

ORIGINAL RESEARCH

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SOMATOSENSORY AND MOTOR EVOKED POTENTIALS AS PROGNOSTIC INDICATOR OF WALKING AFTER SPINAL CORD INJURY

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ABSTRACT

Background: Walking recovery is one of the main goals of patients after SCI. Walking is rated as primary goal and desire (together with bladder and bowel function) irrespective of the level of lesion. Past literature terms walking as long-term outcome or as a primary means of mobility after SCI. In patients with SCI clinical and electrophysiological examinations are directed towards predicting functional recovery.

Methods: A systematic research of all papers was made by the authors using the PRISMA 2009 guidelines. Using the various search engines 56 articles were found and 22 were selected for the present study. Out of these 17 were included for the final stage

Result: Electrophysiological measures can provide information that complements clinical assessments such as the American Spinal Injury Association sensory and motor scores in the evaluation of outcomes after spinal cord injury (SCI).

Conclusion: The authors review and summarize the literature regarding tests that are most relevant to the study of SCI recovery—in particular, motor evoked potentials and somatosensory evoked potentials (SSEPs). Both SSEP and MEP provide data clinically significant as a prognostic indicator.

Keywords: Somatosensory Evoked Potentials, Motor Evoked Potentials, Walking, Spinal Cord Injury, Electrophysiology.

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INTRODUCTION

In patients with acute traumatic spinal cord lesions the clinical examination is usually the first and most important diagnostic approach for the assessment of a Spinal Cord Injury (SCI). The clinical examination determines the level of the lesion, the extent of motor and sensory deficits, and initiates further neurological and radiological examinations (X-ray, CT scan, MRI). The results of such examinations are essential in the choice of the best treatment approach (ie surgical and conservative procedures) and in goal planning of the therapeutic rehabilitation program.¹

Ambulatory capacity is of critical interest since it will determine if the patients will be wheelchair-bound.² Clinical examination of patients with traumatic SCI is usually the first and most important approach in the diagnostic assessment of an acute spinal trauma. The American Spinal Injury Association (ASIA) score, which is based on long-lasting clinical experience, allows the clinician to perform a standardized clinical examination to evaluate the extent of SCI and also to predict the degree and prognosis of functional disability.³

In patients with SCI clinical and electrophysiological examinations are directed towards predicting functional recovery. This review intends to show how far electrophysiological recordings are able to broaden the clinical assessment of SCI patient and its consequences. The aim of this review is (1) to illustrate the significance of electrophysiological recordings in the diagnostic and prognostic assessment of patients with SCI. (2) to monitor the extent of recovery of spinal cord function (by recording spinal impulse transmission) in relation to the degree of ambulatory capacity during the rehabilitation program.

The clinical diagnosis of incomplete motor and /or sensory SCI lesion, such as sacral sparing, in patients with acute SCI provides a good prognosis for recovery of spinal cord function¹. The initial neurological examination serves as a baseline for evaluation over the first hours to days after injury. It should be sufficiently detailed to detect deterioration in neurological status, using the International Standards for Neurological and Functional Classification of Spinal Cord Injury (American Spinal Injury Association [ASIA], 1996) as the clinical situation allows.

Based upon neurological assessment within the first week of injury, 80 percent to 90 percent of those with complete injuries (ASIA A) will remain

complete. Of those who convert to incomplete injuries, only 3 percent to 6 percent will recover functional strength in the lower extremities.^{4,5} Sensory incomplete, motor complete (ASIA B) individuals comprise about 10 percent of all new injuries. This group has a mixed prognosis.

Overall, approximately 50 percent of those who are initially classified as ASIA B will become ambulatory⁵. Prognosis depends upon the type of sensory sparing. Those motor complete subjects with preserved sacral pin sensation, indicating partial function in the spinothalamic tracts, have a prognosis for lower extremity recovery approaching that of motor incomplete individuals⁴. For those without pin sensation, prognosis for recovery of ambulation ranges from 10 percent to 33 percent⁴. The majority of individuals with motor incomplete injuries upon initial examination recover the ability to ambulate. For individuals with motor incomplete, ASIA C injuries, about 75 percent will become community ambulators.^{6,7,8}

Prognosis is excellent for those initially classified as ASIA D. Younger individuals have a better prognosis for ambulation with a similar injury severity. Prognosis is poorer in those above 50–60 years of age.^{6,8} The preceding information on expected neurological recovery can help in setting long-term goals during the acute period.

