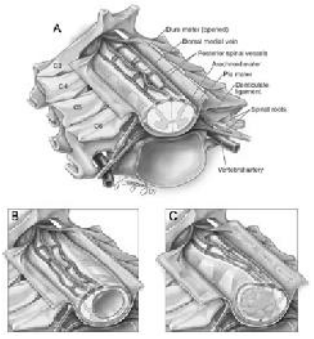
Spinal Cord Mapping Techniques and Monitoring for Intramedullary Spinal Cord Tumors

Kent Rice, M.S., REPT, CNIM, DABNM, FASNM

Sr. Manager Education and Training, Nuvasive Clinical Services

Intramedullary spinal cord tumor

- Intramedullary spinal cord tumors are rare (2-4% of all CNS tumors). Most commonly:
  - Children: Astrocytomas
  - Adults: Ependymomas
- These slow growing tumors expand within the spinal cord and can distort the surface anatomy

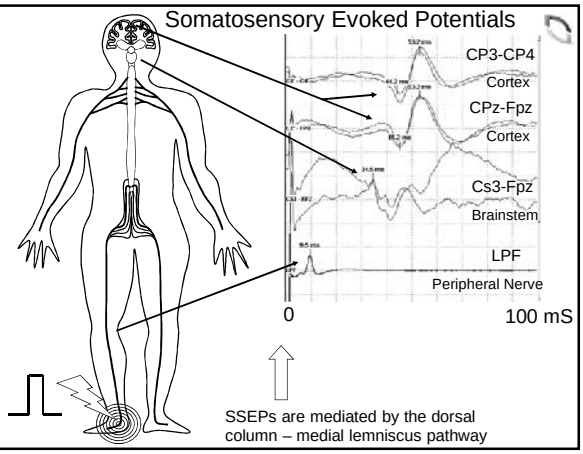


Yanni 2010

Monitoring Methodology for Intramedullary Spinal Cord Tumors

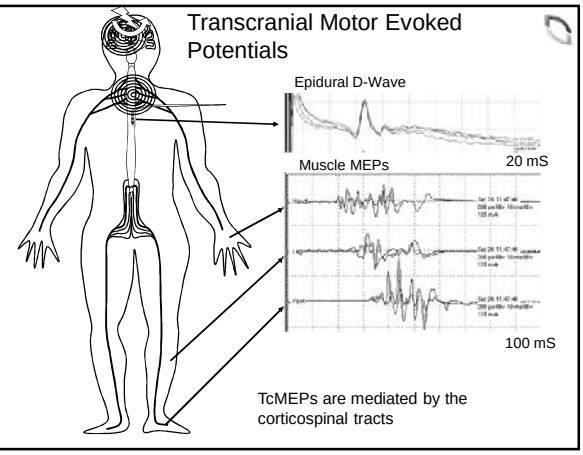
- Intramedullary tumors are located inside of the spinal cord requiring an invasive approach
- Sensory and motor tracts of the cord are at greatest risk
- Monitoring:
  - Upper and lower limb SSEPs and TcMEPs are monitored along with D-wave MEPs
- Mapping:
  - Spinal cord mapping for identification of the dorsal median sulcus (dorsal column mapping) and corticospinal tracts

Somatosensory Evoked Potentials



SSEPs are mediated by the dorsal column – medial lemniscus pathway

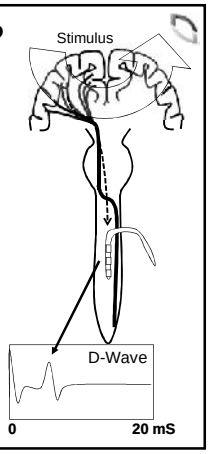
Transcranial Motor Evoked Potentials



TcMEPs are mediated by the corticospinal tracts

What is the D-wave?

