

White Paper
Intraoperative Neurophysiologic Monitoring:
Modern Application in Hospitals,
Medical Centers and
Integrated Healthcare Systems

Information for administrators
And program directors

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**American
Neuromonitoring
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ABBREVIATIONS

AMR	Abnormal Muscle Response
BAER, AER	Brainstem Auditory Evoked Responses
CAP	Compound Action Potential
CMAP	Compound Muscle Action Potentials
DECS	Direct Electrical Cortical Stimulation
ECoCh, ECoG	Electrocochleogram
EMG	Electromyography
ENT	Ear Nose and Throat Surgery (Otolaryngology)
EPs	Evoked Potentials
IOM, INM	Intraoperative Neurophysiological Monitoring
ION	Intraoperative Neurophysiology
IS	Idiopathic Scoliosis
MEP	Motor Evoked Potentials
MIOM	Multi-modality Intraoperative Monitoring
M-SEP	Median Nerve Somatosensory Evoked Potentials
NMEP	Neurogenic Motor Evoked Potentials
NPV	Negative Predictive Value
PPV	Positive Predictive Value
S-EMG	Spontaneous EMG
SCEP	Sensory Cord Evoked Potentials
SEP, SSEP	Somatosensory Evoked Potentials
T-EMG	Triggered or Evoked Electromyography
TCD	Trans-cranial Doppler
TceMEP	Transcranial Electrical Motor Evoked Potentials
T-SEP	Tibial Nerve Somatosensory Evoked Potentials
TES, TCES	Transcranial Electrical Stimulation
UH, UHC	UnitedHealthcare, Inc.

GLOSSARY

dura mater	the tough fibrous membrane that envelops the brain and spinal cord
epidural	situated upon or administered outside the dura mater
extubation	the removal of the tube after intubation of the larynx or trachea
hyperesthesia	increased sensitivity to stimulation
kyphosis	abnormal backward curvature of the spine
latency	delay period between stimulus and response for SSEP
percutaneous	effected or performed through the skin
scoliosis	a lateral curvature of the spine
sequelae	an after effect of disease or injury

Background

Introduction

Intraoperative Neurophysiologic Monitoring (IONM) is the application of a variety of electrophysiological and vascular monitoring procedures during surgery to allow early warning and avoidance of injury to nervous system structures.

The purpose of IONM is to reduce the incidence of iatrogenic (e.g., arising from medical treatment) and randomly induced neurological injuries to patients during surgical procedures. IONM consequently confers possible benefits at many levels including:

- Improved patient care
- Reduced patient neurological deficits
- Improved surgical morbidity and mortality
- Reduced hospital stay and medical costs
- Reduced overall insurance burden

IONM procedures have evolved from the original use of single modality somatosensory evoked potential (SSEP) monitoring (allowing monitoring of the main sensory pathways) in the 1970s. A plethora of other modalities is also available including Electroencephalography (monitoring of the brain surface), Brainstem Evoked Potentials (monitoring hearing pathways), Electromyography and Brain mapping (identification of specific areas of function) among many others.

Although compensation has lagged scientific development, IONM is now recognized and remunerated by most insurers. Billing codes for SSEPs were adopted for IONM usage seven years ago (Figure 1) when most IONM equipment could acquire only two or four channels of information. Current technology allows sixteen, or even thirty two channels of data to be monitored for a single case. Motor Evoked Potentials which allow monitoring of the main pathways for movement have had separate billable codes for three years.

Numerous types of surgeries benefit from and thus utilize IONM. These can be generally classified by surgical specialty into orthopedic, neurosurgical, cardiac, otolaryngological, plastic (peripheral nerve), and urologic. The efficacy of IONM has been best studied in spinal surgery where significant benefits occur including reduction in quadriplegia and death¹. IONM is now considered a standard of care in this group and is likely to remain so for the foreseeable future². This does not

¹ Epstein et al. assessed the clinical usefulness of IONM during cervical spine decompression by comparing 218 patients that were not monitored with 100 patients that were. There was a 3.7% incidence of quadriplegia and a 0.5% incidence of death in the unmonitored patients. There was no incidence of quadriplegia or death in the monitored group (Epstein et al., 1993, *SPINE* 18(6): 737-74).

² McCann, Kelley et al, Somatosensory Evoked Potential Monitoring in Surgery for Pediatric Spinal Deformity, 2005 Proceedings of the AAOS, Washington DC

even take into account the 'soft' benefits of monitoring. Most studies look at the incidence of monitoring events or changes in data which predict poor patient outcome. Few take into account the effects of improved surgical guidance, the allowance of a more aggressive surgical approach by identification and monitoring of structures, or the avoidance of secondary injury from identification of physiologically important changes such as blood flow changes or anesthetic effects like burst suppression.

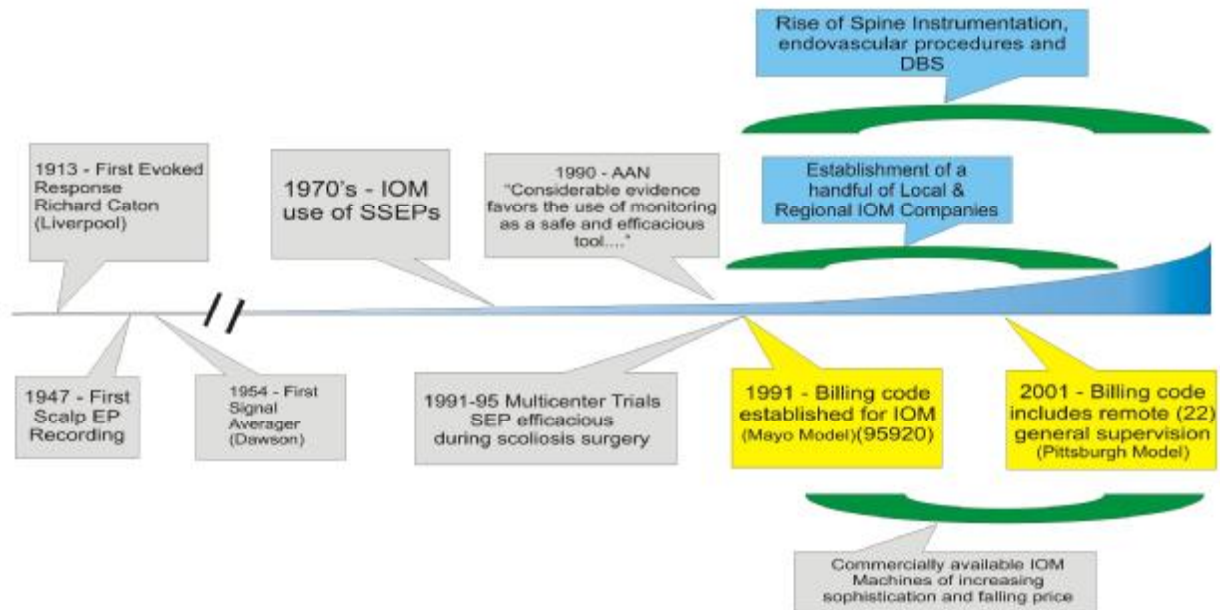


Figure 1 – Brief History of IOM

With the rapid growth in instrumented spinal surgeries over the last 2 decades, the call for IONM services has increased dramatically (see Figure 2 - U. Mich. Health Care IOM growth Rate - from published data).