By testing upper and lower motor scores according to the ASIA protocol in acute SCI patients it is possible to predict recovery of muscle strength and functional outcome, such as the ambulatory capacity.

ELECTROPHYSIOLOGICAL RECORDINGS

Electrophysiological recordings have been used in the management and care of SCI patients since 1970 but are routinely performed only in a few SCI centers¹. These techniques supplement clinical and neuro-radiological examinations and allow the differentiation between lesions of the spinal (ie ascending and descending fibers tracts) and the peripheral nervous system (eg: radicular lesions, plexus, peripheral nerves). They are especially useful compared to clinical examination in uncooperative (due to drugs, language barrier, psychogenic paresis) and unconscious (due to head trauma, artificial ventilation) patients, as the electrophysiological recordings are less dependent upon the cooperation of the patient.¹

Recordings of the spinal pathways

Somatosensory evoked potentials (SSEP)

Using SSEP recordings the integrity of impulse transmission of somato-sensory nerve fibres through parts of the spinal (mainly dorsal column)

and peripheral (peripheral nerve, plexus) nervous system can be tested. Spinal lesions at different levels can be separated from affection of sensory nerve fibres by combined recordings of the SSEP from central (conus medullaris, cervical spine, cortex) and peripheral (plexus) parts of the nervous structures. The recordings are not affected by spinal shock and can reliably be recorded even in sedated and unconscious patients.⁹

Motor evoked potential (MEP)

Following the introduction of painless transcortical magnetic stimulation by Barker and coworkers (1985), integrity of the cortical and spinal motor tract fibres can be assessed even in awake SCI patients. MEP due to transcortical stimulation can be recorded from different proximal and distal muscles of the upper and lower limbs, and can be used to assess the level and extent of the SCI lesion. By combining magnetic stimulation of cortical and peripheral nervous structures (spinal roots, plexus, peripheral nerves), lesions of spinal and/or peripheral nerves underlying a muscle paresis can be differentiated.

Sympathetic skin response (SSR)

The sympathetic skin response (SSR) is a simple and non-invasive electrophysiological test to examine the common efferent pathways of the sympathetic nervous system. Pathways from the spinal cord to the sudomotor sweat glands of hands (palmar), feet (plantar) and the perineal skin region transmitted by pre- and post-ganglionic sympathetic nerve fibres can be evaluated. The SSR to supraspinal magnetic or electric stimulation can be recorded by conventional surface EMG disc electrodes applied to the relevant skin areas. This allows the assessment of lesions of the spinal and peripheral sympathetic nerve fibres subserving respective skin areas.¹⁰

Recordings of peripheral pathways

Electromyographic (EMG) and neurographic recordings In SCI patients EMG and neurographic recordings from upper and lower limb muscles are required in order to assess accompanying peripheral nerve lesions in poly-traumatic SCI patients. In addition, damage of anterior horn cells and ventral nerve roots associated with a SCI (including conus medullaris or motor fibres of the cauda equina) can be evaluated. The combination of motor and sensory neuro-graphic recordings allows the differentiation between muscle paresis due to spinal anterior horn cell/ anterior nerve root lesions or peripheral nerve damage (plexus, peripheral nerve).¹¹ In the latter disorder, both the peripheral sensory and motor nerve fibers are affected, whereas in spinal lesions only the motor

nerve fibers are affected while sensory nerve fibers remain intact.¹²

Reflex-recordings

By studying H-reflexes and F-waves it is suggested that the impairment of motoneurone excitability due to traumatic lesion, spinal shock and development of spasticity can be assessed.^{13,14}

