Neuromodulation

- Spinal Cord Stimulation
- Intrathecal pumps
Neuromodulation

Electrical or chemical modulation of the central nervous system to significantly reduce pain or improve neurologic function
Aristotle / Hippocrates

Heart - central organ of pain
Descartes 1600’s

Descartes' pain pathway: "Particles of heat" (A) activate a spot of skin (B) attached by a fine thread (cc) to a valve in the brain (de) where this activity opens the valve, allowing the animal spirits to flow from a cavity (F) into the muscles causing them to flinch from the stimulus, turn the head and eyes toward the affected body part, and move the hand and turn the body protectively. [5]
20th Century Discoveries

- 1965 - Melzack and Wall report a new theory on Pain

- Coined phrase “Gate Control Theory”
Gate Control Theory

- Hypothesized inhibiting pain centrally could be achieved by nonpainful stimuli

- Believed that afferent nerve impulses lead to spinal cord transmission in Substantia Gelatinosa
How is pain perceived?

- **SENSORY**
  - Intensity, Localization, Discrimination

- **MOOD**
  - Depression, Catastrophising, Anxiety

- **CHEMICAL & STRUCTURE**
  - Neurodegeneration
  - Metabolic (e.g. opioidergic, dopaminergic)
  - Maladaptive Plasticity

- **CONTEXT**
  - Pain Beliefs, Expectation, Placebo

- **COGNITIVE**
  - Hypervigilance, Attention, Distraction

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Somatosensory System


Perception & Discrimination

Affective & Attention

Lateral System

Medial System

Consciousness

Emotion

Ad or C nociceptive drive
Origins of Electrical Stimulation

- 9000 BC - Bracelets used to alleviate headaches and arthritis
- Ancient Egyptians observed Nile catfish use electrical discharge to stun prey
Origins of Electrical Stimulation

- Greeks called stingrays “Narke” or “numbness producing”
  - Term narcosis derived from this
- Romans called stingrays “Torpedo” or “torpor”
  - Torpor = sluggish, dormant, lethargic
Treatment of Headache and Gout
Concept of SCS

Neuropathic pain
Ectopic or spontaneous discharges in C fibres
(Wu 2002)

Paresthesia and dysesthesia
Ectopic discharges in Aβ fibres
(Ochoa 1980, Nordin 1984)

Spinal cord stimulation
Activates Aβ to suppress C and Aδ fibers
Via inhibitory interneurons (Melzack & Wall 1965)

SCS Mechanism of Action

- Nonpainful stimulation of large myelinated A-beta fibers and DRG
- Impedes painful stimuli by unmyelinated C and lightly myelinated A-delta fibers
- Alters local neurochemistry
  - Suppresses excitability of WDR
  - Increased GABA and serotonin
  - Suppression of glutamate and aspartate
  - Alters sympathetic tone increasing blood flow
20th Century Discoveries

- 1960 - Mazars G, Roge, and Mazars Y described neurostimulation of the spinothalamic fasciculus

- Possibly original clinical trial for treatment of chronic neuropathic pain by implanted electrodes
Consequences of Back Pain

- 1 in 14 Americans affected by either C, T, or L pain
- 5 million Americans suffer from chronic LBP
- 31 million Americans experience LBP at any given time
Consequences of Back Pain

- Annual costs for direct or indirect treatments $20-60 billion
- Most back pain resolves < 6 weeks
- <30% are fully improved within 3 months
Surgical Treatment

- 200,000 Americans receive lumbosacral surgery annually

- 20-40% of these experience chronic or recurrence of pain
Indications for Spinal Cord Stimulation

- Failed Back Surgery Syndrome
  - Most common use in USA
- Peripheral vascular disease
  - Most common use in Europe
- Complex Regional Pain Syndrome I and II
- Degenerative low back and radicular leg pain
- Arachnoiditis
- Neuropathic states
  - DM
  - HIV
  - Post herpetic neuralgia
- Postamputation pain
- Compressive CA lesions
- Chest wall pain syndromes
- Demyelinating D/O
- Spinal cord injuries
Indications for SCS

- Spinal stenosis
- Cervical radiculopathy
- Chronic abdominal pain
- Interstitial cystitis or urge incontinence
- Neuropathic perineal pain
- Chronic angina
Potential Future Indications

- Motor functional improvement
- CHF improvement
- PVD improvement
- Reactive airway disease improvement
- Obesity
- Alzheimer’s Disease
- Obsessive Compulsive Disorder
- Traumatic Brain Injury
- Addiction
- Aggressive behavior
Patient Selection for SCS