Accompanying this rise in application of IONM has been an increase in the number of modalities monitored (see Figure 3 - Increasing numbers of applied modalities in IONM) and the complexity of the data produced by monitoring.

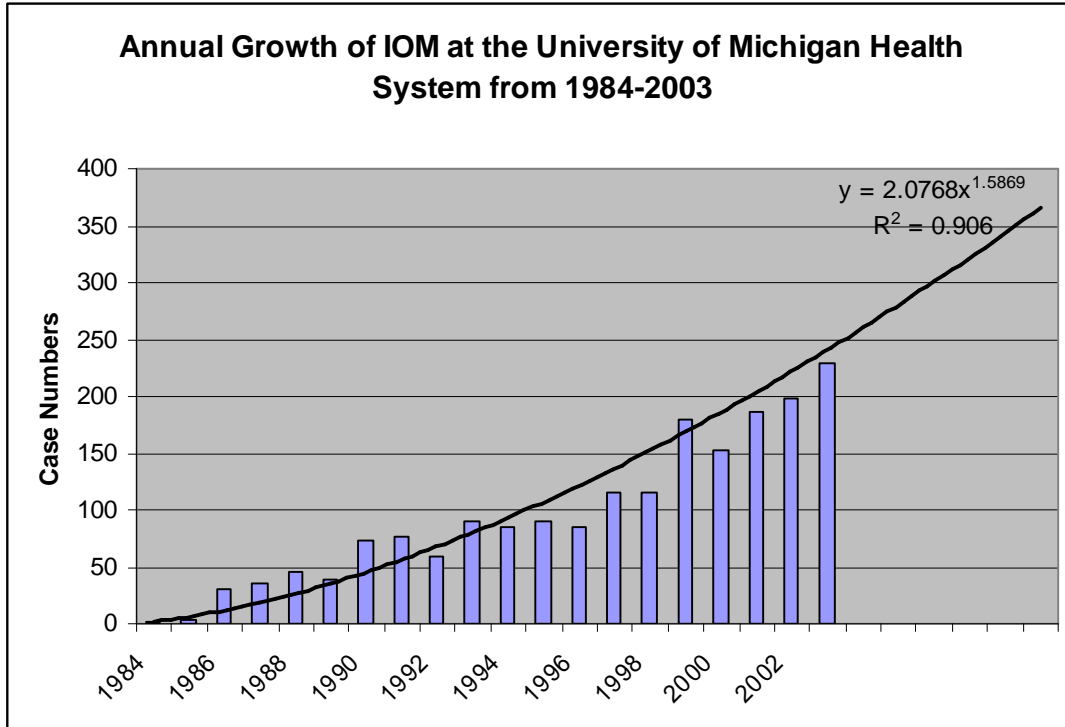


Figure 2 - U. Mich. Health Care IOM growth Rate - from published data³

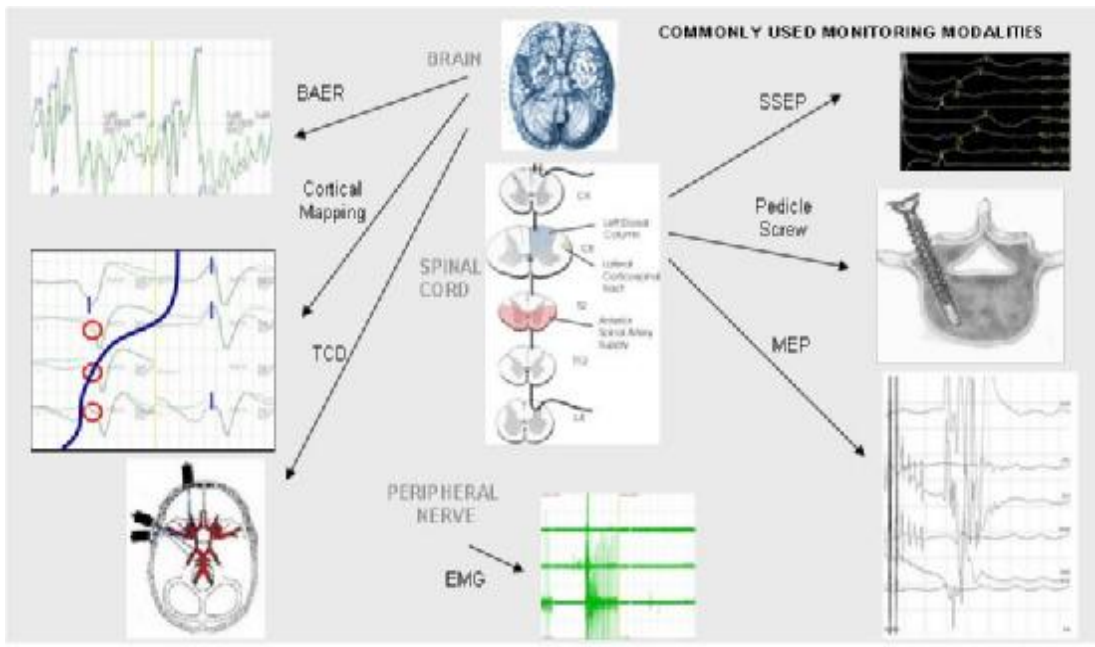


Figure 3 - Increasing numbers of applied modalities in IONM

³ Edwards, B. M.; Kileny, P.; Kovach, D. J.; McCue, J. & Spak, C. (2004), 'Intraoperative Neurophysiologic Monitoring: A Contemporary Brief', *ASHA Leader*.

Do I Need it?

Spinal Surgery and IONM

As noted above, much of the increased utilization of IONM has been driven primarily by spine surgeries. This has moved IONM out of the rarified and into the common place. Many centers that provide spinal surgery require IONM to meet current recommended standards²⁸. The Scoliosis Research Society has supported the use of SSEP monitoring in scoliosis surgery based on scientific evidence of efficacy in reducing injury since 1992⁴.

The movement of spinal surgeries that were previously done only in tertiary care centers into smaller hospitals and spine centers has also bolstered utilization and geographic distribution of IONM.

The Changing Face of IONM

In addition to spinal surgeries, IONM has become increasingly utilized and of value in an expanding range of specialties and surgical types (See Appendix). Part of this expansion has been fostered by the movement of previously surgically based treatments that require IONM into other specialties (e.g. aneurysm coiling - neuroradiology).

IONM has rapidly expanded over recent years to become a complex group of monitoring modalities and is no longer confined to just SSEPs. For instance, data supporting direct monitoring of motor pathways with motor evoked potentials (MEP) has become increasingly of interest (Figure 4) and available. Almost all centers that use MEP monitoring now also use simultaneous SSEP monitoring.⁵

⁴ http://www.srs.org/professionals/positions/evoked_potential.php

⁵ Legatt, A. D. (2002), 'Current practice of motor evoked potential monitoring: results of a survey.', *J Clin Neurophysiol* **19**(5), 454--460.