The H-reflex (first description by Hoffman 1918) is an electrically induced monosynaptic reflex (corresponding to the tendon tap reflex), which includes the function of afferent, spinal-segmental and efferent pathways. The impulse volley evoked by submaximal electrical stimulation of afferent fibres (Ia) of a mixed peripheral nerve excites the a-motoneurons belonging to the same muscle where the stimulated afferent fibres originate by monosynaptic transmission. In contrast, F-waves represent late motor responses observed following supramaximal electrical stimulation of a peripheral nerve causing an antidromic activation of a-motoneurons. Therefore F-waves indicate preserved conduction along the efferent peripheral motor pathway and are of diagnostic value in proximal nerve lesions and are related to the excitability of the segmental motoneurone pool.¹⁵

Prediction of functional outcome

Ambulatory capacity

Walking recovery is one of the main goals after SCI/ walking is related at first place by patients with incomplete SCI. walking recovery is the regained ability to walk independently in the community with or without the use of aid. it is also defined as functional walking. When a patient has gained the ability to walk only few meters with assistance and orthosis ambulation is defined as therapeutic walking. A community ambulator is able to walk reasonable distance in and out of home unassisted by another person.

METHODOLOGY

The aim of the present study was to determine the significance of electrophysiological recordings as a prognostic tool in determining the recovery of ambulatory capacity in Spinal Cord Injury. A systematic search was performed of all papers mentioning spinal cord injury and walking. The literature search was conducted without time limits to identify papers that explicitly mentioned the walking capacity in patients with SCI. Databases included PubMed, Ovid, INMED, ICMR, Cochrane Central Register of Controlled Trials citations, online access to Spinal Cord Journal, Thomas land publications and Physical Therapy Journal. All study designs, including case reports,

were included, with no restrictions on the ages of participants. Non-English articles were excluded.

The following search terms were used: electrophysiological recordings, prognosis prediction and SCI, electrophysiological evaluation and SCI, Neurophysiological monitoring and SCI, Locomotion/ambulation / gait and walking / walking capacity.

RESULTS

SOMATOSENSORY EVOKED POTENTIALS

SSEPs are used for clinical diagnosis in patients with neurologic disease, and many studies have been performed to determine the value of SSEPs in the prediction of walking recovery in SCI patients.^{1,2,3,10,16,17,18,19,20,21,22} Somatosensory evoked potentials provide a means for assessment of ascending spinal tract function. They are generated by stimulating peripheral nerves and recording the response from the patient's scalp. As a prognostic tool, SSEPs have been found to have predictive value in determining ambulation outcomes, although not to a degree more accurate than conventional clinical examination.

A previous study showed a correlation between ASIA motor scores obtained in patients with SCI and their SSEP measures as a predictor of future ambulation, thus further establishing the value of SSEP as a diagnostic tool.² Somatosensory evoked potentials have also been used to assess differences between patients with ischemic SCI and those with traumatic SCI. In another study it was found that both groups of patients had similar motor and sensory deficits and both groups exhibited pathological SSEP recordings. Tibial SSEP recordings in patients with ischemic SCI and both pudendal SSEP and tSSEP recordings in patients with traumatic SCI had predictive power in assessing patient recovery.²³ In another recent study, investigators also confirmed the use of tSSEPs as a predictor of functional and neurological outcomes.²⁴ In another experimental study on primates²⁵ it has been mentioned that both MEP and SSEP were 100% predictive in severe injury and both are complementary to each other.

MOTOR EVOKED POTENTIALS

Motor evoked potentials provide a means for assessment of descending spinal tract function. They are induced by transcranial magnetic stimulation of the motor cortex and recorded on muscles of interest using surface electrodes to determine the level and extent of the SCI lesion.²⁶ Recordings of MEP latencies are thought to reflect the speed of conduction down the corticospinal tract; changes may suggest the level

of remyelination/regeneration/ reconnection of the corticospinal tract over time, and MEP amplitudes have been found to correlate with muscle movement velocity.²⁶ Transcranial magnetic stimulation allows an examination of the conductivity of the motor tracts following cortical or spinal lesions in humans.