- Dx should be indication for SCS
- Diagnosis has neuropathic pain component
- Conservative therapy unsuccessful
- Symptoms lasting > 6 months
- Psychological evaluation usually recommended prior to placement
Patient Selection for SCS

- Lack of significant improvements despite pain meds, antidepressants, and anticonvulsants

- Spinal connection (Lemniscate pathway) to painful connection must be preserved

- Pass SCS trial
Main Components of SCS

Spinal Stimulation Devices

- Battery charger
- Transmitter
- Leads
- Pulse generator
Stimulator Leads

8-Electrode Leads

16-Electrode Surgical Leads
SCS Lead Placement

- Full sterile technique
- Fluoroscopy used
- Epidural space located by LOR
SCS Lead Placement

- Guide lead(s) toward physiologic midline due to tortuous spinal cord
- Place electrodes along posterior surface of dorsal columns
- Confirm impedance before wound closure
## SCS Lead Placement

<table>
<thead>
<tr>
<th>Pain Location</th>
<th>Entry Level</th>
<th>Final Lead Tip Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foot only</td>
<td>L2 or L3</td>
<td>T11-L1</td>
</tr>
<tr>
<td>Leg</td>
<td>L1 or L2</td>
<td>T9-T10</td>
</tr>
<tr>
<td>Leg, hip, and back</td>
<td>T12, L1, and L2</td>
<td>T7-T8 or T9</td>
</tr>
<tr>
<td>Upper chest wall</td>
<td>T6-T8</td>
<td>T1-T2</td>
</tr>
<tr>
<td>Upper extremity</td>
<td>T4-6</td>
<td>C3-C5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lead Location</th>
<th>Resultant Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1-C2</td>
<td>Increased cerebral blood flow, decreased sympathetic activity</td>
</tr>
<tr>
<td>C3-C6</td>
<td>Increased blood flow to arms</td>
</tr>
<tr>
<td>T1-T2</td>
<td>Relieves angina pain, treats CHF</td>
</tr>
<tr>
<td>T11-L3</td>
<td>Vasodilation of legs and feet</td>
</tr>
</tbody>
</table>
SCS Trial

- Varies per institution
- Often 5-7 days
  - Pt returns and leads removed
- Primary risk of short trial is “misreading success”
- Primary risk of long trial is infection
- ≥ 50% pain reduction is success
Permanent Placement

- Lead placement similar to trial except midline incision to allow anchoring of leads
- Leads tunneled to pocket (usually upper buttocks)
- Leads attached to battery and incisions closed
- Paddle leads placed directly in epidural space via laminectomy performed by surgeon
Permanent SCS

- Common Implanted Pulse Generator (IPG) sites:
  - Posteriosuperior gluteal
  - Lower abdomen
  - Usually on side with dominant hand to adjust settings and recharge

- Recharging performed by external recharger every 7-14 days
Medtronic SCS

- One of leaders in SCS since 1980s
- Rechargeable battery life 9 years
- Nonrechargeable battery 5 years
- Up to 16 contacts with 2 leads ports from generator
Medtronic SCS

- 2011 FDA approval for AdaptiveStim
  - Uses accelerometer to detect positional changes
  - Remembers preset stimulation level with pt position
  - Automatically adjusts to pt preprogrammed stimulation

- 90.1% of clinical study pts intended to leave AdaptiveStim on

- 86.5% of clinical study pts reported improved pain relief or convenience with AdaptiveStim

- 80.3% of clinical study pts reported improved comfort during positional changes
Medtronic SCS

- 2013 FDA approval for Full-Body MRI
  - Must be SureScan compatible
  - Leads must be MRI compatible
  - MRI up to 1.5 Tesla
- Must be placed in MRI mode prior to scan
  - Stimulation turned off in this mode
  - Done by MD or pt with MyStim programmer
Boston Scientific SCS

- 5 years battery life
- Up to 16 power sources per generator
- Precision Spectra system
  - Has 32 contacts
  - 4 Lead ports
  - Allows for more coverage of the spinal cord
  - Greater pt flexibility
St. Jude Medical SCS

- 10 year battery life
- 2014 FDA approval Protege SCS system
  - Can receive wireless updates
- SUNBURST Technology
  - Success Using Neuromodulation with BURST
  - Currently under Investigational Device Exemption (IDE) by FDA
Stimulation Modes

- Goal is to replace pain with pleasant paresthesias
- Conventional SCS <1kHz
- New High frequency SCS 10 kHz provides pain relief without generating paresthesias
  - Nevro Corporation SENZA system
- Hybrid SCS at 500 Hz delivers bursts of five pulses 40 times/second
SCS Complications

