In this comprehensive, clinically directed, reference for the diagnosis and treatment of persons with spinal cord injury and related disorders, editors of the two leading texts on spinal cord injury (SCI) medicine have joined together to develop a singular premier resource for professionals in the field. Spinal Cord Medicine, Third Edition draws on the expertise of seasoned editors and experienced chapter authors to produce one collaborative volume with the most up-to-date medical, clinical, and rehabilitative knowledge in spinal cord injury management across the spectrum of care.

This jointly configured third edition builds on the foundation of both prior texts to reflect the breadth and depth of the specialty. Containing 60 state-of-the-art chapters, the book is divided into sections covering introduction and assessment, acute injury management and surgical considerations, medical management, neurological and musculoskeletal care, rehabilitation, recent research advances, system-based practice, and special topics. New and expanded content focuses on the significant changes in the epidemiology of traumatic injury, the classification of SCI, and the latest medical treatments of multiple medical complications. In addition, chapters discuss new surgical considerations in acute and chronic SCI and the many advances in technology that impact rehabilitation and patients’ overall quality of life.

With chapters authored by respected leaders in spinal cord medicine, including those experienced in spinal cord injury medicine, physical medicine and rehabilitation, neurology, neurosurgery, therapists, and researchers, this third edition goes beyond either of the prior volumes to combine the best of both and create a new unified reference that defines the current standard of care for the field.
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To my grandfather, Rabbi Max Kirshblum, who instilled in me the importance of caring for others, especially those who are not being cared for.

To my mentors, who have generously shared their wisdom, and the SCI fellows and residents I have had the pleasure of being involved in training, who have trusted me to guide their clinical growth. I have learned so much from all of them.

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Most importantly, to my wife Anna and my children Aryeh and Sepha, Rena and Jonathan, and Max, who truly give meaning to my life.

Steven Kirshblum, MD

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To my mentors, colleagues, and patients, who have always inspired me to innovate, collaborate, problem solve, and provide the best care possible for the prevention and treatment of disabling human conditions.

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Preface

As the editors of two popular textbooks – Spinal Cord Medicine and Spinal Cord Medicine: Principles and Practice—each in its second edition, we are thrilled to have joined forces to produce a combined third edition. This comprehensive new text will provide practitioners, researchers and students with a singular advanced, clinically-focused reference in the field of spinal cord medicine.

Since the last editions of our textbooks were published, the field of spinal cord medicine has continued to grow at an unprecedented rate. We have seen significant changes in the epidemiology of spinal cord injury, including, for example, the age and etiology of injury; updates to the classification of spinal cord injury with a reformatted worksheet; newer concepts on surgical intervention post-injury; greater understanding and clarification of prognoses; new medications and surgical interventions to treat medical complications; and technological advances that are transforming imaging techniques and rehabilitation. Given these changes, it became clear that an updated reference was needed to capture the progression in science, treatment, and technology that has impacted patient care and overall quality of life for persons with spinal cord injuries.

We are proud that this third edition merges the most important aspects of each previous individual text and incorporates many of the suggestions from our colleagues. The topics covered, including both traumatic and nontraumatic disorders affecting the spinal cord, follow the blueprint of the subspecialty examination for board certification in Spinal Cord Injury Medicine.

Although space constraints limit the inclusion of every aspect of spinal cord medicine, we have selected what we believe to be the most significant advances and innovations. As such, this new edition consists of seven sections and 60 chapters with hundreds of figures and tables. This has been an immense, collaborative effort, one that has involved many contributors representing various disciplines from highly respected academic and clinical organizations in our field.

There are no words to adequately express our appreciation to our associate editors for the tireless work in assisting with identifying authors, editing chapters, and helping to keep this project on track. Similarly, we are most grateful to the authors for sharing their expertise and experience. We are indebted to our readers who seek to expand their knowledge in spinal cord medicine. And most of all, we are humbled by the trust our patients with spinal cord disorders place in us.

As always, we welcome feedback from our colleagues in spinal cord medicine and throughout the medical and scientific communities.

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Vernon W. Lin, MD, PhD

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Neurological Assessment and Classification of Spinal Cord Injury

Steven Kirshblum and Ryan Solinsky

ASSESSMENT OF SPINAL CORD INJURY

The most accurate way to neurologically assess a person who has sustained a spinal cord injury (SCI) is to perform a standardized neurological examination as endorsed by the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) (1), also commonly referred to as the “International Standards.” These Standards provide definitions (Table 5.1) of terminology used by clinicians as well as detailed instructions on examination techniques and classification rules. The examination and classification of a person with SCI are two distinct skills, and therefore will be described separately.

The International Standards were developed to document selected neurologic parameters in a clinical setting (2). Although not the initial intention, these Standards have been used for inclusion/exclusion criteria for research studies, outcome measures for clinical trials, as well as for prognostication of neurological recovery for specific neurological categories of SCI.

In the Standards, the neurological examination of the person with SCI has two main components, sensory and motor, with required and optional elements that should be recorded on a standardized worksheet (Figure 5.1). The required elements allow the determination of the sensory, motor, and single neurological levels, as well as generation of sensory and motor index scores, determination of the completeness of the injury, and impairment classification. The rectal examination, which tests for voluntary anal contraction (VAC) and deep anal pressure (DAP), previously referred to as “deep anal sensation,” is also part of the required components of the examination (1). Optional elements include aspects of the neurological examination that may better describe the patients’ clinical condition (e.g., reflexes) but are not used for numerical scoring or classification. To learn how to use the International Standards, a web-based instructional course (InSTeP) is available through the American Spinal Injury Association (ASIA) (www.asialearning.com). The most recent revisions of the International Standards were published in 2011 (3,4), with an update with clarifications in 2015 (1).

Sensory Examination

The sensory exam is performed on 28 points on both sides of the body (Figure 5.1) that are termed “key sensory points.” Each key sensory point is tested for pinprick sharp/dull discrimination and light touch (LT) appreciation as well as DAP as part of the rectal examination. These specific points were adapted from Austin (5) and Foerster (6) with consensus amongst experienced spinal cord physicians. A three-point grading scale (0–2) is used, with the cheek of the face as the normal control point. Testing is performed with the patients’ eyes closed or vision blocked so that the patient cannot identify the site being tested. For light touch, a tapered wisp of cotton (i.e., from a cotton tip applicator) is used and should be stroked across the skin moving over a distance not to exceed 1 cm, with a score of 2 (intact) being the same touch sensation as on the face and 1 (impaired) if felt different from the face. Hypo or hyperesthesia are both classified as abnormal sensation and are scored as a “1.” A score of 0 (absent) is used if there is no appreciation of sensation.

For the pin examination, a clean (and disposable) safety pin is used, and a score of “2” is given for sensation that is perceived the same as the face with intact ability to differentiate sharp from dull. A score of “1” corresponds to altered sensation (hypo or hyperesthesia) relative to the face with intact ability to differentiate sharp (pin end of the safety pin) from dull (rounded edge of pin). A score of “0” represents absent sensation, but notably a score of “0” is also given for inability to differentiate sharp from dull. If accurate sensory testing is unable to be performed at the key sensory point due to extenuating circumstances (i.e., burns, casts, amputations, etc.), the level is designated as not testable, or “NT,” on the worksheet, or an alternate location within the dermatome can be tested with a notation in the comment box that an alternate site was used. If there is a question whether the patient can definitively discriminate between the sharp and dull edges, 8/10 correct answers is considered accurate, as this reduces the probability of correct guessing to less than 5%.

