Neurophysiology of the pelvic floor in clinical practice: a systematic literature review

Francesca Bianchi, MD[a†]
Giovanna Maddalena Squintani, MD[b†]
Maurizio Osio, MD[c]
Alberto Morini, MD[d]
Cristina Bana, MD[e]
Gianluca Ardolino, MD[e]
Sergio Barbieri, MD, PhD[e]
Laura Bertolasi, MD[f]
Riccardo Caramelli, MD[g]
Filippo Cogiamanian, MD[e]
Antonio Currà, MD[h]
Giuseppe de Scisciolo, MD[g]
Camillo Foresti, MD[i]
Vittorio Frasca, MD, PhD[l]
Emma Frasson, MD[m]
Maurizio Inghilleri, MD, PhD[l]
Luca Maderna, MD[n]
Luisa Motti, MD[o]
Emanuela Onesti, MD[l]
Marcello Calogero Romano, MD[p]
Ubaldo Del Carro, MD[q]

[†]These Authors contributed equally to this work.

[a] Department of Neurology and INSPE, IRCCS San Raffaele, Milan, Italy
[b] Neurology Unit, Neuroscience Department, Azienda Ospedaliera Universitaria Integrata, Verona, Italy
[c] Clinical Neurophysiology Unit, Department of Neurology, ASST Fatebenefratelli Sacco, Milan, Italy
[d] Neurophysiology Unit, Department of Neurology, Ospedale Santa Chiara, Trento, Italy
[e] Clinical Neurophysiology Unit, Department of Neurosciences and Mental Health, Fondazione IRCCS Cà Granda, Ospedale Maggiore Policlinico, Milan, Italy
[f] Department of Neurological Sciences and Vision, Section of Clinical Neurology, University of Verona. Verona, Italy
[g] SOD Neurophysiology, Department NeuroMuscolar Scheletric and Sensory Organs, Azienda Ospedaliero-Universitaria Careggi, Florence, Italy
[h] Academic Neurology Unit, Department of Medical-Surgical Sciences and Biotechnologies, Ospedale A Fiorini, Terracina, LT, Sapienza University of Rome, Rome, Italy
[i] Clinical Neurophysiology Unit, Department of Neurology, Ospedale Papa Giovanni XXIII, Bergamo, Italy
[l] Department of Neurology and Psychiatry, Sapienza University of Rome, Rome, Italy
[m] Neurology Unit, Ospedale Civile di Cittadella, ULSS6 Euganea, Cittadella, Italy
[n] Department of Neurology, IRCCS Istituto Auxologico Italiano, Milan, Italy
[o] Clinical Neurophysiology Unit, Department of Neurology, Arcispedale S. Maria Nuova - IRCCS, Reggio Emilia, Italy
[p] Department of Neurology, AOOR Villa Sofia Cervello, Palermo, Italy
[q] Department of Neurology and INSPE, University Vita-Salute San Raffaele, IRCCS San Raffaele, Milan, Italy

Correspondence to: Francesca Bianchi
E-mail: bianchi.francesca@hsr.it

Summary

Neurophysiological testing of the pelvic floor is recognized as an essential tool to identify pathophysiological mechanisms of pelvic floor disorders, support clinical diagnosis, and aid in therapeutic decisions. Nevertheless, the diagnostic value of these tests in specific neurological diseases of the pelvic floor is not completely clarified. Seeking to fill this gap, the members of the Neurophysiology of the Pelvic Floor Study Group of the Italian Clinical Neurophysiology Society performed a systematic review of the literature to gather available evidence for and against the utility of neurophysiological tests. Our findings confirm the utility of some tests in specific clinical conditions [e.g. concentric needle electromyography, evaluation of sacral reflexes and of pudendal somatosensory evoked potentials (pSEPs) in cauda equina and conus medullaris lesions, and evaluation of pSEPs and perineal sympathetic skin response in spinal cord lesions], and support their use in clinical practice. Other tests, particularly those not currently supported by high-level evidence, when employed in individual patients, should be evaluated in the overall clinical context, or otherwise used for research purposes.

KEY WORDS: electromyography, evoked potentials, neurophysiology, pelvic floor, sacral reflex.

Introduction

Pelvic floor and uro-genital-anal functions rely on a complex neural control system, the integrity of which can be evaluated by clinical examination and diagnostic tools. Electrodiagnostic tests represent a valid method for studying the functional integrity of neural pathways, localizing a pathological process, and possibly revealing its mechanism and severity (Olsen and Rao, 2001; Podnar and Vodusek, 2001a). However, a neurophysiological battery should be tested for its sensitivity and specificity in different diseases and tailored to the clinical and anatomical context (Podnar and Vodusek, 2001b). Moreover, a test's sensitivity and specificity may depend on variables such as diagnostic criteria and normal values (Podnar, 2004a).
A variety of neurophysiological techniques can be applied to study perineal disorders of neurogenic origin, but their clinical value is still questioned. In particular,

abnormal test results may reveal altered function of the structure examined and yield information about the underlying pathogenetic mechanism of neurological diseases or lesions. Conversely, in other clinical scenarios, for example in the presence of syndromes or symptoms having a different etiology or pathogenetic mechanism (e.g., 'generic' urgency or urinary retention, fecal incontinence or constipation, and pelvic pain), or when no clearly defined independent a priori criteria for the 'neurogenic' origin of the symptoms are met, the pathogenetic relevance of an altered test result can often only be assumed. Most of the literature reviews on pelvic floor neurophysiology published to date suggest recommendations on the clinical use of diagnostic tests that are based on expert opinion (Olsen and Rao, 2001; Lefaucheur, 2006; Podnar, 2007). However, a systematic literature analysis involving a selection of the most relevant studies and evaluation of their methodological quality is lacking. We performed a systematic literature review on the usefulness of neurophysiological tests in pelvic floor diseases with the aim of providing clinicians with evidence-based recommendations on their use in clinical practice.

Methods

The key research question was the diagnostic utility of neurophysiological tests in pelvic floor disorders occurring in well-defined neurological diseases. The literature search was conducted on PubMed/Medline, Scopus and Cochrane databases. The databases were searched for eligible articles from their inception date through June 2016 using Medical Subject Headings (MeSH) terms or free terms. Whenever free search terms were used, they were adapted from a pre-existing search strategy and combined with synonyms and abbreviations using the boolean operator "OR". Furthermore, references from relevant articles and pertinent reviews were considered. Only articles published in English were reviewed. Initially, two independent searches were carried out using terms to describe each neurophysiological test and pelvic disorders, respectively. These two preliminary searches were then combined using the boolean operator "AND", and the final search strategy was run. The detailed search strategy for each test is available in the Supplementary Material published with this article. Only articles assessing the diagnostic value of neurophysiological tests in pelvic floor disorders occurring in well-defined neurological diseases were analyzed. Conversely, no consideration was given to studies in which the neurogenic origin of the disease was 'tautologically' assumed on the basis of the results of the neurophysiological test. Furthermore, studies on the efficacy of therapeutic interventions were excluded. The review was performed by members of the Neurophysiology of the Pelvic Floor Study Group of the Italian Clinical Neurophysiology Society. Group members were organized into several subgroups, each of which focused on a single neurophysiological test. To minimize possible bias, the review process was carried out by at least two independent reviewers from each subgroup. Selected studies were assessed for their methodological thoroughness against the six AAEM (American Association of Electrodiagnostic Medicine, Campbell, 1999) criteria for the classification of electrodiagnostic studies, with the exception of the fourth criterion (relating to body temperature monitoring), which was always considered fulfilled since it refers to deep body temperature (Table Is in the Supplementary Material). Articles were graded by the number of criteria met (Table IIs in the Supplementary Material). Regarding the first criterion (prospective study), all papers with an unclear or unspecified prospective design were considered retrospective. The strength of recommendations was defined by adapting the paradigm of the American Academy of Neurology and scored from grade A (best available evidence) to grade D (conflicting or inadequate evidence) (Table IIIs in the Supplementary Material) (Gronseth and French, 2008). Assessments by each reviewer were discussed within each subgroup until agreement was achieved. Results were shared with all the members of the other subgroups and comments or suggestions were invited.

Results

In the following section, the literature search results are presented in separate paragraphs for each neurophysiological test and evidence-based recommendations for the employment of individual tests in pelvic floor disorders are provided. All the included papers with relative evidence scores are listed in the Supplementary Material in separate Tables for each test (Tables IVs-XXIIIs).

Pelvic Floor Electromyography (EMG)

Studies using concentric needle EMG (CNEMG) for qualitative or quantitative evaluation of motor unit potentials (MUPs) from pelvic floor muscles were included, whereas reports on kinesiological EMG (e.g., EMG simultaneously recorded during urodynamic testing) were not. The search returned 3186 citations; in total, 37 papers were included.

1.1 Cauda equina and conus medullaris lesions (Table IVs). In patients with suspected sacral neurogenic lesions, CNEMG is the method of choice to demonstrate denervation and reinnervation signs; bilateral examination of the subcutaneous part of the external anal sphincter (EAS) is suggested (Grade C). Quantitative EMG (QEMG) of the EAS with automated analysis of MUPs (e.g., multi-MUP analysis) is the most widely used method in clinical practice. The values of each MUP parameter are generally compared to the normal values, using both mean values (± standard deviation) and outlier limits criteria; moreover, a set of three MUP parameters with the highest predictive power for neuropathic signs is proposed (i.e., area, duration and number of turns) (Grade B). No optimal set of diagnostic criteria with satisfactory sensitivity and specificity for detecting neuropathic disorders of the EAS has been identified because a higher number of diagnostic criteria for muscle abnormality and more stringent normative limits may increase test specificity but reduce its sensitivity (Podnar, 2004a). Sensitivity ranges from 21 to 70%, specificity from 74 to 99%, positive predictive value from 58 to 99%, and negative predictive value from 47 to 90%, depending on the normative limits chosen and the number of MUP parameters considered (Podnar, 2009a). Compared with the automated multi-MUP technique, the interference pattern (IP) analysis with the

turns/amplitude (T/A) method has lower sensitivity, particularly for detecting neuropathic changes (i.e., sensitivity 29%), and its use is less supported by the evidence (Podnar et al., 2002b). The sensitivity of QEMG analysis is markedly increased, to 94-96%, when the technique is combined with evaluation of sacral reflexes (Podnar, 2008a) (Grade B).

1.2 *Pudendal neuropathy*. No articles were included.

1.3 *Muscular diseases.* No articles were included.

1.4 *Spinal cord lesions* (Table Vs). Data regarding the relevance of EMG to detect axonal damage due to anterograde trans-synaptic degeneration in patients with suprasacral spinal cord injury (SCI) are insufficient to draw any conclusions (Grade D).