- The D-wave is an epidurally-recorded spinal cord motor evoked potential following single pulse transcranial (or direct cortical) motor stimulation.
- "D" indicates "Direct" as in direct activation of descending corticospinal fibers
- The D-wave is the propagated volley of compound action potentials from large corticospinal fibers travelling down the spinal cord.
- Why is it important for spinal cord tumor monitoring?

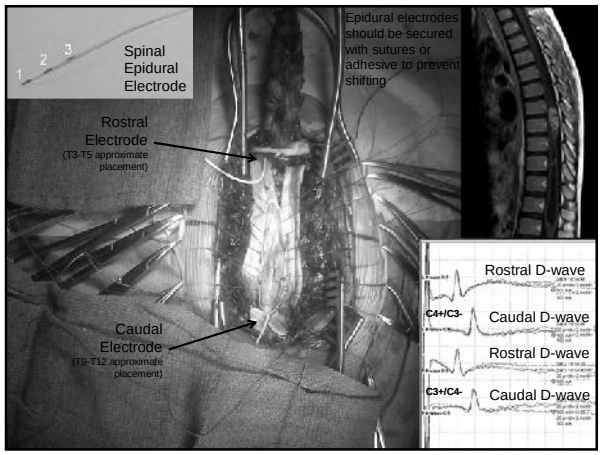


Advantages of D-wave Monitoring:

- Near instantaneous feedback about motor tract transmission
- Minimal patient movement allowing for uninterrupted monitoring
- Stable and insensitive to anesthetic agents, hence fewer false positives
- D-wave amplitude changes have prognostic value for long-term motor function

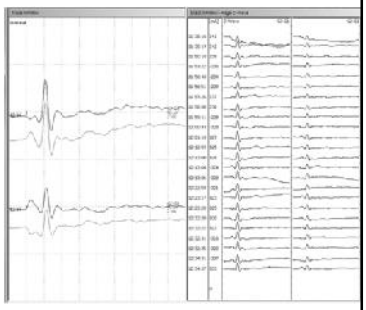
Limitations of D-wave Monitoring

- Cannot be monitored below T10-T11 vertebral level of the spinal cord
- May be absent in some patients with intramedullary spinal cord tumor or post-radiation myelopathy
- Dural adhesions during re-operation may prevent epidural electrode placement
- D-waves are not clearly unilateral
- Electrode or spinal cord positional changes (e.g. scoliosis correction) may cause false D-wave changes
- Purely ischemic injuries to the spinal cord (as in thoraco-abdominal aneurysm surgery) are more effectively detected by muscle-recorded TcMEPs



D-wave Frequency

- Critical injury to motor tracts can occur rapidly during tumor resection
- Therefore, D-waves must be run continuously during this time (every few seconds) pausing only to periodically check muscle TcMEPs and SSEPs
- Averaging D-waves (4-10 sweeps) will help generate clean waveforms



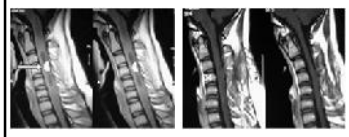
D-wave Criteria

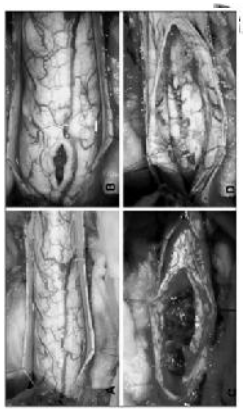
- Report amplitude reduction of 30% or latency changes of 10%
  - This is an early warning
  - Check muscle MEPs (loss with preserved D-wave can indicate temporary post-op deficit)
- Persistent D-wave amplitude reduction of >50% combined with loss of muscle MEPs is associated with permanent motor deficit
- TIP: Time, Irrigation, and Papavarine
  - These interventions may help before considering cessation of tumor resection

Spinal Cord Mapping Techniques

Midline Myelotomy

- Midline myelotomy (spinal cord incision) is routinely performed on intramedullary tumors; however dorsal column dysfunction is the most common cause of postoperative morbidity following myelotomy for spinal cord tumors, reported in 43.6% of patients in one series (Manzano 2008).
- Some of these injuries occur due to misplaced myelotomy