When testing the digits for C6–C8 key sensory points, the dorsal surface of the proximal phalanx should be tested. For the chest and abdomen, sensory testing should be performed at the midclavicular line. A prominent pitfall in performing sensory testing is variation in the caudal extent of the C4 dermatome, at times referred to as the C4 “cape” or “shelf.” Variably, this cervical dermatome can extend in close proximity to the nipple line, making it easy to confuse it with the T3 dermatome. In accordance with the International Standards, if sensation at T1 and T2 key
TABLE 5.1 Glossary of Key Terms

**Dermatome:** The area of the skin innervated by the sensory axons within each segmental nerve (root).

**Myotome:** The collection of muscle fibers innervated by the motor axons within each segmental nerve (root).

**Key muscle functions:** Ten muscle groups that are tested as part of the standardized spinal cord examination.

<table>
<thead>
<tr>
<th>ROOT LEVEL</th>
<th>MUSCLE GROUP</th>
<th>ROOT LEVEL</th>
<th>MUSCLE GROUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>C5</td>
<td>Elbow flexors</td>
<td>L2</td>
<td>Hip flexors</td>
</tr>
<tr>
<td>C6</td>
<td>Wrist extensors</td>
<td>L3</td>
<td>Knee extensors</td>
</tr>
<tr>
<td>C7</td>
<td>Elbow extensors</td>
<td>L4</td>
<td>Ankle dorsiflexors</td>
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<tr>
<td>C8</td>
<td>Long finger flexors</td>
<td>L5</td>
<td>Long toe extensor</td>
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<tr>
<td>T1</td>
<td>Small finger abductors</td>
<td>S1</td>
<td>Ankle plantarflexors</td>
</tr>
</tbody>
</table>

**Non-key muscle functions:** Muscle functions that are not part of the key muscle functions that are routinely tested. In a patient with an apparent AIS B classification, non-key muscle functions greater than three levels below the motor level on each side should be tested to most accurately classify the injury and differentiate between an AIS B and C.

**Motor level:** The most caudal key muscle group that is graded 3/5 or greater with the segments cephalad graded normal (5/5) strength.

**Motor index score:** Calculated by adding the muscle scores of each key muscle group; a total score of 100 is possible. It is now recommended to separate the motor scores into two scores; one for the upper limb and one for the lower limb.

**Sensory level:** The most caudal dermatome to have normal sensation for both pinprick/dull and light touch.

**Sensory index score:** Calculated by adding the scores for each dermatome; a total score of 112 is possible for each pinprick (sharp/dull discrimination) and light touch modalities.

**Non-determinable (ND):** This term is used on the worksheet when any component of the scoring cannot be determined based upon the examination results.

**Neurologic level of injury (NLI):** The most caudal level at which both motor and sensory modalities are intact.

**Skeletal level:** The level at which, by radiological examination, the greatest vertebral damage is found.

**Sacral sparing:** The presence of residual-preserved neurological function at the most caudal aspect of the cord determined by examination of sensory and motor functions. This includes the preservation of light touch or pin (intact or impaired) on either side at the S4–5 dermatome, presence of deep anal pressure (DAP) or voluntary anal contraction (VAC).

**Complete injury:** The absence of sensory and motor function in the lowest sacral segments (i.e., no sacral sparing).

**Incomplete injury:** Preservation of motor and/or sensory function below the neurologic level that includes the lowest sacral segments (i.e., presence of sacral sparing.)

**Zone of partial preservation (ZPP):** Used only with complete injuries, refers to the dermatomes and myotomes caudal to the motor and sensory levels that remain partially innervated. The most caudal segment with some sensory and/or motor function defines the extent of the ZPP.


sensory points is absent and T3 appears intact, T3 should be scored as absent if there is no sensation at T4 (thereby assuming an extended C4 cape).

For persons in whom it may be difficult to identify the T3 and T4 key sensory points (i.e., patients who are obese or have large breasts), the T3 and T4 intercostal spaces can be verified by palpation of the anterior ribs rather than relying on the nipple line; for T3, the intercostal space below the third rib. An alternative method of locating T3 is palpat ing the manubriosternal joint, which is at the level of the second rib. At that point, moving slightly lateral to palpate the second rib and continuing to move in a caudal direction will locate the third rib and the corresponding intercostal space just below it (2).

It is important to test the S4–S5 key sensory point (<1 cm lateral to the mucocutaneous junction) for both sharp/dull discrimination and LT, as this represents functions of the most caudal aspect of the sacral spinal cord. A single key sensory point is used to assess both S4 and S5 dermatomes. In addition, DAP is tested by inserting a lubricated gloved finger into the anus with pressure applied to the anorectal wall. The patient is asked if they can appreciate this digital pressure innervated by the somatosensory components of the pudendal nerve (S4/S5). Consistently perceived pressure is recorded as either present (YES) or absent (NO) on the worksheet. A recommended technique involves pressure applied using the thumb to gently squeeze the anorectal wall against an inserted index finger (7). The term “deep anal sensation” was replaced by DAP in the 2011 revisions, as the term “pressure” reinforced the technique as described previously as opposed to more vigorous techniques that may relay information by other pathways (3). If a patient has intact sensation to sharp/dull discrimination or LT at S4/S5, DAP is not required for classification in the current ISNCSCl exam. However, the motor portion of the anorectal exam should still be completed to assess for motor sparing (described later). Optional elements of the sensory examination include joint movement appreciation and position sense and awareness of deep pressure/pain. Joint movement appreciation and position sense can be tested in the upper (little finger at the proximal interphalangeal joint, thumb, and wrist) and
lower extremities (great toe, ankle, and knee). Scoring is as follows: 0 (absent)—if unable to report joint movement correctly, 1 (impaired)—if consistently correct (8/10) on large movements of the joints but inconsistent on small movements of the joints (10° or less), 2 (normal) if consistently correct on small movements of joints, and “NT” if the patient is unable to understand and follow directions or if unable to test the joint (i.e., cast or amputation). Deep pressure/pain appreciation of the limbs is only tested if other sensory modalities are absent and performed by applying firm pressure for 3 to 5 seconds at different locations (wrist, nail bed of the thumb, little finger, small and great toe, or ankle) after establishing a baseline with the patient by applying pressure using the index finger or thumb on the chin. Scoring is 0 (absent) if no pressure is felt peripherally, and 1 (present) if felt reliably when pressure is applied. It is important to recognize that these are optional tests whose scoring has not been validated and not used to classify the injury. If performed, they can be documented in the comments box on the worksheet.

