Functional Outcomes After Spinal Cord Injury

Kenneth C. Parsons, MD
Speaker Bio

Dr. Kenneth C. Parsons, MD

- Paradigm Medical Director
- 30 years of experience in caring for patients with spinal cord injuries
- Board certified in physical medicine and rehabilitation
- Served for 10 years as the chairman of the steering committee for the Consortium for Spinal Cord Medicine
- Past-president of the American Spinal Injury Association
Anticipate functional outcomes after traumatic spinal cord injury (SCI) and the trajectory of motor recovery for complete and incomplete injuries by:

- Level of injury
- ASIA/ISNCSCI Impairment Scale
- Time course of motor recovery in “key muscles”
- Affect of comorbid conditions
- Ambulation options
Agenda

- Acute SCI diagnosis & evaluation
  - Common syndromes
  - Motor recovery time course
- Outcomes by level of motor complete injury
- Impact of secondary and co-morbid conditions
- Ambulation outcomes
  - Historical ambulatory aides
  - Exoskeleton criteria
  - Exoskeleton options
Etiology of SCI

Annual incidence 25-35/million general population

Grouped Etiology

- Vehicular (42.5%)
- Falls (19.0%)
- Violence (19.1%)
- Sports (11.2%)
- Other/Unknown (8.2%)
Factors That Affect The Transverse and Longitudinal Extent of Injury

- Severity of impact trauma & spine distortion
- Secondary trauma
  - Brain injury
- Cardiopulmonary complications:
  - Hypotension
  - Hypoxia
The goal of emergency management is to preserve axons in the spinal cord and prevent complications:

- Immobilize spine
- Support lordosis
- Logroll when turning
  - Pressure relief
  - Bronchial drainage
- Remove from hard surface ASAP
Initial Evaluation
THE PATIENT IS HERE!
CT: Computerized Tomography

- Bone detail
- Reformatting images
- After metrizamide myelography

**Figure 1.** Fracture-dislocation of cervical spine with dural tear. Axial postmyelography CT image through the C5-6 disc. Fractures of the vertebral body (solid curved arrows) and widening of the facet joint space (straight arrows) can be seen. Leakage of myelographic contrast into the right C5-6 facet joint space and leakage into the posterior paraspinal soft tissues indicate a dural tear (open curved arrows).
MRI: Magnetic Resonance Image

- Visualize soft tissues
  - Spinal canal and cord dimensions
  - Occult disc herniation
- Cord edema vs. hemorrhage

**Figure 4.** Traumatic cervical disc herniation. Sagittal short TR/short TE (T1-weighted) (a) and sagittal long TR/long TE (T2-weighted) (b) spin-echo MR images of the cervical spine. T1- and T2-weighted images demonstrate posterior extrusion of disc material causing compression of the cervical spinal cord (arrow). The T2-weighted sequence also demonstrates increased signal within the cervical cord indicating cervical cord contusion. There is effacement of the CSF space both anterior and posterior to the cord.
MRI Evaluation

- Disruption of inter-spinous ligament
- Compression fracture of C4
- Discontinuity of inferior end plate
Figure 1. Computed tomography scan through C1 and C2 illustrating a case of atlantoaxial rotatory dislocation. Valuable information is gained regarding bony alignment and the likely position of the vertebral arteries.

Figure 2. Magnetic resonance image, sagittal plane, demonstrating a type II odontoid fracture with interposition of the transverse ligament between the odontoid process and the body of C2.
Evaluation of Complex Injuries
Conus vs. Cauda Equina Injury?
ASIA/ISNCSCI Impairment Scale

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Common Errors in Sensory Maps & Testing
Sensory Evaluation on the Face
Sensory Pathways

Fig. 52  Sensory pathways from the periphery through the spinal cord to the postcentral gyrus.