1.5 *Parkinsonisms* (Table VIs). In multiple system atrophy (MSA) studies, single-MUP analysis is the most commonly used technique, and MUP duration together with percentage of polyphasic MUPs are the two main electromyographic parameters considered. QEMG of the EAS muscle, especially use of the single MUP technique with inclusion of late components for measuring MUP duration, shows neurogenic MUP changes in MSA patients compared with controls, with an abnormality rate of more than 70% (Grade B). Qualitative EMG of the EAS muscle in MSA does not improve the diagnostic accuracy of clinical diagnosis (Aerts et al., 2015) (Grade C). The value of sphincter EMG in differentiating MSA from idiopathic Parkinson's disease (IPD) is still debated (Grade D) because of differences in patient selection and disease duration, as well as technical reasons (e.g., different methods for assessing MUP duration, whether or not to include late MUP components) (Podnar and Fowler, 2004). Neurogenic abnormalities in sphincter EMG may also be found in the early phase of progressive supranuclear palsy (PSP), however, these finding are not useful for differentiating PSP from MSA (Grade B). Owing to the small number of studies and patients investigated, it is difficult to reach specific conclusions about the usefulness of sphincter EMG in other forms of parkinsonism.

Pudendal Nerve Terminal Motor Latency (PNTML)

The search returned 285 citations; three papers were included.

2.1 Cauda equina lesions (Table VIIs). Data regarding the usefulness of PNTML in patients with suspected cauda equina lesions are scarce and conflicting (Grade D).

2.2 Sacral plexopathy (Table VIIIs). Data are inadequate (Grade D).

2.3 Pudendal neuropathy**.** No articles were included.

2.4 Pudendal neuralgia and pelvic pain**.** No articles were included.

Sacral Reflexes

The search returned 2798 citations; 32 papers were included.

3.1 Cauda equina and conus medullaris lesions (Table IXs). Bilateral neurophysiological evaluation of the bulbocavernosus reflex (BCR) is useful in patients with chronic cauda equina or conus medullaris lesions; increased latency or non-elicitable responses are the most frequent abnormal findings (Grade B). There are no significant differences in the sensitivity of the BCR between mechanical and electrical stimulation in men (Grade B), whereas electrical stimulation has been demonstrated to be more sensitive than mechanical stimulation in women (Podnar, 2014) (Grade C). The combined use of CNEMG and BCR increases the sensitivity of single neurophysiological tests in men (from 81-83% with single/double electrical stimulation of the BCR to 94-96% with CNEMG+BCR testing) (Podnar, 2008a) and in women (from 92-96% to 96-100%) (Podnar, 2014) (Grade B). The pudendal-urethral reflex (PUR) elicited by single electrical or mechanical stimulation may be altered in conus and cauda equina lesions (Grade C).

3.2 Pudendal neuropathy. No articles were included.

3.3 Peripheral neuropathies (Table Xs). The BCR has been tested in patients with acquired or genetic neuropathy of different etiologies and sexual dysfunction, mostly to investigate the utility of the test in the diagnosis of neurogenic impotence. Since the test showed a low rate of alterations in patients with neuropathy, the BCR is not useful to detect the neurogenic origin of sexual dysfunction in patients with peripheral neuropathy (Grade B). Only one study investigating patients with familial amyloidotic polyneuropathy (Portuguese type) and sexual dysfunctions found a higher rate of BCR abnormality (Alves et al., 1997) (Grade C).

3.4 Sacral plexopathy (Table XIs). Data are inadequate (Grade D).

3.5 Spinal cord lesions (Table XIIs). Given that alterations of the sacral reflexes are present in only a small number of patients and that the alterations described are conflicting, sacral reflexes are not useful for diagnosing spinal cord lesions (Grade B).

3.6 Parkinsonisms (Table XIIIs). Sacral reflexes have been tested in patients with MSA, to explore the hypothesis of anatomical localization of nervous system lesions in Onuf's nucleus, but the results were conflicting (Grade D).

Pudendal Somatosensory Evoked Potentials (pSEPs)

The search returned 2799 citations; 17 papers were included.

4.1 Cauda equina and conus medullaris lesions (Table XIVs). pSEPs can be altered (absent or delayed cortical response) in patients with cauda equina or conus medullaris lesions, with a high abnormality rate (Grade B).

4.2 Peripheral neuropathies (Table XVs). Data are insufficient to draw conclusions (Grade D).

4.3 Lumbosacral plexopathy (Table XVIs). Available data are scarce and inadequate to draw conclusions (Grade D).

4.4 Spinal cord lesions (Table XVIIs). Results of studies on patients with heterogeneous suprasacral spinal cord lesions or multiple sclerosis (MS) show that pSEPs are altered in spinal cord lesions, being found to be abnormal (absent response or delayed-latency cortical response) in most patients (44-92%) (Grade B).

4.5 Parkinsonisms (Table XVIIIs). Data regarding the utility of pSEPs in demonstrating involvement of the sacral ascending somatosensory pathway in patients with MSA are scarce and conflicting (Grade D). Due to inadequate data, no conclusions can be drawn about the usefulness of pSEPs in the differential diagnosis of parkinsonisms (Grade D).

Perineal Sympathetic Skin Response (pSSR)

The search returned 134 citations; eight papers were included.

5.1 Spinal cord and cauda equina lesions (Table XIXs). In patients with spinal cord injuries, the pSSR correlates with the anatomical level and severity (i.e., complete or incomplete) of lesions. In particular, the pSSR is usually absent in patients with a lesion level above the thoracolumbar (TL) segments (T10-L2), especially in the presence of complete lesions (Grade B), due to the loss of integrity of the sympathetic outflow between brain centers and the TL intermediolateral column. By contrast, the pSSR is usually preserved in patients with lesions below the TL segments or cauda equina lesions (Grade B). For lesions in segments T10-L2, pSSRs are more variable, with consequent low reliability (Grade B). Available data on the use of pSSR testing in MS patients with sexual dysfunction are insufficient to draw conclusions (Grade D).
5.2 Peripheral neuropathies (Table XXs). Data regarding the usefulness of pSSR evaluation in patients with acquired peripheral neuropathy and sexual dysfunctions are conflicting (Grade D). A sympathetic skin response (SSR) evoked by electrical stimulation of the pudendal nerve at the penis and recorded from the sole of the foot may be precociously altered in patients with familial amyloidotic polyneuropathy (Portuguese type) (Alves et al., 1997) (Grade C).

Perineal Motor Evoked Potentials (pMEPs)
The search returned 30 citations; six papers were included.
6.1 Cauda equina lesions (Table XXIs). The latency of pMEPs after lumbosacral magnetic stimulation is increased in patients with cauda equina lesions, indicating a slowing of peripheral motor fiber conduction (Grade B).
6.2 Spinal cord lesions (Table XXIIs). Despite methodological differences, all studies investigating pMEPs in patients with spinal cord lesions and pelvic floor dysfunctions showed a high rate of abnormalities. However, there is general consensus on the marked variability of responses and methodological issues, also in normal subjects (Brostrom, 2003). These factors limit the clinical value of this method (Grade D).
6.3 Parkinsonisms (Table XXIIIs). Data regarding the utility of pMEPs in the diagnosis of MSA are insufficient (Grade D).

Discussion

Neurophysiological testing is recognized as an essential tool for identifying pathophysiological mechanisms, refining clinical diagnosis, making rational treatment choices, and practicing “knowledge-based medicine” in neurological diseases (Vodusek, 2005). Although clinical neurophysiology is practiced in almost all neurology departments, pelvic floor neurophysiology requires specific knowledge about neurophysiological techniques and a sound anatomo-clinical background (Fowler et al., 2002). A number of relevant critical reviews discuss the methodological aspects and diagnostic value of neurophysiological tests in pelvic floor disease (Fowler et al., 2002; Vodusek, 2005; Lefaucheur, 2006), but the actual clinical usefulness of these tests is not yet completely clarified. We performed a systematic literature review to provide clinicians with evidence-based recommendations on the use of neurophysiological tests in clinical practice. Only studies designed to assess the diagnostic value of individual neurophysiological tests in specific neurological diseases involving the pelvic floor were considered. Our results confirm the usefulness of some tests in specific clinical conditions and the absence of evidence to support the diagnostic value of other tests often routinely employed in clinical practice. The results concerning each test are discussed in detail below. Tables IVs to XXIIIs in the Supplementary Material report all the included papers with relative evidence scores, listed for each neurophysiological test in the different pelvic floor diseases. Table I in the text summarizes the main evidence-based recommendations related to the single tests grouped for individual pelvic floor diseases.
EMG: CNEMG is able to reveal muscle denervation and reinnervation signs after motor neuron or axonal damage. As expected, EMG of sphincter muscles plays a key role in the detection, pathophysiology characterization and prognostic evaluation of sacral peripheral motor lesions. The EAS is the most extensively studied muscle in clinical practice owing to its accessibility and reliability; qualitative EMG is not supported by evidence, while use of QEMG is suggested for the technique’s easier interpretation (Podnar and Vodusek, 2001b). Because of the close inter-correlations between overall MUP parameters, the multi-MUP technique evaluating three parameters (area, duration and number of turns) has the highest predictive power (sensitivity and specificity) and is recommended (Grade B). There exists no standardized set of diagnostic criteria for the diagnosis of neuropathic signs of the EAS muscle which have both satisfactory sensitivity and satisfactory specificity; instead, criteria have been proposed for 'possible', 'probable' and 'definite' pathological results of QEMG in the EAS muscle (Podnar, 2004a). Conversely, quantitative IP analysis with the T/A technique is not supported by the evidence due to its low sensitivity to detect neuropathic changes (Podnar et al., 2002b). Over the last decades, sphincter EMG has been widely employed in suspected MSA in which there is selective degeneration of Onuf’s nucleus neurons resulting in denervation-reinnervation of sphincter muscles. Quantitative sphincter EMG is able to detect neurogenic changes in patients with clinically diagnosed MSA, with an abnormality rate of more than 70%: the available evidence supports a Grade B recommendation. Qualitative EMG of the EAS muscle in MSA does not improve clinically based diagnostic accuracy (Aerts et al., 2015) (Grade C). However, some disagreement persists regarding the diagnostic value of sphincter EMG in parkinsonisms because of the high variability of abnormality criteria. Furthermore, clinical diagnosis of the disease lacks histopathological confirmation in most cases. Available evidence regarding the value of sphincter EMG in distinguishing MSA from IPD is conflicting, even in the early stages of the disease (Grade D). Neurogenic abnormalities in sphincter EMG may also be found in the initial phase of PSP; nevertheless, these findings are not useful for separating PSP from MSA (Grade B). Due to the small number of studies and patients included, it is difficult to reach specific conclusions about the utility of sphincter EMG in other forms of parkinsonisms.
PNMTL: PNTML examination tests conduction of the fastest distal sacral motor nerve fibers within the pudendal nerve. In recent decades, this examination has

gained popularity, with studies reporting prolonged latencies in various diseases (Podnar, 2003a). More recently, however, its diagnostic value and sensitivity have been questioned because of doubts over its feasibility and reliability.