**Motor Examination**

The required elements of the motor examination consist of testing 10 key muscles: 5 in the upper limb and 5 in the lower limb on each side of the body (Table 5.1). Other muscles are also clinically important, but are viewed as optional in that they do not contribute to the motor index scores or levels. It is recommended that the muscles should be examined in a rostral to caudal sequence, starting with the elbow flexors (C5 tested muscle) and finishing with the ankle plantar flexors (SI muscle). Testing of all key muscles during the initial as well as the follow-up examinations is performed with the patient in the supine position, to allow for a valid comparison (and reproducibility) of scores throughout the phases of care. Muscles are graded and recorded on the standard worksheet on a six-point scale from 0 to 5 (8). For purposes of inter-rater reliability, it has been recommended that only whole numbers (not including pluses and minuses) should be used when comparing data from one institution with another.

Although each of the key muscles has one root listed, usually two segments innervate these muscles (i.e., for biceps C5 and C6). The key muscles have been chosen because of their consistency for being innervated primarily by the segments indicated and for their ease of testing in the supine position. In most circumstances, if a particular muscle has a grade of 3/5, it is considered for the purposes of this classification to have full innervation by at least the more rostral nerve root segment and is considered useful for functional activities. A muscle initially graded as normal (5/5) would be considered to be fully innervated by both spinal root segments (Figure 5.2).

Placing the joints in the proper position during manual muscle testing (MMT) and stabilizing above and below the joint tested is important for accurate grading, especially if the muscles may have less than antigravity strength (1). Careful consideration toward muscle substitution masquerading as key muscle movements must be considered. Common substitutions include forearm supination mimicking wrist extension (C6), shoulder external rotation substituting for elbow extension (C7), wrist extension with tenodesis substituting for long finger flexion (C8), and finger extension appearing as small finger abduction (T1).

Triggering of co-contracting spasticity (e.g., use of active elbow flexion to trigger elbow extension spasms) may also cause inaccuracies in the motor exam if not appreciated. In the lower extremities, abdominal or adductor contractions may also appear (with or without the addition of spasticity) as hip flexion and ankle dorsiflexion may mimic long toe extension. The InSTeP training videos are recommended to visualize all of these positions (www.asialearning.com).

Patients’ clinical condition may prevent the completion of an accurate examination. Limiting factors such as pain and deconditioning may be present such that a muscle only grades a 4/5. If the examiner feels that the patient would otherwise have normal strength, the muscle should be graded as a 5* to indicate that inhibiting factors were present and documented in the comment box on the worksheet. When the patient is not fully testable for any reason, including spasticity that prevents accurate stabilization of the joint, uncontrolled clonus, severe pain, a fracture present limiting the exam, the cognitive status impacts participation, or a contracture limiting greater than 50% of full range of motion, the examiner should record NT instead of a numerical score.

In a patient with a potentially unstable spine, care must be taken when performing MMT. When examining a newly injured individual with a lesion below T8 vertebral level, the hip should not be flexed passively or actively beyond 90°, as this may place too great a kyphotic stress on the lumbar spine. In this circumstance, isometric assessment of hip flexion is appropriate.

VAC is tested by inserting a lubricated gloved finger and asking the patient to “squeeze my finger as if to hold back a bowel movement” and graded as either present (YES) or absent (NO) in the appropriate box on the worksheet. Care must be taken during this exam for patient modesty, as well as to differentiate volitional contraction from anal spasm when the finger is inserted or anal contraction triggered by Valsalva.

A number of optional muscles (diaphragm, deltoids, abdominal muscles, medial hamstrings, and hip adductors) may also be tested and may be helpful in determining motor sparing of certain regions of the spinal cord and motor incompleteness but are not used to obtain a motor index score. The diaphragm can be tested by measurement of the vital capacity or under fluoroscopy. Movement of the hemidiaphragm two or more inter-spaces generally indicates normal function. The deltoid, while important with respect to the function it provides for reach of the upper extremity, is not used for motor scoring because it cannot properly be tested in the supine position. Beevor’s sign can test the abdominal muscles (innervated by T6–T12). While asking the patient to flex the neck and trunk (a half sit-up or crunch), if the patient has a lesion between T9 and T11, the umbilicus will move rostrally because the upper abdominal muscles are innervated at and above T10. A negative Beevor’s sign (no movement of the umbilicus with trunk flexion) is present when the abdominals have full innervation or total absence of abdominal innervation. Palpating the abdominal muscles during the test helps distinguish between these, as no umbilical movement without any palpable contraction is a sign of absence of innervation. This test should not be performed during the acute stages of thoracic/lumbar injuries. The hip adductor muscle, while not used as part of the motor score, is an important muscle.
to monitor, as it is often the first muscle to recover in the lower extremity.

Although not a part of the ISNCSCI, deep tendon reflex testing may be useful to regularly assess along with anal wink and bulbocavernosus reflex for identifying phases of spinal shock (9) and identification of upper versus lower motor neuron dysfunction. Spasticity and autonomic assessments can also help providers develop a more comprehensive understanding of an individual’s deficits and are described elsewhere within this text.

CLASSIFICATION OF SPINAL CORD INJURY

Utilizing a standard method of neurological assessment is important to help determine the course of recovery and the effect of interventions in the treatment of SCI.

There have been many systems developed for the classification of SCI that have been based on bony patterns of injury, mechanism of injury, neurological function, and functional outcome (10–16). A full history of the classifications used in SCI is reviewed elsewhere (17,18). In brief, in 1969, Frankel described a five-grade system of classifying traumatic SCI, with a division into “complete” and “incomplete” injuries (19). In 1982, the American Spinal Injury Association (ASIA) published a booklet Standards for Neurological Classification of SCI (20) that defined basic terms and examination in SCI, as well as described a number of anatomically incomplete clinical syndromes. Other scales and examination techniques have also been described (21–24), some that utilize additional muscle groups, such as used in the NASCIS trials (2,24). El Masry et al., however, found that the ASIA and NASCIS motor scoring systems are comparable in representing motor deficits and recovery (25).

Definitions and classifications over the years have changed with multiple revisions of the Standards. This includes the muscles tested, areas of dermatomes and key sensory points, terminology used, and the name of the classification itself. In 1992, the ASIA Impairment Scale (26) replaced the Frankel classification and was further revised in 1996, 2000, and 2011 (3) with an update in 2015 (1). The 1992 standards were endorsed by the International Medical Society of Paraplegia (now named the International Spinal Cord Society [ISCoS]), and at that time termed the

FIGURE 5.1 Worksheet for the use of recording sensory and motor components. (continued)

DEFINITIONS OF TERMS IN SPINAL CORD INJURY

Tetraplegia, preferred to the term quadriplegia, is defined as impairment or loss of motor and/or sensory function in the cervical segments of the spinal cord due to damage of neural elements within the spinal cord. It does not include brachial plexus lesions or injury to the peripheral nerves outside the neural canal (1). Tetraplegia results in impairment of function in the arms as well as possibly the trunk, legs, and pelvic organs. Paraplegia refers to an impairment of motor and/or sensory function in the thoracic, lumbar, or sacral (but not cervical) segments of the spinal cord secondary to damage of neural elements within the spinal canal. With paraplegia, arm functioning is spared, but depending on the level of injury, the trunk, legs, and pelvic organs may be involved. Paraplegia can also refer to cauda equina (CE) and conus medullaris injuries, but not lumbosacral plexus lesions or injuries to peripheral nerves outside the neural canal. The terms quadraparesis (tetraparesis) and paraparesis are discouraged because they describe incomplete lesions imprecisely.