The current focus is now on multi-modality intraoperative monitoring (MIOM). IONM now involves a broad assortment of electrophysiological techniques including triggered electromyography (EMG), spontaneous and free running signals such as electroencephalography (EEG) and EMG, D waves for spinal surgeries and Deep Brain Stimulation (DBS) firing patterns for intracerebral electrode placement [which are not addressed by this determination]. The number and types of techniques continue to grow.

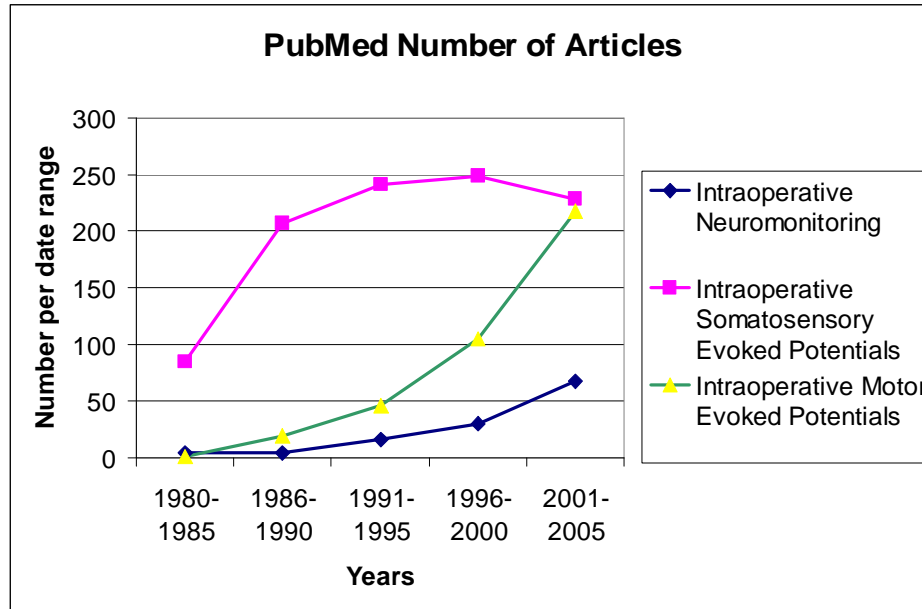


Figure 4 - PubMed returns on number of articles per time frame and search criteria

Many surgeries require IOM to provide guidance for structure identification including sensory or motor cortical mapping, peripheral nerve identification or protection and vascular surgeries or endovascular procedures associated with potential neural tissue ischemia.

Delitis noted that intraoperative neurophysiology has become an “integral part of neurosurgery” and is considered to have three roles: “prevention (neuroprotection), documentation of surgically induced neurological injury, and education for the young neurosurgeon gaining neurosurgical skills”.⁶

⁶Delitis, V. & Sala, F. (2001), 'The role of intraoperative neurophysiology in the protection or documentation of surgically induced injury to the spinal cord.', *Ann N Y Acad Sci* **939**, 137--144.

Insourcing vs. Outsourcing for IONM

IONM arose from an insourcing model, provided by the hospitals own technologists and overseeing physicians. In the 1970s, skilled IONM PhD neurophysiologists and audiologists, recognizing the growing need for IONM outside teaching centers, moved out from under physician or medical department supervision and into the private sector, establishing primarily technologist based IONM outsourcing companies. There are now literally dozens of outsourced IONM companies in the United States. The vast majority of these are small in size and local in service delivery (see Figure 5). The lack of licensing requirement and oversight utilization has lead to varied levels of expertise and a relative lack of standardization in service provision. Some companies still provide access to physician oversight, some do not.

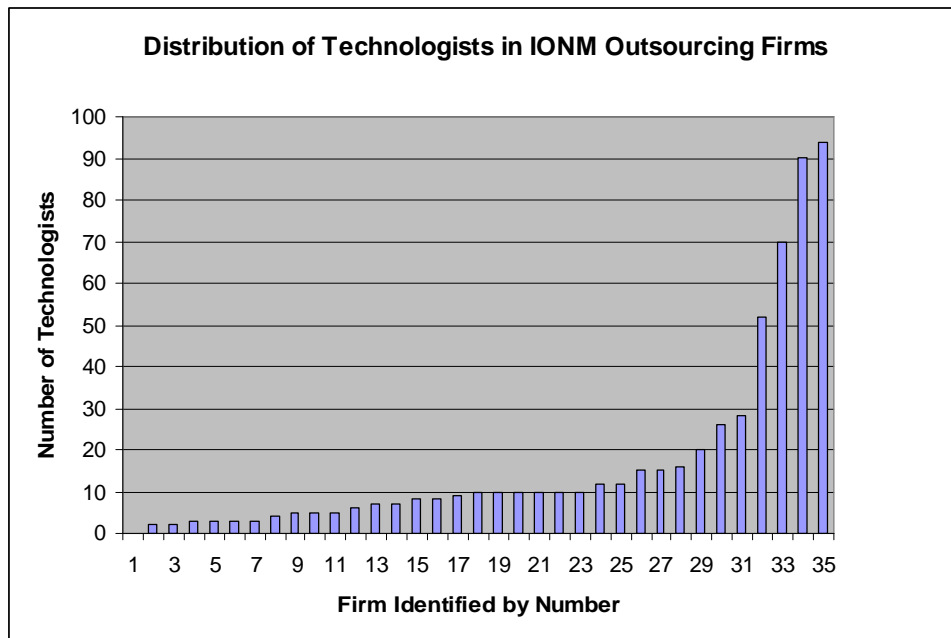


Figure 5 - Distribution of Technologists in a sample of 37 outsourcing IONM companies in the USA

Despite these difficulties, many hospitals, including university teaching centers, choose to outsource some or all of their IONM. Depending upon the situation, there may be advantages to one or the other or a combination of both. Reasons to outsource may include:

- Costs of maintenance of an internal program.
- Flexibility to deal with varying demand levels.
- Providing a wide scope of complex monitoring.
- Lack of availability of trained personnel.
- Off hours availability of technologist or oversight staff.

A hospital may also want to look to a service provider with:

- Ability to support or facilitate research
- Ability to guarantee up to date training and credentialing
- Consistency of service across multiple centers

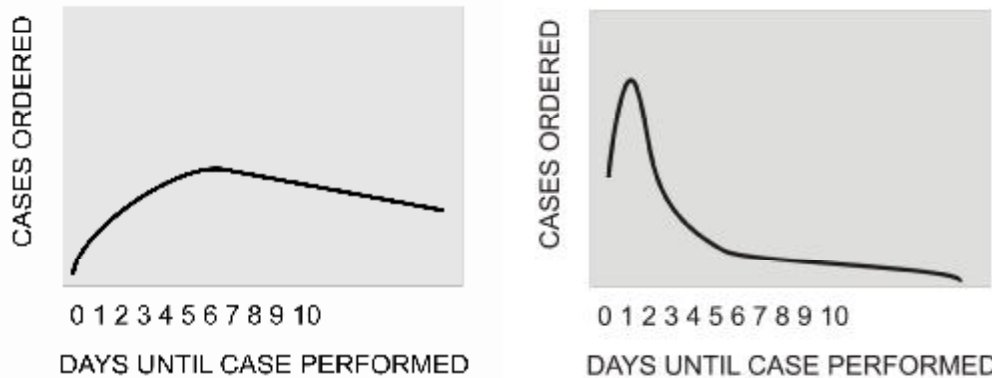


Figure 6 - Typical pre-ordering patterns for in-sourced (left) and outsourced (right) IONM

As illustrated in Figure 8, in-sourced programs may have difficulty meeting rising and fluctuating demands for monitoring and respond by limiting immediate access to monitoring. As a consequence, monitoring plays a larger role in the logistics of arranging surgery. Outsourced programs (if large enough) tend to bring a larger pool of resources to bear, at least partially removing IONM as a limiting step in surgical planning. As a consequence, IONM for the majority of cases are ordered the same or next day.

