Intraoperative Neurophysiological Monitoring: Neural security

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No conflicts of interest to declare

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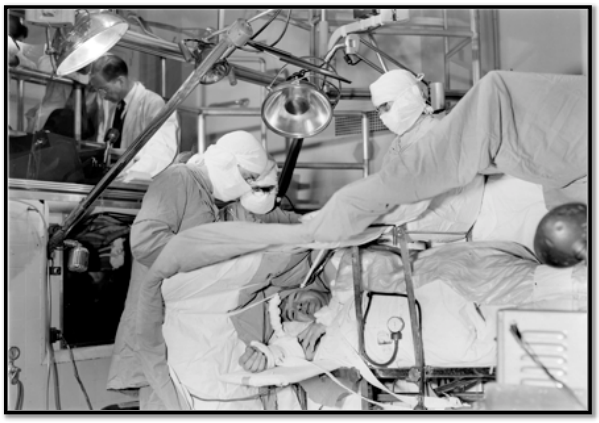
Recent victim of property theft.

Needs of a Security System

- Must do the job!
- Cost-effective
- Multi-modality
- Redundant
- Simple to operate

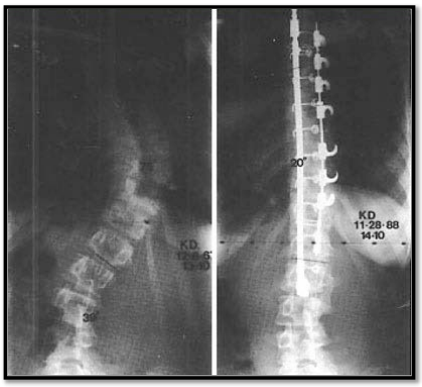
Intraoperative Neurophysiological Monitoring Historical perspective

- Seminal work of Sherrington and Penfield in brain mapping ushered the filed of intraoperative neurophysiological testing



Intraoperative Neurophysiological Monitoring Historical perspective

- Harrington rods and aggressive surgeries for scoliosis prompted development of spinal cord evoked potential and SSEP monitoring by Tamaki *et al.*



Intraoperative Neurophysiological Monitoring Historical perspective

"Our neuromonitoring system is state of the art. The art is just that advanced…"

Intraoperative Neurophysiological Monitoring Today

Intraoperative Neurophysiological Monitoring

- Clinical applications in monitoring:
  - Cerebral cortex
  - Subcortical fibers
  - Brainstem
  - Cranial nerves
  - Spinal cord
  - Nerve roots