The sensory level is the most caudal dermatome to have normal (score of 2) sensation for both sharp/dull discrimination and light touch. This is determined by a grade of 2 (normal/intact) in all dermatomes beginning with C2 and extending caudally to the first segment that has a score of less than 2 for either sharp/dull discrimination or light touch. The intact dermatome level located immediately above the first dermatome level with impaired or absent light touch or pin sensation is designated as the sensory level. As the right and left sides may differ, the sensory level should be determined for each side.

For a single sensory level, the most rostral of all is taken. If sensation is abnormal at C2, the sensory level is designated as C1 (1). If sensation is intact through S4–S5, the sensory level should be recorded as intact (“INT”) rather than as S4–S5. If the patient is unable to reliably appreciate sensation when tested on the face, then “NT” should be recorded and “ND” (not determinable) should be documented in the appropriate area on the worksheet with no sensory level given.

Sensory index scoring is calculated by adding the scores for all dermatomes, for a total score possible of 112 (56 on each side) for sharp/dull discrimination and light touch. If “NT” has been documented at any level, then a sensory score is calculated by adding the scores for all dermatomes, for a total score possible of 112 (56 on each side) for sharp/dull discrimination and light touch. If “NT” has been documented at any level, then a sensory score is calculated by adding the scores for all dermatomes, for a total score possible of 112 (56 on each side) for sharp/dull discrimination and light touch.

Muscle Function Grading

<table>
<thead>
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<th>Description</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>No movement</td>
</tr>
<tr>
<td>1</td>
<td>Voluntary contraction</td>
</tr>
<tr>
<td>2</td>
<td>Active movement, full range of motion (ROM) with gravity eliminated</td>
</tr>
<tr>
<td>3</td>
<td>Active movement, full ROM against gravity</td>
</tr>
<tr>
<td>4</td>
<td>Active movement, full ROM against gravity and moderate resistance</td>
</tr>
<tr>
<td>5</td>
<td>Normal active movement, full ROM against gravity and sufficient resistance to be considered normal</td>
</tr>
</tbody>
</table>

Sensory Grading

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Absent</td>
</tr>
<tr>
<td>1</td>
<td>Impaired or decreased sensation</td>
</tr>
<tr>
<td>2</td>
<td>Normal</td>
</tr>
</tbody>
</table>

When to Test Non-Key Muscles:

In a patient with an apparent AIS B classification, non-key muscle functions more than 3 levels below the motor level on each side should be tested to most accurately classify the injury differential between AIS B and C.

Movement:

- Shoulder: Extension, abduction, adduction, internal rotation
- Elbow: Flexion
- Wrist: Extension
- Finger: Extension at metacarpal joint, extension at proximal joint, and abduction at metacarpal joint
- Thumb: Extension
- Hip: Extension, adduction, internal rotation
- Knee: Extension
- Ankle: Extension and plantarflexion
- Toes: Flexion and extension
- Halters and Toes: Dorsi- and Plantarflexion
- Hallux and Toes: Dorsi- and Plantarflexion

AIS Impairment Scale (AIS) Grade:

<table>
<thead>
<tr>
<th>AIS Grade</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>Complete disability</td>
</tr>
<tr>
<td>B</td>
<td>Sensory incomplete</td>
</tr>
<tr>
<td>C</td>
<td>Motor incomplete</td>
</tr>
<tr>
<td>D</td>
<td>Motor complete</td>
</tr>
</tbody>
</table>

Steps in Classification

1. Determine sensory levels for right and left sides.
2. Determine motor levels for right and left sides.
3. Determine the neurological level of injury (NLI).
4. Determine whether the injury is Complete or Incomplete.
5. Determine AIS Impairment Scale Grading (AIS Grade):
The motor level is defined as the lowest key muscle that has a grade of at least 3, providing all key muscles represented by segments rostral to that level are graded as 5 (1). The motor level may differ by side of the body; a single motor level would be the more rostral of the two. If “NT” has been documented as part of the exam, and this muscle is required for determination of the motor level, the designation of the motor level for that side should be deferred and ND is documented on the worksheet.

For myotomes that are not clinically testable by MMT (i.e., above C5, T2–L1, and S2–S5), they are assumed to have full innervation if sensory innervation for sharp/dull discrimination and LT at the corresponding level are also intact. For example, if the sensory level is C4 and there is no C5 motor function strength (or strength graded as <3), the motor level is C4. In the case where the C5 motor function is graded at least 3 on both sides of the body, with a sensory level on the right of C3 and on the left of C4, with impaired sensation at C4 on the right, the motor level on the right would be C3 (and C5 on the left). Since the C4 dermatome on the right is impaired, it is presumed that the C4 myotome is also impaired. Therefore, the motor level is designated as C3, since the patient does not meet the criteria of having a key muscle function (in this case the C5 muscle) ≥3/5 with all levels above (in this case including C4) scoring as normal. On the left side, the C4 dermatome is normal so that the C4 myotome is considered normal, and as a result the left motor level is C5.

If, for example, all upper limb key muscle functions are normal, with intact sensation to T6, the motor level defers to the sensory level and is recorded as T6. If however, with a T6 sensory level, the T1 muscle function is graded a 3 (or a 4) instead of a 5, while T6 is still the sensory level, the motor level would be T1, as all the muscle levels above the T6 level are not normal.

It is important to recognize and document if neurologic deficit is unrelated to SCI. For example, in a patient with a thoracic level injury who also has a brachial plexus injury, a note should be made in the comment box on the worksheet to correctly classify the patient’s spinal level of injury (thoracic level), rather than assigning a higher (cervical) level due to a non-SCI-related injury.

Motor index scoring is calculated by adding the muscle scores of each key muscle group. In the past, a total motor score of 100 (25 for each extremity) was calculated, but it is no longer recommended to add the upper and lower limb scores together. Rather it is recommended to separate the motor scores into 2 scores: one for the upper limbs and one for the lower limbs (1,28). The motor scores provide a means of numerically documenting changes in motor function. If “NT” has been documented for any muscle, then a motor index score cannot be calculated.

The neurological level of injury (NLI) refers to the most caudal segment of the spinal cord with normal sensory and at least antigravity muscle function on both sides of the body, provided that there is normal (intact) sensory and motor function rostrally. Motor and sensory levels are the same in <50% of complete injuries, and the motor level may be multiple levels caudal to the sensory level at 1 year post injury (29).

The single neurological level is the single most caudal levels at which both motor and sensory modalities are intact on both sides of the body (i.e., the highest of all the motor and sensory levels). If the motor level is C7 and the sensory level is C8, the overall single NLI is C7. The (single) NLI is used when determining the ASIA Impairment Scale (AIS) grade, especially differentiating AIS C from D.

The motor level and upper extremity motor index score better reflect the degree of function as well as the severity of impairment and disability, relative to the NLI, after motor complete tetraplegia (29). This is because the sensory level may place the neurologic level more rostral, thereby incorrectly implying poorer motor function.

