CHAPTER 12

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Clinical Neurophysiology

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ABBREVIATIONS USED IN TEXT

BCR – bulbocavernosus reflex
CMAP – compound muscle action potential
CMCT – central motor conduction time
CNEMG – concentric needle electromyography
EAS – external anal sphincter
ED – erectile dysfunction
EMG – electromyography
GSI – genuine stress incontinence
IP – interference pattern
MEP – motor evoked potential
MSA – multiple system atrophy
MU – motor unit
MUP – motor unit potential
PD – Parkinson's disease
PNTML – pudendal nerve terminal motor latency
QST – quantitative sensory testing
SEP – somatosensory evoked potential
SFEMG – single fibre electromyography
SSR – sympathetic skin responses
SUI – stress urinary incontinence
T/A – turns / amplitude

Clinical Neurophysiology

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INTRODUCTION

Neurophysiological investigations of the bladder and anorectum originated over 60 years ago, and have evolved with the developments in general clinical neurophysiology. The data from these investigations can assist clinicians in diagnosing neurological disease or injury of the uro-genital-anal organs. Another application of neurophysiological testing is in research, to identify the neural pathways that mediate urogenital and anorectal function. Compared to neurophysiological testing of the limbs and trunk, pelvic neurophysiological testing is relatively limited, primarily because of the restrictions imposed by pelvic neuroanatomy.

This chapter details the investigations, their applications and limitations, enabling investigators and clinicians to make a well informed decision about using these tests.

The present text is based on the two previous chapters on clinical neurophysiology prepared for the International Consultations on Incontinence.[1, 2]

A. GENERAL CONSIDERATIONS

I. HISTORICAL BACKGROUND

Neurophysiological techniques to investigate pelvic organ and pelvic floor function evolved as general clinical neurophysiological techniques developed and were applied to these structures. Sphincter EMG was first performed by Danish investigators [3] working with the founder of electromyography Buchthal. This was followed by the use of kinesiological EMG recordings during urodynamics. [4] Latency recordings of the bulbocavernosus reflex were reported [5] soon after electrical stimulation for motor conduction studies had been introduced. Recording of evoked potentials following repetitive stimulation of the pudendal nerves [6] and other pelvic sensory nerves developed within a few years of the introduction of somatosensory evoked potential recordings into general clinical practice. Cortical and nerve root stimulation by first electrical [7] and then magnetic stimulation[8] while recording from pelvic floor musculature followed afterwards.

II. CLASSIFICATION OF CLINICAL NEUROPHYSIOLOGICAL TESTS

It is possible to classify neurophysiological tests in different ways. As the tests are an extension of the clinical examination, a functional anatomic approach to classification makes most sense. For the purpose of this categorisation, the nervous system is divided into the *somatic* and the *autonomic* nervous systems. The somatic nervous system provides motor innervation to the skeletal muscles and joints, and sensory innervation from skin and muscle spindles. The autonomic nervous system provides motor innervation to the viscera and other endorgans not under voluntary control (e.g., sweat glands). Its sensory fibers are referred to as *visceral afferents.* Both systems have *central* pathways (neurons participating in spinal cord and supraspinal control) and *peripheral* nerves (those going to and from endorgans).

We have applied this simplified classification to the

innervation of the pelvis, generally classifying the electrophysiological tests as tests of the a) the somatic motor system (EMG, terminal motor latency measurements/ motor nerve conduction studies, and motor evoked potentials (MEP)); b) the somatosensory system (sensory neurography, somatosensory evoked potentials (SEP)); c) reflexes, which assess whole reflex arcs including sensory and motor nerves; and d) the autonomic nervous system (i.e., assessing the function of sympathetic or parasympathetic fibres).

III. GENERAL METHODOLOGICAL CONSIDERATIONS

1. Equipment

Clinical neurophysiological tests are conducted with complex electronic instruments and various devices that come into contact with the patient. Though this equipment is mostly standard, some specially constructed electrodes or stimulating devices have been devised to conform to uro-genito-anal anatomy. As long as the standards of electrical safety are adhered to, the risk to patients is negligible.

The most common form of neurophysiological testing is *electrophysiological*, whereby neurons are depolarized with electrical current. Surface electrodes, which are applied to skin or mucosal surfaces, or needle electrodes are used for electrical stimulation and to record bioelectrical activity. The important neurophysiological difference between surface and needle electrodes is their selectivity, and the practical difference is their invasiveness. The choice and application of electrodes is guided by the need for selective recording or stimulation. Less commonly, special devices are used for magnetic and mechanical stimulation. To date, there are no generally accepted guidelines for conducting individual uro-genital-anal neurophysiological tests.

2. Stimulation Parameters

The electrical stimulus should be specified and characterised both in technical (e.g., rectangular pulse, 0.2 ms, 15 mA) and physiological terms (e.g., 3-times sensory threshold). A stimulus with defined technical parameters may have variable biological effects because of the variable influences of electrode condition, contact, tissue conductivity etc. Supramaximal stimulation is preferred to elicit a compound muscle action potential (CMAP) or sensory nerve action potential [9]. Supramaximal stimuli yield responses with the largest amplitude and shortest latency, and are the least variable and most reproducible. The sites at which stimulation electrodes are applied should be described using anatomical terms.

3. Recording Parameters

a) Apparatus settings

For recording, the apparatus settings (gain, sweep speed) have to be adapted to the known range of amplitudes, latencies, and duration of the response and it has to be appropriately displayed for analysis. Particularly important is the frequency setting of filters: for surface electrode recordings it is typically 2 Hz – 1000 Hz; for needle EMG recordings, it is 5 – 10000 Hz for concentric needle or 500 – 10000 Hz for single fibre needle.

Placement of electrodes on the scalp for evoked potential recordings is defined according to the 10-20 International EEG System.

b) Reproducibility and Reliablity

Any potential elicited by stimulation should be reproducible; therefore, as a rule, at least two consecutive recording procedures need to be performed. Some responses need to be averaged because of their small amplitude to improve the signal-to-noise ratio. Therefore, many repetitions of stimulation/recording need to be done (typically 100-200). Even such an averaged recording needs to be repeated at least twice. CMAPs or M waves, MEP, sacral reflexes and sympathetic skin responses (SSR) are recognisable after single stimuli. However, as a rule, several responses are recorded to demonstrate reproducibility. In contrast, other responses (e.g., sympathetic skin responses) show marked fatigability with stimulus repetition.

c) Waveform Analysis

For a particular stimulation procedure, the shape, latency, and amplitude of the recorded potentials are analysed. Morphologically, a particular response (or part of it) needs to be recognised as present or absent. The shape of potentials is important to accurately determine the latency and amplitude of the response. The onset of the response (for M waves, MEP and sacral reflex testing) or the individual peaks of the potentials (for SEP) are used to determine the latency. The amplitudes are analysed relative to the baseline or “peak to peak”.

4. Anatomic Correlates of Neurophysiologic Tests

a) Nerve conduction, evoked potential and reflex studies

The electrophysiological responses obtained on nerve stimulation are compound action potentials and relate to populations of biological units (neurons, axons, motor units, muscle fibres, etc.). *Latency* and *amplitude* are commonly measured parameters during neurophysiologic testing. If the onset of the potential is measured, the latency of a compound potential represents the fastest conduction through a particular neural channel. As a general rule, latency measurements are not markedly affected by technical factors, but provide little information about the loss of biological units, either motor units or axons. The amplitude of the compound potential correlates with the number of activated biological units **(Figure 1)**. In theory, the amplitudes are the more relevant physiological parameter, as they reflect the functional or structural loss of biological units. Unfortunately, amplitudes are also strongly influenced by many poorly controllable technical factors, and are quite variable. Measurements of latencies and amplitudes of evoked potentials and reflex responses, including sympathetic skin responses, relate not only to conduction in peripheral and central neural pathways, but also to trans-synaptic transmission.

b) Electromyography (EMG)

Knowledge of the structure and function of the motor unit is fundamental to understanding the application of EMG. Motor neurons, which innervate striated muscle, lie in the anterior horn of the spinal cord. (Neurons that innervate the sphincters lie in Onuf's nucleus in the sacral spinal cord; they are somewhat smaller than those innervating skeletal limb and trunk muscles). Within the muscle, the motor axon tapers and then branches to innervate a certain number of muscle fibres, which are scattered throughout the muscle. The innervation is such that it is unlikely that muscle fibres that are part of the same motor unit will be adjacent to one another **(Figure 2)**. This dispersion of muscle fibres is said to be non-random, although the stage of development at which it occurs and the factors determining the arrangement are not known [10]. It is difficult to estimate the number of muscle fibres innervated by a single axon (i.e., the "innervation ratio") or the number of motor units supplying a muscle by clinically available neurophysiological techniques.

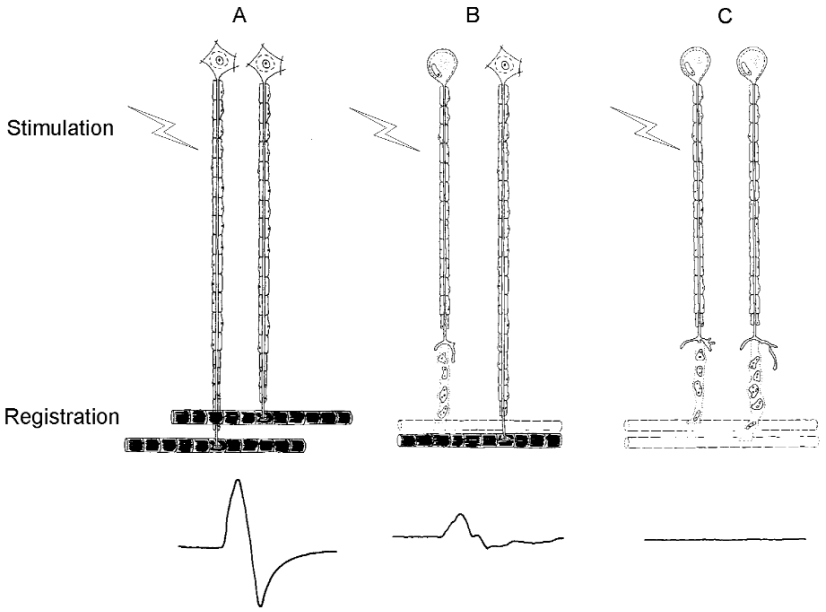


Figure 1. Schematic representation of Compound Muscle Action Potential changes after a motor nerve lesion. On electrical stimulation of normal nerve (A) a "normal" response is obtained. In partial denervation (B) the response is smaller. In complete denervation (C) no response can be obtained. (Note that the latency of response in a partial lesion may be normal due to preservation of nerve fibres with normal conduction).

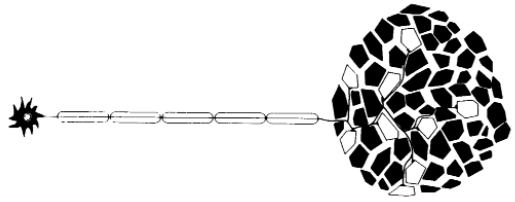


Figure 2. Schematic representation of a motor unit. The alpha motor neuron with its cell body, its myelinated axon and the peripheral nerve endings is shown. The muscle fibres innervated by this alpha motor neuron are shown in white. (Note that the muscle fibres from one motor unit are intermingled with motor fibres from other motor units).

B. CLINICAL NEUROPHYSIOLOGICAL TESTS

The objectives, methods, technical performance, diagnostic performance and clinical value will be described. Only specific issues shall be addressed herein, as others have been dealt with in the general section above or are dealt with in textbooks. Though this chapter is not all-inclusive, it does provide a substantial overview of previous and current relevant literature.

I. SOMATIC MOTOR SYSTEM TESTS

1. Electromyography (EMG)

The term "EMG" is often used for several different diagnostic procedures, the common denominator of which is the recording of bioelectrical activity from muscle. The term applies particularly to electromyographic recordings from striated muscles.

EMG is used to differentiate between normal, denervated, reinnervated, and myopathic muscle.

Although EMG abnormalities are detected as a result of a host of different lesions and diseases, there are in principle only two standard manifestations which can occur: a) disease of the muscle fibres themselves, and b) changes in their innervation. Myogenic changes may result from muscle disease, possibly even from direct trauma (for instance: to the anal sphincter during vaginal delivery). Neurogenic changes may be attributable to injury at any level along the lower motor neuron supplying the external anal sphincter, extending from the sacral nerve roots to the small branches within the external sphincter. In the pelvic floor muscles, only neurogenic changes are well recognised and routinely evaluated.