- **Pain and temperature**
- **Touch and proprioception**
Incomplete SCI Syndromes

**Incomplete Spinal Cord Syndromes**

- **Spinal cord orientation**
  - Dorsal columns (position sense)
  - Lower limb
  - Trunk
  - Upper limb
  - Lateral pyramidal tract (motor)
  - Lateral spinothalamic tract (pain and temperature) crosses from opposite side before ascending
  - Anterior spinal artery

- **Central cord syndrome**
  - Central cord hemorrhage and edema.
  - Parts of 3 main tracts involved on both sides. Upper limbs more affected than lower limbs.

- **Anterior spinal artery syndrome**
  - Artery compressed by bone or cartilage spicules; shaded area affected. Motor function and pain sensation lost bilaterally below injured segment; position sense preserved.

- **Brown-Séquard’s syndrome**
  - One side of cord affected. Loss of motor function and position sense on same side and of pain sense on opposite side.

- **Dorsal column syndrome (uncommon)**
  - Position sense lost below lesion; motor function and pain sense preserved.

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“Motor Sparing”

Motor level of injury
Motor Key Muscles

KEY MUSCLES

Elbow flexors
Wrist extensors
Elbow extensors
Finger flexors (distal phalanx of middle finger)
Finger abductors (little finger)

0 = total paralysis
1 = palpable or visible contraction
2 = active movement, gravity eliminated
3 = active movement, against gravity
4 = active movement, against some resistance
5 = active movement, against full resistance
NT = not testable

Hip flexors
Knee extensors
Ankle dorsiflexors
Long toe extensors
Ankle plantar flexors

Voluntary anal contraction (Yes/No)

TOTALS

(MAXIMUM) (50) (50) (100)

MOTOR SCORE
Sacral Sparing

*Neurologic rectal exam*

1. Peri-anal pin sensation
2. Proprioception
3. Voluntary sphincter contraction
4. Pelvic reflex

*Fig. 4–5. Sacral sparing.*
ASIA/ISNCSCI Impairment Scale

ASIA IMPAIRMENT SCALE

☐ A = Complete: No motor or sensory function is preserved in the sacral segments S4-S5.

☐ B = Incomplete: Sensory but not motor function is preserved below the neurological level and includes the sacral segments S4-S5.

☐ C = Incomplete: 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.

☐ D = Incomplete: 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.

☐ E = Normal: motor and sensory function are normal

CLINICAL SYNDROMES

☐ Central Cord
☐ Brown-Sequard
☐ Anterior Cord
☐ Conus Medullaris
☐ Cauda Equina

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Impairment of the Autonomic Nervous System After SCI
Functional Outcomes By Level of "Motor Complete" Injury

C1-3
C4
C5
C6
C7-8
T1-9
T10-L1
L2-S5

http://www.pva.org/site/apps/ka/ec/product.asp?c=ajlRK9NJLcJ2E&b=6423003&en=atJJKXMDI9LSJ7NGI8LPL3PQLnJUI3NIJhIVJeNYLxE&ProductID=883869

Or give me your business card and I will email the link to you
### TABLE 6. Expected Functional Outcomes

**Level C7-8**

Functionally relevant muscles innervated: Latissimus dorsi; sternal pectoralis; triceps; pronator quadratus; extensor carpi ulnaris; flexor carpi radialis; flexor digitorum profundus and superficialis; extensor communis; pronator/flexor/extensor/abductor pollicis; lumbricals (partially innervated)

**Movement possible:** Elbow extension; ulnar/wrist extension; wrist flexion; finger flexions and extensions; thumb flexion/extension/abduction

**Patterns of weakness:** Paralysis of trunk and lower extremities; limited grasp release and dexterity secondary to partial intrinsic muscles of the hand