The zone of partial preservation (ZPP) is defined as the dermatomes and myotomes caudal to the sensory and motor levels that remain partially innervated in an individual with a neurologically complete (AIS A) injury (see the following section) (1). The ZPP should be recorded on the worksheet by documenting the most caudal segment with some sensory and/or motor function. A single segment for each ZPP rather than the entire range of partially innervated segments should be documented. For example, in an individual with AIS A tetraplegia, if the right sensory level is C5 and some sensation extends to C8, then C8 is recorded as the right sensory ZPP. For ZPP description, motor function does not follow sensory function (i.e., in a case of a T6 level of injury, impaired sensation (1/2) at T7 does not imply that there is intact/impaired motor function at T7). If there is no ZPP (no partially innervated segments below a motor or sensory level), the motor or sensory level should be entered as the ZPP (1). With an incomplete injury, the ZPP is not applicable, and “NA” is recorded.

A neurological complete injury is defined as the absence of sensory and motor function in the lowest sacral segments (no sacral sparing), and an incomplete injury as partial preservation of sensory and/or motor function as determined by examination of the most caudal segment (S4–S5) (sacral sparing). Sacral sparing is tested by sharp/dull discrimination and LT at the anal mucocutaneous junction (S4/S5 dermatome) on both sides, as well as testing VAC of the external anal sphincter (the motor aspect) and DAP as part of the rectal examination. If any of these are present (representing sacral sparing), intact or impaired, even on one side, the individual has an incomplete injury. According to this definition, a patient with cervical SCI can...
have sensory and motor function in the trunk or even in the lower extremities but unless sacral sparing is present, the injury is classified as “complete” with a long ZPP. When sacral sparing is used to define incompleteness in the acute phase post injury, motor recovery is significantly more likely to occur than when it is not (30). The “sacral sparing” definition of the completeness of the injury was adopted by the ASIA Standards Committee in 1992 (26). Prior to this, an injury was considered “incomplete” if motor or sensory function extended >3 levels below the injury. The sacral sparing definition has been considered a more stable definition, because fewer patients convert from incomplete to complete status during neurologic recovery in the acute and subacute period.

The ASIA Impairment Scale (AIS) has five grades, which are listed in Table 5.2. The determination of the AIS is described in Table 5.3.

**AIS A:** Motor and sensory complete—no sacral sparing including sharp/dull discrimination or LT sensation at any of the S4–S5 dermatomes; no VAC and no DAP. In this case, a ZPP is documented on the worksheet. If the injury is complete, the standardized worksheet will read “N-O-O-O-N” across the bottom—“no” for VAC, the four 0’s for no S4–S5 sensation for LT or sharp/dull discrimination modalities on either side of the body, and “no” for DAP (2).

**AIS B:** Motor complete and sensory incomplete. Sensory but not motor function is preserved at the most caudal sacral segments S4–S5, AND no motor function is preserved greater than 3 levels below the motor level on either side of the body.

**AIS C:** Motor incomplete: Motor function is preserved at the most caudal sacral segments on VAC OR the patient meets the criteria for sensory incomplete status (sensory function preserved at the most caudal sacral segments [S4–S5] by LT, sharp/dull discrimination, or DAP), with sparing of motor function greater than 3 levels below the ipsilateral motor level on either side of the body. This includes key or non-key muscle functions to determine motor incomplete status. (The use of non-key muscles will be explained in the following section.) For AIS C—less than half of the key muscle functions below the NLI have a muscle grade of ≥3.

If a patient has a sensory incomplete lesion and absence of all the key muscle groups below the level but has the presence of VAC, the appropriate classification is AIS C. In a case like this, however, one should be careful that they are feeling the anal sphincter volitionally contract rather than contracting gluteal muscles or a reflex sphincter contraction (as noted earlier). When in doubt, the patient should be scored as having volitional contraction of the anal sphincter (31).

Once a patient is classified as having a motor incomplete injury, it is important to distinguish between an AIS C and D. Injuries are classified as an AIS C if more than half of the key muscles below the single NLI of the patient are graded as less than 3/5.

**AIS D:** Motor incomplete status as mentioned earlier (specifically motor function is preserved by VAC OR the patient meets the criteria for sacral sensory incomplete status, with sparing of motor function greater than 3 levels below the ipsilateral motor level on either side of the body), with at least half (half or more) of the key muscles below the single NLI having a muscle grade of ≥3.

It is important to note that to distinguish an AIS C versus D, the motor scores below the single NLI are used, whereas to distinguish between an AIS B versus a C, the motor level on each side of the body is used. The reason for using the motor level to distinguish an AIS B versus C is to avoid the possible situation when a patient may regain sensation in a single additional caudal level, changing the AIS from “C” to a “B.” For example, if a patient initially had a motor level of C5 and a sensory level of C4 with sensory sparing at S4/S5 and some motor sparing only in C6–C8, using the neurologic level, this patient would qualify for AIS C (because C8 motor is >3 levels below the neurologic level [C4]). If the patient regains normal sensation over time in the C5 dermatome (with no other changes), the neurologic level becomes C5, and the patient would revert from an AIS C to a B because C8 is no longer greater than 3 levels below the neurologic level, indicating “worsening” despite neurologic improvement. This is avoided by using the motor level, since the designation is independent of the sensory level.

**AIS E:** All components of the standardized neurological examination are normal. The grade E is used in follow-up when testing an individual with a previously documented

### TABLE 5.2 ASIA Impairment Scale

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Complete: No motor or sensory function is preserved in the sacral segments S4–S5.</td>
</tr>
<tr>
<td>B</td>
<td>Sensory Incomplete: Sensory but not motor function is preserved at the most caudal sacral segments S4–S5, AND no motor function is preserved &gt;3 levels below the motor level on either side of the body.</td>
</tr>
<tr>
<td>C</td>
<td>Motor Incomplete: Motor function is preserved at the most caudal sacral segments (S4–S5) on VAC OR the patient meets the criteria for sensory incomplete status (sensory function preserved at the most caudal sacral segments [S4–S5] by LT, sharp/dull discrimination, or DAP), with sparing of motor function &gt;3 levels below the ipsilateral motor level on either side of the body.</td>
</tr>
<tr>
<td>D</td>
<td>Motor Incomplete: Motor incomplete status as defined above, with at least half (half or more) of key muscle functions below the single NLI having a muscle grade ≥3.</td>
</tr>
<tr>
<td>E</td>
<td>Normal: If sensation and motor function as tested with the ISNCSCI are graded as normal in all segments, and the patient had prior deficits, then the AIS grade is E. Someone without a SCI does not receive an AIS grade.</td>
</tr>
</tbody>
</table>

AIS, ASIA impairment scale; DAP, deep anal pressure; ISNCSCI, international standards for neurological classification of spinal cord injury; LT, light touch; NLI, neurologic level of injury; PP, partial preservation; SCI, spinal cord injury; VAC, voluntary anal contraction.


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SCI that has recovered normal function. If no neurological deficits are found at initial testing, then the AIS does not apply. When a component of the scoring and classification cannot be determined (e.g., the sensory level, motor level NLI, AIS grade, or ZPP) based upon the examination, “ND” (not determinable) should be appropriately documented on the worksheet (1). For example, if “NT” (not testable) is used in the scoring for the examination, and the motor, sensory or NLI, or AIS grade cannot be determined based upon this, then “ND” should be used for the designation of these levels and AIS grade on the worksheet. The reason for the “NT” grade should be documented in the “Comments box.”