Although insourcing of IONM can make it difficult to maintain the flexibility and economies of scale that a larger IONM vendor can provide it does have its own advantages, especially if the requirements of the program are limited and specialized to a particular type of monitoring (e.g. primarily carotid endarterectomies) or if internal expertise and willingness are present. These include:

- More intimate control over the monitoring provided
- Ability to oversee the entire program
- Ability to limit utilization where there is an uncompensated cost to the hospital

Managing your Risk and Compliance

The whole point of IONM is to reduce clinical risk to the patient. Like any other hospital program, thoughtful implementation is required to maximize this potential while delivering quality of service, maintaining compliance and reducing administrative and medico-legal risks to the hospital and its surgeons and personnel. The following sections address some items that should be considered.

The Need for Oversight

As the demand for IONM services has grown, so has the demand for professional oversight of the IONM technologists.

The IONM field is not regulated through a State licensing framework. Since there is no specific educational pathway for technologists leading to a specialty in intraoperative monitoring there is no resultant formal licensing for IONM technologists as there is for many other medical and non-medical professionals. Standards of practice and education for IONM technologists are provided by a number of professional societies,⁷ as described in more detail below.

The most widely accepted credentialing process for IONM technologists is through the American Board of Registration of Electroencephalographic and Evoked Potential Technologists (ABRET) which grants a Certification in Neurophysiologic Intraoperative Monitoring (CNIM) to candidates with at least a bachelors degree. ABRET administers a written examination to candidates who have completed training with experience in at least 100 IONM cases.⁸ In 2008, ABRET indicated that it will be changing the requirements for CNIM in 2010 to an associate's degree in neurodiagnostic testing leading to a registration in Evoked potential or Electroencephalography testing⁹. ABRET's argument for this change is an attempt to improve standardization of training in the field. Opponents point to a resultant overall reduction in educational requirement without evidence of improved expertise in IONM¹⁰, where experience must extend far outside diagnostic EPs or EEG applied in a completely different environment

⁷ Societies include: *The American Board of Registration of Electroencephalographic and Evoked Potential Technologists (ABRET)* www.abret.org. This is a technologist credentialing organization. *The American Society of Electroneurodiagnostic Technologists (ASET)* www.aset.org is a technologist society that promotes the electroneurodiagnostic (END) field as a whole. *The American Clinical Neurophysiology Society (ACNS)* www.acns.org is primarily a physician directed society promoting education in clinical neurophysiology. *The American Society of Neurophysiological Monitoring (ASNM)* www.asnm.org is a physician and graduate level society that promotes IONM through research, education, and legislation.

⁸ Briefings on Credentialing, hcPro March 2007 Vol8, No 3

⁹ http://www.abret.org/exam_info/cnim_req_2012.php

¹⁰ ASNM Monitor, 2008

Figure 7 and Figure 8 show the gradual increase in CNIM certificates over recent years.

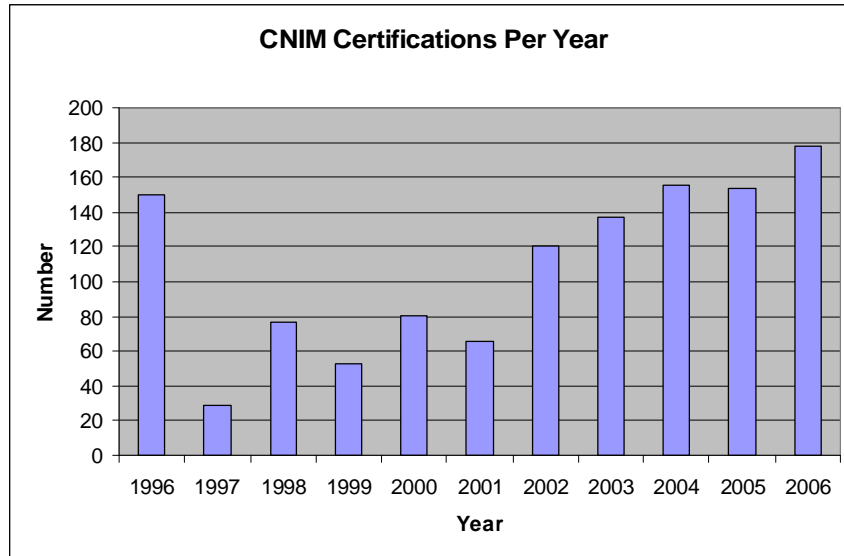


Figure 7 - Yearly CNIM Certifications Granted

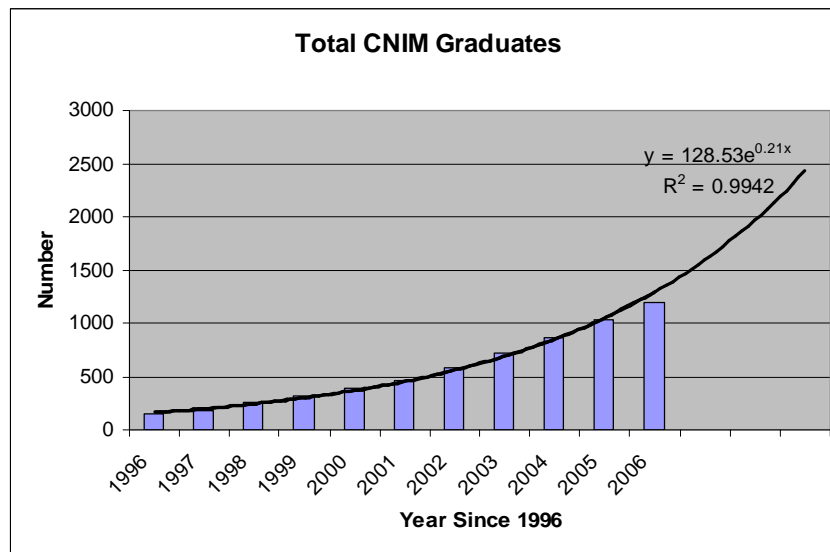


Figure 8 - Total CNIM Certification Trending (before certification requirement change)

A second organization, the American Board of Neurophysiological Monitoring (ABNM), grants an advanced certification to candidates with at least a Master's level degree in biological sciences. Diplomates of the Board (DABNM) have completed a minimum of 300 cases and have passed both written and oral examinations.

Currently there are only around 100 D'ABNM certified technologists / neurophysiologists working in the world and their numbers are increasing quite

slowly. There have been declining numbers of DABNM certifications in recent years (see figure 4).