Two consensus statements, one neurourological (Fowler et al., 2002) and the other gastroenterological (Barnett et al., 1999), did not recommend this test for routine evaluation in patients with sacral dysfunctions. Our literature analysis to verify the diagnostic value of PNTML examination, performed according to the St. Mark's technique (Kiff and Swash, 1984) in patients with peripheral nervous system diseases, returned only three studies, two of which were carried out on patients with cauda equina lesions and one in sacral plexopathy.

The results were conflicting or insufficient to draw conclusions (grade D).

We found no studies investigating the sensitivity and specificity of PNMTL testing in patients with well-defined pudendal neuropathy or neuralgia. Most studies assumed a 'neurogenic' origin of the symptoms on the basis of neurophysiological results, without any established a priori and independent criteria supporting the diagnosis of neuropathy.

***Sacral reflexes*:** The sacral reflexes are mediated through the sacral spinal cord segments and their afferent/efferent connections with the pelvic floor through the pudendal nerve. BCR examination is the most commonly used electrophysiological test in clinical practice. While evaluation of the BCR is less useful in peripheral neuropathies, it demonstrated high sensitivity in revealing abnormalities of the sacral reflex arc due to peripheral fiber or sacral spinal cord damage in patients with chronic cauda equina or conus medullaris lesions (Grade B).

The sensitivity of BCR in men and women is increased when the test is performed in combination with QEMG of the EAS muscle. An electrodiagnostic protocol combining EAS QEMG and BCR should be performed in all patients with suspected cauda equina or conus medullaris lesions (Grade B).

Though supported by fewer data, the PUR may be altered (absent or with an increased latency) in conus or cauda damage (Grade C). Sacral reflexes are altered in few patients with suprasacral lesions and they are not useful for evaluating spinal cord damage (Grade B). Some studies investigated the association between the BCR and sexual dysfunctions in spinal cord lesions. Since BCR evaluation provides information about the conus and cauda equina by testing the integrity of the sacral reflex arc, and since reflex erections (REs) imply an intact sacral arc, a significant association between presence/absence of the BCR and sparing/absence of REs has been reported. Sacral reflexes in MSA and parkinsonisms are not conclusive (Grade D).

pSEPs: evaluation of pSEPs provides information about the integrity of the somatosensory afferent pathways from the pudendal nerve to the parietal cortex. This technique has demonstrated utility in detecting alterations throughout the afferent somatosensory pathway in patients with spinal cord or cauda equina lesions and pelvic symptoms (Grade B).

Few studies have compared the diagnostic yield of pSEPs and posterior tibial SEPs (tSEPs) in patients with spinal cord lesions and pelvic symptoms. Although some suggest that pSEPs provide no more information about spinal cord function than tSEPs (Betts et al., 1994; Zivadinov et al., 2003), others demonstrated a higher sensitivity of tSEPs (Rodi et al., 1996b; Ashraf et al., 2005) or pSEPs (Sau et al., 1997). Further studies are needed to confirm these data.

pSSRs: The SSR is used to examine sympathetic sudomotor activity by measuring skin conductance changes in response to peripheral nerve electrical stimulation. The SSR is mediated through myelinated somatosensory afferent fibers, a central autonomic network, and sympathetic cholinergic efferent fibers modulated by complex supraspinal control.

The sympathetic fibers controlling perineal sudomotor activity are thought to originate from the TL segments (T10-L2) of the spinal cord. Therefore, integrity of the pathway between brain centers and the TL sympathetic intermediolateral column may be tested through evaluation of pSSRs (Tas et al., 2007).

These reflexes are usually absent in patients with lesions above the TL segments (T10-L2), generally preserved in patients with lesions below the TL segments or with cauda equina lesions, and more variable in the presence of lesions within segments T10-L2 (Grade B). pSSR evaluation in patients with peripheral neuropathies yielded conflicting results (Grade D). The pSSR has also been studied in patients with spinal cord lesions and erectile dysfunctions, and a positive correlation between presence/absence of psychogenic erection and presence/absence of pSSR has been demonstrated.

pMEPs: Transcranial magnetic stimulation can be used to test the motor efferents to the pelvic floor muscles. Studies investigating the diagnostic role of pMEPs in patients with neurological disorders are sparse and heterogeneous.

Some reported good reliability of pMEPs in discriminating patients with central nervous system disorders from healthy subjects, and their usefulness in cauda equina lesions. However, there is agreement on methodological limitations (lack of responses to cortical stimulation in some healthy subjects due to the difficulty of stimulating deep cortical structures and recording small target muscles, and a marked variability of responses). These factors limit the clinical value of this method (Grade D).

Concluding Remarks

Based on our review of these selected studies, we can conclude that the utility of pelvic floor neurophysiological tests is widely recognized and supported by the evidence. Reasonably, tests showing the highest levels of evidence should be included in specific protocols designed to investigate specific diagnostic aspects.

Other tests, not currently supported by high-level evidence, could be used in research settings to demonstrate or corroborate their diagnostic value. Pelvic floor neurophysiological tests should be performed by trained neurophysiologists, in officially recognized laboratories, with formal control of the quality of the results.

Moreover, test usefulness in individual patients should be evaluated in the overall clinical setting to explain the correlation between neurophysiological findings and pelvic floor dysfunction.

Table I - Summary of recommendations for the use of neurophysiological tests in pelvic floor diseases.

Pelvic floor disease	Test	Method*	Anatomical pathway	Clinical usefulness	Recommendation
Cauda equina and conus medullaris lesions	CNEMG	Multi-MUP analysis of EAS[1]	Sacral alpha motor neurons, EAS	Useful for assessing collateral reinnervation occurring after axonal or neuronal sacral motor lesions	Grade B
	PNTML	St. Mark's technique[2]	Pudendal nerve distal motor fibers	Undefined	Grade D
	Sacral reflexes	BCR[3]	Sacral reflex arc	Useful for assessing both peripheral branches of the sacral reflex arc and the conus medullaris	Grade B
		PUR[4]	Sacral reflex arc	Useful for assessing both peripheral branches of the sacral reflex arc and the conus medullaris	Grade C
	pSEPs	Pudendal nerve stimulation, cortical recording[5]	Pudendal sensory fibers, sacral spinal cord	Useful for assessing both pudendal afferent fibers and the sacral spinal cord	Grade B
	pSSR	Median nerve stimulation, perineal skin recording[6]	Post-ganglionic sympathetic fibers	Useful for demonstrating the integrity of the sympathetic pathway in cauda and conus lesions	Grade B
	pMEPs	Magnetic stimulation of the Lumbosacral roots[7]	Sacral roots, plexus and pudendal nerve motor fibers	Useful for assessing sacral motor neurons	Grade B
Peripheral neuropathies	Sacral reflexes	BCR3	Sacral reflex arc	Not useful for assessing sexual dysfunction in peripheral neuropathy	Grade B
	pSEPs	Pudendal nerve stimulation, cortical recording[5]	Pudendal nerve sensory fibers	Undefined	Grade D
	pSSR	Median nerve stimulation, perineal skin recording[6]	Post-ganglionic sympathetic fibers	Undefined	Grade D
Sacral plexopathy	PNTML	St. Mark's technique[2]	Pudendal nerve distal motor fibers	Undefined	Grade D
	Sacral reflexes	BCR[3]	Peripheral branches of sacral reflex arc	Undefined	Grade D
	pSEPs	Pudendal nerve stimulation, cortical recording[5]	Sacral peripheral sensory fibers	Undefined	Grade D

Pelvic floor disease	Test	Method*	Anatomical pathway	Clinical usefulness	Recommendation
Spinal cord lesions	CNEMG	Multi-MUP analysis of EAS[1]	Sacral alpha motor neurons	Clinical usefulness for assessing axonal damage due to anterograde trans-synaptic degeneration in suprasacral SCI	Grade D
	Sacral reflexes	BCR1, PUR4, PAR[8]	Sacral spinal cord	Not useful in suprasacral spinal cord lesions	Grade B
	pSEPs	Pudendal nerve stimulation, cortical recording[5]	Central somatosensory pathway from sacral region to the cortex	Useful for detecting central nervous system lesions	Grade B
	pSSR	Median nerve stimulation, perineal skin recording[6]	Sympathetic efferent fibers	Useful for assessing dysfunction of sympathetic fibers in lesions above TL level	Grade B
Parkinsonisms	pMEPs	Transcranial magnetic stimulation[7]	Central motor pathway from the cortex to sacral muscles	Undefined	Grade D
	CNEMG	Quantitative MUP analysis of EAS[1]	Sacral alpha motor neurons, EAS	Useful for assessing neurogenic changes in patients with clinical diagnosis of MSA Clinical usefulness in distinguishing MSA from IPD Not useful for distinguishing MSA from PSP	Grade B Grade D Grade B
	Sacral reflexes	BCR1, PAR[8]	Sacral spinal cord	Undefined	Grade D
	pSEPs	Pudendal nerve stimulation, cortical recording[5]	Somatosensory afferent volley	Undefined	Grade D
	pMEPs	Transcranial and lumbosacral magnetic stimulation[7]	Central and peripheral motor pathway from the cortex to sacral muscles	Undefined	Grade D

Abbreviations: BCR=bulbocavernosus reflex; CNEMG=concentric needle EMG; EAS=external anal sphincter; MUP=motor unit potential; pMEPs=perineal motor evoked potentials; PNTML=pudendal nerve terminal motor latency; pSEPs=pudendal nerve somatosensory evoked potentials; PAR=pudendal-anal reflex; PUR=pudendal-urethral reflex; pSSR=perineal sympathetic skin response. *References for methods: [1] Podnar and Vodusek, 2001b; [2] Swash and Snooks, 1986; [3] Podnar, 2008b, Podnar, 2014; [4] Awad et al., 1981, Blaivas et al., 1981; [5] Niu et al., 2010, Niu et al., 2015; [6] Tas et al., 2007; [7] Brostrøm, 2003; [8] Rodi et al., 1996b.

Supplementary material

SEARCH STRATEGIES

The literature search strategy for each neurophysiological technique is reported below.

1. Pelvic floor electromyography (EMG)

The MeSH or free terms "EMG", "electromyography" and "surface EMG" were combined, through the boolean operator "AND", with the following MeSH or free terms: "conus medullaris syndrome", "conus medullaris lesions", "cauda equina syndrome", "cauda equina lesions", "cauda syndrome", "cauda lesions", "pudendal neuropathy", "pelvic floor" OR "anal sphincter" OR "urethral sphincter" AND "muscular diseases" OR "myopathy", "Parkinson's disease", "parkinsonian disorders", "multiple system atrophy", "urinary retention", "stress urinary incontinence", "fecal incontinence", "constipation", "rectal prolapse", "erectile dysfunction", "pelvic pain".