If there are non-SCI-related causes of weakness, this should be documented and taken into account when classifying the injury (32). For example, in a patient with a T8 fracture and complete paraplegia who also has a left brachial plexus injury, notation should be made that the sensory and motor deficits in the left arm are due to brachial plexus injury, not SCI, and the patient may still be classified with an NLI of T8.

Having a well-defined classification of SCI allows clinicians and researchers to study the effects of drug and rehabilitation interventions and determine prognosis. The AIS is currently the most valid and reliable classification to assess SPI and is used by the National Spinal Cord Injury Database. Computerized classifications programs have been developed utilizing this schema (33,34), and algorithms are available at www.ISNCSCIalgorithm.com and http://ais.emsci.org. A number of articles have posed challenging cases as well as some potential improvements to the classification (32,35–39); however, the classification at this time has remained unchanged since 2015.

Non-Key Muscles
In cases where an individual appears to have a classification of AIS B, non-key muscles (see Table 5.4) greater than 3 levels below the motor level on each side should be additionally tested (1). As discussed previously, the presence of active non-key muscles greater than 3 levels below the motor level indicates an AIS C injury as opposed to AIS B (1). Non-key muscles do not need to be examined as a routine part of the ISNCSCI examination, but only in suspected cases of AIS B versus AIS C. The presence of any muscle function in these muscles should be documented in the comments section of the worksheet.

RELIABILITY OF EXAMINATION
The examination and classification (use of the ISNCSCI) has been found overall to be valid, reliable, and sensitive to change, most especially in patients with neurologically complete injuries (39–46). The amount of training plays an important role in understanding and performing the examination and classification schema due to impact on reliability (40,45,46).

Cohen et al. found high reliability of the LT, sharp/dull discrimination, and motor scores; inter-rater reliability values ranged from .96 to .98, and intra-rater reliability values were .98 to .99 (40). Marino et al. also demonstrated that the motor and sensory examination is reliable, with inter-rater reliability of the motor exam of .97, LT = .96, and sharp/dull discrimination .88, when conducted by trained examiners. Sharp/dull discrimination scores had the lowest reliability, possibly because of the complexity of differentiating sharp from dull sensation (41).
The reliability of individual dermatome and myotome scores is less than that for summed scores (42,43). Due to the ISNCSCI having no palmar sensory test location, the GRASSP may potentially be a more sensitive measure to assess upper limb function following tetraplegia (47). Given that pin testing is the principle assessment responsible for determining the level of injury (48), a modified and shorter examination may be indicated. Further study is under way.

Because the exam can be time consuming, both for the pediatric patient and the examiner, a shortened examination with 16 dermatomes tested (as opposed to 56 dermatomes) was studied and found to provide good correlation to the full examination (52). This shortened exam may be useful for evaluating children with SCI who cannot tolerate the full exam.

Vogel et al. reported that there was good agreement on repeated pinprick and light touch sensation at S4–5 (anorectal) in the pediatric population for all age groups and types of injury (tetra/paraplegia) (7). However, for DAP and VAC, there was weaker agreement in many of the younger age groups. Therefore, the use of the anorectal exam in all children/youth for designation of injury severity or clinical research trials is not necessarily supported (7).

**CLINICAL SYNDROMES OF SPINAL CORD INJURY**

Multiple clinical syndromes of SCI have been described in the literature and include central cord, Brown–Sequard, anterior cord, posterior cord, CE, conus medularis, and discomplete syndromes. The majority of these syndromes have remained largely unchanged since they were originally described, with the exception of central cord syndrome. None of the clinical syndrome definitions contain precise, quantitative criteria such as percentage of muscles with a specific finding.

Central cord syndrome (CCS) is the most common of the clinical syndromes, accounting for approximately 50% of incomplete injuries and 9% of all traumatic SCI (53). This is characterized by greater motor weakness in the upper extremities greater than the lower extremities, in association with sacral sparing (54). At the level of injury there is lower motor neuron (LMN) weakness as well as sensory loss, with upper motor neuron (UMN) paralysis below the lesion level. In addition to the motor weakness, other features include bladder dysfunction and varying sensory loss below the level of the lesion. CCS most commonly occurs in older persons with cervical spondylosis who suffer a hyperextension injury, typically from a fall, followed by motor vehicle crashes. However, CCS may occur in persons of any age and is associated with other etiologies, predisposing factors, and injury mechanisms. The postulated common mechanism of injury involves compression of the cord both anteriorly and posteriorly by degenerative changes of the bony structures, with inward bulging of the ligamentum flavum during hyperextension in an already narrowed spinal canal (53–58). Occurring with or without fracture or dislocation, CCS was initially described as caused by hemorrhage to the central cord. However, subsequent research notes that the findings of this syndrome are predominately due to white matter lesions, with potential further gray matter involvement (when accompanied with LMN findings in upper extremities) (55–57). The findings of the upper extremities being relatively more involved than the lower extremities was initially postulated as due to a more central location of fibers of the upper limb within spinal cord motor tracts (with the lower limbs more peripherally located) (54,58). This has been challenged with more recent studies being supportive of a disproportionate distribution of the corticospinal tract contributing to hand and upper extremity function, thereby any injury to the tract leading to more accentuated symptoms in these areas (59).

### TABLE 5.4 Non-Key Muscles for ISNCSCI Classification of Individuals as AIS C Versus AIS B

<table>
<thead>
<tr>
<th>MOVEMENT</th>
<th>ROOT LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder: Flexion, extension, adduction, internal, and external rotation Elbow: Supination</td>
<td>C5</td>
</tr>
<tr>
<td>Elbow: Pronation Wrist: Flexion</td>
<td>C6</td>
</tr>
<tr>
<td>Finger: Flexion at proximal joint, extension Thumb: Flexion, extension, and abduction in plane of thumb</td>
<td>C7</td>
</tr>
<tr>
<td>Finger: Flexion at MCP joint Thumb: Opposition, adduction, and abduction perpendicular to palm</td>
<td>C8</td>
</tr>
<tr>
<td>Finger: Abduction of the index finger</td>
<td>T1</td>
</tr>
<tr>
<td>Hip: Adduction</td>
<td>L2</td>
</tr>
<tr>
<td>Hip: External rotation</td>
<td>L3</td>
</tr>
<tr>
<td>Hip: Extension, abduction, internal rotation Knee: Flexion Ankle: Inversion and eversion Toe: MP and IP extension</td>
<td>L4</td>
</tr>
<tr>
<td>Hallux and Toe: DIP and PIP flexion and abduction</td>
<td>L5</td>
</tr>
<tr>
<td>Hallux: Adduction</td>
<td>S1</td>
</tr>
</tbody>
</table>

AIS, ASIA impairment scale; DIP, distal interphalangeal; IP, interphalangeal; ISNCSCI, international standards for neurological classification of spinal cord injury; MCP, metacarpophalangeal; MP, metatarsalphalangeal; PIP, proximal interphalangeal.