**FIM/Assistance Data:** Exp = Expected FIM Score / Med = NSCISC Median / IR = NSCISC Interquartile Range

**NSCISC Sample Size:** FIM = 43 / Assist = 35

<table>
<thead>
<tr>
<th>Expected Functional Outcomes</th>
<th>Equipment</th>
<th>FIM/Assistance Data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Respiratory</strong></td>
<td>Low endurance and vital capacity secondary to paralysis of intercostals; may require assist to clear secretions.</td>
<td></td>
</tr>
<tr>
<td><strong>Bowel</strong></td>
<td>Some to total assist</td>
<td>• Padded tub bench with commode cutout or shower commode chair</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Adaptive devices as needed</td>
</tr>
<tr>
<td><strong>Bladder</strong></td>
<td>Independent to some assist</td>
<td>Adaptive devices as indicated</td>
</tr>
<tr>
<td><strong>Bed Mobility</strong></td>
<td>Independent to some assist</td>
<td>Full electric hospital bed or full to king standard bed</td>
</tr>
<tr>
<td><strong>Bed/Wheelchair Transfers</strong></td>
<td>Level: Independent, Uneven: Independent to some assist</td>
<td>With or without transfer board</td>
</tr>
<tr>
<td><strong>Pressure Relief/Positioning</strong></td>
<td>Independent</td>
<td>• Wheelchair pressure relief cushion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Postural support devices as indicated</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Pressure-relief mattress or overlay may be indicated</td>
</tr>
<tr>
<td><strong>Eating</strong></td>
<td>Independent</td>
<td>Adaptive devices as indicated</td>
</tr>
<tr>
<td><strong>Dressing</strong></td>
<td>Independent upper extremities; independent to some assist lower extremities</td>
<td>Adaptive devices as indicated</td>
</tr>
<tr>
<td><strong>Grooming</strong></td>
<td>Independent</td>
<td>Adaptive devices as indicated</td>
</tr>
<tr>
<td><strong>Bathing</strong></td>
<td>Upper body: Independent; Lower extremity: Some assist to independent</td>
<td>• Padded transfer tub bench or shower/commode chair</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Handheld shower</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Adaptive devices as needed</td>
</tr>
<tr>
<td><strong>Wheelchair Propulsion</strong></td>
<td>Manual: Independent all indoor surfaces and level outdoor terrain; some assist with uneven terrain</td>
<td>Manual: Rigid or folding lightweight or folding wheelchair with modified rims</td>
</tr>
<tr>
<td><strong>Standing/Ambulation</strong></td>
<td>Standing: Independent to some assist Ambulation: Not indicated</td>
<td>Hydraulic or standard standing frame</td>
</tr>
<tr>
<td><strong>Communication</strong></td>
<td>Independent</td>
<td>Adaptive devices as indicated</td>
</tr>
<tr>
<td><strong>Transportation</strong></td>
<td>Independent car if independent with transfer and wheelchair loading/unloading; independent driving modified van from captain’s seat</td>
<td>• Modified vehicle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Transfer board</td>
</tr>
<tr>
<td><strong>Homemaking</strong></td>
<td>Independent light meal preparation and homemaking; some to total assist for complex meal prep and heavy housecleaning</td>
<td>Adaptive devices as indicated</td>
</tr>
<tr>
<td><strong>Assist Required</strong></td>
<td>• Personal care: 6 hours/day</td>
<td>8* 12* 2–24*</td>
</tr>
<tr>
<td></td>
<td>• Homecare: 2 hours/day</td>
<td></td>
</tr>
</tbody>
</table>

*Hours per day.
Expected Functional Outcome Categories

1. Respiratory function
2. Bowel function
3. Bladder function
4. Bed mobility
5. Bed/wheelchair transfers
6. Wheelchair propulsion
7. Pressure relief/positioning
8. Standing/ambulation
9. Eating
10. Grooming
11. Dressing
12. Bathing
13. Communication methods
14. Equipment required
15. Transportation options
16. Homemaking skills
17. Assistance required
FIM: Functional Independence Measure