- Lead migration (most common) or breakage in 18-22% of pts
- Infection (*Staph aureus* most common)
- CSF leakage
- Paralysis (0.03%)
- Battery failure
- Loss or change of efficacy

- Variability in relief based upon pt position
  - Possibly prevented with AdaptiveStim
- Electrode dislocation or breakage
- Lead and/or IPG failure
Other Treatments and New Innovations

- Peripheral Nerve Stimulation
- High Frequency Stimulation
Peripheral Nerve Stimulation

- Direct electrical stimulation of involved nerves outside of the CNS
- Discovered when Wall and Sweet stimulated their own trigeminal nerve
- Related to “Peripheral Nerve Field Stimulation” (PNfS)
  - Placement of PNS leads within SQ peripheral receptive fields of a single nerve or overlapping multiple nerves
  - Can be efficacious for truncal, axial back, and neck pain where conventional SCS sometimes does not help
  - Can be combined with SCS to create hybrid systems
Peripheral Nerve Stimulation

- Extracranial stimulation for chronic pain
  - Branches of Trigeminal Nerve
    - Supra* and Infraorbital Nerves most frequent
  - Occipital Nerve**
  - Supratrochlear Nerve
  - Sphenopalatine Ganglion
  - Vagus Nerve
High Frequency SC Stimulation

- Conventional SCS <1kHz
  - Generate non-painful paresthesias
- New High frequency SCS 10 kHz provides pain relief without generating paresthesias
- Al-Kaisy\textsuperscript{24} showed 88% (72 of 82) pts reported reduction in pain from trial
- Pain scores reduced from 8.4 to 3.3 after permanent
High Frequency SC Stimulation

- Nevro Corporation
  - Senza system
- Not currently FDA approved in the US
- Clinical trials being performed worldwide
- Waiting on data comparing HF v. Conventional stimulation

Secondary Senza Benefits

- 2 leads placed anatomically T8-T11
- Concordant paresthesia mapping NOT done
- No need to lighten sedation for paresthesia testing “providing maximum comfort to the patient.”

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Conclusions

- Significant improvement in SCS technology over last 40 years
- Supportive data showing marked improvement of patients with various chronic pain conditions
- More studies still needed on both costs and therapeutic effectiveness of SCS
- Technology advancements continue to produce newer treatments, improved outcomes for pts, and expand the use of SCS and PNS/PNfS
Intrathecal Infusion Pumps

- 1898-August Bier with first spinal analgesia by injecting cocaine into the intrathecal space of himself, his assistant and 6 patients
- 1979- use of intrathecal morphine for intractable cancer pain as well as obstetric analgesia
- 1981- first clinical use of an implantable intrathecal opioid delivery device used in chronic pain of malignancy
Basics

- Deliver small doses of medication directly into the spinal fluid
- Consists of programmable pump implanted under the subcutaneous tissue of the abdomen and connected to a small catheter which is tunneled to the site of entry into the intrathecal space
- Pumps need to be refilled every 1-3 months
Pump Insertion
Pump Insertion

- Typically performed by a neurosurgeon
- Place under strict sterile conditions
- Lateral positioning
- Access the intrathecal space with a relatively large (17-gauge) tuohy needle
- Access below the termination of the spinal cord (L1-L2 in most adults)
Pump Insertion
Pump Insertion

2 Suture Points
The Intrathecal Pump
### Drugs Delivered Intrathecally

<table>
<thead>
<tr>
<th>Drug</th>
<th>Max Dosage</th>
<th>Max Concentration</th>
<th>Caution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morphine</td>
<td>15mg/d</td>
<td>30mg/ml</td>
<td>Inflammatory masses</td>
</tr>
<tr>
<td>Hydromorphone</td>
<td>4mg/d</td>
<td>10mg/ml</td>
<td></td>
</tr>
<tr>
<td>Bupivacaine</td>
<td>30mg/d</td>
<td>40mg/ml</td>
<td>Elderly-blockade</td>
</tr>
<tr>
<td>Fentanyl</td>
<td>No known max</td>
<td>2mg/ml</td>
<td></td>
</tr>
<tr>
<td>Sufentanil</td>
<td>No known max</td>
<td>50μg/ml</td>
<td></td>
</tr>
<tr>
<td>Clonidine</td>
<td>1mg/d</td>
<td>2mg/ml</td>
<td>Hypotension, sedation, peripheral edema, arrhythmia</td>
</tr>
<tr>
<td>Ziconotide</td>
<td>19.2μg</td>
<td>100μg/ml</td>
<td></td>
</tr>
</tbody>
</table>
Potency Conversions

PO x3  IV x10  EPI x10  IT


29. Schade, CM. Spinal Cord Stimulation. TPS. 2014 October