The definitive diagnostic criteria for traumatic CCS remains undefined, with surveys demonstrating lack of consensus on the degree of upper extremity weakness or lower extremity sparing required for classification (60,61). Research has demonstrated that upper and lower extremities recovery is not significantly altered even with greater motor discrepancies between the two, and the AIS remains most predictive of recovery (62).

CCS usually has a favorable prognosis (53,63–65). The typical pattern of recovery occurs earliest and to the greatest extent in the lower extremities, followed by bowel and bladder function, upper extremity (proximal), and then intrinsic (distal) hand function. The prognosis for functional recovery of ambulation, activities of daily living (ADL), and bowel and bladder function are dependent upon the patient’s age, with a less optimistic prognosis in older patients relative to younger patients (63,64). Patients <50 years of age are more successful in achieving independent ambulation than older patients (87%–97% vs. 31%–41%). Similar differences were seen between the younger and older patients in independent bladder function (83% vs. 29%), independent bowel function (63% vs. 24%), and dressing (77% vs. 12%). However, for persons with initial neurological examinations (within 72 hours) with a classification of AIS D tetraplegia, prognosis for the recovery of independent ambulation is excellent, even for those whose age is >50 (66).

When initially described in the 1950s, surgical decompression of CCS was discouraged as potentially leading to worse functional outcomes. While decompression is now accepted, controversy regarding the role of timing of surgical intervention continues in CCS. Retrospective reviews to date have not demonstrated functional improvement associated with early decompression (67–69), though a single ambispective study has shown motor improvement at 6 months for select CCS patients who received decompression prior to 24 hours after injury (69).

A syndrome with similar clinical features of upper extremity paresis or paralysis with minimal to no lower extremity involvement is “cruciate paralysis” (70–75). This may occur with fractures of Cl and C2, with neurological compromise of the brain stem at the cervicomедullary junction (71) as opposed to CCS that is usually localized in the mid- to lower segments of the cervical spinal cord (i.e., C4–C5). Respiratory insufficiency occurs in roughly 25% of patients and cranial nerves can also demonstrate deficits. Overall, the prognosis for cruciate paralysis is excellent, with studies noting over 50% of patients with complete recovery (71). Wallenberg proposed an anatomical explanation for this clinical syndrome (76), suggesting that the decussating fibers of the upper limb lay in a more rostral, medial, and ventral location in the cervicomедullary junction compared to a more lateral and caudal location of the lower limb decussating fibers. Therefore, injury to the canal where the upper extremity fibers travel alone after decussation causes preferential injury to the upper limbs. Neuroanatomical evidence to support this hypothesis, however, has not been found (77).

Brown–Sequard syndrome (BSS) is characterized by asymmetric paresis with hypaesthesia more marked on the less paretic side and accounts for 2% to 4% of all traumatic SCI (76–82). In the classic presentation of BSS, there is (a) ipsilateral loss of all sensory modalities at the level of the lesion, (b) ipsilateral flaccid paralysis at the level of the lesion, (c) ipsilateral loss of position sense and vibration below the lesion, (d) contralateral loss of pain and temperature below the lesion, and (e) ipsilateral motor loss (UMN-mediated) below the level of the lesion. Almost 90% of these cases are in the cervical level, and 66% are classified as AIS D (53).

Understanding the underlying neuroanatomy allows for an insight into this constellation of signs. Spinothalamic tract decussation within the spinal cord leads to contralateral loss of pain and temperature when injured. Corticospinal and dorsal column tracts decussate within the brain stem, explaining for clinical findings of loss of motor, proprioception and vibration sense ipsilateral to the lesion.

Although BSS has traditionally been associated with knife injuries that cause hemisection, a variety of etiologies including those that result in closed spinal injuries with or without vertebral fractures may be the cause (81–83). In addition, neoplastic causes and intramedullary inflammatory lesions, such as in multiple sclerosis, can result in partial or complete BSS. In clinical practice, however, only a limited number of patients present with pure BSS. More often, patients present clinically with a combination of features from Brown–Sequard and CCS, with relatively varying degrees of ipsilateral hemiplegia and contralateral hemianalgesia. This has been termed Brown–Sequard plus syndrome (81).

Despite the variation in presentation, considerable consistency is found in the prognosis of BSS. Recovery usually takes place in the ipsilateral proximal extensors and then in the distal flexors (84,85). Motor recovery of any extremity having a pain/temperature sensory deficit occurs before the opposite extremity, and these patients may expect functional gait recovery by 6 months.

Nearly, 75% to 90% of patients ambulate independently at discharge from rehabilitation and 70% perform functional skills and ADL independently (53,79,83). The most important predictor of function is whether the upper or lower limb is the predominant site of weakness: when the upper limb is weaker than the lower limb, patients are more likely to ambulate at discharge (81). Recovery of bowel and bladder function is also favorable, with continence achieved in 82% and 89%, respectively, in one study (81).

The anterior cord syndrome (ACS) accounts for 2.7% of traumatic SCI and involves a lesion affecting the anterior two-thirds of the spinal cord while preserving the posterior columns. ACS may occur from retropulsed disc or bone fragments (86), direct injury to the anterior spinal cord, or most commonly with vascular injury or occlusion of the anterior spinal artery that provides the blood supply to the anterior spinal cord (87). This can occur during surgery to the aorta (especially with clamping above the renal artery) or other processes that could decrease blood flow to the spinal cord (i.e., vertebral burst fracture). There is a variable loss of motor as well as pinprick sensation with a relative preservation of light touch, proprioception, and deep-pressure sensation. Usually patients with ACS have only 10% to 20% chance of muscle recovery, and even in those with some recovery, there is poor muscle power and coordination (88).

The posterior cord syndrome is the least frequent of incomplete SCI syndromes and has been omitted from recent versions of the International Standards. It is characterized by preservation of pain, temperature, and touch appreciation with varying degrees of motor preservation and an absence of all dorsal column function. Prognosis for ambulation is poor, secondary to the proprioceptive deficits.
Conus Medullaris and Cauda Equina Injuries (Table 5.5): The conus medullaris, which is the terminal segment of the adult spinal cord, lies at the L1 vertebra and ends at the inferior aspect of the L1 vertebra. The segment above the conus medullaris is termed the epiconus, consisting of spinal cord segments L4–S1. Nerve roots extend from the conus medullaris caudally as the CE. As nerve roots and UMN are tightly consolidated in this region, injuries to the conus medullaris and epiconus can present clinically with varied findings. Typically, lesions to the epiconus primarily affect the lower lumbar roots with relative sparing of sacral reflex arcs. This translates clinically into UMN findings in sacral segments with spasticity likely developing in toe flexors, ankle plantar flexors, and hamstrings and in patients having positive bulbocavernosus reflexes.

