the anal sphincter demonstrated that individual MUAP and multi-MUAP analyses were most sensitive for differentiating neuropathic from normal muscle. Mean quantitative parameters from the three techniques are different, so normative data from one technique cannot be used for another.

Motor unit recruitment refers to the pattern in which motor units are recruited by the spinal cord. Muscle increase force by increasing the frequency and number of individual motor units are firing. Therefore, as voluntary effort is increased, an increased number and frequency of MUAPs should be seen. At maximum effort, so many motor units are firing that individual MUAPs cannot be distinguished, resulting in an interference pattern. Computerized software programs exist to measure interference patterns as well.

The main advantage of CNE is the ability to quantify neuromuscular function. Electrodiagnostic instrument parameters, such as filter settings, gain, and sweep speed must be standardized and reported if quantitative CNE measurements are to be compared. Waveforms will differ depending on filter settings. Since sphincter MUAPs are smaller than other striated muscles, it is important to know the commonly used settings. Amplifier gain is typically reduced to 50 µV and filter settings are set at 10 Hz and 10 Hz with a sweep speed of 10 ms/div.

**URETHRAL EMG**

Concentric needle EMG of the striated urethral sphincter is done with the woman in the dorsal lithotomy position. Anesthetic cream can be applied to the external urethral meatus 10 minutes prior to the study to optimize patient comfort. The CNE is inserted 5 mm above the external urethral meatus. The striated urethral sphincter is located at the mid-urethra, 1.5 cm from the external urethral meatus. Figures 8 and 9 demonstrate two commonly seen patterns of urethral EMG seen in the urodynamic laboratory. Our previous work has shown significant differences in urethral EMG activity in women with stress urinary incontinence; however, these differences in motor unit recruitment are almost always seen with coughing, while baseline EMG activity is not significantly different between women with and without stress urinary incontinence.

**EXTERNAL ANAL SPHINCTER**

Needle examination of the anal sphincter is also done with the patient in dorsal lithotomy after application of anesthetic cream.
The external anal sphincter can be located with a digital rectal examination and the CNE inserted parallel to the muscle at 3 and 9 o’clock. Twenty MUAPs should be examined from each site.

Clinical Applications

Concentric needle EMG has been used in pelvic floor muscles to confirm the association between pelvic nerve injury and vaginal delivery, stress incontinence, and fecal incontinence. Significant changes in MUAP morphology have been reported after vaginal childbirth by multiple authors. Needle EMG of the levator ani and external anal sphincter muscles has shown electromyographic evidence of denervation with reinnervation in women with stress urinary incontinence and pelvic organ prolapse. Two studies have used quantitative CNE of the urethral sphincter in women undergoing incontinence surgery. Fisher and colleagues demonstrated more advanced neuropathic changes in women with persistent stress urinary incontinence. Kenton and colleagues studied 89 women undergoing Burch urethropexy with CNE and found significant differences in EMG parameters of women with successful incontinence surgery, suggesting that these women had better innervation of their urethral sphincters. Specific EMG criteria were established, which could predict surgical success 100% of the time.

Gregory recently reported quantitative CNE data from the anal sphincter of 23 nulliparous and 28 vaginally parous women. Motor unit action potentials from the 23 nulliparas had significantly higher amplitudes, longer durations, and more phases, lending further evidence that vaginal childbirth results in pudendal neuropathy.

Concentric needle EMG of the anal sphincter can also be used to map the anal sphincter prior to surgical repair. The examination should include the anterior quadrant in addition to the 3 and 9 o’clock positions. This will provide information about where the muscle is intact/disrupted and about whether the muscle has sustained denervation or denervation/reinnervation injury.

Some normative CNE MUAP parameters have been reported for the external anal sphincter and levator ani. No normative data exists for the striated urethral sphincter.

CONCLUSIONS

Much of our current understanding of the etiology of pelvic floor disorders has come from both NCSs and EMG of the pelvic floor muscles in women with stress incontinence, fecal incontinence, and pelvic organ prolapse. We understand that surgery can impact pelvic innervation, and electrodiagnosis has also confirmed the relationship between vaginal childbirth and pudendal neuropathy. The degree of denervation and pelvic floor injury can be measured, and therefore studied. Such measurements have some correlation with clinical outcomes, but further research refining techniques and establishing normative EDX parameters for the urethral sphincter, anal sphincter and levator ani are imperative. No normative data exists for the striated urethral sphincter.

Electrodiagnostic testing has both clinical and research applications in pelvic floor disorders. Clinical evidence suggests that certain types of reconstructive surgery may impact pelvic floor innervation. Zivkovic measured perineal nerve terminal motor latencies before and after vaginal reconstructive surgery and found significantly prolonged terminal motor latencies in women who underwent vaginal needle suspension procedures. Similarly, Benson found significantly prolonged pudendal and perineal nerve terminal motor latencies in 27 women undergoing vaginal prolapse repair, while the terminal motor latencies of 21 women undergoing abdominal prolapse repair were not

Figure 8  Urethral EMG
The tracing on the left shows normal baseline urethral activity with the bladder at rest. Notice the significant increase in motor unit activity of the same patient on the right, when she is asked to cough.

Figure 9  Urethral EMG
Contrast these urethral EMG tracings with those in Figure 7. Notice the motor unit potential activity at baseline (on the left) is similar to that in Figure 6. However, in this woman with severe stress incontinence there is almost not increase in motor unit activity with cough.
different. He then compared postoperative perineal terminal motor latencies of the women with "optimal" and "suboptimal" prolapse repairs. Pudendal neuropathy was significantly more common in the women with "suboptimal" repairs. In a well-done randomized controlled trial of abdominal versus vaginal reconstructive surgery, Benson found superior anatomic results of prolapse repair in the abdominal group. Another randomized controlled trial also demonstrated anatomic superiority of the abdominal approach. These data suggest that vaginal reconstructive surgery results in denervation of the pelvic floor musculature, which may impact anatomic success of the surgery. There is also increasing data that preoperative pelvic floor denervation may impact surgical outcomes, particularly for continence procedures. Two recent studies demonstrated a relationship between urethral sphincter neuropathy and outcome of continence surgery.

Pelvic floor EDX studies may aid in the clinical diagnosis of some pelvic floor disorders and help to predict outcomes of incontinence surgery. However, confirmatory studies are necessary. Clinicians who wish to add electrodiagnosis to their clinical evaluation of patients with pelvic floor disorders should have proper training in nerve conduction studies and EMG or should work in a multidisciplinary setting with a neurologist or physiatrist trained in electrodiagnosis.

References