2. Pudendal nerve terminal motor latency (PNTML)

The free terms "pudendal nerve terminal motor latency", "pudendal latency" and "PNTML" were combined, through the boolean operator "AND", with the following MeSH or free terms: "conus medullaris syndrome", "conus medullaris lesions", "cauda equina syndrome", "cauda equina lesions", "cauda syndrome", "cauda lesions", "polyradiculopathy", "pudendal neuropathy", "urinary retention", "stress urinary incontinence", "urge urinary incontinence", "neurogenic bladder", "lower urinary tract symptoms", "fecal incontinence", "constipation", "rectal prolapse", "pelvic organ prolapse", "erectile dysfunction", "sexual dysfunction", "pelvic pain".

3. Sacral reflexes

The MeSH or free terms "bulbocavernosus reflex", "bulbocavernosus reflex decreased", "pudendal reflex", "anal reflex", "bladder reflex", "urethral reflex" and "perineal reflex" were combined, through the boolean operator "AND", with the following MeSH or free terms: "conus medullaris syndrome", "conus medullaris lesions", "cauda equina syndrome", "cauda equina lesions", "cauda syndrome", "cauda lesions", "radiculopathy", "pudendal neuropathy", "diabetic neuropathy", "diabetes", "disc protrusion", "discopathy", "disc herniation", "lower motor neuron disease", "spinal cord disease", "spinal cord injury", "spinal cord lesions", "myelitis", "multiple sclerosis", "Parkinson's disease", "parkinsonian disorders", "multisystem atrophy", "spastic paraparesis", "central nervous system disease", "upper motor neuron disease", "urinary retention", "stress urinary incontinence", "urge urinary incontinence", "neurogenic bladder", "fecal incontinence", "constipation", "erectile dysfunction", "sexual dysfunction", "pelvic traumas", "pelvic surgery", "pain", "pelvic pain".

4. Pudendal somatosensory evoked potentials (pSEPs)

A first search was run combining the MeSH term "evoked potentials" and the free term "pudendal". Then the results of the first search were combined, through the boolean operator "AND", with the following MeSH or free terms: "conus medullaris syndrome", "conus medullaris lesions", "cauda equina syndrome", "cauda equina lesions", "cauda syndrome", "cauda lesions", "radiculopathy", "pudendal neuropathy", "diabetic neuropathy", "diabetes", "disc protrusion", "discopathy", "disc herniation", "lower motor neuron disease", "spinal cord disease", "spinal cord injury", "spinal cord lesions", "myelitis", "multiple sclerosis", "Parkinson's disease", "parkinsonian disorders", "multisystem atrophy", "spastic paraparesis", "central nervous system disease", "upper motor neuron disease", "urinary retention", "stress urinary incontinence", "urge urinary incontinence", "neurogenic bladder", "fecal incontinence", "constipation", "erectile dysfunction", "sexual dysfunction", "pelvic traumas", "pelvic surgery", "pain", "pelvic pain".

5. Perineal sympathetic skin reflex (pSSR)

The MeSH or free terms "galvanic skin response", "skin reflex", "sympathetic skin response", "sympathetic skin reflex" and "sympathetic skin potentials" were combined, through the boolean operator "AND", with the following MeSH or free terms: "conus medullaris syndrome", "conus medullaris lesions", "cauda equina syndrome", "cauda equina lesions", "cauda syndrome", "cauda lesions", "radiculopathy", "pudendal neuropathy", "sacral plexopathy", "spinal cord disease", "spinal cord injury", "spinal cord lesions", "urinary retention", "stress urinary incontinence", "urge urinary incontinence", "neurogenic bladder", "fecal incontinence", "constipation", "rectal prolapse", "erectile dysfunction", "sexual dysfunction", "pelvic pain".

6. Perineal motor evoked potentials (pMEPs)

A first search was run combining the MeSH term "motor evoked potentials" and the MeSH or free terms "pelvic floor", "sphincter", "anal sphincter", "urethral sphincter" and "bulbocavernosus". Then, the results of the first search were combined, through the boolean operator "AND", with the following MeSH or free terms: "conus medullaris syndrome", "conus medullaris lesions", "cauda equina syndrome", "cauda equina lesions", "cauda syndrome", "cauda lesions", "radiculopathy", "pudendal neuropathy", "spinal cord disease", "spinal cord injury", "spinal cord lesions", "multiple sclerosis", "Parkinson's disease", "parkinsonian disorders", "multiple system atrophy", "spastic paraparesis", "urinary retention", "stress urinary incontinence", "urge urinary incontinence", "neurogenic bladder", "fecal incontinence", "constipation", "erectile dysfunction", "sexual dysfunction", "pelvic pain".

SUPPLEMENTARY TABLES

Table Is - Literature classification criteria.

1. Prospective study.
2. Diagnosis of disease in the patient population based on clinical criteria independent of the electrodiagnostic procedure under evaluation.
3. Electrodiagnostic procedure described in sufficient detail, or reference provided to a published technique, to permit duplication of the procedure.
4. Body temperature monitored and reported.
5. Reference values for the electrodiagnostic procedure obtained with either (a) concomitant studies of a reference population or (b) previous studies of a reference population in the same laboratory.
6. Criteria for abnormal findings clearly stated, and defined in statistical terms, e.g., range, mean $\pm$ 2 standard deviations (SD), from data derived from the reference population.

Table IIs - Definitions for classification of evidence.

1. Class I evidence: studies that meet all six literature classification criteria.
2. Class II evidence: studies that meet four or five literature classification criteria.
3. Class III evidence: studies that meet three or fewer literature classification criteria.

Table IIIs - Definitions for grading of recommendations.

Grade A: this rating requires at least two consistent Class I studies, reflecting a high degree of clinical certainty.
Grade B: this rating requires at least one Class I study or two consistent Class II studies, reflecting moderate clinical certainty.
Grade C: this rating requires at least one Class II study or two consistent Class III studies, indicating uncertain clinical utility.
Grade D: data inadequate or conflicting.

Table IVs - External anal sphincter EMG in cauda equina and conus medullaris lesions.

Reference	Objective	No. of patients	Technique	Results
Podnar and Vodusek, 2001b	To determine the cumulative sensitivity of MUP parameters to detect neuropathic changes in EAS by using both mean values and outliers	56	Multi-MUP	Se: 62%
Podnar et al., 2002b	To compare the sensitivity of QEMG techniques in detecting neuropathic changes in EAS	56	Multi-MUP; Single MUP; Manual MUP; T/A IP analysis	Se: 62%; Se: 63%; Se: 57%; Se: 29%
Podnar and Mrkaic, 2002	To determine the predictive power of MUP parameters for differentiation of neuropathic and normal EAS	52	Multi-MUP	MUP area, duration and number of turns give identical results to overall MUP parameters
Podnar et al., 2002a	To determine the diagnostic value of EAS QEMG in cauda lesions and the predictive value for sexual dysfunctions	46	Multi-MUP	ABR: 89%
Podnar, 2003b	To compare the sensitivity of QEMG in the subcutaneous and the deep EAS in detection of neuropathic changes	67	Multi-MUP	Subcutaneous EAS, Se: 66%; Deep EAS, Se: 71% Se: 21-70%, Sp: 74-99%
Podnar, 2004a	To define diagnostic criteria for neuropathic changes of MUPs in EAS	86	Multi-MUP	Unilateral study, Se: 57%;
Podnar, 2004b	To compare the sensitivity of unilateral and bilateral MUP parameters of EAS in detection of neuropathic changes	67	Multi-MUP	Bilateral study, Se: 83%
Podnar, 2005	To determine the most useful outlier criteria in MUP analysis for detection of neuropathic changes in EAS	79	Multi-MUP	10-90 and 5-95 percentile ranges are respectively the most sensitive and specific parameter Se: 73%;
Podnar, 2008a	To determine the sensitivity of EAS QEMG, BCR evaluation and their cumulative sensitivity in neurogenic sacral lesions	52	Multi-MUP; Multi-MUP +BCR	Se: 94-96% PPV 69-89%, NPV 56-78%
Podnar, 2009a	To determine the predictive values of QEMG for detection of neuropathic changes in the EAS	75	Multi-MUP	Se: 63%, Sp: 92%, PPV 83%, NPV: 86%;
Podnar, 2014	To determine the sensitivity of EAS QEMG and of CCR evaluation and their cumulative sensitivity in neurogenic sacral lesions	24	Multi-MUP; Multi-MUP + CCR	Se: 96-100%, Sp 62-75%, PPV 50-55%, NPV 97-98%

Abbreviations: MUP=motor unit potential; EAS=external anal sphincter muscle; QEMG=quantitative EMG; BCR=bulbocavernosus reflex; CCR=clitorido-cavernosus reflex; T/A=turns/amplitude analysis; IP=interference pattern; Se=sensitivity; Sp=specificity; PPV=positive predictive value; NPV=negative predictive value; ABR=abnormality rate.

Table Vs - External anal sphincter EMG in spinal cord lesions.

Reference	Objective	No. of patients	Technique	Results	Evidence
Podnar, 2011	To evaluate the diagnostic value of EAS EMG in chronic supra-sacral SCI	16	MUP count at rest; Multi-MUP	ABR: 25%; ABR: 0%	Class 2
Tankisi et al., 2016	To evaluate the diagnostic value of EAS EMG in chronic supra-sacral SCI	12	MUP analysis; T/A IP analysis	ABR 58%; ABR 91%	Class 2

Abbreviations: EAS=external anal sphincter muscle; SCI= spinal cord injury; MUP=motor unit potential; T/A=turn/amplitude analysis; IP=interference pattern; ABR=abnormality rate.

Table VIs - Sphincter EMG in parkinsonisms.