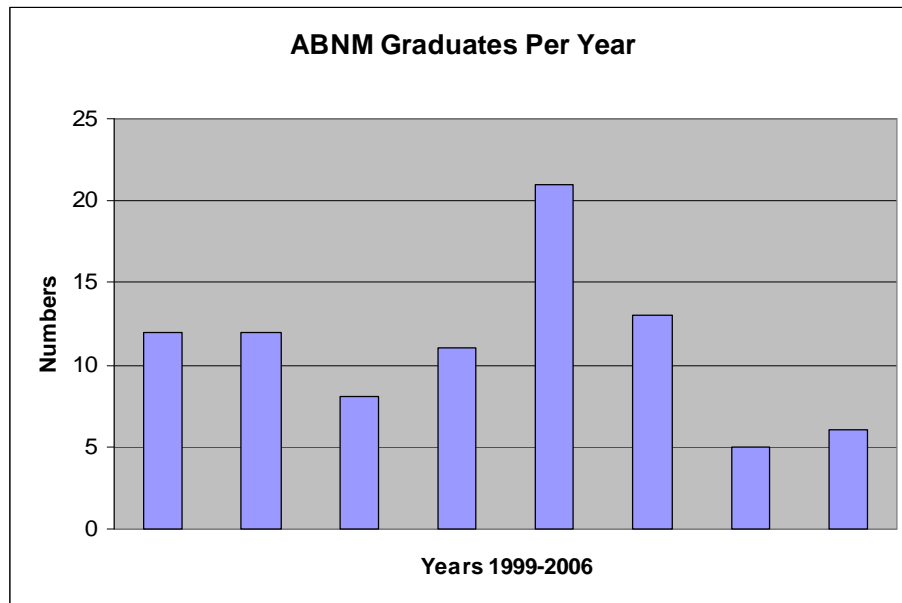


Figure 9 - DABNM certification numbers by year

Both CNIM and DABNM level technologists are generally quite skilled in performing intraoperative neurophysiologic tests. They require competencies ranging from basic electrical engineering and computer science to neuroanatomy and neurophysiology. However, the complexity and sophistication of the surgical procedures monitored is generally quite high and decisions for intervention can happen quite suddenly and unpredictably. Current training requirements do not include a general clinical backing or clinical treatment experience. Therefore supervision by an experienced physician is of great benefit.¹¹

Unfortunately, increasing demand for IONM professional supervision has not been met with increasing resources. Long hours, required attendance in the operating room or undivided attention to monitoring along with opportunity costs (loss of other clinical income) and the associated liability risk act as significant deterrents. A relative scarcity of oversight service and a movement to unsupervised technologist only outsourcing has contributed to many cases being

¹¹ This view is supported by The American Society of Electroneurodiagnostic Technologists (ASET) guidelines for the scope of practice for electroneurodiagnostic (END) technology, which recommend that END technologists “work under the supervision of a physician who is responsible for interpretation and clinical correlation of the results. This physician is not usually physically present during the procedures and so the technologist must be able to analyze data during the recording, making certain that the information being obtained is valid and interpretable.” (See Scope of Practice for Electroneurodiagnostic Technology ASET, October 2005 (http://www.aset.org/files/public/Scope_of_Practice.pdf)).

monitored solely by technologists. Cases of failure of monitoring with patient injury have been reported when technologist supervision was inadequate.¹²

What to Look For in an Outsourced IONM Company

When looking at external IONM services you should take into consideration the following factors and questions:

Training

- Ask for a copy of the company internal training curriculum.
- Is the training program auditable?
- Is the training of the technologist matched to the level of case complexity when assigning to cases?

Credentialing

- Does the company internally credential people for types of cases or monitoring modalities?
- Does it accept other company credentialing at face value?
- Do the technologists have external credentialing through ABRET or ASNM?
- Do the technologists have regular opportunity for review of their work?

Scheduling

- Does the company provide easy access to scheduling?
- Can they audit their scheduling to identify problems and take corrective action to avoid future problems when things go wrong?

Dependability

- Does the company provide night and weekend coverage?
- Does the company have local technologists for the majority of cases or do they have to be brought in?
- Does the company track monitoring errors or problems and investigate them to insure high quality monitoring in line with published statistics?

Range of Case types Monitored

- Can the company offer a full range of monitoring to fill the needs of your case load? Is their size sufficient to meet varying load requirement?

Multi site integration

¹² See The Atlanta Journal-Constitution, March 24, 2007 "Paralyzed man awarded \$11.7M". Damages awarded against neurologist who entered OR to monitor technician for 10 minutes at outset of case.

- Can the company provide monitoring at more than one site if appropriate?

Research

- Can the company provide support for research initiatives like access to materials and research knowledgeable personnel?

Oversight and Real Time Monitoring

- How is the data being transported from the operating room in real time to allow for oversight?
- Who is doing the oversight? Physicians with experience in IONM? Senior technologists? PhD neurophysiologists?
- Is oversight compliant with state requirements for licensure
- Do they log remote connections to their machines (most commercial machines allow for this)

HIPPA Compliance

- Is patient data left on monitoring machines any longer than necessary? Is it regularly deleted or moved?
- Is patient information held in a secure HIPAA compliant manner?

References

- Can the company provide references from other surgeons or sites for which it provides monitoring, especially if they have a similar case mix to yours?

Billing Practices

- IONM billing is usually broken into technical and professional components. If the IONM company does not directly charge the hospital for the technical component, do they bill your patients directly and at what rates? How does this fit with hospital practices for reasonable remuneration? Are there any resulting internal (from other providers such as surgeons) or external public relations issues?

Physician Credentialing for IONM

Experience and credentials of physicians currently providing IOM or IOM oversight vary widely in the United States. Even in some large teaching centers, it is considered a role for the junior consultant in neurology, who may have limited or no experience. On the other hand, some physicians with certification in neither a neurologically based specialty nor in electrodiagnosis have developed extensive expertise or published widely and are considered masters in IOM.

Involved specialties

Neurologists, neurosurgeons, anesthesiologists, physiatrists, psychiatrists, family medicine physicians and other physicians who are trained in Intraoperative monitoring.

Positions of societies and academies

ABCN

The American Board of Clinical Neurophysiology examines physicians in clinical neurophysiology with an emphasis on EEG and Evoked Potentials.¹³ They offer a subspecialty examination in Intraoperative monitoring that has both written and oral components, and is open to physicians board certified in neurology, neurosurgery and physiatry following a preceptorship with a recognized master in the field.

APPN

The American board of Psychiatry and Neurology provides subspecialty certification in clinical neurophysiology by written examination. It focuses on primarily EMG and EEG.

Other stakeholders

ABNM

As noted above, the American Board of Neurophysiological Monitoring is a relatively recent board providing certification for non-physician neuromonitorists. The certification is held by a handful of physicians as well.

ABRET

The American Board of Registration of Electroencephalographic and Evoked Potential Technologists provides certification for technologists (CNIM – Certification in Neurophysiologic Intraoperative Monitoring)

Typical Criteria

Criteria for IONM physician credentialing might include requirements such as these:

Basic education: MD or DO

Minimum formal training: Applicants must be able to demonstrate completion of an ACGME/American Osteopathic Association–accredited training program in a primary medical specialty.