According to a study MEPs can contribute toward diagnosing lesions of different neurologic structures within the spinal cord and in predicting the recovery of functional movements.¹ This study shows that MEPs recordings are sensitive to indicate motor tract lesions in approximately 90% of SCI patients and predictive for the recovery of upper and lower limb motor function. In this sense they are of similar prognostic value to clinical examination in the prediction of functional recovery. MEPs can be used in combination with the ASIA protocol to follow the recovery of clinical motor functions in relation to that of descending motor tracts for impulse transmission. In Curt's study², MEPs were highly predictive of ambulatory capacity. All patients with elicited MEPs at the initial examination recovered muscle strength of 3/5 or more of the respective muscles.

Discussion and Conclusion

Electrophysiological measures are able to offer a number of advantages over qualitative clinical measures. Firstly, electrophysiological recordings provide quantitative, objective data that can be analyzed by blinded researchers.²⁷ Secondly, the measures are more flexible and environment independent, thus allowing researchers to perform recordings on unresponsive, uncooperative, or comatose patients.²⁸ Thirdly, measures of evoked potentials complement existing SCI recovery assessments, such as the ASIA sensory and motor scores, as they are able to assess specific parts of the spinal segments and peripheral nerve tracts. In particular, measures can target specific spinal segments below the level of injury.²⁹ Finally, combinations of recording techniques can provide detailed quantitative information about a patient's condition that cannot be determined through other clinical means.¹

Electrophysiological measures are able to provide a significant predictive value similar to clinical bedside examination using ASIA. Electrophysiological studies depict a clearer picture of the neural circuitry. Both SSEP and MEP have been used in the past as an indicator for predicting outcomes after SCI. SSEP and MEP obtained below the lesion of cord have been found to be significantly correlated with ambulation recovery, though SSEP alone can be of limited use.

SSEP and MEP complement each other. Used in conjunction with Clinical examination these electrophysiological measures can be of great value. A reliable, quantitative and objective measure for prognosis of ambulation after SCI can facilitate to structure and implement the

therapeutic retraining protocol for SCI management. There is much promise in using these measures to assess SCI, predict functional outcomes, and inform clinicians about the planning and results of therapeutic interventions.