1. Reduce the risk of postoperative neurological deficits

2. Identify specific neuronal structures and landmarks that cannot be easily recognized due to pathology

3. Research purposes in basic science, pathophysiology and treatment strategies

Intraoperative Neurophysiological Monitoring

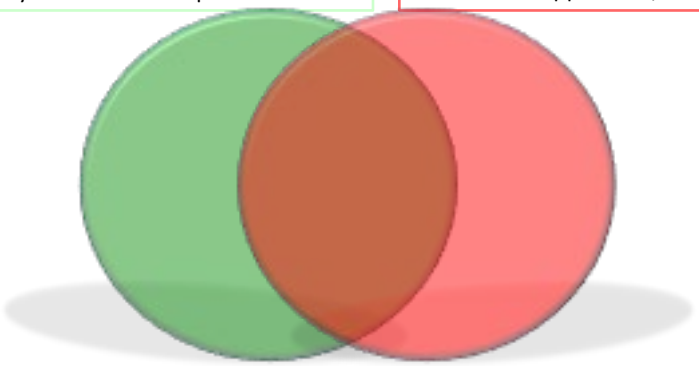
- In IDEAL conditions…

  preventive or corrective actions can be taken to avoid irreversible damage

Intraoperative Neurophysiological Monitoring Controversial

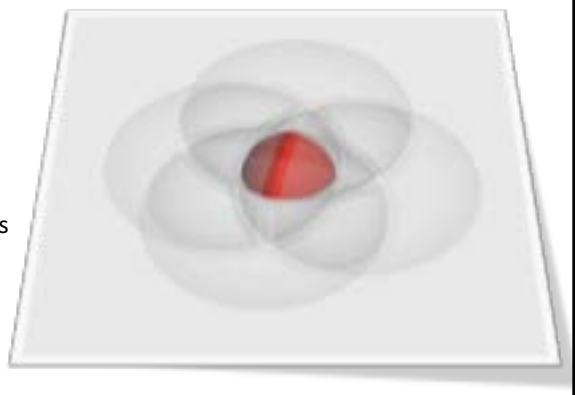
Proponents
-Common surgeries
-High cost of post-op neurological deficits
-Level II evidence of effectiveness
-Readily available technique

Detractors
-Increased costs, time-consuming
-Perceived risk of post-op deficits small
-No Level I evidence
-Inconsistent application, overused



Intraoperative Neurophysiological Monitoring Controversial

- Multiple confounders
  - Surgeon preference
  - Patient expectations
  - Disease complexity
  - Institutional bias
  - Monitoring companies
  - Financial incentives



Intraoperative Neurophysiological Monitoring

- Rational approach to IOM (in *my* opinion!)
  - IOM is an imperfect surgical adjunct:
    - Cannot substitute for common sense
    - Limited clinical application

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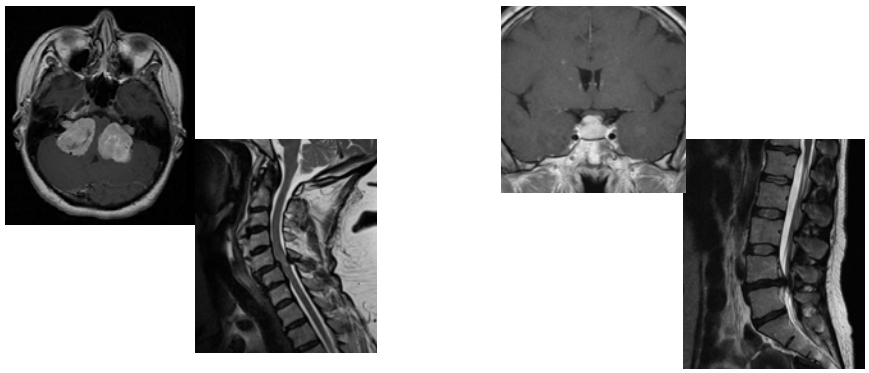


Intraoperative Neurophysiological Monitoring

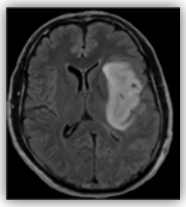
- Rational approach to IOM (in *my* opinion!)
  - IOM is an imperfect surgical adjunct:
    - Cannot substitute for common sense
    - Limited clinical application
      - More universally established for intracranial and intradural spinal pathology due to neurologic deficits already present or at risk of injury
      - Less established in non-deformity and uncomplicated degenerative spinal pathology

Intraoperative Neurophysiological Monitoring Rate of IONM abnormality

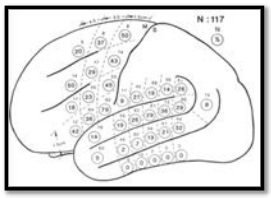
- In the intracranial world, there is more acceptance of the **imperfection** of IONM.

Intraoperative Neurophysiological Monitoring Cortical and Subcortical Pathways

- Tumor resections in or around eloquent cortex
  - MEP and SSEP phase-reversal for peri-Rolandic and insular lesions (Schramm J, *JNS*, 2007)



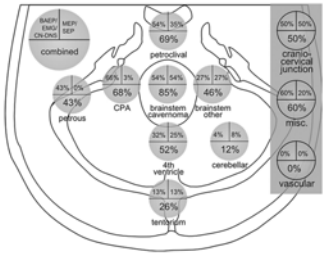
  - Language mapping for dominant temporal lobe and opercular pathology (Ojemann G, *JNS*, 1989)