Required previous experience:

- Applicants must be able to demonstrate that they have participated in the active care or oversight of at least 30 intraoperative monitoring cases in the past 12 months.

¹³ Nuwer M. Regulatory and medico-Legal Aspects of Intraoperative Monitoring. J. Clin Neurophys 19(5):387-395

- A letter of reference must come from the director of the applicant's firm, group or institution where the applicant most recently practiced.

Core privileges in IOM might include, but are not limited to:

- Direct provision of Intraoperative monitoring care in the operating room
- Oversight of appropriately trained technologists providing IOM either on site or in real time from a remote site
- Reporting of IOM data results

Reappointment might be dependent upon:

- Maintenance of current licensing
- Maintenance of subspecialty credentialing if appropriate
- At least 10 hours of CME devoted to electrodiagnosis or IOM
- Participation in the active care or oversight of at least 30 intraoperative monitoring cases in the past 12 months.

Technologist Credentialing for IONM

Many institutions show little understanding of technologist based credentials and the scope of practice that they warrant. Some hospitals have no, or quite limited IONM credentialing. However CNIM certification or 'in progress' CNIM certification with limited responsibility is quickly becoming the credential that hospitals ask for most.

Whereas ABRET's CNIM examination was recently accredited through the National Commission for Certifying Agencies, the D'ABNM carries no such external endorsement.

Even with external certification, neither the CNIM nor the D'ABNM guarantees any specific practical competency in a particular monitoring modality.¹⁴ ABRET's written test looks for an understanding of EEG, ABR, EMG, SSEP and TceMEPs, but does not require practical experience in all of these modalities. Having said that, many IONM technologists may have extensive experience, knowledge and expertise in a wide array of monitoring methodologies.

Specialized monitoring tools such as Transcranial Doppler studies, Deep Brain Stimulation, Electrocortocography, Electroretinography, Electrocochleography, Cortical mapping and Direct Cortical Stimulation are outside the ABRET testing parameters, require additional experience or training and should not be included in any hospital base scope of practice description for IONM technologists.

¹⁴ Note also that, due to ABRET's changes to the CNIM eligibility rules in 2010, the credibility of the certification as an external credentialing tool will be devalued.

Outsourced monitoring companies (or even insourced programs) will usually require hospitals to accept 'in process' CNIM candidates, especially if they are growing and are internally trained. This is not unreasonable, so long as the company (or program) can show that their internal training is adequate, the candidate is progressing along their training pathway, and that they are not assigned to any surgical cases outside their current skill and competency level.

Billing for IONM & CPT Code 95920

For hospitals that insource their IONM, a detailed knowledge of how to properly bill for services is necessary. Even at highly regarded university centers, common errors occur such as:

- Billing for train of four testing using neuromuscular junction testing codes
- Multiple billing of EMG codes
- Billing of incorrect TCD codes
- Incorrect calculation of oversight monitoring time

For those that outsource their IONM, billing considerations may also not be trivial. In some circumstances hospitals have come under scrutiny for the billing practices of contracted physicians or services. It may also be a goal to ensure that the billing practices of an outside company for IONM services are consistent with the hospitals practices with regard to balance billing and patient billing rights.

CPT code 95920, "Intraoperative neurophysiology testing, per hour," was introduced in 1991 as a means for billing both technical (TC) and physician (26 modifier) oversight components of the IONM service. A RUC practice vignette for the code either was not created, or has not been made publicly available. Our conversations with specialists who were involved with the RUC valuation indicate that the initial code was created to represent the 'Mayo model' (see figure 1) of IONM that was in effect at the time. This practice consisted of a single oversight physician in the hospital or operating suite overseeing several technologists in nearby operating rooms.

On October 31, 1997, the Health Care Financing Administration (HCFA) published a final rule with comment period in the Federal Register¹⁵ that required some degree of physician supervision for almost every diagnostic test payable under the physician fee schedule. In keeping with the Mayo model, 95920 required a level 2 of physician supervision (Procedure must be performed under the direct supervision of a physician).

¹⁵ 59048 Federal Register / Vol. 62, No. 211 / Friday, October 31, 1997 / Rules and Regulations

In 2001 the HCFA revised the level of physician oversight for the 95920 code to level 22¹⁶ to take into account the 'Pittsburgh Model' introduced by Dr. R. Scwabassi. This model was introduced at the University of Pittsburgh Medical Center (UPMC) due to a scarcity of oversight services and allowed for remote real time data transfer and electronic supervision of several operating rooms by a single physician from a single site¹⁷. This oversight level is specifically written for *physicians*. IONM oversight is the only CPT code to carry this specific level of physician supervision.

The American Medical Association published updated guidelines in 2002 (CPT 2002) specifying that the time taken to interpret that baseline primary procedure should be excluded from the time used as a basis for billing the code 95920 itself. This avoids duplicate billing for that portion of time¹⁸.

Although the initial oversight portion of the CPT code was clearly aimed at physician delivered oversight services, some paramedical personnel have adopted and bill for this code in certain states, particularly to non-CMS intermediaries. Depending upon the circumstances these may be well qualified or experienced people. Their authority to provide and bill for this service seems to rest on a perceived lack of state specific definition as to whether IONM oversight constitutes the practice of medicine or not¹⁹, ²⁰. Other licensed groups, such as audiologists, include IONM and the "on-line intraoperative interpretation of the recorded neurophysiologic responses"²¹ within their scope of practice.

More recently, the AMA passed resolution 201 in June 2008²². This resolution, brought forward by the American Academy of Neurology, the American Clinical Neurophysiology Society, the American Association of Neuromuscular and Electrodiagnostic Medicine and the American Academy of Physical Medicine and Rehabilitation and then modified by the committee on the basis of presentations, primarily by the American Association of Orthopaedic Surgeons, was adopted as follows: "Resolved that it is the policy of our American Medical Association that supervision and interpretation of intraoperative neurophysiologic monitoring

¹⁶ 22 = May be performed by a technician with on-line real-time contact with physician

¹⁷ HCFA Program Memorandum on Physician Supervision for Diagnostic Tests April 19, 2001 (see http://www.aarc.org/members_area/advocacy/federal/md_supervision_tests.pdf)

¹⁸ See <http://www2.aaos.org/aaos/archives/bulletin/apr02/cod.htm>

¹⁹ In states such as California where the rules regarding the practice of medicine are stringent, non-physicians operating in a business for which physician ownership and operation are required include "any business advertising, offering, and/or providing patient evaluation, diagnosis, care and/or treatment. These are services which can only be *offered or provided* by physicians."¹⁹ This definition would seem to include IONM oversight services which offer initial evaluation of baseline waveforms followed by contemporaneous interpretation of neurophysiological waveforms within a clinical context leading to alterations in treatment.

²⁰ In phone conversation with the Medical Board of California they indicated that they consider IONM oversight to be within the practice of medicine. (2008)

²¹ ASHA (1992), 'Neurophysiologic intraoperative monitoring. Ad Hoc Committee on Advances in Clinical Practice. American Speech-Language-Hearing Association.', *ASHA Suppl*(7), 34--36.