Flow Chart - 1

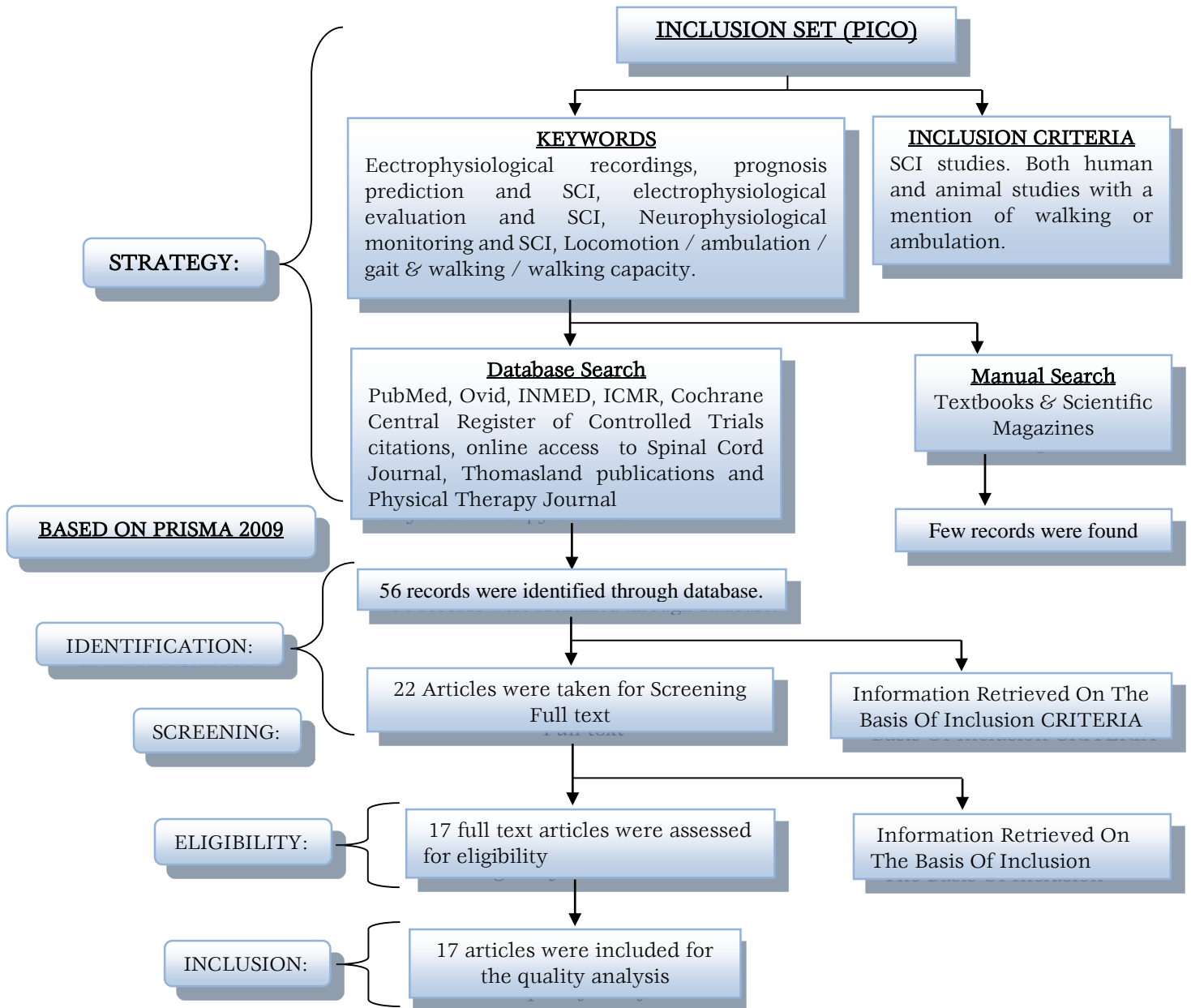


Table 1: Summary of Studies included for quality analysis

Author & Year	Title of the study	Outcome measures	Result & Conclusion
³⁰ Levy WJ,Mc Caffery M and Haigchi S.(1987).	Motor evoked potentials from normal and spinal cord injured cats.	Experimental & co relational study. 30 cats received weight drop injuries to the thoracic spinal cord. Evoked potentials were recorded above, below and in Sciatic nerves.	Examination of the spinal cord signal showed that MEP spinal cord signal below the lesion as a percentage above the lesion was a significant correlate of the ambulation recovery, with a correlation of 0.55. this suggests that evaluation of the SSEP and MEP spinal cord signals may be able to predict longer term recovery in animals and humans.
³¹ Kovindha A, Mahachai R.(1992).	Short-latency somatosensory evoked potentials (SSEPs) of the tibial nerves in spinal cord injuries	Experimental study where Stimulation of the tibial nerves of 76 spinal cord injured patients; revealed short-latency somatosensory evoked potentials (SSEPs) especially P37 recorded from the scalp.	The study demonstrated that SSEPs of the tibial nerves are related to joint sense and seem to relate to the extent of cord damage, especially of central cord and complete cord lesions.
¹⁶ Aalfs, C.M., Koelman, J.H., Meyjes, F.E., and deVisser, B.W. O.(1993).	Posterior tibial and sural nerve somatosensory evoked potentials: a study in spastic paraparesis in spinal cord lesions.	Comparative study on 7 patients with hereditary spastic paraplegia and 8 patients with primary lateral sclerosis. The results were compared with those obtained from a group of 39 control subjects.	Analyses of PTN SEPs in patients suffering from slowly progressive spastic paraplegia (SP), therefore, seem to be a method to indicate a feature of spinal cord dysfunction that is not related to the severity of clinical signs.
¹⁹ Jacobs SR, Yeane NK, Herbison G J, Ditunno Jr. JF.(1995).	Future Ambulation Prognosis as Predicted by Somatosensory Evoked Potentials in Motor Complete and Incomplete Quadriplegia	Prospective cohort study. Twenty-two cervical spinal cord-injured patients were evaluated by examining initial touch and pin sensation, motor strength, and the tibial SEP and relating them to the attainment of functional ambulation.	Both the early postinjury clinical evaluation and the SEP predicted ambulation outcome to a significant degree, but the SEP offered no additional prognostic accuracy over that provided by the clinical examination.
³ Curt A, Keck ME, Dietz V.(1998)	Functional outcome following spinal cord injury: significance of motor-evoked potentials and ASIA scores.	Correlation study on a prospective cohort design. Thirty-six patients with acute and 34 with chronic SCI.	Both ASIA scores and MEP recordings are similarly related to the outcome of ambulatory capacity and hand function in patients with SCI. MEP recordings are of