Lower numbers mean greater burden of care

**Thirteen motor items graded 1 to 7**

7. Complete independence (timely, safely)
6. Modified independence (device, extra time)
5. Supervision
4. Minimal assist (subject does 75%+)
3. Moderate assist (subject does 50-74%)
2. Maximal assist (subject does 25-49%)
1. Total assist (subject does 0-24%)
Medical Equipment Required

- Minimum recommendations
- DME and adaptive devices
- Guidelines are non-prescriptive recommendations
- Generic descriptions
- Individualized to each person after assessment
- Thorough testing required to demonstrate safety and effectiveness before purchase
- Disposable medical products are not included
Expected Respiratory Equipment

C1-3: Two ventilators (bedside, portable) plus ET suction equipment or other suction management device plus generator/battery backup

C4: Same as C1-3 if not ventilator free

C5-S5: No ventilator equipment required (unless...?)
Bowel Scores

Indepen 7
Mod Ind 6
Superv 5
Min 4
Mod 3
Max 2
Total 1

C1-3  C4  C5  C6  C7-8  T1-9  T10-L1  L2-S5

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Assistance Required From Outcomes CPG

- Number of hours required from a caregiver to assist with personal care and homemaking activities in the home
- Safety and independence concerns
- Paid and unpaid hours
- Skilled and unskilled services combined
- Needs may change with aging, weight gain, etc.
- Wide range of individual variables
FIM Assistance Data Cited in Outcomes CPG

- One year post injury FIM assessments
- 405 survivors with motor complete injuries
- National SCI Statistical Center cases
- Median age of 27
Total Hours of Assistance Required

May exceed 24 hours per day in unusual cases

<table>
<thead>
<tr>
<th></th>
<th>C1-3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7-8</th>
<th>T1-9</th>
<th>T10-L1</th>
<th>L2-S5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours</td>
<td>24</td>
<td>24</td>
<td>16</td>
<td>10</td>
<td>8</td>
<td>2</td>
<td>2</td>
<td>0-1</td>
</tr>
</tbody>
</table>

Total Hours of Assistance Required (Paid & Unpaid)
Motor Score Rate of Recovery Time Course

![Graph showing the annualized rate of recovery over time since injury for different types of spinal injury: Complete Paraplegic, Incomplete Paraplegic, Complete Tetraplegic, Incomplete Tetraplegic.](image)
Prediction of Motor Recovery

**Prediction of Lower Extremity Motor Recovery (23)**

<table>
<thead>
<tr>
<th>Manual Muscle Strength at One Month*</th>
<th>Complete Paraplegia</th>
<th>Incomplete Paraplegia</th>
<th>Incomplete Tetraplegia</th>
</tr>
</thead>
<tbody>
<tr>
<td>0/5</td>
<td>5%</td>
<td>26%</td>
<td>24%</td>
</tr>
<tr>
<td>1/5, 2/5</td>
<td>64%</td>
<td>85%</td>
<td>97%</td>
</tr>
</tbody>
</table>

*ASIA key muscles

**Prediction of Upper Extremity Motor Recovery (23)**

<table>
<thead>
<tr>
<th>Manual Muscle Strength at One Month*</th>
<th>Complete Tetraplegia</th>
<th>Incomplete Tetraplegia</th>
</tr>
</thead>
<tbody>
<tr>
<td>0/5</td>
<td>20%</td>
<td>24%</td>
</tr>
<tr>
<td>1/5</td>
<td>90%</td>
<td>73%</td>
</tr>
<tr>
<td>2/5</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

*ASIA key muscles

Motor Recovery may translate into decreased burden of care
Centers of Excellence for SCI Cases

INDIVIDUAL CHARACTERISTICS (PATHOLOGY, AGE & MOTIVATION)

