

# Diagnosis and Prognosis of Traumatic Spinal Cord Injury

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## Abstract

Despite promising advances in basic spinal cord repair research, no effective therapy resulting in major neurological or functional recovery after traumatic spinal cord injury (tSCI) is available to date. The neurological examination according to the *International Standards for Neurological and Functional Classification of Spinal Cord Injury Patients* (International Standards) has become the cornerstone in the assessment of the severity and level of the injury. Based on parameters from the International Standards, physicians are able to inform patients about the predicted long-term outcomes, including the ability to walk, with high accuracy. In those patients who cannot participate in a reliable physical neurological examination, magnetic resonance imaging and electrophysiological examinations may provide useful diagnostic and prognostic information. As clinical research on this topic continues, the prognostic value of the reviewed diagnostic assessments will become more accurate in the near future. These advances will provide useful information for physicians to counsel tSCI patients and their families during the catastrophic initial phase after the injury.

## Keywords

- ▶ spinal cord injury
- ▶ diagnosis
- ▶ prognosis
- ▶ review

Traumatic spinal cord injury (SCI) is a serious disorder that has a profound impact on a patient's physical and psychosocial well-being. The incidence of tSCI is estimated to be 11 to 53 new cases per million population.<sup>1,2</sup> Epidemiological data from the 1980s show that spinal cord injury (SCI) primarily affects young adults (mean age: 29 years). During the last three decades, however, the proportion of elderly SCI subjects increased considerably. Currently, the average age at injury is estimated to be 45 years.<sup>3–5</sup> For all age groups, people with incomplete tetraplegia made up the highest number (30.1%), followed by complete paraplegia (25.6%), complete tetraplegia (20.4%), and incomplete paraplegia (18.5%).<sup>1</sup>

Although promising advances in basic spinal cord repair research have been made, no effective therapy resulting in major neurological or functional recovery after tSCI is available to date.<sup>6</sup> Despite the absence of a cure, significant progress has been made with regard to the care of SCI patients during the 21st century. Since the discovery and use of antibiotics, the prevention of complications, and the introduction of specialized care by the founding fathers of SCI rehabilitation, Dr. Donald Munro and Sir Ludwig Guttmann, survival rates in the SCI population increased dramatically.<sup>7</sup>

After the initial medical stabilization of a patient with tSCI, the following aspects are of importance: (1) invasive

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monitoring and hemodynamic support to maintain mean blood pressure above 90 mm Hg,<sup>8</sup> (2) preventing occurrence of complications, and (3) determining long-term outcomes as accurately as possible. In the early days after the injury, patients and their families want to know whether they will be able to walk again and whether they will be able to perform self-care activities such as feeding, bathing, and clothing.<sup>9</sup>

An accurate assessment of the level and severity of the tSCI is the key for predicting functional outcomes. This review will present the prognostic value and clinical utility of contemporary diagnostic instruments for tSCI.

## Diagnosis

### The Neurological Examination

The initial neurological examination is the most important instrument for the assessment of the severity and level of the injury. For optimal reliability of the initial examination, the patient must be able to cooperate and follow the instructions of the examiner and should not have major distracting injuries such as a complicated tibia midshaft fracture.

Since its introduction in 1969, the Frankel scale, a 5-point severity scale, has commonly been used to determine the severity of the SCI (►Table 1).<sup>10</sup> Patients are classified as complete (grade A), sensory only (grade B), motor useless (grade C), motor useful (grade D), or no neurological deficit/complete recovery (grade E). This scale provided a simple, though nonspecific, scheme for the categorization of SCI. Two major limitations of this scale have been identified: (1) the level of the injury is not incorporated into the classification and (2) the scale's inherent subjectivity in judging what constitutes "useful" motor strength. Moreover, the Frankel scale has limited responsiveness to subtle neurological improvements during recovery.<sup>11</sup>

These methodological shortcomings of the Frankel scale were recognized by the classification committee of the American Spinal Injury Association and in 1992 a major revision of the *International Standards for Neurological and Functional Classification of Spinal Cord Injury Patients* (International Standards) was published.<sup>12</sup> Today, the most recent 2002 revision of the International Standards are used worldwide for the assessment of the severity and level of the injury.<sup>13</sup> The testing of myotomes and dermatomes are the key components of this classification (►Fig. 1).