The EMG signal may be further used to indicate that muscle has been activated through its motor nerve, either by stimulation applied to motor pathways (M wave, MEP) or to sensory pathways (reflex response).

a) General technique for needle EMG in pelvic floor striated muscles

The external anal sphincter (EAS) is the most practical indicator muscle for sacral myotomes because it is easy to access, has enough muscle bulk for exact EMG analysis, and its examination is not too uncomfortable. Intramuscular electrodes need to be appropriately placed in the target muscle. The needle electrode is inserted into the subcutaneous EAS muscle, about 1 cm from the anal orifice, to a depth of a 3-6 mm under the non-keratinised epithelium. For the deeper part of the EAS muscle 1-3 cm deep insertions are made at the anal orifice, at an angle of about 30º to the anal canal axis. [11, 12]In most patients only examination of the subcutaneous EAS muscle is needed. Separate examinations of the left and right EAS muscles are recommended. The needle is inserted into the middle of the anterior and posterior halves of each side ("quadrants") of the EAS muscle. The needle is – after insertion in two positions on each side – turned backwards and forwards in a systematic manner. At least 4 sites in each of the subcutaneous and/or the deeper EAS muscle are thus analysed. [11, 13]

Other pelvic muscles can also be examined with electromyography, including the levator ani, the bulbocavernosus muscle and the striated urethral sphincter muscle. Facility with needle examination requires some practice. As a rule, several sites from one or more skin penetrations are sampled in needle EMG, which is difficult in the small muscles. The audio output from the loudspeaker of the EMG apparatus helps in assessment of the quality of recording as well as in recognition of the electrophysiologic phenomena.

All tests requiring needle electrodes are invasive and some pain is inevitable, even with use of local anaesthetics. Local anaesthesia is infrequently used for needle EMG examination. All abnormalities of parameters evaluated by needle EMG are in principle non-specific, i.e. most abnormalities can occur both in neuropathic or myopathic conditions. It is the overall clinical picture that dictates interpretation of results.

b) Concentric needle (CN) EMG

The examination is conducted usually with a single use, disposable electrode. The needle electrode consists of a central insulated platinum wire inserted through a steel cannula and the tip ground to give an elliptical area of 580 x 150 μm which can record spike or near activity from about 20 muscle fibres. [14] The number of motor units recorded therefore depends both upon the local arrangement of motor units within the muscle fascicle and the level of contraction of the muscle.

The commonly used amplifier filter settings for

CNEMG are 5 Hz – 10 kHz, and need to be defined if MUP parameters are to be measured. [15] When reporting normative data, use of the filter settings employed during data acquisition is obligatory. [16]

CNEMG can provide information on a) insertion activity, b) abnormal spontaneous activity, c) MUPs, and d) interference pattern (IP). In normal muscle, needle movement elicits a short burst of "insertion activity," which is due to mechanical stimulation of excitable muscle cell membranes. This is recorded at a gain setting of 50 μV per division (sweep speed 5-10 ms/division), which is also used to record spontaneous activity. Absence of insertion activity with appropriately placed needle electrode[11] usually means a complete denervation atrophy of the examined muscle. [17]

The amount of recruitable motor units during voluntary and reflex activation can also be estimated. Normally, MUPs should intermingle to produce an "interference" pattern on the oscilloscope during muscle contraction, and during a strong cough. In addition, the number of continuously active MUPs during relaxation, [18] MUP variability as well as MUP recruitment on reflex and voluntary activation can be observed. [17]

MUPs (and occasionally encountered end-plate activity) are recordable in resting sphincter muscles in a relaxed subject. This is in contrast to limb muscles where relaxation is associated with electrical silence by EMG. In addition to continuously firing motor units, new MUPs are recruited voluntarily and reflexly in the sphincters. It has been shown that the two MUP populations differ in their characteristics: reflexly or voluntarily activated high-threshold MUPs being larger than continuously active "low-threshold MUPs". As a consequence, standardised level of activity at which a template based multi-MUP analysis obtains 3-5 MUPs on a single muscle site was suggested [19]. In partially denervated sphincter muscle there is – by definition – a loss of motor units (MUs). This can be estimated during relaxation by counting the number of continuously firing low-threshold MUPs. In patients with cauda equina or conus medullaris lesions, fewer MUPs fire continuously during relaxation, [20] probably due to partial axonal loss. The main obstacle to qualified assessment of reduced number of activated MUs and activation of MUs at increased firing rates (as occurs in limb muscles) is a lack of concomitant measurement of level of contraction of the examined muscle (this can be readily assessed when studying limb muscles).

There are two approaches to analysing the bioelectrical activity of motor units: either analysis of individual MUPs or analysis of the overall activity of intermingled MUPs (the "interference pattern" – IP). Generally three techniques of MUP analysis (manual-MUP, single-MUP and multi-MUP) and 1 technique of IP analysis (turn/amplitude – T/A) are available on advanced EMG systems. [20] A more detailed description is provided in the Appendix.

Both the template based multi-MUP analysis of MUP and T/A analysis of IP are fast (5-10 and 2-3 minutes per muscle, respectively), easy to apply, and, technically, represent clinically useful techniques. Use of quantitative MUP and IP analyses of the EAS is further facilitated by the availability of normative values [16] that can be introduced into the EMG systems' software. It has been shown that normative data are not significantly affected by age, gender, [16] number of uncomplicated vaginal deliveries, [21] mild chronic constipation, [22] and the part of EAS muscle (i.e. subcutaneous or deeper) examined. [21] This makes quantitative analysis much simpler.

- **CNEMG Findings Due to Denervation and Reinnervation**

After complete denervation, all motor unit activity ceases. In a denervated muscle, complete "electrical silence" is noted in the first days after such an event. The diagnosis of complete denervation is confirmed by the absence of muscle response during electrical stimulation. Because motor axons take days to degenerate after injury, this proof is not available for up to 5-7 days after a denervation injury. However, it is rarely necessary to demonstrate complete denervation in the acute stage because the clinical condition is usually obvious. Denervated muscle fibres become hyperexcitable and start to fire spontaneously giving rise to abnormal spontaneous activity, but these may take days or weeks to appear. The "insertion activity" becomes prolonged and short biphasic spikes (fibrillation potentials) and biphasic potentials with prominent positive deflections (positive sharp waves) appear **(Figure 3)**. Thus, concentric needle EMG (CNEMG) correlates of denervation are pathologically prolonged insertion activity and pathological spontaneous activity. Completely denervated muscle may be reinnervated by axonal regrowth from the proximal nerve stump with few muscle fibres constituting "nascent" motor units. In partially denervated muscle, collateral reinnervation takes place. Surviving motor axons will sprout and grow out to reinnervate those muscle fibres that have lost their nerve supply. This results in a change in the

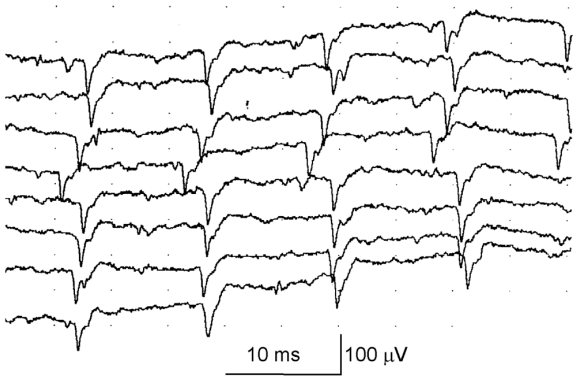


Figure 3. Concentric needle EMG recording from right bulbocavernosus muscle of a 49-years old male with urinary incontinence diagnosed as possible Multiple system atrophy. Pathological spontaneous activity (a burst of positive sharp waves) is shown.

arrangement of muscle fibres within the unit. Whereas in healthy muscle, it is unusual for two adjacent muscle fibres to be part of the same motor unit, following reinnervation, several muscle fibres, all belonging to the same motor unit, come to be adjacent to one another. CNEMG correlates are changes in motor unit potentials (MUPs) (duration, amplitude, number of phases, turns, etc). Early in the process of reinnervation, the newly outgrown motor sprouts are thin. Therefore, they conduct slowly such that the time taken for excitatory impulses to spread through the axonal tree is abnormally prolonged. Moreover, the neuromuscular transmission is unstable due to immaturity of the motor end-plates. The CNEMG correlate is instability of long-duration complex potentials.

With axonal reinnervation, MUPs appear again; first they are short, bi- and triphasic, soon becoming polyphasic, serrated and with prolonged duration. [23] In partially denervated muscle, some MUPs remain and mingle eventually with abnormal spontaneous activity. During reinnervation, MUPs and pathological spontaneous activity in sphincter muscles have a similar appearance, but can be distinguished by an experienced observer. Changes due to collateral reinnervation are reflected by: prolongation of the wave form of the MUP **(Figure 4)** which may have small, late components ("satellite potentials"). MUPs show "instability" due to insecure transmission in newly formed axon sprouts and end-plates. This "instability of potentials" (meaning both "jitter" and "blocking" of individual components in a complex potential) is not routinely assessed during sphincter EMG. Nonetheless, it can be a helpful parameter, and may be evaluated not only by SFEMG, as originally described, [24] but also by CNEMG, if a low frequency cut-off filter of 0.5 (up to 2) kHz is used along with a trigger – delay unit. [25] In skeletal muscle, the diameter of reinnervating axonal sprouts and conduction velocity increase with time, thereby improving synchrony of activation in the reinnervated motor unit. Thus MUP amplitude increases while MUP duration reverts towards normal. However, in degenerative neurological diseases (such as Multiple system atrophy), long duration motor units are a prominent feature of anal sphincter reinnervation [26, 27] **(Figure 4)**, perhaps due to relentless ongoing motor neuron atrophy. It is important to note that in patients with more severe neurogenic lesions, reinnervation may be inefficient resulting in MUP with parameters below confidence limits describing size (area, duration). [12, 28]

c) Single fibre EMG

The SFEMG electrode has similar external proportions to a concentric needle electrode, but with a recording surface diameter of 25 μm. It will pick up activity from within a hemispherical volume 300 μm in diameter, compared to the volume of muscle tissue from which a concentric needle electrode records, which has an uptake area of 2 - 3 mm diameter. [29] Because of the arrangement of muscle fibres in a normal motor unit, a SFEMG needle will record only 1 - 3 single muscle fibres from the same motor unit.

The SFEMG parameter that reflects motor unit morphology is the *fibre density*, which is defined as the mean number of muscle fibres belonging to an individual motor unit per detection site. To assemble this data, recordings from 20 different intramuscular detection sites are necessary. [24]

SFEMG is not widely used in general clinical neurophysiological laboratories. The recording needles are very expensive, and disposable needles are not available.

d) Kinesiological EMG

Kinesiological EMG is used to assess patterns of individual muscle activity/inactivity during defined manoeuvres **(Figure 5)** or during urodynamics. As such, the specific interpretation of electrical activity within a muscle is based on its presence or absence, rather than the type of activity.

When using surface electrodes there are problems related to validity of signal (e.g., artefacts, contamination from other muscles). With intramuscular electrodes, the procedure is more invasive, and there are questions as to whether the whole muscle in large

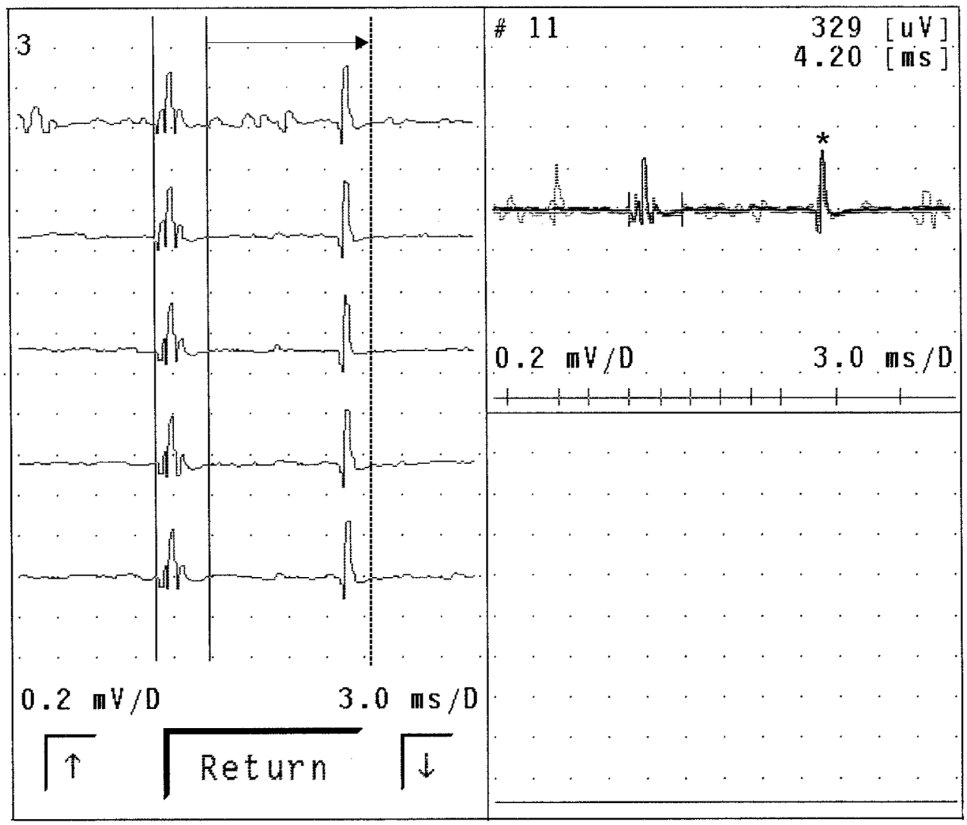


Figure 4. Consecutive firings of motor unit potential (MUP) and its average (left and right, respectively) as obtained from the external anal sphincter (EAS) muscle of 59-year-old woman by multi-MUP analysis. Note that multi-MUP analysis does not preclude inclusion of late components into MUP duration measurement; this is possible by manual correction of duration cursor (see arrow)

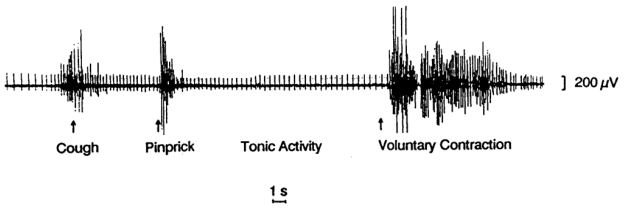


Figure 5. Kinesiological EMG recording from the urethral sphincter muscle of a healthy 53 years old continent female. Recruitment of motor units on reflex manoeuvres and on a command to contract is shown; regular continuous activity of motor units represents "tonic activity". (Recorded with concentric needle electrode).

pelvic floor muscles is properly represented by the sampled muscle portions.