Reference	Objective	No. of patients	Muscle	Technique	Results	Evidece
Kirby et al., 1986	To assess the diagnostic value of sphincter EMG in MSA	14	EUS	Single MUP	ABR: 66%	Class 3
Eardley et al., 1989	To assess the diagnostic value of sphincter EMG in differentiating MSA from IPD	41 MSA; 13 IPD	EUS	Single MUP	Se: 62%, Sp: 92%	Class 2
Wenning et al., 1994	To assess the diagnostic value of sphincter EMG in MSA	49	EAS; EUS	CNEMG	ABR: 86%	Class 3
Beck et al., 1994	To assess the diagnostic value of sphincter EMG in MSA	62	EAS; EUS	Single MUP	ABR: 100%	Class 3
Pramstaller et al., 1995	To assess the diagnostic value of sphincter EMG in MSA	71	EAS; EUS	Single MUP	ABR: 90%	Class 3
Valldeoriola et al., 1995	To assess the diagnostic value of sphincter EMG in the differential diagnosis of parkinsonisms	6 MSA; 12 PSP; 6 IPD	EAS	Single MUP	ABR: 100% in MSA, 41.6% in PSP, 33.3% in IPD	Class 3
Rodi et al., 1996 a	To assess the diagnostic value of sphincter EMG in differentiating MSA from IPD	10 MSA; 14 IPD	EAS	CNEMG; SFEMG	Se: 80%, Sp: 93% in MSA; Se: 80%, Sp: 100% in IPD	Class 3
Palace et al., 1997	To assess the diagnostic value of sphincter EMG in differentiating MSA from IPD	126 MSA; 12 IPD	EAS	Single MUP	ABR: 82% in MSA, 16% in IPD	Class 3
Stocchi et al., 1997	To assess the diagnostic value of sphincter EMG in differentiating MSA from IPD	32 MSA; 30 IPD	EAS	CNEMG	ABR: 75% in MSA, 0% in IPD	Class 2
Schwarz et al., 1997	To assess the diagnostic value of sphincter EMG in differentiating MSA from IPD	15 MSA; 10 IPD	EAS	Single MUP; Sp. activity	N.D. between groups; ABR: 66% in MSA, 0% in IPD	Class 3
Libelius and Johansson, 2000	To assess the diagnostic value of sphincter EMG in differentiating MSA from IPD	13 MSA; 66 IPD	EAS	Single MUP	ABR: 100% in MSA, variable results in IPD	Class 2
Tison et al., 2000	To assess the diagnostic value of sphincter EMG in MSA and in differentiating MSA from IPD	31 MSA; 21 IPD	EAS	Single MUP	Se: 81%, Sp: 67%, PPV: 80%, NPV: 70% in MSA; able to differentiate MSA-IPD	Class 3
Giladi et al., 2000	To assess the diagnostic value of sphincter EMG in differentiating MSA from IPD	10 MSA; 13 IPD	EAS	QEMG; Sp. activity	N.D. between groups; N.D. between groups	Class 2
Colosimo et al., 2000	To assess the diagnostic value of sphincter EMG in IPD	7 IPD	EAS	CNEMG	ABR: 100%	Class 3
Gilad et al., 2001	To assess the diagnostic value of sphincter EMG in MSA	11	EAS	Multi-MUP; Recruitment;	N.D. from normal values; reduced; reduced;	Class 2
Sakakibara et al., 2001	To assess the diagnostic value of sphincter EMG in differentiating MSA from IPD	15 MSA; 21 IPD	EUS	MUP count at rest; SFEMG CNEMG	N.D. from normal values ABR: 93% in MSA, 5% in IPD	Class 3
Lee et al., 2002	To assess the diagnostic value of sphincter EMG in MSA and in differentiating MSA from IPD	23 MSA-p; 22 MSA-c; 21 IPD	EAS	CNEMG	Se: 86–96%, Sp: 67%, PPV: 73–76%, NPV: 82–93% in MSA; Se: 33% in IPD	Class 3
Pellegrinetti et al., 2003	To assess the diagnostic value of sphincter EMG in MSA	13	EAS	CNEMG	ABR: 77%	Class 3
Podnar and Fowler, 2004	To compare the sensitivity of different quantitative EMG techniques in the EAS for diagnosis of MSA	5	EAS	Single MUP; Multi-MUP	Se: 100%; Se: 40%	Class 2
Paviour et al., 2005	To assess the diagnostic value of sphincter EMG in MSA	37	EAS; EUS	CNEMG	ABR: 80%	Class 3
Yamamoto et al., 2005	To assess the diagnostic value of sphincter EMG in the different stages of MSA	84	EAS	Single MUP	ABR: 52% in the I year, 83% in the V year	Class 3
Winge et al., 2010	To assess the diagnostic value of sphincter EMG in the differential diagnosis of parkinsonisms	14 MSA; 8 PSP; 6 IPD	EAS	CNEMG	Mean duration of MUPs significantly longer in MSA-PSP than in IPD	Class 2
Linder et al., 2012	To assess the diagnostic value of sphincter EMG in the differential diagnosis of parkinsonisms in the early stage of the disease	16 MSA; 11 PSP; 121 IPD	EAS	Single MUP	ABR: 62% in MSA, 82% in PSP, 52–54% in IPD	Class 2
Aerts et al., 2015	To assess the diagnostic value of sphincter EMG in the differential diagnosis of parkinsonisms	62 IPD; 94 APs	EAS	CNEMG	Sphincter EMG does not improve diagnostic accuracy	Class 2

Abbreviations: MSA=multiple system atrophy; MSA-p=multiple system atrophy of parkinsonian type; MSA-c=multiple system atrophy of cerebellar type; IPD=idiopathic Parkinson's disease; PSP=progressive supranuclear palsy; APs=atypical parkinsonisms; EAS=external anal sphincter muscle; EUS=external urethral sphincter muscle; MUP=motor unit potential; CNEMG=concentric needle EMG; SFEMG=single fiber EMG; Sp. activity=spontaneous activity; QEMG=quantitative EMG; ABR=abnormality rate; Se=sensitivity; Sp=specificity; PPV=positive predictive value; NPV=negative predictive value; N.D. =not significantly different.

Table VIIs - Pudendal nerve terminal motor latency in cauda equina lesions.

Reference	Objective	No. of patients	Results	Evidence
Swash and Snooks, 1986	To assess the diagnostic value of PNTML in cauda equina lesions	10	ABR: 30%	Class 2
Chuang et al., 2001	To assess the diagnostic value of PNTML in cauda equina lesions	14	ABR: 100%	Class 2

Abbreviations: PNTML=pudendal nerve terminal motor latency; ABR=abnormality rate.

Table VIIIs - Pudendal nerve terminal motor latency in sacral plexopathy.

Reference	Objective	No. of patients	Results	Evidence
Ismael et al., 2000	To assess the diagnostic value of PNTML in lumbosacral plexopathy	19	N: 100%	Class 3

Abbreviations: PNTML=pudendal nerve terminal motor latency; N=normal results.

Table IXs - Sacral reflexes in cauda equina and conus medullaris lesions.

Reference	Objective	No. of patients	Sex	Test	Technique	Results	Evidence
Ertekin and Reel, 1976	To determine the diagnostic value of the BCR in cauda equina lesions	13	M	BCR	Single electrical	Ab: 46%, ↑ Lat: 54%	Class 2
				BCR	Single electrical	Ab: 47%, ↑ Lat: 27%	
Ertekin et al., 1979	To determine the diagnostic value of the BCR in cauda equina or conus lesions	40	M	BCR	Single electrical	Ab: 100% in CLs, ↑ mean sThr, ↑ mean Lat	Class 2
Krane and Siroky, 1980	To determine the diagnostic value of the BCR in cauda equina or conus lesions	20	M	PUR	Single electrical	Ab: 100%	Class 2
Awad et al., 1981	To determine the diagnostic value of the PUR in cauda equina lesions	3	M	PUR	Mechanical	Ab: 100% in CLs, Ab: 40% in ILs	Class 2
Blaivas et al., 1981	To determine the diagnostic value of the BCR in conus lesions	73	39M	BCR	Single electrical	Ab: 68%, ↑ Lat: 14%	Class 2
Moon et al., 1993	To determine the diagnostic value of the BCR in patients with conus lesions and ED	35	M			Ab: 55% (all CLs)	Class 2
Schmid et al., 2003	To assess the association between the BCR, level of lesion and EDs in cauda or conus lesions	9	M	BCR	Single electrical	Ab: 87%	Class 2
Tas et al., 2007	To assess the association between the BCR, level of lesion and EDs in cauda or conus lesions	8	3M	BCR	Single electrical	Se: 81%; Se: 83%; Se: 81%	Class 2
Podnar, 2008 a	To determine the diagnostic value of the BCR, of EAS QEMG, and of their combination in chronic cauda equina or conus lesions	52	M	BCR	Single electrical; Double electrical;	Se: 94-96%	Class 2
				BCR+EAS Multi-MUP		Se: 81%; Se: 83%; Se: 81%	
Podnar, 2008 b	To determine the diagnostic value of the BCR in chronic cauda equina or conus lesions	53	M	BCR			Class 2
Podnar, 2008 c	To compare three different techniques in chronic cauda equina or conus lesions	52	M	BCR	Single electrical; Double electrical;	Se: 70%; Se: 73%; Se: 73%	Class 2
				Combined methods		Se: 82%	
Podnar, 2009 b	To determine the diagnostic value of clinical and neurophysiological evaluation of the BCR in chronic cauda equina or conus lesions	53	M	BCR	Single electrical;	Se: 81%, Sp: 91%, PPV: 95%, NPV: 67%;	Class 2
					Double electrical;	Se: 83%, Sp: 90%, PPV: 96%, NPV: 68%;	
					Mechanical	Se: 81%, Sp: 67%, PPV: 95%, NPV: 29%	
Podnar, 2014	To determine the diagnostic value of the BCR, of EAS QEMG, and of their combination in chronic cauda equina lesions	24	F	BCR	Single electrical;	Se: 92%, Sp: 67%, PPV: 52%, NPV: 95%;	Class 2
					Double electrical;	Se: 96%, Sp: 80%, PPV: 59%, NPV: 96%;	
					Mechanical	Se: 67%	
				BCR+EAS Multi-MUP		Se: 96-100%, Sp: 62-75%, PPV: 50-55%, NPV: 97-98%	
Niu et al., 2010	To determine the diagnostic value of the BCR in acute cauda syndrome	9	F	BCR	Single electrical; Double electrical; Mechanical	Ab/↑ Lat: 72%	Class 2
Niu et al., 2015	To determine the diagnostic value of the BCR in cauda equina syndrome	53		BCR	Single electrical	Ab: 3%, ↑ Lat: 82%	Class 2

Abbreviations: BCR=bulbocavernosus reflex; PUR=pudendal-urethral reflex; EDs=erectile dysfunctions; EAS=external anal sphincter muscle; QEMG=quantitative EMG; MUP=motor unit potential; M=male; F=female; Ab=absent response; Lat=latency; CLs=complete lesions; ILs=incomplete lesions; sThr=sensory threshold; Se=sensitivity; Sp=specificity; PPV=positive predictive value; NPV=negative predictive value.

Table Xs - Sacral reflexes in peripheral neuropathies.

Reference	Objective	No. of patients	Sex	Test	Technique	Results	Evidence
Ertekin and Reel, 1976	To assess the diagnostic value of the BCR in patients with neuropathy and perineal disorders	22	M	BCR	Single electrical	↑ mean Lat	Class 2
Sarica and Karacan, 1987	To assess the diagnostic value of the BCR in patients with diabetic neuropathy and EDs	18	M	pBCR	Single electrical	↑Lat: 20% peripheral neuropathy; ↑Lat: 23% autonomic neuropathy	Class 2
				uBCR	Single electrical	Ab/↑Lat: 93% peripheral neuropathy; Ab/↑Lat: 85% autonomic neuropathy	
Ertekin et al.,1990	To determine the diagnostic value of the BCR in patients with alcoholic neuropathy and EDs	9	M	BCR	Single electrical	↑Lat: 22%	Class 2
Alves et al., 1997	To determine the diagnostic value of the BCR in patients with amyloidotic neuropathy and EDs	15	M	BCR	Single electrical	↑Lat: 67%, Ab: 13%	Class 2

Abbreviations: BCR=bulbocavernosus reflex; EDs=erectile dysfunctions; M=male; pBCR=BCR with glans stimulation; uBCR=BCR with bladder/urethral stimulation; Lat=latency; Ab=absent response.