Motor function testing according to the International Standards encompasses 10 myotomes, specifically C5 to T1

and L2 to S1, corresponding to the five key muscles each in the left and right arms and legs. Motor score testing of the key muscles is graded on a 5-point scale adapted from the Medical Research Council scale.<sup>13</sup>

Sensory examination comprises testing of what are known as key points in each of the 28 dermatomes on both the left and right sides of the body (►Fig. 1). The key points correspond with a defined area of skin in each dermatome where overlapping innervation to adjacent dermatomes is at a minimum, thereby making these areas most suitable for testing the function of each specific dermatome. The dermatomes extend from level C2 to S5, where S4 and S5 are considered as one dermatome. Each key point, including the anal and perianal region, is tested for light touch (with a cotton tip applicator or similar object) and pain (using a pin or similar object). Sensory function is graded as follows: normal = 2; impaired/ distorted = 1; absent = 0; not testable = NT. The latter may be due to a local injury, amputation, or a cast covering the area.<sup>14</sup>

Based on the sensorimotor scores, the level and the severity of the SCI can be determined. The scale most commonly used to classify the severity of the injury is the American Spinal Injury Association (ASIA)/International Spinal Cord Society (ISCoS) neurological standard scale (AIS), better known as the ASIA Impairment Scale. The AIS is a modification of the previously used Frankel scale, and the infralesional function is graded on a 5-point scale from A to E (►Table 2).

Among adult patients with SCI, the intrarater and interrater correlation coefficients for the ASIA motor score assessment have been reported as high as 0.98 and 0.97, respectively.<sup>15</sup> The intrarater and interrater correlation coefficients for the ASIA sensory scores varied from 0.76 to 0.98 and 0.88 to 0.96, respectively. Furlan et al<sup>15</sup> demonstrated that the neurological classification on the whole has a good responsiveness to change.

Diagnostic testing of reflex arcs in acute tSCI is only of limited value. Immediately after the injury, "spinal shock" develops below the level of injury. This may result in reflexes being diminished or even absent within the first 24 to 72 hours after the injury.<sup>16</sup>

### Diagnostic Imaging

Magnetic resonance imaging (MRI) is the technique of choice for the imaging of the spinal cord (►Fig. 2). The typical SCI lesion on MRI is spindle shaped, containing an epicenter of

**Table 1** The Frankel Scale for Spinal Cord Injury That Classifies the Extent of the Neurological/Functional Deficit into Five Grades<sup>10</sup>

| Frankel Scale |               |   |
|---------------|---------------|---|
| A             | Complete      | No motor or sensory function below level of lesion                    |
| B             | Sensory only  | No motor function, but some sensation preserved below level of lesion |
| C             | Motor useless | Some motor function without practical application                     |
| D             | Motor useful  | Useful motor function below level of lesion                           |
| E             | Recovery      | Normal motor and sensory function, may have reflex abnormalities      |

Patient Name \_\_\_\_\_  
 Examiner Name \_\_\_\_\_ Date/Time of Exam \_\_\_\_\_

**ASIA** AMERICAN SPINAL INJURY ASSOCIATION      **ISCOS** INTERNATIONAL SOCIETY OF NEUROLOGICAL CLASSIFICATION OF SPINAL CORD INJURY