IMPAIRMENT

ACTIVITY

PARTICIPATION

SECONDARY IMPAIRMENT

SECONDARY ACTIVITY LIMITATIONS

SECONDARY PARTICIPATION RESTRICTIONS

PERCEIVED HEALTH

PERCEIVED ACTIVITY LIMITATION

PERCEIVED ROLE LIMITATION

QUALITY OF LIFE

REHABILITATION PROCESSES

ENVIRONMENTAL FACTORS, CONSUMER PRODUCTS AND FAMILY SUPPORT

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Limiting Factors

*Examples of what can limit functional outcomes, drive up costs and interfere with re-employment*

- Obesity
  - May mean that more than 24 hours of paid care are necessary per day
  - May mandate that extra equipment is necessary
    - E.g., bariatric lift, power wheelchair, oversized shower commode chair, etc.
  - May outgrow custom DME
  - Special bed requirements will drive up costs
  - Off-loading of pressure areas is more difficult
- Pressure sores
- Co-existing brain injury
- Upper extremity impairments apart from SCI effects
- Dependent ICP
- Bowel incontinence
Historical Ambulation Options

- Long leg braces or KAFOs
- Reciprocating gait orthoses
- Short leg braces or AFOs
- Various combinations

Limitations
- Body powered, energy inefficient
- Static balance determines “hands free” ability
- Fall recovery must be part of the training

Wheelchair is faster and more efficient
Body Weight Supported Ambulation

“Activity Based Therapy”
Four Exoskeleton Models are Currently in Development

- **ReWalk**: FDA cleared for sale in USA
- **Indego**: 
- **Ekso**: 
- **Rex**: Available in UK and New Zealand

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Who Qualifies to Use These Devices?

- Persons with SCI or other neurological disorders
- Must have medical clearance for full weight bearing and walking activity
- Must meet certain height and weight limits
- Adults (18 years and older) without unusual risk of fracture (bone density scan to confirm bone health prior to use)
- Must have adequate range of motion at hips, knees and ankles
- Minimal to moderate levels of spasticity may not interfere
- Must tolerate being upright without light headedness
- Skin must be intact where it interfaces with the device
## Comparison of Four Systems

<table>
<thead>
<tr>
<th>System Requires</th>
<th>ReWalk</th>
<th>Indego</th>
<th>Ekso</th>
<th>Rex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height range</td>
<td>63-75”</td>
<td>61-76”</td>
<td>62-74”</td>
<td>56-76”</td>
</tr>
<tr>
<td>Weight range</td>
<td>Up to 220 lbs</td>
<td>Up to 250 lbs</td>
<td>Up to 220 lbs</td>
<td>Up to 220 lbs</td>
</tr>
<tr>
<td>Pelvis width</td>
<td></td>
<td></td>
<td></td>
<td>Up to 18”</td>
</tr>
<tr>
<td>Pelvis width</td>
<td></td>
<td></td>
<td></td>
<td>Up to 15”</td>
</tr>
<tr>
<td>Crutch capable</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>No, joy stick control</td>
</tr>
<tr>
<td>Heart health</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Bone health</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>System wt.</td>
<td></td>
<td>26 lbs</td>
<td>50 lbs</td>
<td>Also being studied in stroke patients</td>
</tr>
</tbody>
</table>

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Exoskeleton Models

ReWalk

Indego

Ekso
Ekso

“Get Up And Go”
**FirstStep™**
A physical therapist actuates steps with a button push. The user progresses from sit to stand and using a walker to walking with crutches, often in their first session.

**ActiveStep™**
User takes control of actuating steps via buttons on the crutches or walker.

**ProStep™**
The user achieves the next step by moving their hips forward and shifting them laterally. The Ekso device recognizes that the user is in the correct position and steps.

**NEW ProStep Plus™**
Steps are triggered by the user’s weight shift PLUS the initiation of forward leg movement.
Users should be:

- Between 56” and 76”
- Weigh less than 220 lbs
- Hip width of 15” or less

Designed for use on solid, stable surfaces, such as those inside the home or workplace.