The kinesiological sphincter EMG recordings in health show continuous activity of MUPs at rest. Such tonic activity has been recorded for up to two hours[30] and even after subjects have fallen asleep during the examination. [31]

It can be recorded in many but not all detection sites of the levator ani muscle. [32] The urethral and anal sphincter as well as the other pelvic floor musculature (e.g. pubococcygei) can be voluntarily activated typically for less than 1 minute. [32, 33] Timely activation of the levator ani muscle has been demonstrated to be an important aspect of stable bladder neck support; its activation precedes activity of other muscles in the cough reflex. [34]

Currently, kinesiological EMG is primarily used in polygraphic urodynamics studies to assess detrusor/sphincter coordination.

Sphincter activity during voiding is characterised by the cessation of all EMG activity prior to detrusor contraction. Pathologic incoordination of the detrusor and sphincter is called detrusor sphincter dyssynergia.

e) Clinical applications of EMG in urinary incontinence

• Disorders of Pelvic Floor Denervation

Trauma, surgery, neurologic and vascular disease have all been implicated in denervation of pelvic floor muscles. They are presented in the following subsections.

1. Traumatic Peripheral Denervation

After pelvic floor trauma, gross changes of denervation and reinnervation may be detected in pelvic floor motor units. Following a cauda equina or a conus medullaris lesion, the MUP are prolonged and polyphasic, [35] of increased amplitude, area, number of turns. [20] Surgical dissections can also affect the innervation of the sphincter and lead to loss of motor units and reinnervation of those surviving. [36] The bulbocavernosus muscle is particularly useful for examining in men with suspected recent minor partial denervation as it lacks on-going activity of low-threshold MU during relaxation. In women it is difficult to localise the muscle because it is thin. A recommended algorithm for neurophysiological investigation in a case of suspected cauda equina lesion is shown in Figure 7.

2. Denervation Due to Neurologic Disease

Definite "neuropathic" changes can be recorded in sphincter muscles of patients with multiple system atrophy (MSA), the condition formerly called Shy-Drager syndrome[26, 37-40] (Figure 5). MSA is a progressive neurodegenerative disease, which is often mistaken for Parkinson's disease (PD). Urinary incontinence and erectile dysfunction occur in this condition, often some years before the onset of obvious neurological features. [41] Sphincter EMG has been used in distinguishing MSA from Parkinson's disease [26, 37, 42, 43] . EMG is probably not helpful to distinguish MSA from the later stages of Parkinson's disease and from progressive supranuclear palsy. [44] Extensive discussion on the subject can be found in Vodusek 2001. [45]

In patients with acute idiopathic autonomic neuropathy and lower urinary tract dysfunction the EMG of external sphincter muscles was reported as normal. [46]

3. Stress Incontinence

Pelvic floor muscle denervation has been implicated in the pathophysiology of genuine stress incontinence (GSI). [47] EMG techniques have been used to identify sphincter injury after childbirth and to evaluate women with GSI. Fibre density in the EAS measured by SFEMG was increased in women with urinary stress incontinence. [48] Stress incontinence and genitourinary prolapse were associated with partial denervation of the pelvic floor. [49] CNEMG revealed a significant increase in duration of individual motor units in the pubococcygeus labour and vaginal delivery. [50] The changes were most marked in women who had urinary incontinence 8 weeks after delivery, who had a prolonged second stage of labour, and had given birth to heavier babies.

One recent report claims urethral sphincter EMG can assist in selecting the type of surgery for patients with intrinsic sphincter deficiency. [51]

Myogenic histological changes in pelvic floor muscles after vaginal delivery were also reported, [52] with some EMG support by another group. [53] Myopathic EMG changes (i.e. short, small MUPs) may, however, be a consequence of deficient reinnervation. [12, 28]

The practical value of the urethral sphincter CNEMG in women with urinary incontinence is not defined, but needs to be pursued. Although CNEMG of the urethral sphincter seems the logical choice in patients with urinary incontinence of possibly neurogenic origin, only a small amount of pathological muscle tissue remains in many incontinent parous women. [36] CNEMG findings generally will not affect therapeutic considerations. [54]

f) CNEMG Findings in Women with Idiopathic Urinary Retention

In young women with urinary retention (or obstructed voiding) complex repetitive discharges in profuse amounts in the external urethral sphincter against a full background of rapidly firing motor units have been described, suggesting that these findings are of pathogenic and diagnostic significance. The external urethral sphincter was also hypertrophic in this disorder. A large percentage of these women were hirsute and had polycystic ovaries. Only Fowler's group has extensively reported on this new clinical entity. [55, 56] Findings have been corroborated so far by one other group. [57]

The interpretation of spontaneous discharges is tempered by the consideration that the striated urethral sphincter is prone to develop such activity during needle movement, muscle contraction, or even spontaneously in chronically partially denervated sphincters, and is present even in a proportion of asymptomatic women. [58, 59, 60] The distinguishing featu-

re of the spontaneous EMG activity defining the particular pathology in women with retention seems to be its abundance, but the issue -– as well as the diagnostic entity itself -– remains disputed.

g) EMG Changes in Primary Muscle Disease

There are only a few reports of pelvic floor muscle EMG in generalised myopathy. In skeletal muscle, the "typical" features of a myopathy are small, low amplitude polyphasic units recruited at mild effort. Myopathic potentials have not been observed in the pelvic floor even in patients with a generalised myopathy. [61] In a nulliparous woman with limb-girdle muscular dystrophy, histology revealed involvement of pelvic floor muscles, but concentric needle EMG of the urethral sphincter was normal. [62] Myopathic changes were observed in the puborectalis and the EAS in patients with myotonic dystrophy. [63]

h) Kinesiological EMG Findings on Urodynamic and Anorectal Studies

In health, voiding is characterised by cessation of EMG activity in the urethral sphincter prior to detrusor contraction. This coordination is impaired with lesions between the lower sacral segments and the upper pons. Consequently, sphincter EMG activity is not inhibited, and often increased before detrusor contraction (i.e., 'detrusor-sphincter dyssynergia'). On the basis of the temporal relationship between urethral sphincter and detrusor contractions, three types of dyssynergia have been described. [64] Pseudodyssynergia may be seen during abdominal straining, coughing, attempted inhibition of an involuntary bladder contraction… Sphincter contraction or at least failure of relaxation during involuntary detrusor contractions was reported in patients with Parkinson's disease; [65] striated sphincter behaviour in this disease has also been called bradykinetic.

Neurogenic uncoordinated sphincter behaviour has to be differentiated from "voluntary" contractions (due to anxiety) that may occur in the unnatural laboratory setting. The pelvic floor muscle contractions of the so-called non-neurogenic voiding dyssynergia may be a learned abnormal behaviour, [66] and may be encountered in adults and particularly children with dysfunctional voiding. [58]

The pubococcygeus in the healthy female reveals similar activity patterns to the urethral and anal sphincters at most detection sites: continuous activity at rest, often some increase of activity during bladder filling, and reflex increases in activity during any activation manoeuvre performed by the subject such as talking, deep breathing, coughing. The pubococcygeus relaxes during voiding; the muscles on either side act in unison. [32] In stress-incontinent patients, the patterns of activation and the co-ordination between the two sides can be lost;[67] a delay in muscle activation on coughing has also been demonstrated, as compared to continent women. [34]

Little is known about the complex activity patterns of different pelvic floor muscles (the urethral sphincter, urethrovaginal sphincter, anal sphincter muscle, different parts of the levator ani). It is generally assumed that they all act in a co-ordinated fashion functionally as one muscle. However there are demonstrable differences between the intra- and peri-urethral sphincter in healthy females [68] and in activation of the levator ani and the urethral sphincter. [69] Co-ordinated behaviour is frequently lost in abnormal conditions, as has been shown for the levator ani, urethral, and anal sphincter. [70-73] [83]

Kinesiological needle EMG analysis of the urethra with the patient at rest and coughing may predict the outcome after certain types of incontinence surgery. [74] In young men with a low urinary flow rate, EMG of the striated urethral sphincter may reveal that outflow obstruction is not due to bladder striated sphincter dyssynergia.

Current concepts suggest that defecation requires increased rectal pressure co-ordinated with relaxation of the anal sphincters and pelvic floor muscles. Pelvic floor relaxation allows opening of the anorectal angle and perineal descent, facilitating faecal expulsion. During straining puborectalis activity during evacuation measured by EMG was generally inhibited, (i.e., in 66 % of healthy subjects). The external anal sphincter was also inhibited during evacuation. However observations by EMG and defecography suggest that the puborectalis may not always relax during defecation in healthy subjects. Puborectalis activity measured by EMG was unchanged in 9 % and increased in 25 % of healthy subjects. [75] Thus, while "paradoxical" puborectalis contraction during defecation is used to diagnose pelvic floor dyssynergia in patients with typical symptoms, this finding may be related to variations from the normal.

i) EMG Changes in "Idiopathic" Faecal Incontinence

"Idiopathic" faecal incontinence refers to patients in whom this symptom is not attributable to an underlying neurological or other disorder. In women, anal sphincter injury during vaginal delivery and pudendal nerve injury caused by chronic straining and/or

vaginal delivery are commonly implicated to cause anal sphincter weakness in idiopathic faecal incontinence. With the advent of endoanal ultrasound, anal sphincter EMG is not used to define external anal sphincter defects. Since pudendal nerve latencies are inaccurate markers of a pudendal neuropathy, sphincter EMG may provide a sensitive measure of denervation (fibrillation potentials) and can usually identify myopathic (small polyphasic motor unit potentials), neurogenic (large polyphasic motor unit potentials) or mixed injury. In addition to the anal sphincter, the puborectalis muscle can also be examined. In a recent study, [76] 33 out of 51 (65 %) patients with "idiopathic" faecal incontinence examined by CNEMG had a neurogenic or mixed (i.e. neurogenic and myogenic) injury pattern in the external anal sphincter, 11 patients in the ischiocavernosus, and 19/44 patients in the puborectalis muscle. A neurogenic or mixed injury pattern confined to the external anal sphincter probably reflects involvement of the inferior rectal branch or intrasphincteric branches of the pudendal nerve. In contrast, involvement of the external sphincter and ischiocavernosus suggests a pudendal neuropathy, since direct trauma to 2 separate levels, (e.g., affecting the inferior rectal and perineal branches) seems unlikely in the absence of a clear history. CNEMG should be conducted if proximal neurogenic process, (e.g., affecting the spinal cord or sacral roots) is suspected on clinical grounds. The utility of CNEMG as a prognosticator of success after repair of sphincter defects deserves further study.