**MOTOR** KEY MUSCLES (scoring on reverse side)

|    |                          |                          |  |
|----|--------------------------|--------------------------|--|
| C5 | <input type="checkbox"/> | <input type="checkbox"/> | Elbow flexors                                    |
| C6 | <input type="checkbox"/> | <input type="checkbox"/> | Wrist extensors                                  |
| C7 | <input type="checkbox"/> | <input type="checkbox"/> | Elbow extensors                                  |
| C8 | <input type="checkbox"/> | <input type="checkbox"/> | Finger flexors (distal phalanx of middle finger) |
| T1 | <input type="checkbox"/> | <input type="checkbox"/> | Finger abductors (little finger)                 |

UPPER LIMB TOTAL (MAXIMUM)  +  =   
 (25) (25) (50)

**SENSORY** KEY SENSORY POINTS

0 = absent  
 1 = impaired  
 2 = normal  
 NT = not testable

Light Touch: R L R L  
 Pin Prick: R L R L

TOTALS: (MAXIMUM) (56) (58) (58) (58)

NEUROLOGICAL LEVEL: The most caudal segment with normal function. Sensory: R L, Motor: R L.

COMPLETE OR INCOMPLETE? Incomplete = Any sensory or motor function in S4-S5. ASIA IMPAIRMENT SCALE.

ZONE OF PARTIAL PRESERVATION: Exact extent of partially involved segments. Sensory: R L, Motor: R L.

**Figure 1** The scoring form of the *International Standards for Neurological and Functional Classification of Spinal Cord Injury Patients*, available on the following Web site: [http://www.asia-spinalinjury.org/publications/59544\\_Sc\\_Exam\\_Sheet\\_r4.pdf](http://www.asia-spinalinjury.org/publications/59544_Sc_Exam_Sheet_r4.pdf)

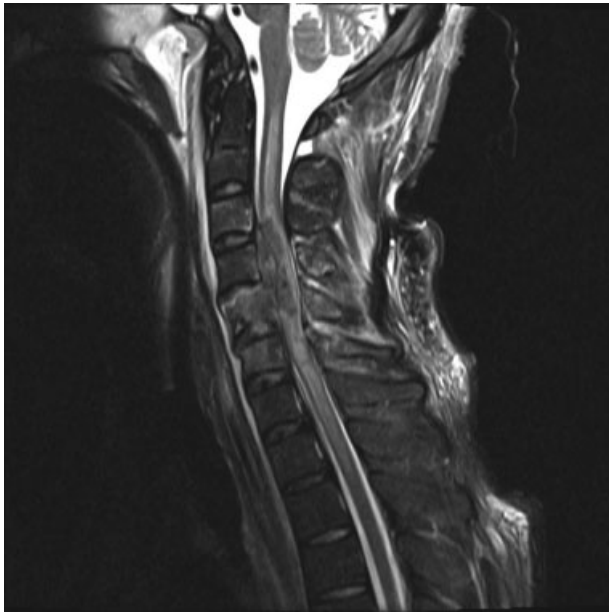
hemorrhage surrounded by a halo of edema; the latter has a greater rostral-caudal extent than the central hemorrhage.<sup>17</sup> Although clearly specified indications have not been postulated yet, several authors advise that patients with a suspected spinal cord injury should undergo an MRI examination as soon as possible.<sup>18-20</sup> Given currently available evidence, however, MRI does not provide additional prognostic information on neurological outcomes in a fully cooperative

patient with tSCI with a stable neurological condition and an uncomplicated injury of the spinal column.<sup>21-23</sup>

If, however, a spinal column injury has been detected on computed tomography and an accurate examination of the neurological status is not possible, MRI may provide some prognostic information. In 2007, Miyanji et al demonstrated that the extent of (1) maximal spinal cord compression, (2) spinal cord hemorrhage, and (3) cord swelling are associated