- Vascular pathology
  - Multi-modality IONM to guide permissive ischemia during temporary clipping of aneurysms (Guo L, *Clin Neurophysiol,* 2011)

Intraoperative Neurophysiological Monitoring Brainstem and cranial nerves

- Slotty PJ, *et al.* Intraoperative neurphysiological monitoring during resection of infratentorial lesions: the surgeon's view. *JNS*, 2016
  - 305 consecutive patients undergoing surgery for posterior fossa pathology
    - Correlated IONM alterations with posterior fossa lesion location
  - CN IONM alteration in 130/305 cases (52%)
  - SSEP/MEP IONM alteration in 43/305 cases (14%)
  - Combined IONM changes in 15/305 cases (5%)



CN: Sensitivity=98%; Specificity=77%
Long tract: Sensitivity=95%; Specificity=85%

62% of IONM alterations resulted in neurological deficits
Brainstem and petroclival locations associated with combined IONM deficits

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Intraoperative Neurophysiological Monitoring SPINE

- Multimodality monitoring
  - No level I evidence to support IONM
    - Doubtful large prospective, randomized, blinded controlled trials will be conducted
      - Logistic, ethical and medicolegal concerns
  - Level II evidence

Intraoperative Neurophysiological Monitoring SPINE: Specificity and Sensitivity

- Sutter M, *et al.* The diagnostic value of multimodal intraoperative monitoring during spine surgery: a prospective study of 1017 patients. *Eur Spine J*, 2007

  - 1017 complex spinal surgeries with multi-modality IOM
  - 935 true negative
  - 8 false negative
  - 66 true positive
  - 8 false positive

-89% sensitivity (identifying potential neurologic injury)

-99% specificity (ruling out neurologic injury)

Intraoperative Neurophysiological Monitoring SPINE: Prospective Observational Study

- Eager M, *et al*. Intraoperative neurmonitoring: lessons learned from 32 case events in 2095 spine cases. *Am J Electroneurodiagnostic Tech*, 2011

  – 2095 consecutive spinal surgeries with IOM at UVA Dept. of Orthopedics
  – 32 cases of intraoperative events were identified (1.5%)
    - 17 cases of IOM changes → Decision to intervene
      – 5 cases of severe hypotension
      – 7 cases of deformity over-correction
      – 1 pedicle breach
      – 4 cases of positional neuropathy
    - 15 cases of IOM change → Decision not to intervene
      – 4 cases of during spinal cord biopsy (positive controls)
      – 4 cases of false-positive IOM findings
      – 4 cases of improved SSEP after decompression
      – 3 cases of spontaneous EMG due to medial screw breach → foot drop, re-operation

Intraoperative Neurophysiological Monitoring SPINE: Meta-analysis done poorly

- Thirumala PD, *et al*. Value of intraoperative neurophysiological monitoring to reduce neurological complications in patients undergoing anterior cervical spine procedures for cervical spondylotic myelopathy. *J Clin Neurosci*, 2016

  – Adults, systematic review of IOM in cervical spondylotic myelopathy
  – Elective anterior cervical procedures
    - Of 22 studies identified, ONLY 2 involved the use of IOM
  – 173 patients
  – IOM group showed a trend toward less inferior outcomes (0.9% vs 2.7% new neurological complication)
  – "sufficient evidence does not exist to make recommendations regarding the use of different IOM modalities…"

Intraoperative Neurophysiological Monitoring SPINE: "Meta-analysis" done poorly

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Intraoperative Neurophysiological Monitoring SPINE: larger observational studies

- Bhagat S, *et al*. An evaluation of multimodal spinal cord monitoring in scoliosis surgery: a single center experience of 354 operations. *Eur Spine J*, 2015

  - Retrospective review of prospectively collected data on 354 consecutive deformity surgeries; multi-modal IOM possible in 315 patients.
  - Age range 2-79, mean 27.
  - Overall incidence of IOM alerts 7.1% (required intervention by surgical team)
  - New permanent neurological deficits 1.6%
  - 23 true positive alerts
  - 2 false positives
  - 290 true negatives, no false negatives
  - Sensitivity of 100%, Specificity of 99.3%