Table XIs - Sacral reflexes in sacral plexopathy.

Reference	Objective	No. of patients	Muscle	Technique	Results	Evidence
Ismael et al., 2000	Determine the diagnostic value of BCR in lumbosacral plexopathy	19	F	BCR	↑Lat: 89%, Ab: 10%	Class 3

Abbreviations: BCR=bulbocavernosus reflex; F=female; Lat=latency; Ab=absent response.

Table XIIs. Sacral reflexes in spinal cord lesions

Reference	Objective	No. of patients	Sex	Test	Technique	Results	Evidence
Ertekin and Reel, 1976	To determine the diagnostic value of the BCR in suprasacral spinal cord lesions	19	M	BCR	Single electrical	mean Lat: N.D.	Class 2
Krane and Siroky, 1980	To determine the diagnostic value of the BCR in suprasacral spinal cord lesions	15	M	BCR	Single electrical	↓ mean Lat, ↓ mean Thr	Class 2
Awad et al., 1981	To determine the diagnostic value of the PUR in suprasacral spinal cord lesions	8		PUR	Single electrical	↑ mean Lat	Class 2
Blaivas et al., 1981	To determine the diagnostic value of the PUR in suprasacral spinal cord lesions	99	61M	PUR	Mechanical	Ab: 7%	Class 2
Bilkey et al., 1983	To determine the diagnostic value of the PUR in suprasacral spinal cord lesions	44		PUR	Single electrical	↓ mean Lat	Class 2
Dykstra et al., 1987	To determine the diagnostic value of the PUR in suprasacral spinal cord lesions	17		PUR	Single electrical; Mechanical	mean Lat: N.D.	Class 2
Kirkeby et al., 1988	To determine the diagnostic value of the PAR in patients with MS and EDs	29	M	PAR	Train of 5 electrical stimuli	↑ Lat: 28%	Class 2
Eardley et al., 1991	To determine the diagnostic value of the PUR in patients with MS and urinary symptoms	9	M	PUR	Single electrical	mean Lat: N.D.	Class 2
Moon et al., 1993	To determine the diagnostic value of the BCR in patients with suprasacral spinal cord lesions and EDs	41	M	BCR	Single electrical	↑ Lat: 5%	Class 2
Koldewijn et al., 1994	To determine the diagnostic value of the PAR and UAR in suprasacral spinal cord lesions	73	54M	PAR, UAR	Single electrical	PAR: Ab 22%, ↑ Lat 25%; UAR: Ab 23%, ↑ Lat 11%	Class 2
Ghezzi et al., 1995	To determine the diagnostic value of the BCR in MS and the association between BCR and EDs	34	M	BCR	Single electrical	↑ Lat: 9%	Class 2
Rodi et al., 1996 b	To determine the diagnostic value of the PAR in patients with MS and urinary symptoms	21	8M	PAR	Single electrical	↑ Lat: 33%	Class 2
Schmid et al., 2003	To assess the association between the BCR, lesion level and EDs in suprasacral spinal cord lesions	23	M	BCR	Single electrical	N: 100%	Class 2
Ashraf et al., 2005	To determine the diagnostic value of the BCR in suprasacral spinal cord lesions and the association between the BCR and EDs	40	M	BCR	Single electrical	Ab: 5%, ↑ Lat: 7%	Class 3
Tas et al., 2007	To assess the association between the BCR, lesion level and EDs in suprasacral spinal cord lesions	17	14M	BCR	Single electrical	N: 100%	Class 2
Niu et al., 2010	To determine the diagnostic value of the BCR in suprasacral spinal cord lesions	30	F	BCR	Single electrical	↑ Lat: 8%	Class 2
Podnar, 2011	To determine the diagnostic value of the BCR in chronic suprasacral spinal cord lesions	16	M	BCR	Single electrical; Double electrical	↓ Thr: 25%	Class 1
Tankisi et al., 2016	To determine the diagnostic value of the BCR in chronic suprasacral SCI	12	11M	BCR	Single electrical;	↑ Lat: 8%	Class 2

Abbreviations: BCR=bulbocavernosus reflex; PUR=pudendal-urethral reflex; PAR=pudendal-anal reflex; UAR=urethral-anal reflex; MS=multiple sclerosis; SCI=spinal cord injury; EDs=erectile dysfunctions; M=male; F=female; Lat=latency; N.D. =not significantly different from normal values; Thr=reflex threshold; Ab=absent response; N=normal results.

Table XIIIs - Sacral reflexes in parkinsonisms.

Reference	Objective	No. of patients	Sex	Test	Technique	Results	Evidence
Stocchi et al., 1997	To determine the diagnostic value of the BCR in the differential diagnosis between MSA and IPD	32 MSA; 30 IPD	19M; 18M	BCR		N: 100% in MSA; N: 100% in IPD	Class 2
Pellegrinetti et al., 2003	To determine the diagnostic value of the PAR in MSA	13	7 M	PAR	Single electrical	↑Lat: 54%	Class 2
Wang et al., 2016	To determine the diagnostic value of the BCR in MSA	51	27M	BCR	Single electrical	↓ elicitation rate; ↑ mean Lat; ↓ mean Amp	Class 2

Abbreviations: BCR=bulbocavernosus reflex; PAR=pudendal-anal reflex; MSA=multiple system atrophy; IPD=idiopathic Parkinson's disease; M=male; N=normal results; Lat=latency; Amp=amplitude.

Table XIVs - Pudendal somatosensory evoked potentials in cauda equina and conus medullaris lesions.

Reference	Objective	No. of patients	Sex	Results	Evidence
Moon et al., 1993	To determine the diagnostic value of pSEPs in patients with conus medullaris lesions and EDs	35	M	Ab: 69%; ↑Lat: 11%	Class 2
Niu et al., 2010	To determine the diagnostic value of pSEPs in acute cauda equina syndrome	9	F	Ab: 22%; ↑Lat: 67%	Class 2
Niu et al., 2015	To determine the diagnostic value of pSEPs in cauda equina lesions	53	M	Ab: 4%; ↑Lat: 74%	Class 2

Abbreviations: pSEPs=pudendal somatosensory evoked potentials; EDs=erectile dysfunctions; M=male; F= female; Ab=absent response; Lat=latency.

Table XVs - Pudendal somatosensory evoked potentials in peripheral neuropathies.

Reference	Objective	No. of patients	Sex	Results	Evidence
Alves et al., 1997	To determine the diagnostic value of pSEPs in patients with amyloidotic polyneuropathy and EDs	15	M	↑Lat of lumbar response: 60%	Class 2

Abbreviations: pSEPs=pudendal somatosensory evoked potentials; EDs=erectile dysfunctions; M=male; Lat=latency.

Table XVIs - Pudendal somatosensory evoked potentials in sacral plexopathy.

Reference	Objective	No. of patients	Sex	Results	Evidence
Ismael et al., 2000	To determine the diagnostic value of pSEPs in lumbosacral plexopathy	19	F	ABR: 5%	Class 3

Abbreviations: pSEPs=pudendal somatosensory evoked potentials; F=female; ABR=abnormality rate.

Table XVIIs - Pudendal somatosensory evoked potentials in spinal cord lesions.

Reference	Objective	No. of patients	Sex	Results	Evidence
Kirkeby et al., 1988	To determine the diagnostic value of pSEPs in patients with MS and EDs	29	M	↑ Lat: 90%	Class 2
Eardley et al., 1991	To determine the diagnostic value of pSEPs in patients with MS and LUTSs	24	9M	Ab/↑ Lat: 87%	Class 2
Moon et al., 1993	To determine the diagnostic value of pSEPs in patients with suprasacral spinal cord lesions and EDs	41	M	Ab: 56%, ↑ Lat: 27%	Class 2
Betts et al., 1994	To determine the diagnostic value of pSEPs in patients with MS and EDs, and compare pSEPs and tSEPs	44	M	Ab/↑ Lat: 77% for pSEPs; Ab/↑ Lat: 79-82% for tSEPs	Class 2
Ghezzi et al., 1995	To determine the diagnostic value of pSEPs in patients with MS, and the association between pSEPs and EDs	34	M	↑ Lat: 77%	Class 2
Rodi et al., 1996 b	To determine the diagnostic value of pSEPs in patients with MS and LUTSs, and compare pSEPs and tSEPs	21	8M	Ab/↑ Lat: 48% for pSEPs; Ab/↑ Lat: 86% for tSEPs	Class 2
Sau et al., 1997	To determine the diagnostic value of pSEPs in patients with MS, and compare pSEPs and tSEPs	16	5M	Ab/↑ Lat: 87% for pSEPs; Ab/↑ Lat: 31% for tSEPs	Class 2
Yang et al., 2001	To determine the diagnostic value of pSEPs in patients with MS and EDs	13	M	Ab/↑ Lat: 70% (bilateral stimulation); Ab/↑ Lat: 92% (unilateral stimulation)	Class 2
Zivadinov et al., 2003	To assess the relationship between pSEPs and sexual dysfunctions in patients with MS, and compare pSEPs and tSEPs	31	16M	ABR: 50% (pSEPs, tSEPs) in symptomatic patients; ABR: 57% (pSEPs), 43% (tSEPs) in asymptomatic patients	Class 3
Ashraf et al., 2005	To determine the diagnostic value of pSEPs in suprasacral spinal cord lesions, assess the association between pSEPs and EDs, and compare pSEPs and tSEPs	40	M	Ab: 22%, ↑ Lat: 20% for pSEPs; ABR 65% for tSEPs	Class 2
Niu et al., 2010	To determine the diagnostic value of pSEPs in suprasacral spinal cord lesions	30	F	Ab/↑ Lat: 87%	Class 2
Tankisi et al., 2016	To determine the diagnostic value of pSEPs in chronic suprasacral SCI	12	11M	Ab: 92%	Class 2

Abbreviations: pSEPs=pudendal somatosensory evoked potentials; tSEPs=tibial somatosensory evoked potentials; MS=multiple sclerosis; EDs=erectile dysfunctions; LUTSs=lower urinary tract symptoms; SCI=spinal cord injury; M=male; F female; Lat=latency; Ab=absent response; ABR=abnormality rate.

Table XVIIIs - Pudendal somatosensory evoked potentials in parkinsonisms.

Reference	Objective	No. of patients	Sex	Results	Evidence
Pellegrinetti et al., 2003	To determine the diagnostic value of pSEPs in MSA	13	7M	Ab/↑ Lat: 69%	Class 2
Wang et al., 2016	To determine the diagnostic value of pSEPs in MSA	51	27M	mean Lat: N.D.	Class 2

Abbreviations: pSEPs=pudendal somatosensory evoked potentials; MSA=multiple system atrophy; M=male; Ab=absent response; Lat=latency; N.D. =not significantly different from normal values.

Table XIXs - Perineal sympathetic skin response in spinal cord and cauda equina lesions.