		Outcome Measures: (1) ASIA motor and sensory scores (2) MEP recordings of upper and lower limb muscles, and (3) outcome of ambulatory capacity and hand function	additional value to the clinical examination in uncooperative or incomprehensive patients. The combination of clinical examination and MEP recordings allows differentiation between the recovery of motor function (hand function, ambulatory capacity) and that of impulse transmission of descending motor tracts.
¹⁷ Dietz V, Wirz M, Curt A and Colombo G (1998).	Locomotor pattern in paraplegic patients: training effects and recovery of spinal cord function	ASIA Scores and evoked potential recordings	Only in incomplete paraplegic patients was there recovery, albeit statistically insignificant, of spinal cord function according to the sensory and motor scores obtained in the neurological examination during the time period before onset of training.
Kirshblum SC, O'Connor KC.(1998).	Predicting neurologic recovery in traumatic cervical spinal cord injury.	Review study	A return of the early SSEP components in the initial stage of SCI can proceed to clinically detectable improvements of motor and sensory function. SSEP are a simple, noninvasive, and objective means of offering evidence of a lack of neurologic deficit.
³ Curt A and Dietz.V (1999)	Electrophysiological recordings in patients with spinal cord injury: significance for predicting outcome	Review study	Electrophysiological recordings (motor evoked potentials (MEP) and somatosensory evoked potentials (SSEP)) are of similar significance in predicting functional outcome of ambulatory capacity, hand- and bladder function as the clinical examination according to the ASIA standards. Electrophysiological recordings supplementary to the clinical examination are helpful for planning and selecting the appropriate therapeutical approaches within the rehabilitation programme
² Curt A & Dietz V.(1999)	Ambulatory Capacity in Spinal Cord Injury: Significance of Somatosensory Evoked Potentials and ASIA Protocol in Predicting Outcome	ASIA motor and sensory scores; (2) tibial and pudendal SSEP graded in 5 categories, from normal to absent; (3) ambulatory capacity	ambulatory capacity in patients with acute spinal cord injury; in noncomprehensive or uncooperative patients the SSEP