- It is not designed for use on slippery, unstable, or soft surfaces, on in areas that contain debris or small objects, such as ice, snow, sand, grass, mud or gravel

Designed to climb steps that meet typical building code standards for staircases

- Minimum tread of 12.2”
- Maximum riser of 7”

REX can walk on a curbed slope of up to 1:8 (7.1 degrees) and a general slope of up to 1:12 (4.8 degrees).

REX can walk on a camber of up to 1:50 (1.1 degrees)

New Zealand and UK
From Joy Stick Control to Brain Control

A wearable robot
A research team at the University of Houston is working to create an interface that will allow the human brain to control a robotic exoskeleton that gives paralyzed users the ability to walk. The device is currently controlled by joystick.

How it will work:
1. Sensors on skullcap read brain activity, which is transmitted to a computer
2. The computer translates the brain activity and sends a signal to the exoskeleton, guiding the device without using the joystick

About the device:
- **Developer**: Rex Bionics, of New Zealand
- **Cost**: $150,000
- **Weight**: 84 pounds; newer model will be 64 pounds *
- **Battery life**: 2 hours of continuous walking

* User carries none of the weight
Sources: Rex Bionics; University of Houston

Jay Carr / Houston Chronicle
Potential Benefits, Yet To Be Determined

- Will exoskeleton ambulation replace wheelchair mobility?
- Impact on health, wellness, socialization & psychological benefits?
- Will it potentiate neurological recovery?
- Is it a useful therapeutic modality?
- Will function be improved?
- Will users avoid complications?
- Will long-term health & wellness be facilitated?
- Safety and fall recovery?
Sample Data from an Indego User

Exoskeletons capture data that is useful for setting goals and understanding progress

This is the data collected from “Mr. K,” a T7 complete paraplegic, from his eighth time using the Indego.

<table>
<thead>
<tr>
<th>Data measurement</th>
<th>“Mr. K’s” data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of steps</td>
<td>1,376</td>
</tr>
<tr>
<td>Average speed</td>
<td>0.3 m/s 1 mph = 0.45 m/sec</td>
</tr>
<tr>
<td>Exact distance walked</td>
<td>½ mile</td>
</tr>
<tr>
<td>Total walking time</td>
<td>45 minutes</td>
</tr>
<tr>
<td>User’s contribution versus device contribution</td>
<td>Device contributed 100% (Mr. K is a complete para)</td>
</tr>
<tr>
<td>Force generated by user’s muscles</td>
<td>Mr. K’s muscle force provided as much as 95% from quadriceps and 27% from hamstrings with FES alternating 10 steps on/10 steps off</td>
</tr>
</tbody>
</table>
Main Outcome Measures

- Walking outcomes include timed walk tests, metabolic cost, gait cycle kinetics, ability to walk on varied surfaces and terrains.

Secondary Outcome Measures

- Impact on bowel function, bladder function, pain, spasticity, body composition and medication requirements.

Quality of Life Measures

Long-term use data

Therefore:

- Paradigm is not yet endorsing or recommending purchase of exoskeletons for home use, especially with the supervision requirements and the need for evidence of health benefits and usage data over time.

The decision about purchase will rest with the payer
Conclusions

- Preliminary studies seem to demonstrate that *powered exoskeletons* have potential as mobility devices and to facilitate improvements to body functions and activities for non-ambulatory or poorly ambulatory SCI patients

- *Not all persons* are suited to use all or any of these devices

- Technology is in *early stages* of development

- Medical *benefits* and potential *risks* are being defined

- **Recommendations** to potential users
  - “Avoid obesity, contractures and osteoporosis to improve your suitability for use of an exoskeleton”

- Health care professionals should critically evaluate the demonstrable benefits and risks of integrating powered exoskeleton ambulation into *traditional* rehabilitation programs

- Early incorporation of these systems into clinical research environments may be useful to assist clinicians and researchers in *rehabilitation programs, in the future, after “cure” interventions*
Thank you!

Q&A