2. Pudendal nerve conduction tests

Measurement of motor conduction velocity is routinely used to evaluate limb motor nerves, distinguishing between a demyelinating and axonal neuropathy. To make the measurement requires access to the nerve at two well-separated points and measurement of the distance between them, a requirement that cannot be met in the pelvis. Another way to evaluate peripheral motor nerve function is the measurement of the distal (or terminal) motor latency of a muscle response, requiring only a single distal stimulation. [9] The muscle response is the compound muscle action potential (CMAP) or M wave. [9] Pudendal nerve terminal motor latency (PNTML) can be measured by recording with a concentric needle electrode from the bulbocavernosus, the EAS and the urethral sphincter muscles in response to bipolar surface stimulation placed in the perianal/perineal region. [77-79] The latencies differed, depending on the different techniques used.

The most widely employed technique to obtain pudendal distal motor latency relies on stimulation with a special surface electrode assembly fixed on a gloved index finger, known as the St Mark's stimulator. [80]

It consists of a bipolar stimulating electrode on the tip of the gloved finger with the recording electrode pair placed 8 cm proximally on the base of the finger. The finger is inserted into the rectum or vagina and stimulation is performed close to the ischial spine. Transvaginal stimulation can also be used. If a catheter-mounted electrode is used for recording, EMG responses from the striated muscle of the urethral sphincter can be obtained. The amplitude of this response theoretically reflects the number of excitable motor units in the striated urethral sphincter. Some studies report that the pudendal terminal motor latency increases with age. [81, 82] [83]

A number of studies have looked at PNTML in stress incontinence, [84, 85] in relation to vaginal delivery, [82, 86, 87] pelvic prolapse, [49, 88] and pelvic surgery. [88]

However, experts differ in their estimation of validity of the test, primarily because the reproducibility, sensitivity and specificity of the test are uncertain (in one study, approximately 50 % of patients with prolonged PNTML had normal anal canal squeeze pressures);[89].

Furthermore, in contrast to earlier studies, more recent studies suggest the test does not predict improvement, or the lack of improvement, after surgical repair of anal sphincter defects. [90] A prospective evaluation of anorectal physiologic tests in 90 patients with faecal incontinence did not find that PNTML results changed treatment decisions. [91] Indeed, the American Gastroenterological Association statement indicated that "PNTML cannot be recommended for evaluation of patients with faecal incontinence". [92] Currently, the utility of measuring pudendal nerve latencies in urinary incontinence is doubtful.

3. Anterior sacral root (cauda equina) stimulation

Anterior root stimulation has been used to study conduction of the sacral nerve roots.

Transcutaneous stimulation of deeply situated nervous tissue became possible with development of special electrical [93] and magnetic [94] stimulators. When applied over the spine, these stimulators acti-

vate the roots as they exit the vertebral canal. [95] This technique was applied to sacral root stimulation soon after the device became available. [7]

Electrical stimulation with needle electrodes at vertebral laminae Th12-L1 elicit M waves in the bulbocavernosus and EAS muscle. [96]

Needle EMG rather than non-selective surface electrodes should be used to record pelvic floor and particularly sphincter responses to electrical or magnetic stimulation of the cauda equina. These stimuli nonselectively depolarise underlying neural structures, thereby activating several muscles innervated by lumbosacral segments. Motor evoked potentials (MEP) are recorded less frequently with magnetic, compared to electrical stimulation. [8, 97] [8]

Temporary invasive percutaneous stimulation of individual roots in sacral foramina is used to identify patients with lower urinary dysfunction or faecal incontinence who are likely to benefit from long-term stimulation, e.g. with the Interstim (Medtronic, Inc.). This device delivers intermittent electrical stimulation to the sacral roots, for the treatment of intractable frequency and urgency, and idiopathic urinary retention. [98, 99] It is believed that the stimulation modulates the neural signals that result in the pathologic bladder symptoms. Prior to permanent implantation of the device, patients undergo percutaneous lead placements. Stimulation of the nerve roots at the level of the appropriate sacral foramina results in observable muscle contraction in the foot and perineum. These responses can be identified as MEP or reflex responses on the basis of their latency.

Demonstrating the presence of a perineal MEP on stimulation over lumbosacral spine may occasionally be helpful in patients without voluntarily or reflexly activated muscles; it may help differentiate sensory from motor limb involvement of the sacral reflex arc, and it also identifies the motor fibre component of a particular root before introducing therapeutic electrical stimulation. However, the clinical value of the test has yet to be established and there are no sensitivity and specificity data on test results in individual patients.

4. Motor evoked potentials

Using magnetic or electrical stimulation, it is possible to depolarise the motor cortex and record a response from the pelvic floor. [8, 100] Magnetic cortical stimulation is better tolerated than electrical stimulation, which has now been abandoned in awake subjects.

By performing the stimulation at two different sites (brain and spinal roots), it is possible to record three different conduction times: a total conduction time, a peripheral conduction time, and a central conduction time **(Figure 6)**. The total conduction time corresponds to the transit time from brain to target muscle. The peripheral conduction time is the transit time from sacral roots to the muscle. The central conduction time is obtained by subtracting the peripheral conduction time from the total conduction time. The total conduction time can be measured both at rest and during a facilitation procedure. [8]

MEPs from the EAS, [101-103] the urethral sphincter, [102] the bulbocavernosus muscle, [101, 103] and the levator ani muscle[101] have been reported. Recently, carefully collected normative values for the urethral sphincter and the puborectal muscle in adult women have been reported for transcranial magnetic stimulation. [104, 105] The necessity to

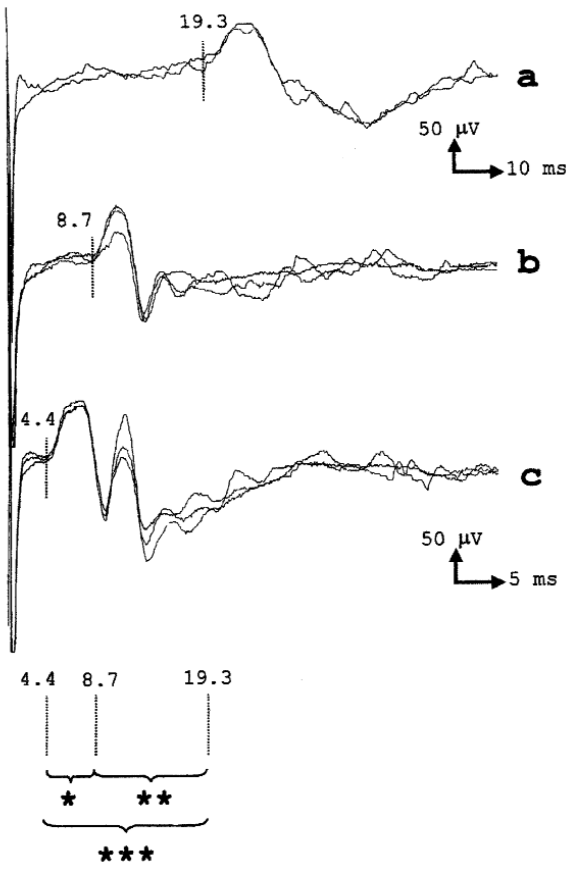


Figure 6. MEPs recorded by concentric needle in the external urethral sphincter of a 51-year-old-woman. Cortical (a), thoracic (b), and sacral (c) stimulation. Central motor conduction time (CMCT) is calculated as cortical - lumbar latency (** = 10.6 ms). Cauda equina motor conduction time is calculated as lumbar - sacral latency (* = 4.3 ms). (From [104], with permission).

use concentric needle EMG for recording[103] has recently been reconfirmed. [106]

Substantially longer central conduction times have been found in patients with multiple sclerosis and spinal cord lesions as compared to healthy controls. [107] However all patients in this study had clinically recognisable cord disease. Therefore, this technique does not contribute to the diagnosis. [108]

Conceptually, MEP may help to differentiate neuropathology between motor and sensory pathways. However, larger studies are necessary to clarify the clinical utility of these measurements.

II. SENSORY SYSTEM TESTS

There are several methods of sensory testing for the genitourinary and anorectal tract. Clinical neurological testing includes perineal and external genital skin sensation for light touch and pinprick, and sensation of bladder filling during cystometry. Anorectal sensory testing can be clinically assessed through rating of applied stimuli. More objective sensory testing can be performed with quantitative sensory testing (QST), assessing perception; and sensory neurography, and somatosensory evoked potentials (SEP), which evaluate the integrity of sensory pathways.

1. Sensory measurements during cystometry

During routine cystometry bladder sensation is assessed by recording first sensation of bladder filling, first desire to void and strong desire to void. [109]

The International Continence Society recommended the following specifications during sensory assessments: specify patient's position (supine, standing, other), bladder volume at time of testing, site of applied stimulus, number of times the stimulus was applied, number of responses recorded, sensation that was recorded (filling sensation, pulsing/throbbing sensation, etc.), and type of applied stimulus (electrical, mechanical, chemical, others). [110] The type of equipment, stimulus parameters, and absolute values as well as normal values for the specific system should be reported. During sensory testing, interaction (e.g., conversation) between the subject and investigator should be minimised to avoid bias. A semi-objective technique, in which subjects push buttons on a small key-pad device during cystometry to signal bladder sensations is an interesting advance. [111] Though thresholds evaluated by this technique are correlated with cystometric findings, [112] it is not widely employed in clinical practice.

Bladder and urethral sensory thresholds have also been measured during electrical stimulation, [113-117] and mechanical traction on the bladder trigone. [118] There is no established clinical use for any of these tests other than simple reporting of sensation during cystometry.

Another test applied during cystometry is cold testing. In vitro studies suggest the bladder has cold receptors. [119] The bladder cooling test has been evaluated in patients with and without neurological conditions as well as in normal controls. [120] Perception of cold was normal in all control subjects and in patients with stress-incontinence. The test has also been suggested as useful in provoking bladder instability, and in determining abnormalities in bladder sensation.

2. Assessment of anorectal sensation

Rectal sensation is assessed by progressively distending a latex balloon manually or a polyethylene balloon by a barostat while measuring thresholds for first perception, desire to defecate, and severe discomfort. [121] The barostat is a rigid piston within a cylinder that has a computer-controlled servo mechanism. Alternatively, the intensity of perception during rectal distension can be recorded by a visual analogue scale during phasic distensions of graded intensity. [122] The advantages of evaluating rectal sensation by a barostat as opposed to manual distension include a precise rate of distension, the ability to measure balloon pressure and volume, (i.e. compliance) and the potential for altering the rate of distension. The rate and pattern of distension affect rectal perception and internal sphincter relaxation. [123] Sensory assessments of the rectum are particularly useful for identifying sensory disturbances in patients with a rectal evacuation disorder or faecal incontinence. Correcting reduced rectal sensation by pelvic floor retraining (i.e., biofeedback therapy) can improve symptoms in these patients. [121, 124]

Anal sensation is assessed by determining the perception threshold to an electrical stimulus or temperature change in the anal canal. Electrosensitivity is nonphysiological and does not activate mucosal receptors. [92] Anal sensitivity to temperature change is reduced in faecal incontinence. [125]

3. Quantitative sensory testing

Quantitative sensory testing (QST) of the urogenitoanal system provides more objective and reproducible data than routine clinical testing. QST sensory modalities applied to the evaluation of urogenital function includes vibration , temperature, and electrical current. However, only limited experience exists for urogenitoanal QST. There is no commonly accepted, detailed, standardised test, and the specificity and sensitivity of the tests are not known. Thus, there is no established utility for QST in the evaluation of incontinence. The relationship of cutaneous quantitative sensory tests to bladder and urethral sensation and function is unknown. The physiological, psychophysiological and methodological issues and controversies will not be addressed in this chapter, and the reader is referred to in-depth reviews. [126]

4. Sensory neurography

Nerve conduction velocities of the dorsal nerve of the penis can be calculated by placing a pair of stimulating electrodes across the glans and a pair of recording electrodes across the base of penis. A nerve action potential can be recorded with an amplitude of about 10 μV. [127] It can also be recorded by stimulating trans-rectally [128] or transperineally. Limited reproducibility with a flaccid penis, can be overcome by a pharmacologically-induced erection, which extends the dorsal nerve. [129] There is no known association between penile sensory neuropathy and bladder/sphincter dysfunction.

5. Electroneurography of dorsal sacral roots

A few studies have recorded activity in sacral roots during electrical stimulation. During stimulation of dorsal penile and clitoral nerve, compound sensory action potentials may be directly recorded intraoperatively when the sacral roots are exposed. [130] This helps to preserve roots mediating perineal sensation in spastic children undergoing dorsal rhizotomy and reduce the incidence of postoperative voiding dysfunction. [131] These tests are limited to their very specific intraoperative indications.