Taricco 2008

Avoiding dorsal column injury

- With inability to identify normal anatomic landmarks, inadvertent dorsal column injury can occur.
- Electrophysiologic mapping of dorsal column tracts can help guide the myelotomy and increase safety

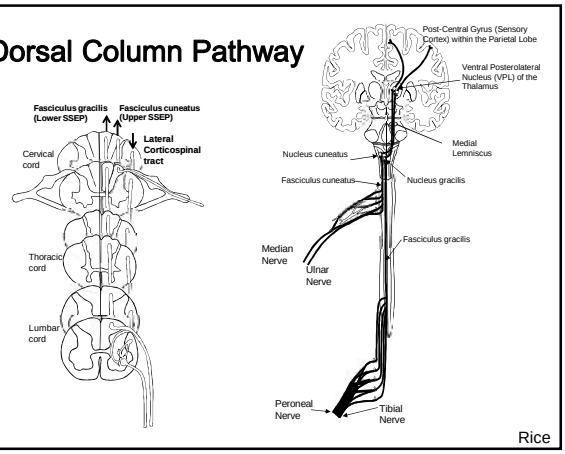
http://www.neurochirurgia-ire.it/eng/5-5_Ependymoma_Lymphoma_Medulloblastoma.shtml

Techniques for Dorsal Column mapping:

- Record SSEPs from dorsal column
  - Requires specialized electrode array
- Stimulate dorsal column with a bipolar probe
  - Record from the peripheral nerve (DNEP)
  - Record from the scalp (cortical SSEP)

This is our preferred method!

Dorsal Column Pathway



Rice

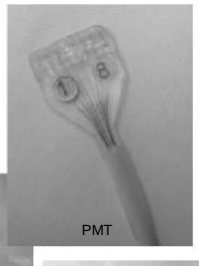
Recording SSEPs from Dorsal Column

- An 8-contact dorsal column electrode array is placed directly on the spinal cord. All contacts are referenced to a needle in a nearby muscle
  - A small patty is placed over the electrode to ensure contact
- Left and right PTN are stimulated and 100-200 responses are averaged. Two trials are required to show reproducibility.
  - Sweep: 50 mS; Bandpass: 30-3000 Hz
  - Rep Rate can be increased to 13.3 Hz
- Report the site of maximal amplitude for each side. Midline will be halfway between the two sites

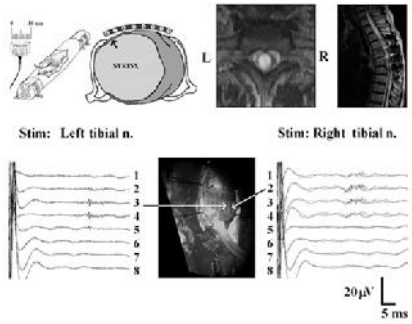
Yanni 2010

Dorsal Column Electrode

Ad-Tech



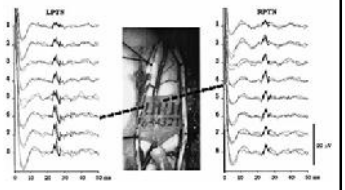
Example SSEP data recorded using dorsal column electrode