Reference	Objective	No. of patients	Sex	Stimulation technique	Recording site	Results	Evidence
Courtois et al., 1998	To assess the relationship between the pSSR, lesion level and PE in chronic SCI	54	M	Supralesional electrical	Genital skin	Ab/↑ Lat: 73% in lesions above TL, 50% at TL, 23% below TL level	Class 2
Rodic et al., 2000	To assess the relationship between the pSSR, lesion level/completeness and bladder function in patients with chronic SCI or cauda lesions	90	70M	Median nerve electrical	Perineal skin	Ab: 100% in lesions above TL, 60% at TL (CLs) level; N: 100% in cauda lesions	Class 2
Schmid et al., 2003	To assess the relationship between the pSSR, lesion level and EDs in chronic SCI	32	M	Median nerve electrical	Perineal skin	Ab: 82% in lesion above TL, 20% in lesion at or below T12 level	Class 2
Tas et al., 2007	To assess the relationship between the pSSR, lesion level and sexual dysfunctions in chronic SCI	25	17M	Median nerve electrical	Perineal skin	Ab: 64% in lesion levels above TL (CLs), 8% in lesion at or below T12 level	Class 3
Secil et al., 2007	To assess the diagnostic value of the pSSR in MS and the relationship between the pSSR and sexual disorders	40	F	Median nerve electrical	Perineal skin	Ab/↑ Lat/↓ Amp: 50%	Class 2

Abbreviations: pSSR=perineal sympathetic skin response; PE=psychogenic erection; EDs=erectile dysfunctions; SCI=spinal cord injury; MS=multiple sclerosis; M=male; F=female; Ab=absent response; Lat=latency; Amp=amplitude; TL=thoracolumbar; CLs=complete lesions; N=normal results.

Table XXs - Perineal sympathetic skin response in peripheral neuropathies.

Reference	Objective	No. of patients	Sex	Stimulation technique	Recording site	Results	Evidence
Ertekin et al., 1987	To determine the diagnostic value of the pSSR in diabetic impotent men with or without peripheral polyneuropathy	32	M	Penile electrical and mechanical	Genital skin	Ab/↑ Lat/↓ Amp: 53%; No differences related to the polyneuropathy	Class 2
Ertekin et al., 1990	To determine the diagnostic value of the pSSR in alcoholic impotent men with or without peripheral polyneuropathy	15	M	Penile electrical and mechanical	Genital skin	N.D.	Class 2
Alves et al., 1997	To determine the diagnostic value of the pSSR in patients with amyloidotic neuropathy and EDs	15	M	Penile electrical stimulation	Palm skin; Plant skin	Ab/↑ Lat: 60% for SSR recorded at the palm and 93% at the sole of the foot	Class 2

Abbreviations: pSSR=perineal sympathetic skin response; EDs=erectile dysfunctions; M=male; Ab=absent response; Lat=latency; Amp=amplitude; N.D.=not significantly different from normal values; SSR=sympathetic skin response.

Table XXIs - Perineal motor evoked potentials in cauda equina lesions.

Reference	Objective	No. of patients	Stimulation site	Recording site	Electrode type	Results	Evidence
Schmid et al., 2005	To determine the diagnostic value of pMEPs in cauda equina lesions	14	Motor cortex; LS roots	EUS	Surface	↑ mean Lat of peripheral responses; Ab cortical/peripheral responses: 100% CLs	Class 1

Abbreviations: pMEPs=perineal motor evoked potentials; LS=lumbosacral; EUS=external urethral sphincter; Lat=latency; Ab=absent response; CLs=complete lesions.

Table XXIIs - Perineal motor evoked potentials in spinal cord lesions.

Reference	Objective	No. of patients	Stimulation site	Recording site	Electrode type	Results	Evidence
Eardley et al., 1991	To determine the diagnostic value of pMEPs in patients with MS and LUTSs	10	Motor cortex; LS roots	EUS	Needle	Ab cortical responses: 50%, ↑ CCT: 20%	Class 2
Ghezzi et al., 1995	To determine the diagnostic value of pMEPs in MS and the association between pMEPs and EDs	34	Motor cortex; LS roots	BC	Surface	↑ CCT: 61%	Class 2
Brostrøm, 2003	To determine the diagnostic value of pMEPs in patients with MS and LUTSs	16	Motor cortex; LS roots	PR	Needle	↑ mean CCT, ↑ rate of Ab cortical responses	Class 1
Schmid et al., 2005	To determine the diagnostic value of pMEPs in patients with suprasacral SCI or MS and LUTSs	19	Motor cortex; LS roots	EUS	Surface	↑ mean CCT, Ab cortical responses: 100% in CLs	Class 1

Abbreviations: pMEPs=perineal motor evoked potentials; MS=multiple sclerosis; LUTSs=lower urinary tract symptoms; EDs=erectile dysfunctions; SCI=spinal cord injury; LS=lumbosacral; EUS=external urethral sphincter muscle; BC=bulbocavernosus muscle; PR=puborectalis muscle; Ab=absent response; CCT=central conduction time; CLs=complete lesions.

Table XXIIIs - Perineal motor evoked potentials in parkinsonisms.

Reference	Objective	No. of patients	Stimulation site	Recording site	Electrode type	Results	Evidence
Pellegrinetti et al., 2003	To determine the diagnostic value of pMEPs in MSA	13	Motor cortex; LS roots	BC	Needle	↑ CCT: 15%; ↑ Lat of cortical and peripheral responses: 8%	Class 2
Winge et al., 2010	To determine the diagnostic value of pMEPs in the differential diagnosis of parkinsonisms	14 MSA; 8 PSP; 6 IPD	Motor cortex; LS roots	EAS		N.D. between groups	Class 2

Abbreviations: pMEPs=perineal motor evoked potentials; MSA=multiple system atrophy; PSP=progressive supranuclear palsy; IPD=idiopathic Parkinson's disease; LS=lumbosacral; BC=bulbocavernosus muscle; EAS=external anal sphincter muscle; CCT=central conduction time; Lat=latency; N.D.=not significantly different.

References

Aerts MB, Esselink RA, Abdo WF et al (2015). Ancillary investigations to diagnose parkinsonism: a prospective clinical study. J Neurol 262(2):346-356.

Alves M, Conceição I, Luis ML (1997). Neurophysiological evaluation of sexual dysfunction in familial amyloidotic polyneuropathy-Portuguese type. Acta Neurol Scand 96(3):163-166.

American Association of Electrodiagnostic Medicine, Campbell WW (1999). Guidelines in electrodiagnostic medicine. Practice parameter for electrodiagnostic studies in ulnar neuropathy at the elbow. Muscle Nerve 8:S171-205.

Ashraf VV, Taly AB, Nair KP et al (2005). Role of clinical neurophysiological tests in evaluation of erectile dysfunction in people with spinal cord disorders. Neurol India 53(1):32-35.

Awad EA, Smith A, Bilkey W et al (1981). Bulbo-sphincteric reflex latency: technique. Prog Clin Biol Res 78:145-150.

Barnett JL, Hasler WL, Camilleri M (1999). American Gastroenterological Association medical position statement on anorectal testing techniques. American Gastroenterological Association. Gastroenterology 116(3):732-760.

Beck RO, Betts CD, Fowler CJ (1994). Genitourinary dysfunction in multiple system atrophy: clinical features and treatment in 62 cases. J Urol 151(5):1336-1341.

Betts CD, Jones SJ, Fowler CG et al (1994). Erectile dysfunction in multiple sclerosis. Associated neurological and neurophysiological deficits, and treatment of the condition. Brain 117(6):1303-1310.

Bilkey WJ, Awad EA, Smith AD (1983). Clinical application of sacral reflex latency. J Urol 129(6):1187-1189.

Blaivas JG, Zayed AA, Labib KB (1981). The bulbocavernosus reflex in urology: a prospective study of 299 patients. J Urol 126(2):197-199.

Brostrom S, Frederiksen JL, Jennum P et al (2003). Motor evoked potentials from the pelvic floor in patients with multiple sclerosis. J Neurol Neurosurg Psychiatry 74(4):498-500.

Chuang TY, Cheng H, Chan RC et al (2001). Neurourologic findings in patients with traumatic thoracolumbar vertebra junction lesions. Arch Phys Med Rehabil 82(3):375-379.

Colosimo C, Inghilleri M, Chaudhuri KR (2000). Parkinson's disease misdiagnosed as multiple system atrophy by sphincter electro-myography. J Neurol 247(7):559-561.

Courtois FJ, Gonnaud PM, Charvier KF et al (1998). Sympathetic skin responses and psychogenic erections in spinal cord injured men. Spinal Cord 36(2):125-131.

Dykstra D, Sidi A, Cameron J et al (1987). The use of mechanical stimulation to obtain the sacral reflex latency: a new technique. J Urol 137(1):77-79.

Eardley I, Nagendran K, Lecky B et al (1991). Neurophysiology of the striated urethral sphincter in multiple sclerosis. Br J Urol 68(1):81-88.

Eardley I, Quinn NP, Fowler CJ et al (1989). The value of urethral sphincter electromyography in the differential diagnosis of parkinsonism. Br J Urol 64(4):360-362.

Ertekin C, Almis S, Ertekin N (1990). Sympathetic skin potentials and bulbocavernosus reflex in patients with chronic alcoholism and impotence. Eur Neurol 30(6):334-337.

Ertekin C, Ertekin N, Mutlu S et al (1987). Skin potentials (SP) recorded from the extremities and genital regions in normal and impotent subjects. Acta Neurol Scand 76(1):28-36.

Ertekin C, Reel F (1976). Bulbocavernosus reflex in normal men and in patients with neurogenic bladder and/or impotence. J Neurol Sci 28(1):1-15.

Ertekin C, Reel F, Mutlu R et al (1979). Bulbocavernosus reflex in patients with conus medullaris and cauda equina lesions. J Neurol Sci 41(2):175-181.

Fowler CJ, Benson JT, Craggs MD et al (2002). Clinical Neurophysiology. In: Abrams P, Cardozo L, Khoury S, Wein A (Eds.). Incontinence, 2nd International Consultation on Incontinence, Health Publication, Plymouth, pp 389-424.

Ghezzi A, Malvestiti GM, Baldini S et al (1995). Erectile impotence in multiple sclerosis: a neurophysiological study. J Neurol 242(3):123-126.

Gilad R, Giladi N, Korczyn AD et al (2000). Quantitative anal sphincter EMG in multisystem atrophy and 100 controls. J Neurol Neurosurg Psychiatry 71(5):596-599.

Giladi N, Simon ES, Korczyn AD et al (2000). Anal sphincter EMG does not distinguish between multiple system atrophy and Parkinson's disease. Muscle Nerve 23(5):731-734.

Gronseth G, French J (2008). Practice parameters and technology assessments: what they are, what they are not, and why you should care. Neurology 71(20):1639-1643.