6. Somatosensory evoked potentials (SEP)

Somatosensory evoked potentials are electric waveforms of biologic origin elicited by stimulation of a sensory nerve (or a sensory innervated area – dermatome). The most commonly performed tests in the urogenitoanal region are pudendal somatosensory evoked potentials (SEP), which assess conduction in large fibre pathways between the site of nerve stimulation and the parietal sensory cortex. Potentials can also be measured at the spinal level (spinal SEP). Visceral (thin) fiber pathways are assessed by recording SEPs while stimulating the proximal urethra and bladder, although this is technically not depolarization of nerves, but a mesh of afferents ("dermatome").

a) Pudendal somatosensory evoked potentials

• Cerebral SEP

On electrical stimulation of the dorsal penile/clitoral or perineal nerve, a cerebral SEP can be recorded. [6, 8, 132-137] **(Figure 7)** This SEP is as a rule of highest amplitude at the central recording site (Cz -2 cm : Fz of the International 10-20 EEG System)[138] and is highly reproducible – **Figure 8)**. The first positive peak at about 40 ms (called P1 or P40) is usually clearly defined in healthy subjects using a stimulus 2-4 times stronger than the sensory threshold. [132, 135] The presence and amplitude of subsequent negative (at c. 55 ms) and positive waves are quite variable between subjects. [6, 8, 134, 136]

Pudendal SEPs have been advocated in patients with neurogenic bladder dysfunction, e.g. in multiple sclerosis. However, even in patients with multiple sclerosis and bladder symptoms, the tibial cerebral SEP was more often abnormal than the pudendal SEP. The combination of an abnormal pudendal SEP with a normal tibial SEP suggests isolated conus involvement. [139] Moreover, the pudendal evoked potential was less useful than a neurological examination for identifying neurological disease in patients with uro-genital symptoms. [140] Classically described pudendal SEP techniques probably stimulate both dorsal penile/clitoral nerves, perhaps reducing the sensitivity of the test. However, newer techniques of pudendal SEP that isolate each dorsal penile/clitoral nerve may be more sensitive for identifying a pudendal neuropathy. [141] Following spinal cord injury, tibial and pudendal SEPs are of some value for predicting recovery in bladder control. [142] Cerebral SEP during penile/clitoral stimulation may be useful for intraoperative monitoring. [143, 144] Pudendal SEP were used to study the mechanism of sacral neuromodulation. [145]

• Spinal SEP

Stimulating the dorsal penile nerve and recording with surface electrodes at the level of the Th12-L2 vertebrae (and the S1, Th6 or iliac spine as reference) reveals the postsynaptic segmental spinal cord

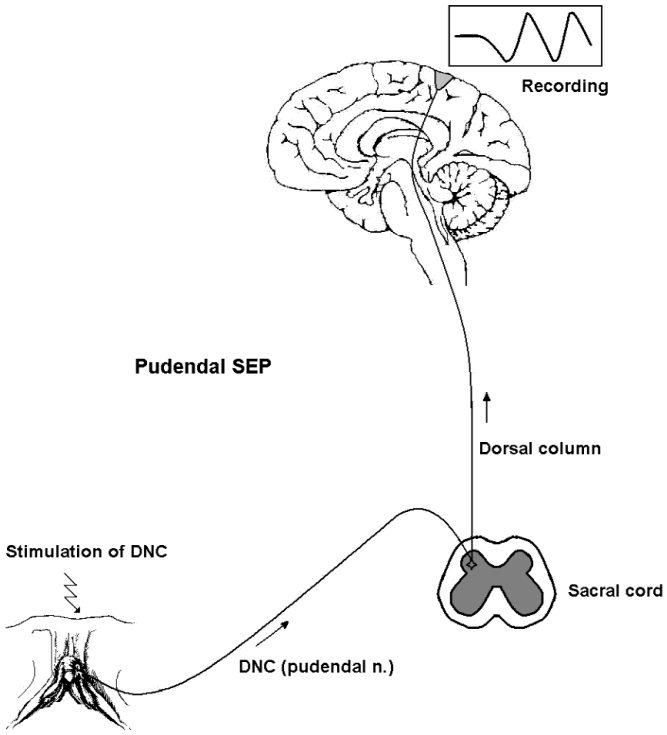


Figure 7. Pudendal somatosensory evoked potentials (SEP). Following depolarization of the pudendal nerve, the signal is carried through the dorsal column in the spinal cord to the somatosensory cortex. The recording is usually made with surface electrodes placed on the scalp overlying the interhemispheric cleft, where genital somatic sensation is mapped on the sensory cortex. A normal pudendal SEP waveform and latency demonstrates the integrity of the sensory axis from the dorsal nerve to the sensory cortex.

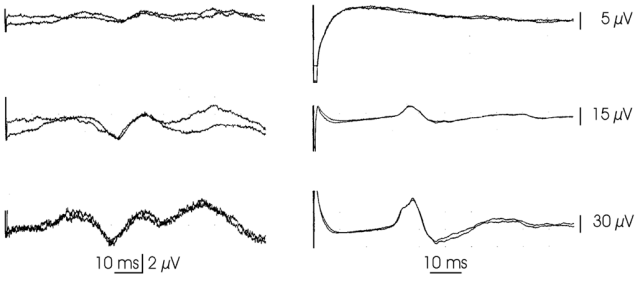


Figure 8. SEPs (traces on the left) and sacral reflexes (traces on the right) in a healthy woman. Cerebral SEPs are recorded from Cz - 2 cm; sacral reflexes from the anal sphincter. The dorsal clitoral nerve is being stimulated with rectangular electrical pulses at 2 Hz. Stimulation and recording is performed with surface electrodes. The cerebral SEP and sacral reflex are recorded simultaneously. In the upper row the stimulation is just above sensory threshold, in the middle row the stimulation is 1.5, and in the lower row at 2-times sensory threshold (pulse duration 0.2 ms; two consecutive averages of 128 responses are superimposed).

activity (the spinal SEP). [6, 8, 135, 146] **(Figure 9)** Unfortunately, this spinal SEP may be difficult to record in healthy obese male subjects and in women. [6, 8, 135] These recordings are not routinely performed.

b) Cerebral sep on electrical stimulation of urethra and bladder

Cerebral SEP can be recorded while stimulating the visceral afferents of the bladder mucosa[147], proximal urethra, and anorectum. [97] **(Figure 10)** When making such measurements, it is very important to use bipolar stimulation, to avoid depolarising somatic afferents. [102, 148] These cerebral SEPs have been shown to have a maximum amplitude over the midline (Cz -2 cm : Fz). [148] As the potential is of low amplitude (1 μV and less) and has a variable configuration, it may be difficult to identify in some control subjects. [146, 148] The typical latency of the most prominent negative potential (N1) has been reported to be about 100 ms, but data from different authors vary. [146, 148-150] Visceral SEPs theoretically are more relevant to neurogenic bladder dysfunction than the pudendal SEP, as the A-delta sensory afferents from bladder and proximal urethra accompany the autonomic fibres in the pelvic nerves[148] but data so far are limited. A comparison of SSR to urethral stimulation in spinal cord injury patients revealed SSR was superior for assessing the integrity of visceral afferent fibres. [151]

III. SACRAL REFLEXES

1. Terminology and Reflex Arcs

Of the sacral reflexes, the anal and bulbocavernosus reflex can be clinically evaluated. Both reflexes have afferent and efferent limbs in the pudendal nerve, and are centrally integrated at the S2 to S4 cord levels. The term "sacral reflexes" refers to electrophysiologically recordable responses of perineal/pelvic floor muscles to stimulation in the uro-genito-anal region **(Figure 11)**. It is possible to use electrical, [5, 149, 152, 153] mechanical, [154] or magnetic [97] stimulation at various sites to elicit these reflexes, and to record responses by electromyography from all the different pelvic floor/perineal muscles**.** Electrical stimulation can be applied at the dorsal penile nerve[5, 152, 153, 155, 156] the dorsal clitoral nerve, [132, 157-159] perianally, [144, 160], via the perineum, [161] at the bladder neck/proximal urethra, and to bladder mucosa –

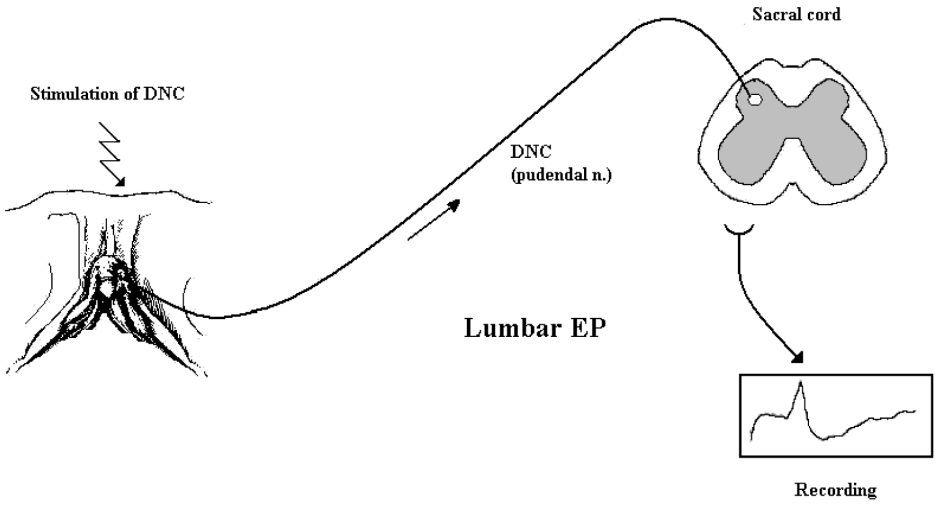


Figure 9 . Pudendal lumbar evoked potentials. Although it is theoretically possible to assess the sensory branches distal to the spinal cord with this technique, the low amplitude responses are often difficult to record.

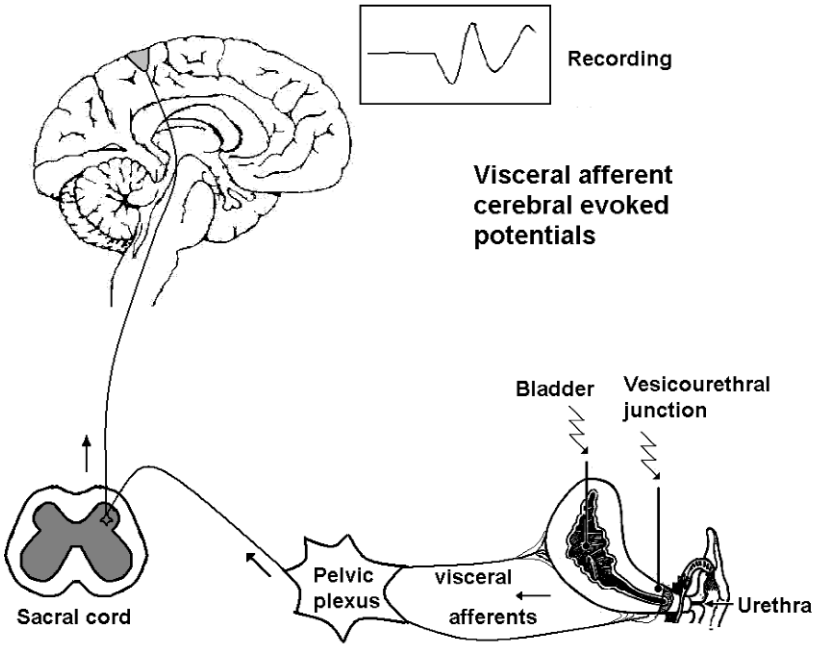


Figure 10. Visceral afferent evoked potentials to the cortex. Since the bladder wall and vesicourethral junction (VUJ) are innervated with visceral afferents, evoked potentials with the stimulation of these areas can give information about the integrity of pelvic visceral afferent pathways. The signal is carried via the pelvic plexus to the sacral spinal cord and a recording can be made from the somatosensory cortex. (Note that visceral sensation in general has not been well documented on the sensory cortex.)

using a catheter-mounted ring electrode[162, 163] (these have been referred to as "vesicourethral" and "vesicoanal" reflexes, depending from which muscle the responses are recorded). These latter reflexes have visceral afferents as the afferent arm. The pudendal nerve itself may be stimulated transrectally, transvaginally[164] or by applying needle electrodes transperineally. [165]

Electrical stimulation of the dorsal penile or clitoral nerve elicits (somatosomatic) sacral reflexes with mean latencies of 31 - 38.5 ms (**Figure 12**). [5, 132, 152, 155-159] Stimulation of the perianal skin, bladder neck or proximal urethra elicits sacral reflexes with mean latencies between 50 - 65 ms. [153, 160, 163] This latency is longer compared to responses conveyed by the pudendal nerve, suggesting that the afferent limb for these responses involves visceral afferent fibres accompanying the pelvic nerves, which are thinly myelinated and have a slower conduction velocity than the thicker pudendal afferents. With visceral denervation (e.g. following radical hysterectomy) the viscerosomatic reflexes (from both bladder and urethral stimulation) may be lost while the bulbocavernosus reflex is preserved. Loss of bladder-urethral reflex with preservation of bladder-anal reflex has been described with urethral afferent injury after recurrent urethral surgeries. [166]