Yanni 2010

Dorsal Column SSEP Mapping Technique: Inherent Limitations

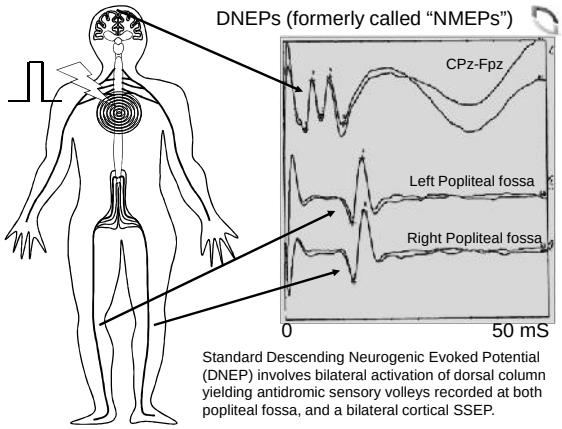
- Dorsal column transmission potentials tend to be low amplitude and desynchronized
  - Spinal cord pathology may significantly worsen amplitude and temporal dispersion
- Localization depends on identifying maximal amplitude
  - No clear cutoff or binary decision due to volume-conducted nature of the electric signal
- Cost of electrode



Deletis 2001

Spinal cord stimulus mapping using cortical SSEPs and Descending Neurogenic Evoked Potentials (DNEPs)

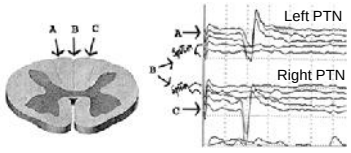
- Useful for identifying the midline of the cord prior to myelotomy in spinal cord tumor surgery
  - This may help to preserve the fasciculus gracilis tracts
- The midline may be distorted by the tumor and may not be a straight line; thus mapping at multiple sites may be necessary
- Stimulation of the dorsal tracts can be identified by the antidromic sensory volley from the nerve (DNEP) and also by the distribution of the cortical SSEP



Standard Descending Neurogenic Evoked Potential (DNEP) involves bilateral activation of dorsal column yielding antidromic sensory volleys recorded at both popliteal fossa, and a bilateral cortical SSEP.

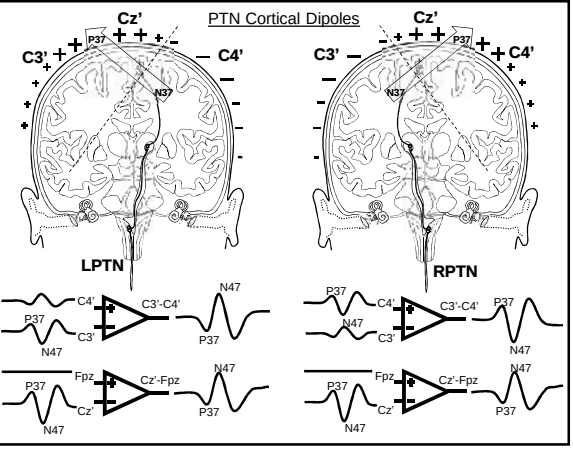
Example of DNEP method

- Recording is performed over the posterior tibial nerve at the medial malleolus.
- This example occurred in the thoracic region T3-T7.
- For cervical surgery, DNEPs can be additionally recorded from median and/or ulnar nerves.



Bipolar side-by-side probe (2-3 mm spacing) used.
9.1 Hz; 0.2 mS; 3 mA to max of 8 mA.
Average 50-100 trials.