Lower conus medullaris lesions affecting neural segments S2 and below will present with LMN deficits of the anal sphincter and bladder due to damage of the anterior horn cells of S2–S4. These lower conus lesions are clinically indistinguishable from CE injuries (see the following paragraph). Bladder and rectal reflexes are diminished or absent, depending on the exact level and extent of the lesion. There is paralysis of the bladder detrusor muscle due to destruction of the preganglionic parasympathetic (PS) fibers, with retention of urine and overflow incontinence. In men, there is failure of penile erections and ejaculation due to the destruction of the preganglionic PS neurons and the somatic motor ventral horn cells, respectively. Emission of semen can still occur because the motor fibers to the ductus deferens and seminal vesicles have sympathetic innervation. Motor strength in the lower limbs may remain intact to a variable degree, depending on degree of injury to nerve roots arising from more rostral segments (L2–S1). The lumbar nerve roots may be spared partially or totally in the conus medullaris, referred to as “root escape.” If the roots are affected as they travel with the sacral cord in the spinal column, this will result in LMN damage with diminished or absent reflexes. In some conus injuries, the knee reflexes may be preserved, but the ankle reflexes will be affected. In low conus lesions, the S1 segment is not involved and therefore, the ankle reflexes are normal, a finding accounting for most instances of failure to recognize the clinical syndrome. Due to the small size of the conus medullaris, lesions are more likely to be bilateral as compared to those of the CE. With conus medullaris lesions, recovery of completely paralyzed muscles is limited.

Injuries caudal to the L1 vertebral level predominantly do not cause injury to the spinal cord, but rather to the CE or nerve rootlets supplying the lumbar and sacral segments of the skin and muscle groups. Cauda Equina Syndrome (CES) therefore is a LMN syndrome that presents with patchy and often asymmetric findings of lumbosacral impairment ranging from complete flaccidity to seemingly unaffected due to the relative mobility of these neural segments. Atrophy and flaccid paralysis of lower extremity musculature (L2–S2) and varying sensory loss in radicular patterns is common. Additionally, loss of deep tendon reflexes and bowel/bladder involvement is seen frequently. Patients may classically have “saddle anesthesia” (loss of sensation in the upper inner legs, inner aspects of the buttocks and perineum regions) with accompanying loss of bulbocavernous and anal wink reflexes. With significant LMN components to this syndrome, prognosis for recovery is better than incomplete UMN syndromes. This is likely due to the resiliency of the nerve roots to injury, with early deficits potentially due to neurapraxia demonstrating progressive recovery over weeks to months. As CE rootlets are histologically peripheral nerves, regeneration is possible.

Separation of CE and conus lesions in clinical practice is difficult, because the clinical features as well as levels of

<table>
<thead>
<tr>
<th>SYMPTOM</th>
<th>EPICONUS</th>
<th>CONUS MEDULLARIS</th>
<th>CAUDA EQUINA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture level</td>
<td>T12 and above</td>
<td>T12/L1–L2</td>
<td>At and below L2</td>
</tr>
<tr>
<td>Pain</td>
<td>Uncommon</td>
<td>Uncommon</td>
<td>Very common and may be</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>severe</td>
</tr>
<tr>
<td>Bowel/Bladder reflex</td>
<td>Present (UMN findings)</td>
<td>Absent* most commonly (LMN</td>
<td>Absent (LMN findings)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>findings)</td>
<td></td>
</tr>
<tr>
<td>Anal and bulbocavernos reflex</td>
<td>Present</td>
<td>Absent* (LMN findings)</td>
<td>Absent (LMN findings)</td>
</tr>
<tr>
<td>Muscle tone</td>
<td>Increased (UMN findings)</td>
<td>*(LMN findings)</td>
<td>Decreased (LMN findings)</td>
</tr>
<tr>
<td>MSR</td>
<td>Increased*</td>
<td>*(LMN findings)</td>
<td>Decreased (LMN findings)</td>
</tr>
<tr>
<td>Symmetry of weakness</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Sensation</td>
<td>In dermatomal distribution</td>
<td>Absent in saddle distribution and may be dissociated</td>
<td>In dermatomal distribution</td>
</tr>
<tr>
<td>Recovery prognosis</td>
<td>Limited</td>
<td>Limited</td>
<td>Possible</td>
</tr>
</tbody>
</table>

*Unless a high conus lesion.

1Depends if nerve roots are affected. If so, then is decreased.

Ankle plantarflexors and hamstrings, not knee jerks.

LMN, lower motor neuron; MSR, muscle stretch reflexes; UMN, upper motor neuron.

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injury of these lesions overlap (53). (See Table 5.5.) Isolated conus lesions are rare since the roots forming the CE are wrapped around the conus. Traumatic SCI will likely produce a combination syndrome or a pure CE lesion. The conus may be affected by a fracture of L1, whereas a fracture of L2 or lower impinges solely on the CE. Sacral fractures as well as fractures of the pelvic ring also damage the CE, as well as the sacral plexus. Bullet wounds can penetrate the bony structures to traumatize the cauda and conus. Intrinsic tumors of the conus medullaris can selectively damage the conus.

Cauda equina lesions can be considered as multiple radiculopathies and as such electrodiagnostic studies may be helpful in the diagnosis. The electromyographic abnormalities in cauda lesions would be widespread and bilateral (but often asymmetrical). Other methods of studying root or nerve function (H-reflexes, F waves, root stimulation, somatosensory evoked potentials) may be used to aid in diagnosis. Conus medullaris lesions will cause electrical abnormalities in muscles where the LMNs are affected.

SCI clinical syndromes can be the result of both traumatic and nontraumatic etiologies. CCS and conus medullaris syndromes are most likely due to falls, whereas motor vehicle crashes are the primary etiology for BSS. In contrast, Anterior Cord and Posterior Cord syndromes are more frequently the result of a nontraumatic injury. CES is almost equally due to traumatic and nontraumatic etiologies (53).

DISCOMPLETE INJURIES

Neurological pathways within the spinal cord may be spared even after a neurologically complete injury on clinical exam. The term “discomplete injury” was introduced by Dimitrievic and colleagues (89,90) to describe a clinically complete SCI with neurophysiological evidence of residual function and connectivity between above and below the injury. Subsequent studies have demonstrated degrees of intact localization with quantitative sensory testing below the neurological level of injury in complete injuries (AIS A) without sparing of clinical motor, LT or sharp/dull discrimination (91–95). Finnerup et al. performed quantitative sensory testing below the level of injury (including thermal stimulation, pressure, pinch and pain sensitivity) in 24 subjects with AIS A (with no sparing of voluntary motor function or preserved sharp/dull discrimination or LT sensation below the injury) and found that 50% had vague localized sensation to the stimuli (95). All patients had no cortical response to lower extremity (posterior tibial nerve) SSEP. There was no relationship between the presence of this sensory perception with level of injury or etiology. There was also no correlation between the presence of sensory perception with the presence or severity of spasticity or chronic neuropathic pain (95).

Neuropathological studies found a similar percentage (50%) of anatomically discomplete injuries in persons with clinical complete injuries (89,91). Further, recent research on epidural stimulation in clinically complete injuries suggests the presence of such latent tracts (96). However, it is still unclear where the spared information travels and what the preservation of these pathways represents. Knowledge of retained neural communication across a SCI may have consequences for treatment strategies and enhancing functional recovery and further study is needed.

CONCLUSION

Performance of an accurate examination as recommended by the ISNCSI will allow the professional to classify the individual using the ASIA Impairment Scale. Using consistent terminology and definitions will allow for improved communication between clinicians, researchers, and patients.

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