The longer latency anal reflex (the contraction of the EAS on stimulation of the perianal region) is quite variable thus limiting its usefulness as a diagnostic tool. On perianal stimulation, a short latency response can also be recorded, as a result of depolarisation of motor branches to the EAS, possibly involving antidromic travelling of the depolarisation, with

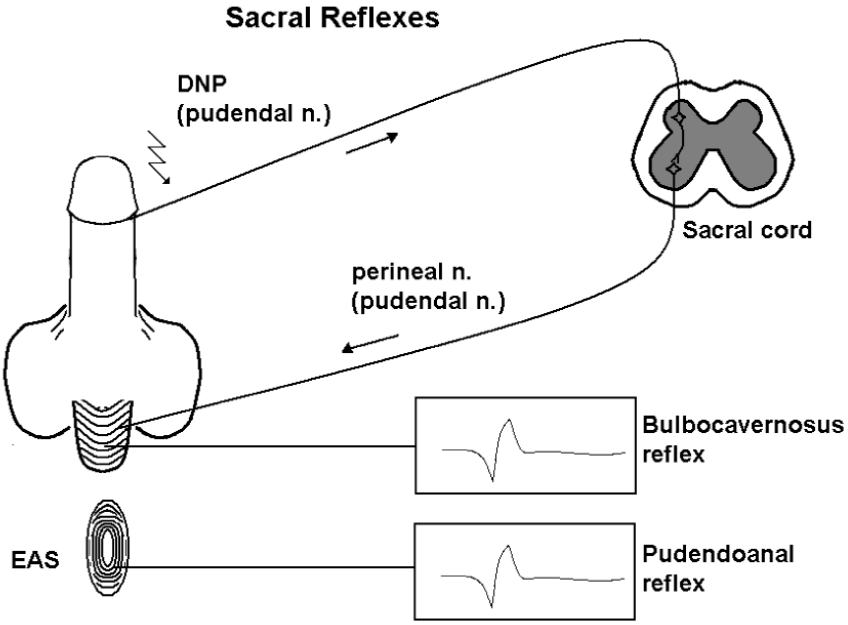


Figure 11. Sacral reflex arc. Following the depolarization of dorsal nerve of the clitoris (DNC), the signal is conducted through oligosynaptic connections in the sacral cord, and then carried through the perineal branch of the pudendal nerve to the bulbocavernosus and external anal sphincter muscles, where the recording can be made.

Figure 12. Concentric needle recording from the bulbocavernosus muscle on stimulation of dorsal penile nerve (with surface electrodes) in a 67-year-old healthy man. Upper beam shows the sacral reflex on just suprathreshold stimulation, the middle beam on stimulation increased by 30 percent, and lower beam on maximal tolerable stimulation (in this case 60 percent suprathreshold). Observe the early component of the sacral reflex being joined by the second component at stronger stimulation; the division in two components is blurred at very strong stimulation. Observe also the slight shortening of latency of the first component at stronger stimulation in comparison with just suprathreshold stimulation.-

"returning" of the depolarisation orthodromically to the sphincter at a branching point of the motor axon.

EMG recording of the bulbocavernosus reflex has been shown to be more reliable than the clinically assessed response (e.g. observing and palpating the contraction) in males and particularly in females. [167] The recording of the reflex latency should increase the sensitivity to record abnormalities, but true sensitivity and specificity of the test are not known. The test has been studied extensively and is used in many laboratories in everyday practice to demonstrate objectively the integrity of the S2-S4 reflex arc. As with other tests of conduction, it is not sensitive to partial axonal lesions.

2. Sacral reflex following electrical stimulation

The sacral reflex evoked on dorsal penile or clitoral nerve stimulation (the "bulbocavernosus reflex") was shown to be a complex response, often forming two components. [153, 156, 168] The first component with a typical latency of about 33 ms, is the response that has been most often called the bulbocavernosus reflex. It is stable, does not habituate, and has other attributes of an oligosynaptic reflex response. [168] The second component has a latency similar to the sacral reflexes evoked by stimulation perianally or from the proximal urethra. The second component is not always demonstrable as a discreet response. The two components of the reflex may behave somewhat differently in control subjects and in patients. In healthy subjects it is usually the first

component that has a lower threshold. In patients with partially denervated pelvic floor muscles, often the first reflex component cannot be obtained with single stimuli, but on strong stimulation the later reflex component does occur. [156] Using double stimuli facilitates the reflex response and may reveal in such a patient the first component, which was not obvious on stimulation with single stimuli. [169] A complete reflex arc lesion should not be inferred by absence of a response if only single pulse is used for stimulation. In children it has been shown that during voiding sacral reflexes are un-elicitable but in presence of spinal cord lesions such as myelodysplasia this normal suppression is lost. [170]

Sacral reflex responses recorded with needle or wire electrodes can be analysed separately for each side from the EAS or bulbocavernosus muscle. [156] Using unilateral dorsal penile nerve blocks, the existence of two unilateral BCR arcs has been demonstrated. [171, 172] Thus by detection from the left and right bulbocavernosus (and probably also the EAS) muscles separate testing of right and left reflex arcs can be performed. Sensitivity of the test can be increased by use of the inter-side latency difference (normative limits: < 3 ms). [172] In cases of unilateral (sacral plexopathy, pudendal neuropathy) or asymmetrical lesions (cauda equina), a healthy reflex arc may obscure a pathological one.

Continuous intraoperative recording of sacral reflex responses on penis/clitoris stimulation is feasible if double pulses[130, 173] or a train of stimuli are used.

Reflex responses of the external urethral sphincter to electrical penile stimulation have also been recorded with microtip transducer catheter as pressure rises, with latencies between 27 and 41 ms. [174]

3. Sacral reflex via mechanical stimulation

Mechanical stimulation has been used to elicit BCR in both sexes[175] and found to be a robust technique. Either a standard reflex hammer or a customised electromechanical hammer can be used. [154] Such stimulation is painless and can be used in children. The latency of the BCR elicited mechanically is comparable to the electrically elicited reflex in the same patients, but may be either slightly shorter or longer[154] because of particular electromechanical device used. [176]

4. Clinical applications of sacral reflexes in urinary incontinence

Sacral reflex responses on stimulation of the dorsal penile and clitoral nerve may be absent or delayed in incontinent patients with conus/cauda lesions. [101] [120] However, a reflex with a normal latency does not exclude the possibility of an axonal lesion in its reflex arc. Furthermore, much delayed sacral reflex responses are compatible with normal bladder and sexual function as found in patients with hereditary motor and sensory demyelinating neuropathy. [177]

Most reports deal with abnormally prolonged sacral reflex latencies, but a very short reflex latency raises the possibility of the tethered cord syndrome, [178] due to the low location of the conus and shorter nerve roots. Shorter latencies of sacral reflexes in patients with suprasacral cord lesions have also been reported. [157]

Sacral reflex recording was suggested as a supplementary test to CNEMG examination of pelvic floor muscles in patients with suspected peripheral nervous lesions. [17] [26] **(Figure 13).**

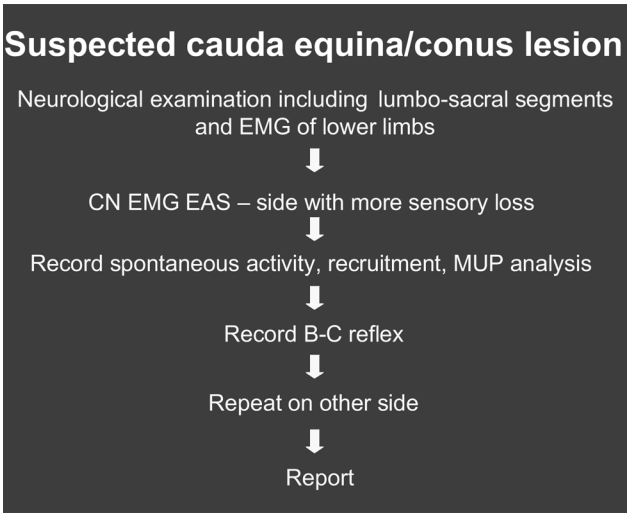


Figure 13. Protocol for examination of a patient with suspected cauda equina/conus lesion.

IV. AUTONOMIC NERVOUS SYSTEM TEST

Most uro-neurophysiological methods discussed so far assess myelinated fibres, but not the autonomic nervous system, especially the parasympathetic component, which is most relevant for pelvic organ functions. Methods for evaluating the autonomic nerves innervating the pelvic viscera are not available. Cystometry indirectly evaluates the parasympathetic innervation to the bladder. However, from a clinical

neurophysiological point of view direct electrophysiological testing would be desirable.

1. Tests in generalised autonomic neuropathy

Cardiovascular autonomic function tests are useful for identifying generalised autonomic dysfunction in patients with bladder or gastrointestinal motility disturbances[179] In cases when a general involvement of thin fibres is expected, an indirect way to examine autonomic fibres is to assess thin sensory fibre function .

Directed genito-urinary assessment of thin visceral sensory fibres are tested by stimulating the proximal urethra [180] or bladder, and by recording sacral reflex responses or cerebral SEP

2. Smooth muscle electromyography

Technical problems have limited smooth muscle electromyography of the detrusor muscle. [181] Depolarisation in detrusor muscle has been studied by EMG in the whole animal bladder. [182]

There has been some research in the area of genital smooth muscle electromyography, [183-185]but there is no evidence to prove their clinical utility in the evaluation of urinary tract function.

3. Sympathetic skin response (SSR)

The sympathetic nervous system mediates sweat gland activity in the skin. Changes in sweat gland activity lead to changes in skin resistance. On noxious stimulation (such as a sudden noise, electrical pulse, etc.) a potential shift can be recorded with surface electrodes from the skin of the palms and the soles, and has been reported to be a useful parameter in assessment of neuropathy involving non-myelinated nerve fibres. [186] The response, known as the sympathetic skin response (SSR), can also be recorded from perineal skin and the penis. [187-190] The SSR is a reflex, which consists of myelinated sensory fibres, a complex central integrative mechanism and a sympathetic efferent limb with postganglionic nonmyelinated C fibres.

SSR is the only electrophysiological method directly testing sympathetic fibres. Limited literature exists regarding the relationship between SSR results and bladder dysfunction. One study reports that diabetic cystopathy was associated with autonomic neuropathy as detected by SSR. [191] A correlation has been shown between the absence of the SSR response in the foot and bladder neck dyssynergia following spinal cord injury;[192] recording from the perineal region increases the diagnostic sensitivity for assessing sympathetic nerve function within the thoracolumbar cord. [193]

The test is not sensitive for partial lesions as only complete absence of response can be regarded as abnormal. Its utility in evaluating bladder and urethral dysfunction is not established.

C. GENERAL COMMENTS ON NEUROPHYSIOLOGICAL TESTING

I. EVIDENCE BASED USE, CRITERIA FOR ABNORMALITY, SENSITIVITY AND SPECIFICITY OF CLINICAL NEUROPHYSIOLOGICAL TESTS

Evidence-based medicine is founded on the assessment of evidence for and against the efficacy of particular types of therapeutic intervention. Clinical neurophysiology testing should thus demonstrate evidence that testing improves outcome (through treatment choice and patient selection), which would provide a strong basis for its use. However, testing and therapeutic intervention are different concepts, and neurophysiological testing has another important objective, which is not applicable to interventions and lies outside the scope of evidence-based medicine. It is to generate knowledge about the situation to be treated in a given patient, so that the practitioner can formulate rational treatment options based on knowledge rather than do so blindfold; that is, he or she can practice “knowledge-based medicine” (Griffiths et al, see Chapter on Functional testing).

To judge the importance of this second objective different criteria are needed. Particularly in the referral setting, the physician is confronted with complicated cases in whom the underlying pathophysiology is quite uncertain, and what is required is to identify all the factors that may be contributing. Neurophysiology is necessary in assessment of neurogenic dysfunction because it contributes to “knowledge-based medicine”, whether or not there is narrowly-defined “evidence” that it improves outcomes.

Of course, it remains true that we should seek evidence of the conventional kind for and against testing. The co-sponsor of this consultation (the ICUD) recommends that, as a minimum, any test should be subjected to three questions:

1. Does the test have good technical performance, for example, do three aliquots of the same urine sample give the same result when subjected to 'stix' testing?
2. Does the test have good diagnostic performance, ideally against a "gold standard" measure?
3. Does the test have good therapeutic performance, that is, does the use of the test alter clinical management, does the use of the test improve outcome?

All these questions are relevant for clinical neurophysiology, and in this chapter we have attempted to provide some answers.