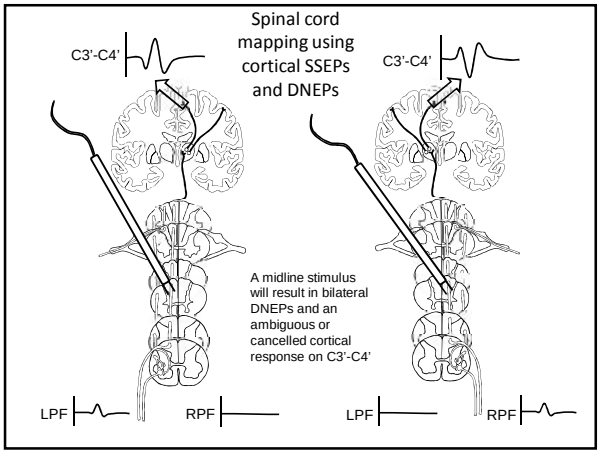
Quinones-Hinojosa 2002



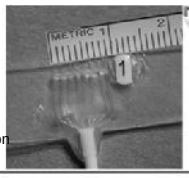
Side-by-Side bipolar probe

Technique

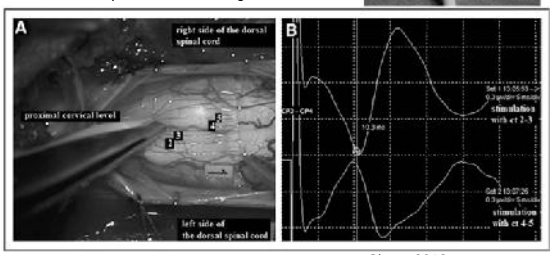
- A bipolar stimulator should be used to maintain specificity. Side-by-side preferred with 1-2 mm spacing. A concentric probe could also be used. A dorsal column electrode can also be used if desired.
- Stimulus intensity with this configuration should require only 1-3 mA, possibly as low as 0.3 mA.
- The surgeon must hold the probe on the spinal cord until averaging is sufficient for adequate responses
  - Record CP3-CP4, CPz-Fpz, Left and Right popliteal fossa
  - In cervical surgery, add median and/or ulnar, and Erb's point.



Direct spinal cord stimulation via 8-contact spinal minielectrode



Scalp recording shown is CP3-CP4, illustrating inversion of the cortical response with left vs right stimulation



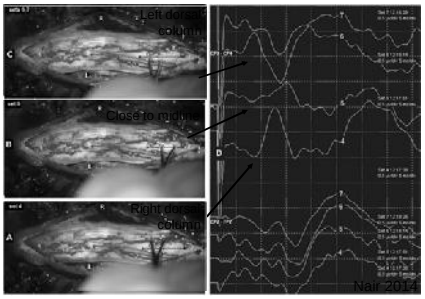
Simon 2012

T3 dorsal column stimulus mapping: the "phase reversal" technique

At T3, the fasciculus gracilis tracts are stimulated with a side-by-side bipolar probe (3.17 Hz, 0.3-0.5 mA, 0.3 mS)

The phase reversal is seen between left and right column stimulation.

At midline, the response should be diminished or absent.



Nair 2011

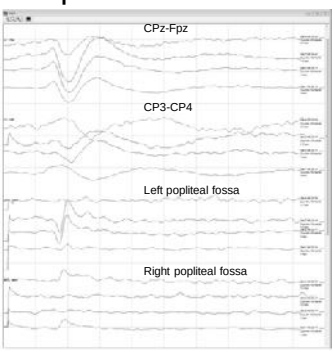
Note: CPz-Fpz recording does not show phase reversal; however, can identify excessive current spread.

Dorsal column stimulus mapping example

Red traces indicate right or right, near midline

Blue traces indicate clear left sided dorsal column stimulation.

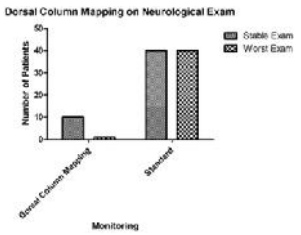
Stimulation at 4.47 Hz, 1.0 - 1.3 mA, 0.2 mS



Dorsal Column Mapping for Intramedullary Spinal Cord Tumor Resection Decreases Dorsal Column Dysfunction

Ankit Indravadan Mehta, MD, Cindy A. Mokhtare, MS, CNIM, Aatif M. Husain, MD, Isaac O. Karikari, MD, Betsy Hughes, MD, Tiffany Hodges, MD, Oren Gottfried, MD, and Carlos A. Bagley, MD

- In a retrospective comparison of 80 patients without dorsal column mapping to 11 patients with mapping, the rate of new dorsal column deficit was 50% compared to 9% with mapping (P=0.01)
- A concentric bipolar probe was used at 2 mA and 0.1 mS pulses
- Recording was performed at CP3-CP4, Erb's point, Median, Ulnar, and Tibial nerves.