**Table 2** The American Spinal Injury Association/International Spinal Cord Society Neurological Standard Scale (Better known as the "ASIA Impairment Scale")<sup>13</sup>

| ASIA Impairment Scale |  | Lesion     |
|-----------------------|--|------------|
| A                     | No motor or sensory function is preserved in the sacral segments S4-S5   | Complete   |
| B                     | Sensory but not motor function is preserved below the neurological level and includes the sacral segments S4-S5  | Incomplete |
| C                     | Motor function is preserved below the neurological level, and more than half of key muscles below the neurological level have a muscle grade less than 3 | Incomplete |
| D                     | Motor function is preserved below the neurological level, and at least half of key muscles below the neurological level have a muscle grade of 3 or more | Incomplete |
| E                     | Motor and sensory functions are normal   | Normal     |



**Figure 2** Sagittal T2-weighted magnetic resonance image of the cervical spinal cord in a patient with a traumatic spinal cord injury. The three classical features of a severe spinal cord injury, including spinal cord hemorrhage (C4–C6), spinal cord edema (C1–T3, very distinct), and spinal cord swelling (C1–T3, not very distinct) are present.

with a poor prognosis for neurological recovery.<sup>24</sup> However, clinically utilizable predictive values of MRI have not been published yet (►Table 3).

### Electrophysiological Examination

The integrity and function of axons in the spinal cord can also be measured with us electrophysiological recordings such as somatosensory evoked potentials and motor evoked potentials. These instruments are particularly valuable in patients who cannot participate in a reliable physical examination. Based on the latency and amplitude of the evoked response, an estimation can be made on the severity and prognosis of the injury (►Table 3).<sup>25–27</sup> 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.<sup>25</sup> It is for this reason that electrophysiological examinations of the limbs are currently not indicated in the evaluation of cooperative patients with tSCI.

### Prognosis

In 2008, Ditunno et al published the results of a panel study in which the priorities for recovery of independent functional activities after tSCI were questioned.<sup>28</sup> Recovery preferences for bladder and bowel function were the highest, closely followed by recovery of walking. In clinical practice, one of the most prominent questions patients and their families ask during the early days after the injury is: “Will I (he/she) ever be able to walk again?” Until recently, physicians experienced the greatest difficulties in answering this question accurately.

Recent advances in clinical SCI research have led to the introduction of valuable tools for the prediction of functional outcomes after tSCI.

Recently, Goodwin-Wilson et al introduced the use of “evidence-based process maps” for SCI rehabilitation.<sup>29</sup> In these process maps, the range of daily activities of patients with a specified severity (AIS) and level of injury are presented for each week postinjury. Using this method, physicians are able to provide patients with a framework for expected short-, intermediate- and long-term outcomes. This benchmarking approach is not only for the benefit of patients with tSCI, it also provides a better insight into the complete rehabilitation process for health care professionals. For optimal applicability of the process maps, it is important to determine the severity and level of the injury accurately prior to the start of the rehabilitation program.

Although a broad range of functional outcomes are of interest in the tSCI population, the prognostication of ambulation outcomes have been studied most intensively.<sup>9</sup> The severity of the injury is the principal prognostic factor for the prediction of ambulation outcomes after tSCI. In clinical practice, the distinction between “complete” and “incomplete” SCI is commonly made to express the injury’s severity. However, van Middendorp et al recently demonstrated that this distinction results in a suboptimal prediction for ambulation outcomes after tSCI.<sup>4</sup> A more nuanced method for the prediction of ambulation outcomes can be achieved with use of the ASIA/ISCoS neurological standard scale (see ►Table 2). With use of the AIS grades, more accurate predictions can be made than with distinction between a “complete” and an “incomplete” injury (►Table 3).<sup>4,30</sup> As can be discerned from ►Table 3, patients with AIS grades A and D have the smallest (8.3%) and biggest (97.3%) probability of being able to walk independently 1 year after the injury, respectively. On the contrary, the variability of the probable ambulation outcomes in patients with AIS grades B and C remains relatively high.<sup>31</sup>