Clinical diagnosis requires that measures obtained in individual patients be compared to population norms with the intent of determining whether they are "normal" or "abnormal". Data can be classified as "abnormal" only with the understanding that they are compared to a sample from the normal population. Predictive statements are made possible by the use of tolerance limits. For most clinical neurophysiological tests, one-tailed tolerance limits are recommended. For any given limit of normality, there is a certain probability of falsely interpreting values (obtaining false-positives or false-negatives). Further confounding these issues is the practice of applying multiple criteria of abnormality. But ultimately, the adequacy of any given normal limit in discriminating between normal and abnormal must be supported by appropriate clinical or clinico-pathological correlations; for uroneurophysiological techniques, such data are scarce.

II. USEFULNESS OF CLINICAL NEUROPHYSIOLOGICAL TESTS IN EVALUATION OF INDIVIDUAL PATIENTS WITH LOWER URINARY TRACT OR ANORECTAL DYSFUNCTION

Whenever pathophysiology is uncertain or unpredictable, and especially if irreversible treatment is necessary or contemplated, it is an ethical requirement to gather quantitative knowledge of the dysfunction in order to make a rational treatment choice. In such situations, the aim of clinical neurophysiological evaluation is to identify all factors contributing to the dysfunction, expected or unexpected; therefore the evaluation must be comprehensive. In most patient groups with neurogenic incontinence, the pathophysiology is unpredictable and comprehensive urodynamic evaluation is essential in order to practice knowledge-based medicine; in selected patients from these groups, clinical neurophysiological testing will clarify issues related to the neural control of lower urinary tract, relevant for understanding pathophysiology. Most patients, however, will not require a precise definition of the neurological lesion.

As is generally true for electrophysiological tests, uroneurophysiological examinations are particularly useful for substantiating the clinical diagnosis of a peripheral nerve lesion. The potential usefulness of testing in an individual patient needs to be analysed in the overall clinical setting. The indications for testing are guided primarily by expert opinion, not on definitely established criteria derived from controlled studies.

In the incontinent patient without other signs or symptoms of a neurologic condition, neurophysiological testing is generally unnecessary.

III. USEFULNESS OF CLINICAL NEUROPHYSIOLOGICAL TESTS IN RESEARCH

Uro-neurophysiological techniques have been most often applied in research. They were used to substantiate hypotheses that a proportion of patients with sacral dysfunction, such as stress urinary and idiopathic faecal incontinence, have involvement of the nervous system;[49, 50, 80, 86] to assess the integrity of the sacral nervous system in patients with suprasacral spinal cord injury;[194] to identify consequences of particular surgeries;[195] to elucidate the innervation of pelvic floor muscles;[153, 196, 197], to study the physiology of contraction of sphincter muscle, [198] and to describe activation patterns of pelvic floor muscles. [32, 67] Suggestions of increased efficacy of sacral neurostimulation with the use of neurophysiologic tests have been made. [145, 199]

D. RECOMMENDATIONS

I. CLINICAL RECOMMENDATIONS

The available neurophysiological tests and their clinical utility are summarised in **Table 1.**

The information gained by clinical examination and urodynamic testing may be enhanced by uroneurophysiological tests in selected patient groups with urinary incontinence, particularly those with lesions within the peripheral nervous reflex arc.

Clinical neurophysiological testing should be performed in accredited laboratories, by trained and certified staff, with formal control of the quality of the results. Ideally, the uroneurophysiologist should be in liaison with general clinical neurophysiologists.

It seems optimal to create interdisciplinary programs between urology, urogynecology, proctology, and neurology departments. Organisation of such teams in tertiary medical centres should be encouraged.

II. RECOMMENDATION FOR TECHNICAL STANDARDS

Methods for external anal sphincter CNEMG have been standardised. [17] [26] A similar effort should be done for other perineal/pelvic floor muscles, and for the sacral reflex recording. [17, 200]

It should be mentioned that even in "general" clinical neurophysiology there is no consensus on standardisation of tests. This is mainly due to different historical backgrounds of testing developed in different laboratories; the need to standardise methods is, however, recognised.

At this stage, the authors repeat the suggestions for technical standards for CNEMG (**Table 2**) and the sacral reflex on penile/clitoral stimulation (the "bulbocavernosus" reflex) (**Table 3**). [1, 2]

III. RESEARCH RECOMMENDATIONS

Further research is recommended both to further explore, validate and standardise some current tests that appear promising, as well as to explore development of new techniques.

Clinical neurophysiological methods should be used to define the neural control in lower urinary tract function, demonstrating both the nervous system's "hardware" (integrity of anatomy) as well as "software" (level of activity, excitation thresholds…) for co-ordinated urinary storage and voiding, in physiological and in pathological conditions.

Several lower urinary tract dysfunction syndromes are known or suspected to have a neurogenic component; these issues should be further clarified.

1. Currently Used Tests

A. Explore

a. Kinesiological EMG in SUI, urgency/frequency

b. Clinical value of computerised EMG analysis data

c. Standardisation of urethral sphincter CNEMG; normative data

B. Explore motor and sensory conduction studies, in relation to

a. Standardisation and validation of stimulation and recording techniques

b. Reproducibility

c. Gender, age, vaginal parity effects

d. Correlation with symptoms and functional and stuctural information gained by urodynamic testing and imaging

e. Clinical role definition in Stress Urinary Incontinence

f. Intraoperative monitoring

C. Explore sacral reflexes

a. Standardisation for urethral/bladder stimulation

b. Reproducibility

c. Gender, age, vaginal parity effects

d. Correlation with symptoms and functional and stuctural information gained by urodynamic testing and imaging

e. Clinical role definition in surgical procedures and predicting therapy outcomes.

f. Differential involvement of BCR and viscerosomatic sacral reflexes (and pudendal and visceral SEP) in patients with very localised lesions.

Table 1. Electrodiagnostic tests.

Test	Technical Performance* (good, fair, poor, unknown)	Diagnostic Performance# (good, fair, poor, unknown)	Therapeutic Performance+ (good, fair, poor, controversial, research only)
Kinesiological EMG	Good	Fair	Good, Grade C
CNEMG	Fair	Good,	Grade C
SFEMG	Fair	Fair	Poor, Grade C
PNTML	Good	Poor	Controversial, Grade D
Anterior Sacral Root Stimulation	Unknown	Unknown	Research only
Motor Evoked Potentials	Unknown	Unknown	Poor, Grade C
Quantitative Sensory Testing	Variable (different techniques)	Unknown	Research only
Pudendal Cerebral SEP	Good	Fair	Poor, Grade B
Pelvic Visceral SEP	Unknown	Unknown	Research only
Sacral reflex test	Good	Good,	Grade B
Viscero-somatic reflex	Unknown	Unknown	Research only
Autonomic testing	Variable (different techniques)	Fair	Research only

This table is a summary of existing electrodiagnostic tests, with the ICUD criteria for Methods of Assessment and Investigation applied to them. The majority of the assignments are based on expert opinion, as the literature is limited. See text for full explanations of each test.

*Technical performance refers to reproducibility and reliability of test results

#Diagnostic performance refers to sensitivity/specificity of test

+Therapeutic performance refers to the test's ability to alter clinical management and/or improve outcome.
Grading based on the Oxford System:

Grade A recommendation usually depends on consistent level 1 evidence and often means that the recommendation is effectively mandatory and placed within a clinical care pathway

Grade B recommendation usually depends on consistent level 2 and or 3 studies, or 'majority evidence' from RCT's

Grade C recommendation usually depends on level 4 studies or 'majority evidence' from level 2/3 studies or Delphi processed expert opinion

Grade D "No recommendation possible" would be used where the evidence is inadequate or conflicting

Table 2. Suggested technical standards for concentric needle EMG.

a. Type of electrode	*concentric needle;*
b. Placement of electrodes	*transcutaneous, (guided by palpation);*
c. Specifications of signal processing equipment (and its setting)	*stand. EMG equip.; filters 5 Hz -10 kHz, 10 ms/div., 50-500 μV/div. (further defined with particular algorithm for analysis); multi-MUP or single-MUP analysis*
d. Decision algorithms	*detection of pathologic spontaneous activity; quantification of MUPs*
e. Normative data see [16, 20]	

Table 3. Suggested technical standards for sacral (bulbocavernosus) reflex testing.

a. Type of electrodes for stimulation	*surface;*
b. Type of stimulation	*electrical, 0.2 ms duration of single stimulus, "supramaximal" strength, manual triggering, 10 repetitions; if absent, use double pulse stimulation, or train of stimuli;*
c. Placement of stimulating electrodes	*penis / clitoris;*
d. Type of electrodes for recording	*concentric needle or surface;*
e. Placement of recording electrodes	*subcutaneous EAS; in males also bulbocavernosus muscle;*
f. Specifications of signal processing equipment (and its setting)	*standard EMG equipment, filters 10 Hz - 10 kHz, 10 ms/div., 50-1000 μV/div.; documentation facilities;*
g. Decision algorithms for analysis	*presence; optional – minimal latency of 10 consecutive responses (onset);*
h. Normative data *[79, 172]*	

a) New Technology Developments

a. Methodologies for kinesiological EMG

b. Advanced surface EMG analysis

c. Sacral parasympathetic evaluation

d. Detrusor muscle EMG

2. Gaining New Insights into LUT Pathophysiology

a. Neurophysiological changes induced by therapeutic electrostimulation

b. Selection of patients, and outcome correlates for therapeutic electrostimulation

c. The role of clinical neurophysiology for choice of treatment of urinary incontinence in defined patient groups

3. Lower Urinary Tract Dysfunction Syndromes

a. The role of sensory dysfunction should be explored.

b. The role of neurogenic versus "myopathic" involvement of pelvic floor muscles in idiopathic urinary stress incontinence, prolapse, and idiopathic faecal incontinence should be further clarified.

c. The pathophysiology of dysfunctional voiding and defaecation should be explored by a combination of techniques including EMG.

d. The relatively recently introduced clinical entity – young women with urinary retention and pathological repetitive discharges on urethral sphincter CNEMG – should be further explored, preferably in a multicenter study, using a combination of symptom assessment, EMG, urodynamic tests and imaging.

E. APPENDIX

ANALYSIS OF THE CONCENTRIC NEEDLE EMG SIGNAL

There are two approaches to analysis of the bioelectrical activity of motor units, either analysis of individual MUPs or analysis of the overall activity of intermingled MUPs (the "interference pattern"- IP). Generally three techniques of MUP analysis (manual-MUP, single-MUP and multi-MUP) and 1 technique of IP analysis (turn/amplitude – T/A) are available on advanced EMG systems. [20] [28]

First technique of MUP analysis follows an algorithm similar to the original protocol used by Buchthal and his school, [201] who measured MUP duration and amplitude from paper prints made from oscilloscope. In advanced EMG systems instead of measurements from the paper, MUPs are analysed from the screen. Several seconds of continuous EMG activity during relaxation or at slight reflex/voluntary activation from an individual site are "frozen" on the screen. Signals are then visually examined for the content of individual MUPs, which may then be measured automatically by the EMG system. Although duration cursors are set automatically by the EMG system, they should always be checked and reset by the operator if necessary. Using this modified "manual-MUP" analysis the highest number of MUPs (up to 10) can be obtained from the particular examination site. It takes 2-3 minutes for each site to