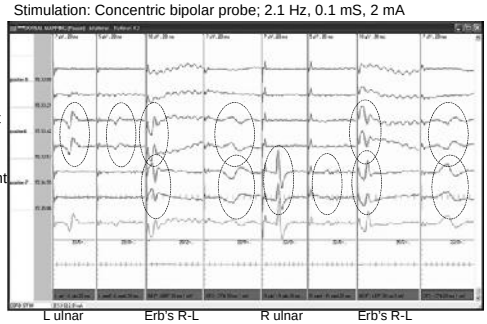
Mehta 2012

Example: Mapping Results

Stimulation: Concentric bipolar probe; 2.1 Hz, 0.1 mS, 2 mA

Blue = left dorsal column

Red = right dorsal column



Mehta 2012

Corticospinal tract mapping during removal of intramedullary spinal cord tumor

D-wave Collision Technique for mapping corticospinal tract

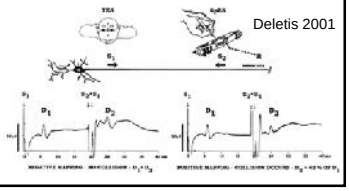
- Record a D-wave
- Stimulation of the corticospinal tract at the surgical site will collide with the descending volley from transcranial stimulation.
- Any amplitude decrement in the descending collided D-wave compared to the uncollided D-wave represents stimulated corticospinal tract fibers

Interventional Neurophysiological Mapping during Spinal Cord Procedures

V. Deletis A. Bueno De Camargo

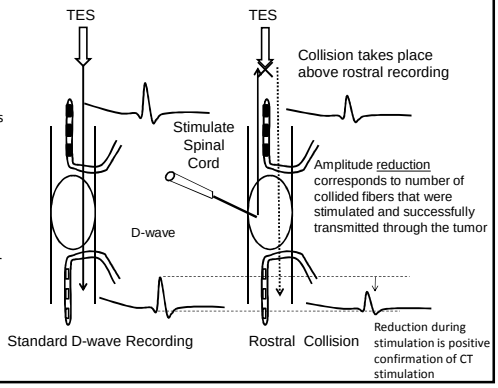
First stimulation is transcranial only, producing the baseline D-wave. The second stimulus is simultaneous transcranial stimulation and spinal cord stimulation at 2 mA with a handheld probe.

Deletis 2001



D-wave Collision Technique

Spinal cord stimulation occurs simultaneous with transcranial single pulse stimulation, leading to a collision effect if the probe is over the CST.

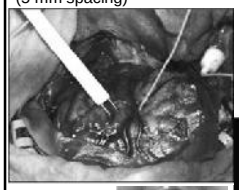


Case reports using 60 Hz stimulation technique

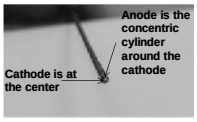
- These reports utilized a cortical mapping stimulus technique with a familiar stimulating device: Ojemann cortical stimulator
  - 60 Hz biphasic pulses, 1 mS/phase, delivered in 1-2 second trains
- Duffau 1998
  - Used probe with 5mm spacing, 0.4 - 1 mA, to identify corticospinal tract and halt resection in three patients
- Duffau 2003
  - Used new probe with 2 mm spacing; same stimulus parameters
- Quinones-Hinojosa 2002
  - Two patients, with 5mm bipolar probe 0.75-1 mA
- Ghandi 2015
  - Used a concentric bipolar probe for increased specificity; Stimulation ranging 0.1 - 1 mA

Bipolar Probes

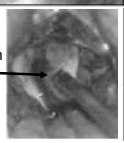
Ojemann probe:
Used primarily in cortical mapping (5 mm spacing)



Concentric Bipolar
Yields high specificity (low current spread)



Duffau's 2 mm side-by-side bipolar probe



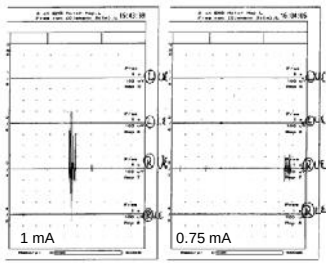
Current is highly localized at the small tip of this probe

Direct motor tract stimulation

Example:

Direct corticospinal stimulation using a side-by-side bipolar probe within a cervical intramedullary tumor.