Intraoperative Neurophysiological Monitoring SPINE: Database driven

- Cole T, *et al*. Intraoperative neuromonitoring in single-level spinal procedures: a retrospective propensity score-matched analysis in a national longitudinal database. *Spine*, 2014

  – Adults, MarketScan national database (2006-2010)
  – Elective single level spinal decompression and simple fusion
    - Tumor, trauma surgeries excluded
  – 86K surgeries, 12.7% reported IOM
  – IOM group for lumbar laminectomy had fewer neurologic complications (0% vs 1.2%)
  – IOM made no difference in new neurologic complications for ACDF, lumbar discectomy, or lumbar fusion
  – Payments for surgeries were higher in IOM group (8-24%)

  – For elective single-level spinal procedures, IOM resulted in decreased complications for lumbar laminectomies

Intraoperative Neurophysiological Monitoring SPINE: Database driven

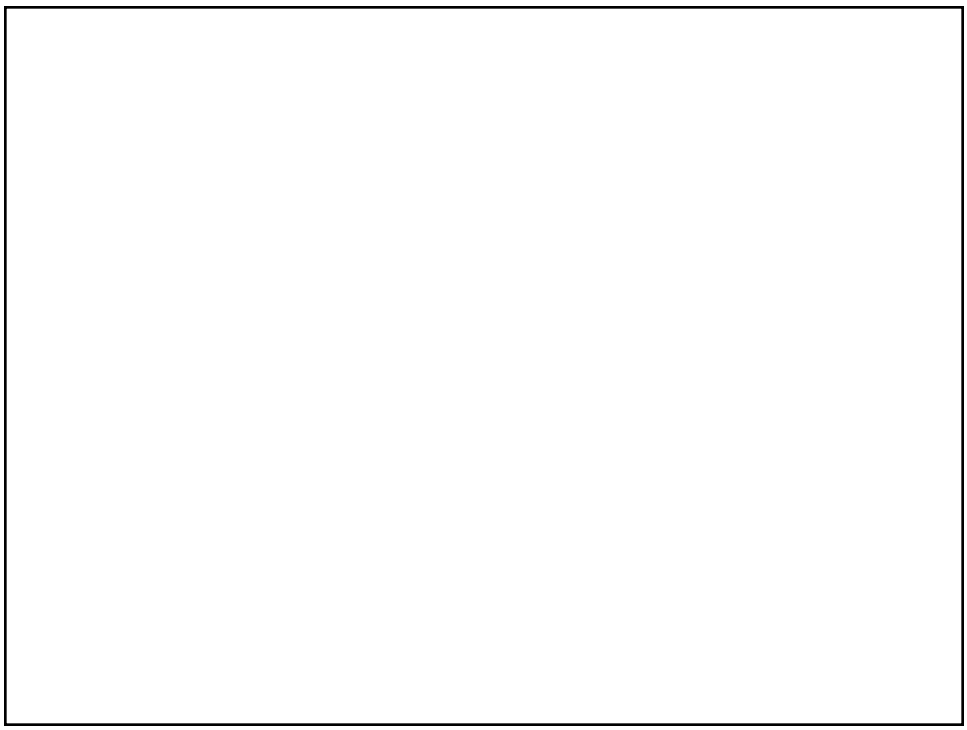
- Ney JP, *et al*. Does intraoperative neurophysiologic monitoring matter in noncomplex spine surgeries? *Neurology*, 2015

  – Adults, National Inpatient Sample (2007-2012)
  – Spinal decompressions and simple fusions
    - Revision surgeries, complicated approaches, tumor, trauma surgeries excluded
  – 1.1 million surgeries, 4.9% reported IOM
  – IOM group had fewer neurologic complications (0.8% vs 1.4%)
  – With *multiple regression adjustments*:
    - IOM group with fewer neurologic complications (odds ration 0.6)
    - Hospital charges increased 9%
      – IOM group had more spinal fusions than simple decompressions
    - LOS was reduced by 0.26 days in IOM group