Providing a solution to the suboptimal accuracy of the two mentioned approaches, a novel, simple, and highly accurate prediction rule for independent ambulation outcomes after tSCI was published in 2011.<sup>32</sup> The prediction rule consists of five prognostic parameters: age (<65 versus ≥65 years of age); motor scores of the quadriceps femoris (myotome L3) and gastroc-soleus (myotome S1) muscles; and light touch sensation of dermatomes L3 and S1 (►Table 4). Considering the best score of each pair of myotomes and dermatomes, this novel prediction rule showed excellent discrimination in distinguishing independent walkers from dependent walkers and non-walkers (area under the curve: 0.956,  $p < 0.001$ , 95% confidence interval: 0.936 to 0.976; ►Fig. 3).<sup>32</sup> Further studies are needed to introduce prediction rules not only for ambulation outcomes but also for autonomic functions such as bladder, bowel, cardiorespiratory, and reproductive functions.

### Future Perspectives

The International Standards are currently the reference standards for the assessment of the severity and level of

**Table 3** Predictive Value of Various Prognostic Approaches for Independent Ambulation Outcomes 6 Months or 1 Year Postinjury

| Predictor                      | Distance (Timing)           | N (total) | Subgroups        | n (%)    | NPV (%) | 95% CI    | PPV (%) | 95% CI    | Ref |
|--------------------------------|-----------------------------|-----------|------------------|----------|---------|-----------|---------|-----------|-----|
| Complete versus incomplete SCI | 10 m (1 y, 6 mo)            | 492       |                  |          |         |           |         |           | 32  |
|                                |                             |           | Complete         | 240 (49) | 91.7    | 87.4–94.8 | 8.3     | 5.2–12.6  |     |
| AIS grades                     | 10 m (1 y, 6 mo)            | 492       | Incomplete       | 252 (51) | 28.6    | 23.0–34.2 | 71.4    | 65.9–77.0 |     |
|                                |                             |           | A                | 240 (49) | 91.7    | 87.4–94.8 | 8.3     | 5.2–12.6  | 32  |
|                                |                             |           | B                | 66 (13)  | 60.6    | 47.8–72.4 | 39.4    | 27.6–52.2 |     |
|                                |                             |           | C                | 76 (16)  | 38.2    | 27.3–50.0 | 61.8    | 50.0–72.8 |     |
| SSEP (tibial nerve)            | 500 m (6 mo)                | 31        | D                | 110 (22) | 2.7     | 0.6–7.8   | 97.3    | 92.2–99.4 |     |
|                                |                             |           | Absent           | ?        | 93      | –         | 7       | –         | 29  |
|                                |                             |           | Present, altered | ?        | 30      | –         | 70      | –         |     |
|                                |                             |           | Normal           | ?        | 0       | –         | 100     | –         |     |
| MEP (anterior tibial muscle)   | ≥ Household distances (1 y) | 22        | Absent           | 9 (41)   | 78      | 40.0–97.2 | 22      | 2.8–60.0  |     |
|                                |                             |           | Present          | 13 (59)  | 8       | 0.0–36.0  | 92      | 64.0–99.8 |     |
| MRI (no data available)        | 500 m (6 mo)                | 36        | Absent           | ?        | 78      | –         | 22      | –         | 25  |
|                                |                             |           | Normal           | ?        | 0       | –         | 100     | –         |     |
|                                | –                           | –         |                  |          |         |           |         |           | –   |

SCI, spinal cord injury; AIS, American Spinal Injury Association/International Spinal Cord Society neurological standard scale; MRI, magnetic resonance imaging; NPV, negative predictive value; PPV, positive predictive value; CI, confidence interval; MEP, motor evoked potential; SSEP, somatosensory evoked potential.