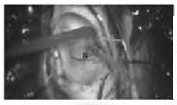
Responses identified from right hand muscles.



200 uV/div; Sweep = 1 sec

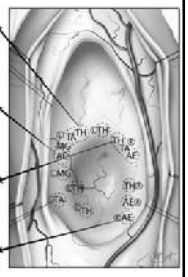
Quinones-Hinojosa et al. Spinal cord mapping as an adjunct for resection of intramedullary tumors: surgical technique with case illustrations. Neurosurg 2002; 51: 1199-1207.

Map of responses



High-resolution direct microstimulation mapping of spinal cord motor pathways during resection of an intramedullary tumor

60Hz biphasic 1 mS pulses; intensity 0.1 to 1.0 mA



Bandpass: 30-500 Hz 10 mS/div

Spinal cord mapping with high-frequency pulse-train MEPs

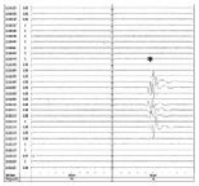
- While the 60 Hz stimulus technique may be effective at recruitment of gray matter, white matter recruitment (as in subcortical white matter mapping) is better achieved using short, high-frequency pulse trains (250-500 Hz)
- This is essentially the same technique we use for TcMEP, DcMEP, and cortical and subcortical mapping.
- Why not use this to map the corticospinal tracts?

"Continuous" motor mapping of the spinal cord

- Barzilai (2017) used a stimulated Cavitron ultrasonic surgical aspirator (CUSA) device to perform continuous stimulation during tumor resection.
  - Similar to subcortical mapping technique described by Shiban (2015)
- Stimulus parameters:
  - 3-pulse trains, 200 uS pulses, ISI = 3mS, 1.2 Hz; 0.5-2 mA, with CUSA as a monopolar cathode
- Regular monitoring (TcMEP, D-wave etc.) was halted during mapping, yet still the primary decision-maker for intervention
- CST proximity to stimulus threshold relationship has NOT been established for spinal cord

Stimulated CUSA probe

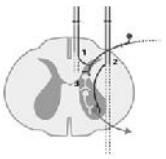
Triggered MEP responses to direct spinal cord stimulation



Left AH Right AH

Caveat to MEPs elicited by spinal cord stimulation

- It has long been established that sensory fiber stimulation can elicit muscle responses via reflex connections in the cord.
  - Nerve, dorsal root, and dorsal column tracts
  - The latter are sometimes referred to as "centrally mediated H-reflexes"
- For this reason, spinal cord-to-muscle techniques have been largely abandoned for lack of specificity.
- A muscle response during spinal cord mapping may represent sensory tract stimulation. No way to know which, right??

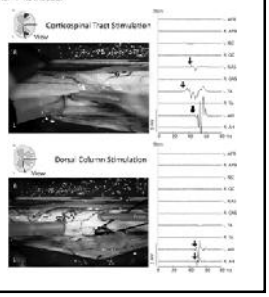


Deletis 2018

Deletis does it again…

A 2018 published study now shows evidence that:

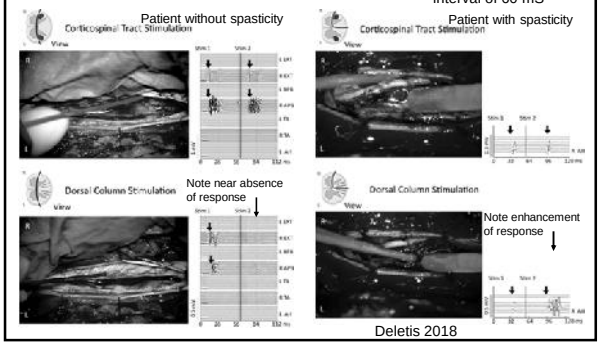
- Mapping of the spinal cord using double train stimulation allows neurophysiological distinction of corticospinal tract from dorsal column pathways during spinal cord surgery in patients with and without pre-existing spasticity.
- The corticospinal pathway to the lower motor neuron has a short recovery time in contrast to the sensory-motor reflex pathway; thus sensory-elicited MEPs respond differently to the second train stimulus



Double-train spinal cord stimulation

Corticospinal tract stimulation produced identical responses. Dorsal column stimulation produced no response, or a different response on the second train, based on spasticity.

Paired trains of 3-5 0.5mS pulses, 250-500 Hz, and intertrain interval of 60 mS



Deletis 2018

Summary

- Intramedullary spinal cord tumors are high risk and require particular attention to continuous monitoring of sensory and especially motor tracts.
- D-waves are an essential component of the monitoring
- Dorsal column and corticospinal tract mapping can further help the surgeon identify and protect these tracts

References

- Barzilai O, Lidar Z, Constantini S, et al. Continuous mapping of the corticospinal tracts in intramedullary spinal cord tumor surgery using an electrified ultrasonic aspirator. J Neurosurg Spine. 2017 Aug;27(2):161-8.
- Deletis V, Bueno De Carmago A. Interventional neurophysiological mapping during spinal cord procedures. Stereotact Funct Neurosurg 2001;77:25-28.
- Deletis V, Seidel K, Sala F, et al. Intraoperative identification of the corticospinal tract and dorsal column of the spinal cord by electrical stimulation. J Neurol Neurosurg Psychiatry. 2018 Feb 7. pii: jnnp-2017-317172. doi: 10.1136/jnnp-2017-317172. [Epub ahead of print]
- Duffau H, Capelle L, Sichez J. Direct spinal cord electrical stimulations during surgery of intramedullary tumoral and vascular lesions. Stereotact Funct Neurosurg. 1998;71(4):180-9.
- Gandhi R, Cutis C, Cohen-Gadol AA. High-resolution direct microstimulation mapping of spinal cord motor pathways during resection of an intramedullary tumor. J Neurosug Spine 2015 Feb;22(2):205-10.
- Manzano G, Green BA, Vanni S, Levi AD. Contemporary management of adult intramedullary spinal tumors–pathology and neurological outcomes related to surgical resection. Spinal Cord 46:540–546, 2008.
- Mehta AI, Mohrhaus CA, Husain AM et al. Dorsal column mapping for intramedullary spinal cord tumor resection decreases dorsal column dysfunction. J Spinal Disord Tech 2012; 25(4): 205-9.
- Nair D, Kumaraswamy V, Braver D et al. Dorsal column mapping via phase reversal method: The refined technique and clinical applications. Neurosurg 2014; 74: 437-46.
- Quinones-Hinojosa et al. Spinal cord mapping as an adjunct for resection of intramedullary tumors: surgical technique with case illustrations. Neurosurg 2002; 51: 1199-1207.
- Shiban E, Krieg SM, Obermueller T, et al. Continuous subcortical motor evoked potential stimulation using the tip of an ultrasonic aspirator for the resection of motor eloquent lesions. J Neurosurg. 2015 Aug;123(2):301-6.
- Simon MV, Chiappa KH, Borges LF. Phase reversal of somatosensory evoked potentials triggered by gracilis tract stimulation: Case report of a new technique for neurophysiologic dorsal column mapping. Neurosurg 2012; 3: E783-E788.
- Yanni DS, Ulkatan S, Deletis V et al. Utility of neurophysiological monitoring using dorsal column mapping in intramedullary spinal cord surgery. J Neurosurg Spine 2010; 12: 623-8.