²² AMA resolution 201 (A-08).

constitutes the practice of medicine which can be delegated to non-physician personnel under the direct or on line supervision of the operating surgeon or another physician trained or who has demonstrated competence, in neurophysiologic techniques, and is available to interpret the studies and advise the surgeon during the surgical procedure." There has been some confusion in interpretation of this resolution with some suggesting that it indicates that the surgeon does not need to have the same training or experience as a monitoring physician in order to delegate, which the AANEM has indicated was not the intention²³. In any case, any such delegation may be subject to specific state law²⁴.

The question of who may bill for the interpretation was not addressed by the AMA. Under the National Correct Coding Initiative, the operating surgeon may not bill for CPT code 95920²⁵. When a service is delegated, the delegating physician bills for the delegated service. If the operating surgeon delegates the service but cannot bill for it, then who can? The issue of technologist billing for interpretation remained unclear after the AMA resolution, and remains dependent on payer policy.

Another development in 2008 was the publication by the American Academy of Neurology Professional Association (AANPA) of a Model Medical Policy on April 23, 2008²⁷. The policy recommends a method for IOM service that is rooted in the Medicare concept of physician supervision, i.e. trained technologist in the OR with a supervising physician either on site or in continuous real time communication. It also discusses the utility of IOM in a broad range of procedures, clarifies coding for 95920 and the baseline procedures and makes recommendations about the optimal conditions under which IOM should be conducted.

Real Time Remote Oversight

The need for physician oversight and its provision "in surgery or via electronic link"²⁸ is embraced by current "Best Practice Criteria" for Surgical Spine Specialty Centers such as those of UnitedHealthcare. The accepted use of real time remote monitoring allows the provision of highly expert IONM oversight regardless of location. It also underscores the scarce resource issue in the same way that the introduction of ICU monitoring centers did. Centers providing true

²³ AANEM News, V1 Issue 3, Aug 2008, p 11

²⁴ E.g. Rule 800 3CCR 713-30 Colorado Board of Medical Examiners; Rules Regarding Delegation and Superviaion of Medical Services to Unlicensed Health Care Providers Pursuant to 12-36-106(3)(1), C.R.S.

²⁵ CHAP 11. Version 13.3 National Correct Coding Initiative Policy Manual

²⁷ "Principles of Coding for Intraoperative Neurophysiologic Monitoring (IOM) and Testing". See www.aan.com/globals/axon/assets/4004.pdf

²⁸ UnitedHealth Premium Specialty Center Best Practice Critreia 3/30/2007 Version 3.0

real time remote monitoring oversight incur costs not likely to be born by an individual practitioner. Additionally, like ICU monitoring centers, which have proliferated rapidly since 2004²⁹, they offer a possibility for addressing the resource scarcity issue and of increased efficiency that in turn offers “better outcomes”³⁰.

The methodology of real time remote intraoperative monitoring oversight, described by Keim³¹ in 1985 and later by Krieger and Sclabassi³² in 2001, makes enormous sense. Consequently, virtually every IOM machine vendor has embraced this technology, now offering ‘real time’ networking and allowing remote viewing and communication capabilities with their equipment (see Table 1). Even in centers where monitoring is provided by in house groups, remote connections to the operating room are frequently in use by the overseeing physician.

Table 1 - Remote Monitoring Capabilities of current IOM Equipment

IOM Manufacturer	Web Address	Equipment	Remote Monitoring Tool
Cadwell Laboratories	http://www.cadwell.com/	Cascade	Proprietary Built in
Xltek	http://www.xltek.com/	Protector	Proprietary Built in
Axon	http://www.axonsystems.com/	Eclipse	Proprietary Built in
Nicolet / Viasys	http://www.viasyshealthcare.com/	VikingSelect	Proprietary Built in
Nihon Kohden	http://www.nihonkohden.com	Neuropack	Proprietary Built in

Unlike clinical medicine where the physician has direct access to the patient, during surgery the overseeing neurophysiologic physician has virtually no access. The patient is draped, instrumented, anesthetized and in a sterile field. He or she is often surrounded by sterile surgical personnel. Even access to the patient’s regular physiological data such as blood pressure and heart rate is through the anesthetist and their instruments. Due to the unconscious and sometimes paralyzed state of the patient, monitoring the patient’s neurological integrity is impossible without access to spontaneous and evoked neurophysiologic data. Given these constraints and in conjunction with the presence of a trained technologist in the operating room, placing the overseeing physician who interprets the waveforms next door or across the country differs only in the difference in transmission time. Current broadband capabilities make this a variation of 1-3 seconds. There is no scientific literature suggesting such a treatment variation makes any difference to patient outcomes in IONM or in fact in any neurological injury.

²⁹ Breslow, M. J. (2007), 'Remote ICU care programs: current status.', *J Crit Care* **22**(1), 66--76.

³⁰ Morgan Stanley Research May 15, 2006, Visicu, Inc.

³¹ Keim, R. J. (1985), 'Remote monitoring of evoked potentials', *Otolaryngol Head Neck Surg* **93**(1), 23--27.

³² Krieger, D. & Sclabassi, R. J. (2001), 'Real-time intraoperative neurophysiological monitoring', *Methods* **25**(2), 272--287.

On the contrary, although not specifically stated in many scientific papers discussing IOM, this is the methodology used for physician oversight during their data collection. The papers by Kahn³³ and Smith³⁴ from 2006 and 2007 respectively, describe over 1,500 cases at UPMC using the Computational Diagnostics, Inc. (CDI)³⁵ equipment and techniques, where remote physician oversight is standard practice.

In an editorial comment in *Clinical Neurophysiology* in 2008 concerning "Intraoperative monitoring of the spinal cord," Nuwer states that "A notable technological development is remote on-line supervision of operating room technologists, which allows for good supervision from off site for routine cases."³⁶

As noted above, the 2001 revision of the 95920 CPT code directly addressed this method of delivery which is extensively used by both in sourced and outsourced solutions at many centers and is fast becoming the standard of care for delivery of IONM oversight. It has several advantages.

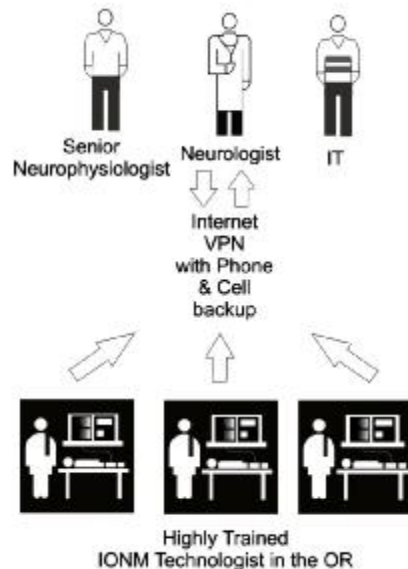


Figure 10 - Real Time IONM Oversight Model

³³ Khan, Mustafa H. MD*; Smith, Patrick N. MD*; Balzer, Jeffrey R. PhD†; Crammond, Donald PhD†; Welch, William C. MD†; Gerszten, Peter MD†; Sclabassi, Robert J. MD, PhD†; Kang, James D. MD*; Donaldson, William F. MD*. (2006), 'Intraoperative Somatosensory Evoked Potential Monitoring During Cervical Spine Corpectomy Surgery: Experience With 508 Cases', *Spine* 31(4), 105-113.