Ismael SS, Amarenco G, Bayle B et al (2000). Postpartum lumbosacral plexopathy limited to autonomic and perineal manifestations: clinical and electrophysiological study of 19 patients. J Neurol Neurosurg Psychiatry 68(6):771-773.

Kiff ES, Swash M (1984). Slowed conduction in the pudendal nerves in idiopathic (neurogenic) faecal incontinence. Br J Surg 71(8):614-616.

Kirby R, Fowler C, Gosling J et al (1986). Urethro-vesical dysfunction in progressive autonomic failure with multiple system atrophy. J Neurol Neurosurg Psychiatry 49(5):554-562.

Kirkeby HJ, Poulsen EU, Petersen T et al (1988). Erectile dysfunction in multiple sclerosis. Neurology 38(9):1366-1371.

Koldewijn EL, Van Kerrebroeck PE, Bemelmans BL et al (1994). Use of sacral reflex latency measurements in the evaluation of neural function of spinal cord injury patients: a comparison of neuro-urophysiological testing and urodynamic investigations. J Urol 152(2 Pt 1):463-467.

Krane RJ, Siroky MB (1980). Studies on sacral-evoked potentials. J Urol 124(6):872-876.

Lee EA, Kim BJ, Lee WY (2002). Diagnosing multiple system atrophy with greater accuracy: combined analysis of the clonidine-growth hormone test and external anal sphincter electromyography. Mov Disord 17(6):1242-1247.

Lefaucheur JP (2006). Neurophysiological testing in anorectal disorders. Muscle Nerve 33(3):324-333.

Libelius R, Johansson F (2000). Quantitative electromyography of the external anal sphincter in Parkinson's

disease and multiple system atrophy. Muscle Nerve 23(8):1250-1256.
Linder J, Libelius R, Nordh E et al (2012). Anal sphincter electromyography in patients with newly diagnosed idiopathic parkinsonism. Acta Neurol Scand 126(4):248-255.
Moon JH, Kang SW, Chun SI (1993). Pudendal somatosensory evoked potential and bulbocavernosus reflex testing in erectile dysfunction. Yonsei Med J 34(1):71-77.
Niu X, Shao B, Ni P et al (2010). Bulbocavernosus reflex and pudendal nerve somatosensory-evoked potentials responses in female patients with nerve system diseases. J Clin Neurophysiol 27(3):207-211.
Niu X, Wang X, Ni P et al (2015). Bulbocavernosus reflex and pudendal nerve somatosensory evoked potential are valuable for the diagnosis of cauda equina syndrome in male patients. Int J Clin Exp Med 8(1):1162-1167.
Olsen AL, Rao SS (2001). Clinical neurophysiology and electrodiagnostic testing of the pelvic floor. Gastroenterol Clin North Am 30(1):33-54, v-vi.
Palace J, Chandiramani VA, Fowler CJ (1997). Value of sphincter electromyography in the diagnosis of multiple system atrophy. Muscle Nerve 20(11):1396-1403.
Paviour DC, Williams D, Fowler CJ et al (2005). Is sphincter electromyography a helpful investigation in the diagnosis of multiple system atrophy? A retrospective study with pathological diagnosis. Mov Disord 20(11):1425-1430.
Pellegrinetti A, Moscato G, Siciliano G et al (2003). Electrophysiological evaluation of genito-sphincteric dysfunction in multiple system atrophy. Int J Neurosci 113(10):1353-1369.
Podnar S, Vodusek DB (2001a). Protocol for clinical neurophysiologic examination of the pelvic floor. Neurourol Urodyn 20(6):669-682.
Podnar S, Vodusek DB (2001b). Standardization of anal sphincter electromyography: utility of motor unit potential parameters. Muscle Nerve 24(7):946-951.
Podnar S, Oblak C, Vodusek DB (2002a). Sexual function in men with cauda equina lesions: a clinical and electromyographic study. J Neurol Neurosurg Psychiatry 73(6):715-720.
Podnar S, Vodusek DB, Stålberg E (2002b). Comparison of quantitative techniques in anal sphincter electromyography. Muscle Nerve 25(1):83-92.
Podnar S, Mrkaić M (2002). Predictive power of motor unit potential parameters in anal sphincter electromyography. Muscle Nerve 26(3):389-394.
Podnar S (2003a). Electrodiagnosis of the anorectum: a review of techniques and clinical applications. Tech Coloproctol 7(2):71-76.
Podnar S (2003b). Electromyography of the anal sphincter: which muscle to examine? Muscle Nerve 28(3):377-379.
Podnar S (2004a). Criteria for neuropathic abnormality in quantitative anal sphincter electromyography. Muscle Nerve 30(5):596-601.
Podnar S (2004b). Bilateral vs. unilateral electromyographic examination of the external anal sphincter muscle. Neurophysiol Clin 34(3-4):153-157.
Podnar S, Fowler CJ (2004). Sphincter electromyography in diagnosis of multiple system atrophy: technical issues. Muscle Nerve 29(1):151-156.
Podnar S (2005). Comparison of different outlier criteria in quantitative anal sphincter electromyography. Clin Neurophysiol 116(8):1840-1845.
Podnar S (2007). Neurophysiology of the neurogenic lower urinary tract disorders. Clin Neurophysiol 118(7):1423-1437.
Podnar S (2008a). Sphincter electromyography and the penilo-cavernosus reflex: are both necessary? Neurourol Urodyn 27(8):813-818.
Podnar S (2008b). Clinical and neurophysiologic testing of the penilo-cavernosus reflex. Neurourol Urodyn 27(5):399-402.
Podnar S (2008c). The penilo-cavernosus reflex: comparison of different stimulation techniques. Neurourol Urodyn 27(3):244-248.
Podnar S (2009a). Predictive values of the anal sphincter electromyography. Neurourol Urodyn 28(8): 1034-1035.
Podnar S (2009b). Predictive value of the penilo-cavernosus reflex. Neurourol Urodyn 28(5):390-394.
Podnar S (2011). Sacral neurophysiologic study in patients with chronic spinal cord injury. Neurourol Urodyn 30(4):587-592.
Podnar S (2014). Utility of sphincter electromyography and sacral reflex studies in women with cauda equina lesions. Neurourol Urodyn 33(4):426-430.
Pramstaller PP, Wenning GK, Smith SJ et al (1995). Nerve conduction studies, skeletal muscle EMG, and sphincter EMG in multiple system atrophy. J Neurol Neurosurg Psychiatry 58(5):618-621.
Rodi Z, Denislic M, Vodusek DB (1996a). External anal sphincter electromyography in the differential diagnosis of parkinsonism. J Neurol Neurosurg Psychiatry 60(4):460-461.
Rodi Z, Vodusek DB, Denislic M (1996b). Clinical uroneurophysiological investigation in multiple sclerosis. Eur J Neurol 3:574–580.
Rodic B, Curt A, Dietz V et al (2000). Bladder neck incompetence in patients with spinal cord injury: significance of sympathetic skin response. J Urol 163(4):1223-1227.
Sakakibara R, Hattori T, Uchiyama T et al (2001). Videourodynamic and sphincter motor unit potential analyses in Parkinson's disease and multiple system atrophy. J Neurol Neurosurg Psychiatry 71(5):600-606.
Sarica Y, Karacan I (1987). Bulbocavernosus reflex to somatic and visceral nerve stimulation in normal subjects and in diabetics with erectile impotence. J Urol 138(1):55-58.
Sau GF, Aiello I, Siracusano S et al (1997). Pudendal nerve somatosensory evoked potentials in probable multiple sclerosis. Ital J Neurol Sci 18(5):289-291.
Schmid DM, Curt A, Hauri D et al (2003). Clinical value of combined electrophysiological and urodynamic recordings to assess sexual disorders in spinal cord injured men. Neurourol Urodyn 22(4):314-321.
Schmid DM, Curt A, Hauri D et al (2005). Motor evoked potentials (MEP) and evoked pressure curves (EPC) from the urethral compressive musculature (UCM) by functional magnetic stimulation in healthy volunteers and patients with neurogenic incontinence. Neurourol Urodyn 24(2):117-127.
Schwarz J, Kornhuber M, Bischoff C et al (1997). Elec-

tromyography of the external anal sphincter in patients with Parkinson's disease and multiple system atrophy: frequency of abnormal spontaneous activity and polyphasic motor unit potentials. Muscle Nerve 20(9):1167-1172.

Seçil Y, Yetimalar Y, Gedizlioglu M et al (2007). Sexual dysfunction and sympathetic skin response recorded from the genital region in women with multiple sclerosis. Mult Scler 13(6):742-748.

Stocchi F, Carbone A, Inghilleri M et al (1997). Urodynamic and neurophysiological evaluation in Parkinson's disease and multiple system atrophy. J Neurol Neurosurg Psychiatry 62(5):507-511.

Swash M, Snooks SJ (1986). Slowed motor conduction in lumbosacral nerve roots in cauda equina lesions: a new diagnostic technique. J Neurol Neurosurg Psychiatry 49(7):808-816.

Tankisi H, Pugdahl K, Rasmussen MM et al (2016). A. pelvic floor electrophysiology in spinal cord injury. Clin Neurophysiol 127(5):2319-2324.

Tas I, Yagiz On A, Altay B et al (2007). Electrophysiological assessment of sexual dysfunction in spinal cord injured patients. Spinal Cord 45(4):298-303.

Tison F, Arne P, Sourgen C et al (2000). The value of external anal sphincter electromyography for the diagnosis of multiple system atrophy. Mov Disord 15(6):1148-1157.

Valldeoriola F, Valls-Solé J, Tolosa ES et al (1995). Striated anal sphincter denervation in patients with progressive supranuclear palsy. Mov Disord 10(5): 550-555.

Vodusek DB (2005). How to diagnose MSA early: the role of sphincter EMG. J Neural Transm 112(12): 1657-1668.

Wang ZY, Chen YH, Xu YY et al (2016). Altered bulbocavernosus reflex in patients with multiple system atrophy. Neurol Res 38(2):138-143.

Wenning GK, Ben Shlomo Y, Magalhães M et al (1994). Clinical features and natural history of multiple system atrophy. An analysis of 100 cases. Brain 117(4):835-845.

Winge K, Jennum P, Lokkegaard A et al (2010). Anal sphincter EMG in the diagnosis of parkinsonian syndromes. Acta Neurol Scand 121(3):198-203.

Yamamoto T, Sakakibara R, Uchiyama T et al (2005). When is Onuf's nucleus involved in multiple system atrophy? A sphincter electromyography study. J Neurol Neurosurg Psychiatry 76(12):1645-1648.

Yang CC, Bowen JD, Kraft GH et al (2001). Physiologic studies of male sexual dysfunction in multiple sclerosis. Mult Scler 7(4):249-254.

Zivadinov R, Zorzon M, Locatelli L et al (2003). Sexual dysfunction in multiple sclerosis: a MRI, neurophysiological and urodynamic study. J Neurol Sci 210(1-2):73-76.