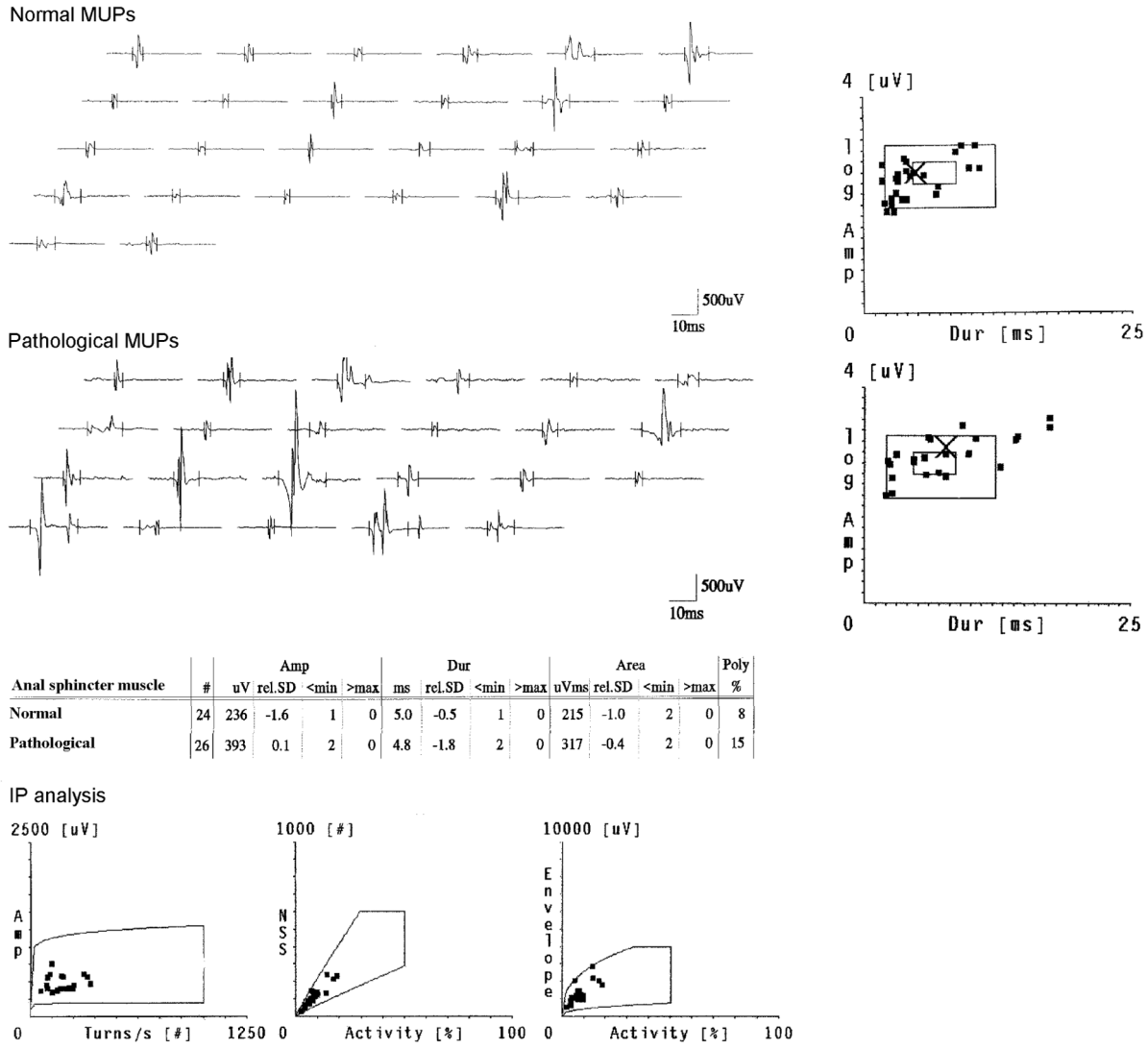
be analysed. This technique is demanding for the operator because reproducible MUPs have to be identified, the one with the smoothest baseline chosen, and in most cases the duration cursors set by the operator manually. The technique is inevitably open to personal bias, especially the determination of MUP duration. At slightly higher levels of voluntary or reflex activation the baseline becomes unsteady, making the technique unreliable – it can be applied only at low levels of activity. [20] [28]

The introduction of the trigger and delay unit led to its widespread use for MUP analysis. [202] During a constant level of EMG activity the trigger unit is set (on each examination site) on the highest amplitude steadily firing MUP. The triggered MUP is averaged until the baseline becomes smooth, which takes about 1-min for each MUP. At each site 1-3 MUPs can usually be obtained. Single-MUP analysis is quite time consuming, and provides fewer MUPs than the previously described technique. It is biased towards high amplitude and high threshold MUPs, and furthermore to personal bias as far as the choice of MUP. [20] [28] However, single-MUP analysis is still the technique that is currently most often used in quantitative analysis of MUPs, because it is widely available for a number of years.

The most recent and sophisticated CNEMG techniques are available only on advanced EMG systems; such is the template operated "multi-MUP" analysis. [203] **(Figure 14)** Here, the operator indicates – during the appropriate level of the crisp EMG activity – when the computer takes the previous (last) 4.8-sec period of the signal. From that signal MUPs are automatically extracted, quantified and sorted into 1-6 classes. [203] Each class represents consecutive discharges of a particular MUP. MUP classes are then averaged and presented (in descending order) according to the number of MUP discharges in the analysed period. [203] Cursors are set automatically using a computer algorithm. The operator has to edit the MUPs; duplicates (MUPs that appear more than once) and "problematic" MUPs (with unclear beginning or the end because of unsteady baseline) are discarded. Thus on each examination site 1-6 different MUPs can be obtained using this technique. [16] [24] Multi–MUP analysis is the fastest and the easiest to apply of the three mentioned quantitative MUP analysis techniques. It can be applied at continuous activity during sphincter muscle relaxation, as well as at slight to moderate levels of activation. [19] [27] Cursors are set automatically, and only exceptionally manual correction is needed. It is suggested that such problematic MUPs, with unsteady baseline and unclear beginning or end, are better discarded. [16] [24] The multi–MUP technique has, however, difficulties with highly unstable and/or polyphasic MUPs found particularly in patients with lower motor neuron lesions; it often fails to sample them, distorts them by averaging, or sorts the same MUP to several classes (recognises it as different MUPs – duplicates). Multi-MUP samples slightly lower number of MUPs per muscle, compared to manual-MUP. [20]

In the small half of the sphincter muscle collecting ten different MUPs has been said to be a minimal requirement on using single-MUP analysis. Using manual-MUP and multi-MUP techniques sampling of 20 MUPs (standard number in limb muscles) from each EAS makes no difficulty in healthy controls[16] [24] and most of patients. [20] [28] Normative data obtained from the EAS muscle by standardised EMG technique using all three MUP analysis techniques (multi-MUP, manual-MUP, single-MUP) have been published. [20]

Several MUP parameters have proven empirically useful in examining limb muscles in the diagnosis of neuromuscular disease. Traditionally, amplitude and duration were measured, and the number of phases was counted[201] Amplitude is the voltage (mV) difference between the most positive and most negative point on the MUP trace **(Figure 15)**. The amplitude of MUPs is largely determined by the activity of those muscle fibres closest (within a 0.5 mm radius) to the recording electrode, where in the normal MU it is unlikely to find more than 2-3 muscle fibres. [14] [22] It is highly sensitive to needle position and even minor adjustments of the electrode result in major amplitude changes, i.e. a change in position by 0.5 mm alters the amplitude 10-100 fold. The MUP duration is the time (ms) between the first deflection and the point when MUP waveform finally returns to the baseline (Figure 12). It depends on the number of muscle fibres of particular MU within 2-3 mm diameter and is little affected by the proximity of the recording electrode to the nearest fibre. [14] [22] The difficulty with duration measurement is in definition of the beginning and end of MUP. Using manual positioning of duration cursors depends on amplifier gain: at higher gain MUPs seem longer. Advanced EMG systems use algorithms including besides minimal amplitude of the trace deflection also the angle of the MUP trace towards the baseline. [203] It was agreed for automated analysis not to include late MUP components (defined "satellite potentials" i.e.



Anal sphincter muscle	#	Amp uV	Amp rel.SD	Amp <min	Amp >max	Dur ms	Dur rel.SD	Dur <min	Dur >max	Area uVms	Area rel.SD	Area <min	Area >max	Poly %
Normal	24	236	-1.6	1	0	5.0	-0.5	1	0	215	-1.0	2	0	8
Pathological	26	393	0.1	2	0	4.8	-1.8	2	0	317	-0.4	2	0	15

Figure 14. Comparison of normal (above) and pathological (below) motor unit potentials (MUPs) sampled by multi-MUP analysis from the right halves of the subcutaneous parts of the external anal sphincter (EAS) muscles. To the right logarithm (amplitude) vs. duration plots of the MUPs are shown; the inner rectangle presents normative range for mean values, and the outer rectangle for "outliers". Below the MUP samples values are tabulated. Three plots on the bottom were obtained by turn/amplitude analysis in the cauda equina patient. Delineated areas ("clouds") present the normative range, and dots individual IP samples.

The normal subject was a 45-year-old woman without pelvic floor dysfunction or abnormalities on neurological examination. Results of MUP and interference pattern (IP) analysis were normal. The pathological sample was obtained from a 36-year old man with damage of the cauda equina caused by central herniation of the intervertebral disc 13 months before the examination. On clinical examination perianal sensation was severely diminished bilaterally. No spontaneous denervation activity was present at the time of the above recording. Mean values for MUP amplitude and area are above normative range, and polyphasicity is increased. In addition, for all presented MUP parameters individual values of more than 2 MUPs are above the "outlier" limits (Table). Note that IP analysis in the patient is within normative range in spite of marked MUP abnormalities.

part of MUP starting at least 3 ms after the end of main part of the MUP. [9, 15, 203] [9, 23, 229] However extreme prolongation of motor units by small, late potentials, often with an intervening isoelectric period are a common finding in some pathological conditions affecting the innervation of the anal sphincter and have therefore been included in manual methods of analysis. [26] [34] Utility of MUP analysis in patients with suspected multi system atrophy (MSA) seems to depend critically on inclusion of late MUP components. [27] [35]

The number of MUP phases is defined by the number of times the potential crosses the baseline. It is counted as "number of baseline crossings plus one" **(Figure 15**). [15] Number of phases or percentage of polyphasic MUPs in muscle can be determined. MUPs are usually called polyphasic when they have at least four phases (mono-, bi-, tri-, and polyphasic), although some authors have defined "polyphasic" as those MUPs having more than four, [23] [31] or even more than five phases. [35] [47] Related to the number of phases is the MUP parameter "number of turns". A turn is defined as a change in direction of the MUP trace, which is larger than specified amplitude but not crossing the baseline **(Figure 15).** Number of turns is MUP parameter particularly sensitive to reinnervation changes in small muscles such as the EAS. [16] [24]

With the on-line computer analysis available on advanced EMG systems a number of further MUP parameters are available, including MUP area, rise time of negative peak, duration of negative peak can be measured. [16, 203] [24, 229] In addition, "thickness" (thickness = area/amplitude)[29] [37] and size index (size index = 2*log (amplitude (mV)) + area/amplitude)[204] can be automatically calculated. In a recent study using advanced statistical methods only MUP parameters area, duration and number of turns were demonstrated to be needed in quantitative MUP analysis. [205]

At higher levels of voluntary and reflex activation, normally a dense IP can be seen. The IP can also be assessed using a number of automatic quantitative analyses, the turn/amplitude (T/A) analysis being the most popular. [206, 207] On applying T/A analysis, with the needle electrode in focus, subjects contract muscle voluntarily or reflexly by coughing. Examinator selects 0.5-sec time epochs of the crisp EMG signal to be analysed using several IP parameters measured automatically by the EMG system. Sampling of IPs using T/A analysis is even faster than multi-MUP analysis. [16] [24] However, sensitivity of IP analysis for detecting neuropathic changes in the EAS muscle of patients with chronic sequels after cauda equina or conus medullaris damage, is only about half of sensitivities of different MUP analysis techniques. [20] [28]

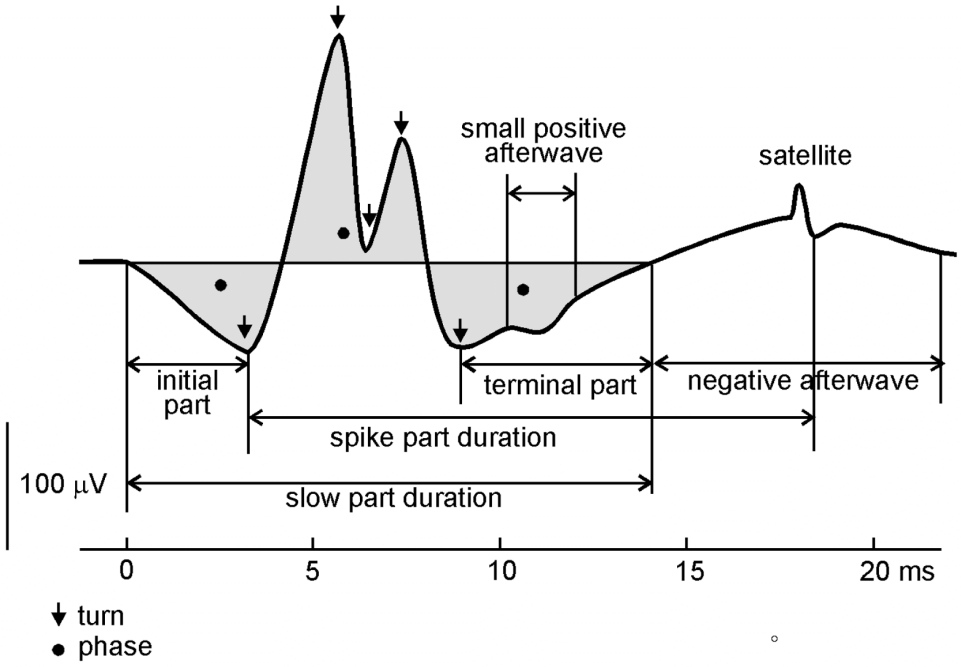


Figure 15. Schematic representation of the Motor Unit Potential to demonstrate different components, and parameters analysed (modified from [16]).

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