Neuromodulation
to restore motor function

Karen Minassian
Ursula Hofstoetter, Keith Tansey, Winfried Mayr

Center for Medical Physics and Biomedical Engineering, Medical University Vienna, Vienna, Austria
Institute of Analysis and Scientific Computing, Vienna University of Technology, Vienna, Austria
Spinal Cord Injury Lab, Crawford Research Institute, Shepherd Center, Atlanta, GA, USA
Neuromodulation

The therapeutic paradigm is the modulation of CNS activity

Neuromodulation is non-destructive, reversible, and adjustable

The field of neuromodulation

Brain
Deep brain stimulation (DBS)

Cranial nerves
Vagus nerve stimulation (VNS)

Spinal cord
el. spinal cord stimulation (SCS)
Implantable drug pumps

Spinal nerves
Sacral nerve stimulation (SN)

Peripheral nerves
Peripheral nerve stimulation (PNS)

Focus of the presentation

Spinal cord stimulation for

the treatment of spinal spasticity and
modification of altered motor control due to

multiple sclerosis and
spinal cord injury

Dependence of the stimulation-induced effects on

Stimulation site, stimulation frequency
Profile of the spinal cord physiology as a result of the lesion
Epidural spinal cord stimulation

- Spinal cord
- Electrodes
- Posterior roots
- Electrode location
- Spinal cord

Cross-section at T12 vertebral level

Continuous stimulation
Epidural spinal cord stimulation
Immediate effects(1)

Posterior column fibers

El. field

Posterior root fibers

Side view of the terminal spinal cord and afferent structures
Epidural spinal cord stimulation

Immediate effects (2)

- Posterior column fibers
- Posterior root fibers

Functional integrity?

Electrical activation

Trans-synaptic activation
Epidural spinal cord stimulation
Immediate effects(3)

Posterior column fibers

Posterior root fibers

Muscle spindles (lower limbs)

Cutaneous mechanoreceptors

Stimulation sites

CC… Clarke’s column; DCN… Dorsal column nuclei

Functional integrity?
Epidural SCS in multiple sclerosis

- 5 subjects with MS
- subdural, extra-arachnoid space over mid-thoracic spinal cord
- stimulation frequency: 150 – 200 Hz


- ‘Lightness’ of the legs, less fatigue, more endurance
- Improvement of limb spasticity
- Regain of voluntary control
- Facilitation of sitting, standing and ambulation
- Increased functional activities of daily living

- more than other 70 with MS
- epidural space over mid-thoracic cord
- stimulation frequency: 30 – 50 Hz

# Epidural SCS in multiple sclerosis

## Selected reports

<table>
<thead>
<tr>
<th>Study</th>
<th># of subjects</th>
<th>Improvements of lower limb function</th>
<th>Stim. site (vertebral)</th>
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## Epidural SCS in multiple sclerosis

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Epidural SCS in multiple sclerosis

Physiological mechanisms of SCS in MS (lower limb function)
Epidural SCS for spasticity control after SCI

Profile of injury and efficacy of SCS


Complete thoracic SCI

Complete cervical SCI

Incomplete cervical SCI

Modulation of segmental mechanisms of spasticity

No benefit/ poor candidates for SCS

Modulation of segmental mechanisms of spasticity

Stim.

Antidromic activity

Dorsal column-brainstem-spinal loop

Motor incomplete

Present SEP
Epidural SCS for spasticity control after SCI
Profile of injury and efficacy of SCS

“There is a great variety of pathologic conditions in chronic spinal cord lesions which will determine whether or not SCS is effective. …”

“… Placement of the electrode is the most critical part of the procedure …”

Epidural stimulation of lumbar cord circuits for spasticity control after SCI (1)

8 Subjects: 7 motor complete, 1 ASIA C

Traumatic SCI C5 to T6

50 – 100 Hz

EMG

Quadriceps
Adductor
Hamstrings
Tibialis anterior
Triceps surae

Epidural stimulation of lumbar cord circuits for spasticity control after SCI (2)

Q, Quadriceps; A, Adductor; H, Hamstrings;
TA, Tibialis anterior; TS, Triceps surae

Epidural stimulation of lumbar cord circuits for spasticity control after SCI (3)

Electrode sites effective to suppress spasticity

Epidural lumbar SCS generates rhythmic activity

Continuous stimulation at 25 – 50 Hz

Complete SCI subject

Human lumbar pattern generator

Non-patterend input  Patterned output

SCS-frequency dependence of generated motor patterns

Lumbar spinal cord stimulation

Complete spinal cord injury

Stimulation-frequency

31 Hz  25 Hz  15 Hz  10 Hz

0.5 mV

Quadriceps

Hamstrings

Tibialis anterior

Triceps surae

Induced Knee-movement

Subject in supine position

Stepping-like rhythmic movement

Standing-like extension movement

Potential for clinical applications

Increased step-cycle synchronized rhythmic activities

Vienna

Los Angeles, Louisville

Standing up and full weight-bearing standing

30-Hz SCS

Q...quadriceps, Ham...hamstrings, TA...tibialis anterior, TS...triceps surae


15-Hz SCS

TA...tibialis anterior, MG...medial gastrocnemius


‘Compensations’ of shifted centre of gravity
Transcutaneous lumbar spinal cord stimulation


Assisted treadmill stepping + transcutaneous SCS

Vienna

Body weight support

Assisted stepping

Atlanta

Body weight support

Robotic gait orthosis

Afferent input

Spinal cord

multi-modal patterned sensory input

tonic input

Transcutaneous spinal cord stimulation

L2
L3
L4
L5
S1
S2

L2
L3
L4
L5
S1
S2
Concept of Restorative Neurology – to augment surviving CNS capabilities

Adapted from Dimitrijevic, Textbook for stereotactic and functional neurosurgery, 1998.
Robotic-assisted treadmill stepping with 30-Hz transcutaneous SCS
Incomplete SCI (ASIA D)

No body weight support, Treadmill speed: 1.6 km/h
no stepping assistance

\[\text{tSCS: Sub-motor thr. 30 Hz}\]
Non-ambulatory, motor-incomplete SCI (ASIA D)

No body weight support, Treadmill speed: 1.6 km/h
no stepping assistance

tSCS: Sub-motor thr. 30 Hz
Epidural SCS for spasticity control after SCI

With regard to lower extremities

Richardson et al., 1978;1979

- Complete SCI
- El. pos. T1-T10
- 50-100 Hz
- 6 subjects,
  All had significant therapeutic effects:
  Complete control of spasticity
  (hypertonia and spasms)

Siegfried et al., 1981

- Complete, ‘severe’ incomplete SCI
- El. pos. lower C - mid T
- 100-120 Hz
- 15 subjects,
  No convincing therapeutic effects

Barolat et al., 1988

- Complete, incomplete SCI
- El. pos. T1-T10
- 50-100 Hz
- 16 subjects,
  14 with significant therapeutic effects:
  Marked reduction of spasms, reduced clonus, improved motor function
Spinal cord stimulation facilitates functional walking  
in a chronic, incomplete spinal cord injured.

2 subjects, ‘low’- ASIA C
Ambulatory function was improved by combining treadmill training and epidural SCS
Improved over-ground walking, reduction in time and energy cost of walking, sense of effort

Richard Herman  
Phoenix, Arizona

Herman et al.  

Carhart et al.  

Huang H et al.  