  – ***167 cases would need to be monitored to spare one new neurologic complication!***

	Neurologic complications, %	
Primary surgery	No IOM	IOM
Anterior cervical fusions	0.15	0.20
Thoracolumbar fusions	0.77	0.49
Discectomies	0.62	0.45
Laminectomies	2.70	1.72

    - Increased IOM hospital charges vs lost wages/higher health care costs/malpractice costs



Intraoperative Neurophysiological Monitoring

Category 1. Recommended

Surgery	Modality
Spinal Deformity	SSEP, MEP, EMG
Resection of intradural extramedullary tumor	SSEP, MEP, EMG
Resection of intramedullary tumor	SSEP, MEP
Anterior approach thoracic spine lesions/disc	SSEP, MEP
ALIF	SSEP, EMG, +/- MEP
Extreme lateral approach	SSEP, EMG
Posterior cervical decompression/fusion	SSEP, MEP, EMG

Surgery	Modality
Tumor resection near eloquent cortex	Motor/speech mapping, SSEP phase reversal
Skull base tumor	SSEP, MEP, EEG
MVD/Posterior fossa (non-Cerebellar hemisphere)	SSEP, MEP, CN EMG, BAEP

Intraoperative Neurophysiological Monitoring

Category 2. Case-based, surgeon discretion

Surgery	Modality
Anterior cervical	SSEP, MEP, EMG
Minimally invasive lumbar	SSEP, EMG
Lumbar fusion reoperation	SSEP, EMG
Cervical laminectomy	SSEP, MEP, EMG
Open lumbar fusion	Triggered EMG
Chiari with syrinx	SSEP, MEP

Emergency case from category 1 or 2

Not needed

- Post cervical foraminotomy/disc
- Thoracic lami for cord decompression or extradural evacuation
- Decompression lumbar lami/disc

MODALITIES	SSEPs	MEPs/CMAPs	EMG
Stimulation	Peripheral sensory nerves	Transcranial scalp electrodes	Free-running: none Triggered: bipolar stimulation of a specific structure
Recording	Cortical and cervicomedullary junction	Extremity muscles (e.g., thenar muscles, tibialis anterior)	Myotome specific
Alert threshold	50% reduction in amplitude 10% increase in latency	Disappearance of signal (all-or-none phenomenon)	Sustained activity (>2 sec)
Advantages	Specific and sensitive to sensory deficits Continuous **monitoring**, no interruption in surgical maneuvers	Specific and sensitive to motor deficits Large signal amplitude, instantaneous feedback	Allows surgical correlation with specific nerve roots Continuous **monitoring** Instantaneous feedback
Disadvantages	False-negative results for motor deficits Low signal amplitude, multitrace averaging required, delayed response (seconds to minutes)	Total intravenous anesthesia Intermittent **monitoring**, interruption in surgery required	No neuromuscular blockade Monitors only nerve roots

Intraoperative Neurophysiological Monitoring Category 1. Recommended

Category 1. Recommended

Surgery	***Test***
Spinal deformity	SSEP, MEP, EMG
Resection of intra-dural spinal lesions	SSEP, MEP, +/- EMG (not needed for intramedullary tumor),
Anterior approach thoracic spine lesions/discs	SSEP, MEP,
Anterior lumbar interbody fusion, ALIF	SSEP, EMG (MEP if you are worried about radicular artery supply to cord during corpectomy…can temporary clamp and see if MEP drops before deciding to take or spare an artery).
Extreme lateral approach (spine)	SSEP, EMG
Posterior fossa/skull base tumor resection	BAEP, cranial nerve EMG, (SSEP, MEP depending on tumor location)
Intraparenchymal tumor resection near eloquent cortex	Mapping (motor, speech) SSEP-Phase reversal (to identify motor cortex)
Posterior cervical decompression & fusion	SSEP, MEP, EMG