		rated as no, therapeutic, functional, or full. The outcome of the ambulatory capacity was assessed after discharge from the rehabilitation program, at least 6 months after trauma.	are of supplemental value to the clinical examination. Therefore, the combination of clinical and electrophysiological examinations can be of additional diagnostic value in the assessment of acute spinal cord injury by the ASIA.
²³ Iseli E, Cavigelli A, Dietz V and Curt A. (1999)	Prognosis and recovery in ischaemic and traumatic spinal cord injury: clinical and electrophysiological evaluation	Comparative study. To compare prognostic factors and functional recovery between paraplegic patients with either ischaemic (28 patients) or traumatic (39 patients) spinal cord injury (SCI).	In both ischaemic and traumatic SCI clinical and electrophysiological examinations are of prognostic value for the functional recovery.
²⁵ Arunkumar MJ, Babu SK and Chandy MJ (2001)	Motor and somatosensory evoked potentials in a Primate model of experimental Spinal Cord Injury.	Eight healthy mature monkeys with a mean weight of 4.2 + 0.9 Kg were chosen for the study. Graded spinal cord injury was caused using 50, 100, 200, 300 gm-cm force by modified Allens' weight drop device. MEP and SSEP recordings were done before injury and at 0, 2, 4 and 6 hours after injury and on the 7th postoperative day.	In a primate model of spinal cord injury, the predictive value of MEP was 80% and SSEP 66.67% (partial injuries); MEP and SSEP signals were cent percent predictive of the outcome in severe injuries. MEP signals, especially the amplitude were found to be highly sensitive to changes in the cord following partial injuries to the spinal cord. Percentage changes of both MEP and SSEP must be precisely monitored as they can be complementary to each other in predicting the final neurological outcome.
³³ Kim YR, Cho KH and Kim SH (2007).	Changes of Somatosensory Evoked Potential Study Following Functional Improvement in Patients With Incomplete Spinal Cord Injury.	Experimental study. 32 Participants. ASIA motor score, ASIA sensory score, and parameters of SEP studies were analyzed & compared between the 2 groups before and after training.	The parameters of SEP studies were improved following functional improvement in patients with incomplete SCI. Our finding suggests that the latency and amplitude of SEP studies could be among the useful diagnostic methods for assessment of functional improvement in patients with incomplete SCI.
³⁴ Xie J and Boakye M. (2008)	Electrophysiological outcomes after spinal cord injury	Review Study	They are able to provide predictive value with a degree of significance similar to that provided by clinical examinations

			using ASIA scoring and provide informative, quantitative data on the changes that occur in neural circuitry. Used in conjunction with conventional clinical examinations, electrophysiological examinations have come to be a good complement for assessing function after SCI. Furthermore, the tests themselves also complement each other in providing a broader picture of the condition.
²⁴ Spiess, M., Schubert, M., Kliesch, U., and Halder P. (2008).	Evolution of tibial SSEP after traumatic spinal cord injury: baseline for clinical trials. Clin. Neurophysiol.	Experimental Study. 297 patients. ASIA light touch (ASIA LT) for neurological assessment and 10m walking test (10MWT) for functional outcome	Initial absence of tSSEP was associated with a poor neurological and functional outcome in about 75% of patients. In the remaining 25%, initially absent tSSEP recovered and was accompanied by a favorable neurological and functional outcome.
³⁵ Clarke CJ, Galen S, Allan DB and Conway BA (2010).	Correlations Between Recovery of Ambulatory Capacity and Lower-Limb Somatosensory Evoked Potentials in Incomplete Spinal Cord Injury.	Co-relational Study. Outcome measures assessed at baseline after 3 and 6 weeks of Lokomat training; (1) Walking Index for Spinal Cord Injury scale (WISCI II), (2) temporal gait analysis, (3) American Spinal Injury Association (ASIA) motor and sensory scores, and (4) Posterior Tibial Nerve SEP	Improvements in ambulatory capacity were seen in both acute and chronic incomplete SCI patients after 6 weeks of Lokomat training. The ASIA motor scores and PT nerve SEP are related to the ambulatory capacity of incomplete SCI patients. Accordingly, the PT nerve SEP may have some prognostic value in relation to recovery of walking and highlights the role of cortical sensorimotor processing in recovery.
³⁶ Middendorp JJV Goss B, Urquhart S, Atresh S, Williams RP and Schuetz M (2011).	Diagnosis and Prognosis of Traumatic Spinal Cord Injury.	Review Study	Based on the latency and amplitude of the evoked response, an estimation can be made on the severity and prognosis of the injury. Although it has been demonstrated that somatosensory evoked potentials are strongly related to ambulation outcomes, this technique does not offer additional prognostic accuracy

			over that provided by the clinical neurological examination
³⁷ Al-Habib AF, Attabib N, Ball J, Bajammal S, Casha S and Hurlbert JR. (2011)	Clinical Predictors of Recovery after Blunt Spinal Cord Trauma.	Review Study	There is level 2 evidence that initial absence of tibial-SSEP is associated with a poor neurological and functional outcome in 75% and a more favorable outcome in 25%; 60% did not have recordable tSSEP.

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