**Table 4** The Five Predictors of a Novel Clinical Prediction Rule for Independent Ambulation Outcomes After Traumatic Spinal Cord Injury<sup>32</sup>

| Variable <sup>a</sup>           | Range of Test Scores | Weighted Coefficient | Minimum Score | Maximum Score |
|---------------------------------|----------------------|----------------------|---------------|---------------|
| Age $\geq$ 65 y                 | 0–1 <sup>b</sup>     | –10                  | –10           | 0             |
| Motor score, myotome L3         | 0–5 <sup>c</sup>     | 2                    | 0             | 10            |
| Motor score, myotome S1         | 0–5 <sup>c</sup>     | 2                    | 0             | 10            |
| Light touch score, dermatome L3 | 0–2 <sup>d</sup>     | 5                    | 0             | 10            |
| Light touch score, dermatome S1 | 0–2 <sup>d</sup>     | 5                    | 0             | 10            |
| Total                           |                      |                      | –10           | 40            |

<sup>a</sup>Only the best score of each myotome or dermatome (i.e., right or left) should be applied for the prediction rule (see text).

<sup>b</sup>0 = no, 1 = yes.

<sup>c</sup>Graded on a 5-point scale adapted from the “Medical Research Council” scale.

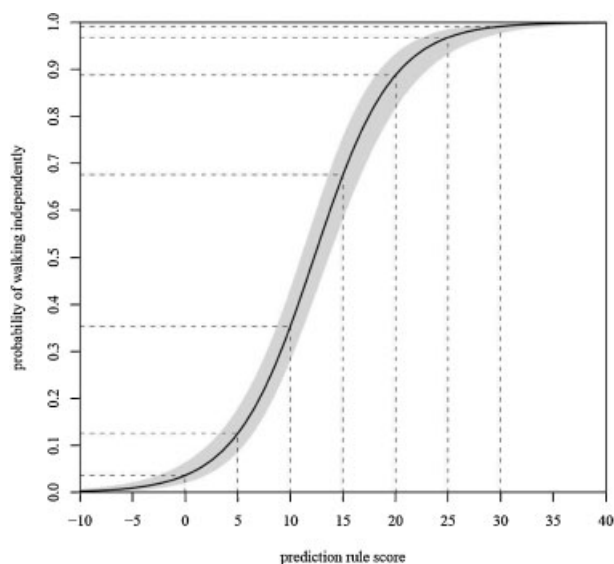
<sup>d</sup>0 = absent, 1 = impaired, 2 = normal.<sup>12</sup>

the injury. Although minor improvements in the neurological diagnostics are to be expected, the principal clinical scientific challenge for the next decade will be to improve the accuracy of the prognostication of functional outcomes after tSCI.

The diagnostic and prognostic value of new imaging techniques in the field of tSCI is also being investigated. Diffusion-weighted imaging and diffusion tensor imaging are promising techniques that may provide a more detailed visualization the injury than conventional MRI.<sup>33–35</sup> A relatively new approach for evaluating the extent of the spinal cord damage is the assessment of biomarker concentrations in the cerebrospinal fluid.<sup>36</sup> Kwon et al showed several biomarkers to be significantly correlated to the severity of

neurological deficits as measured with the International Standards in patients with tSCI.<sup>37</sup> Moreover, the authors stated that the biomarker concentrations have a stronger relation to neurological outcomes when compared with the initial AIS scores.

Despite these promising diagnostic advances, the initial neurological examination according to the International Standards will most likely remain the reference standard for the diagnosis of tSCI for the next decade. Nonetheless, new imaging techniques and biomarkers do have the potential to become incorporated into the standard diagnostic workup for patients with tSCI who are unable to participate in a reliable neurological examination.



**Figure 3** Graphic representation of the predicted probability of independent ambulation 1 year postinjury based on the prediction rule score.<sup>32</sup> The prediction rule score (x-axis, see ► **Table 4**) is plotted out against the probability of walking independently 1 year postinjury (y-axis). The light gray area around the curve represents the 95% confidence interval of the prediction rule based on the regression model. The dashed lines are a visual aid to determine the probability of walking independently.

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