³⁴ Smith, P. N.; Balzer, J. R.; Khan, M. H.; Davis, R. A.; Crammond, D.; Welch, W. C.; Gerszten, P.; Sclabassi, R. J.; Kang, J. D. & Donaldson, W. F. (2007), 'Intraoperative somatosensory evoked potential monitoring during anterior cervical discectomy and fusion in nonmyelopathic patients--a review of 1,039 cases.', *Spine* J7(1), 83--87.

³⁵ See <http://www.cdi.com/>

³⁶ In press

Advantages of real time remote oversight:

- Additional real time layer of dedicated clinical expertise of not only the overseeing physician but senior technologists
- Immediate access to equipment and IT expertise through remote control, troubleshooting and servicing
- Immediate access to remote resources (databases, texts, graphics) for both the technologist and surgeon
- Allows provision and standardization of multi-site or multi-facility monitoring
- Distributed medical liability for monitoring related issues
- Allows immediate communication and interaction between Anesthesia, Surgeon and Neurologist
- Allows centralized reporting & data archiving, facilitating research
- Allows cumulative reporting for QA
- Identifies learning needs of Operating Room monitoring personnel

The disadvantages of real time remote oversight include:

- Lacks face to face patient contact.
- Requires secure internet or communication access
- Requires careful attention to HIPAA compliance
- Requires access to a neurologist during non office hours

Surgeon Risk Management

Who is monitoring whom?

Regardless of any billing standards, some surgeons and hospitals choose not to provide technologist oversight separate from the surgeon. In these cases, responsibility for the setup, quality and accuracy of monitoring falls squarely on the operating surgeon, who is acting as the IONM overseeing physician delegating their IONM expertise to the technologist. In cases where the surgeon and technologist have developed a good working relationship and trust, this may work well, so long as it results in appropriate troubleshooting of technical issues and differentiating them from true clinical events that require timely intervention. Whether it constitutes 'best practices' is another issue.

According to the American Academy of Orthopaedic Surgeons (AAOS), "claims for damages due to postoperative complications... are usually easily defended as recognized risk of the procedure unless there was a delay in diagnosing and treating the complications." The AAOS committee on professional liability advises, "Be on guard against the natural human tendency to deny disagreeable events, and vigorously pursue diagnosis and treatments as soon as possible when there is any suspicion."³⁷

³⁷ AAOS Bulletin, Volume 48, No 2, April 2000

Automated Monitoring

Several spinal instrumentation companies provide automated monitoring solutions for specific surgery types³⁸. Often, this type of monitoring is utilized without the knowledge or supervision of the neuromonitoring department. While this type of technology does point to recognition of the need for monitoring, it has several drawbacks:

- The surgeon or nurse is required to apply the electrodes, the positioning of which dictate the sensitivity of the testing (the instrumentation sales representative is prohibited from touching the patient)
- No one is there to trouble shoot technical issues or machine failure
- Liability and responsibility for interpretation of the data rests with the surgeon who may be over reassured by simplified display interfaces
- The devices are usually more expensive than attended monitoring due to cost of consumables, which are often utilized outside any budgetary restraint
- Limited modality types are available (typically EMG or automated MEPs)
- Comparative efficacy testing to attended monitoring is usually lacking

Surgeons may be under the impression that they can charge for oversight of IONM while using automated devices, however the National Correct Coding Initiative referred to above states otherwise (see Billing for IONM & CPT Code 95920).

³⁸ Nuvasive, Medtronic Nim Spine

Conclusion

Hospital Implementation of IONM should fully speak to the regulatory and clinical realities of the practice of IONM at this time. In particular, it should address the effective delivery of multimodality IONM to patients in a comprehensive, expert and current manner.

IONM is becoming an increasingly complex field requiring scarce expertise. There is a clear trend toward technological leverage of that expertise in a way which benefits patients, as can be seen by the proliferation of the real time web based oversight model.

The advent of MIOM adds only small incremental cost (baseline readings) to IONM while delivering improved resources and better information to the surgeon and patient.

APPENDIX A: Surgical Types where IONM is of Value [and should be available to Institution Clients]

A Note about Evidence Levels in IONM Literature

The ways in which surgeons do or don't employ IONM has not always been based on scientific evidence. Indeed, many surgeons are not fully aware of the scope and breadth of monitoring procedures available nor the strengths and deficiencies in current IONM literature. Surgeons may use IONM for a variety of non exclusive reasons including:

- Patient safety
- Ethical concerns about withholding a potentially useful service
- Medico-legal concerns
- Peer recommendation
- Availability

In a 2007 survey of 180 spine surgeons by Magit,³⁹ SSEPs were the most widely available and preferred monitoring technique used, followed by EMG and MEPs. Almost 70% of those surveyed preferred some neuromonitoring for anterior thoracic/thoracolumbar cases and 55% for posterior thoracic/thoracolumbar cases. Surgeons were more satisfied with greater neuromonitoring availability, and were more likely to use neuromonitoring if they had a fellowship background.

Many surgeons who believe in IONM feel it is unethical or medico-legally unwise to withhold a procedure which gives them additional information for decision making in the operating room. Consequently, as Sala noted, "Because those surgeons who operate with the assistance of INM [IONM] believe in the efficacy of INM to prevent neurological deficits, the possibility to design Class I prospective randomized studies is defeated by ethical and medicolegal concerns of designating a control group."⁴⁰

Such views are echoed by Phillips: "Advocates of most monitoring techniques point to the lack of bad outcomes as proof that their particular technique has value. Since controlled trials . . . are unlikely to occur, teleological arguments may have to be sufficient."⁴¹

³⁹ Magit, D. P.; Hilibrand, A. S.; Kirk, J.; Rehtine, G.; Albert, T. J.; Vaccaro, A. R.; Simpson, A. K. & Grauer, J. N. (2007), 'Questionnaire study of neuromonitoring availability and usage for spine surgery.', *J Spinal Disord Tech* **20**(4), 282--289.

⁴⁰ Sala, F.; Palandri, G.; Basso, E.; Lanteri, P.; Delitis, V.; Faccioli, F. & Bricolo, A. (2006), 'Motor evoked potential monitoring improves outcome after surgery for intramedullary spinal cord tumors: a historical control study.', *Neurosurgery* **58**(6), 1129--43; discussion 1129-43.

⁴¹ Phillips, L. H. & Park, T. S. (1990), 'Electrophysiological monitoring during lipomyelomeningocele resection.', *Muscle Nerve* **13**(2), 127--132.

Delitis and Sala further comment that “the most accurate assessment we can expect today about the real advantages of IONM techniques probably comes from historical control studies. In such studies the neurological outcome in a cohort of patients operated on with the assistance of IONM should be compared with the outcome of patients operated before the introduction of IONM techniques”⁴².

These difficulties in obtaining best evidentiary support must be taken into account when reviewing the relevant literature and making practical decisions about application of IONM.

We believe that there is sufficient clinical and experimental data to support the use of intraoperative neurophysiologic monitoring in a variety of circumstances, where it positively affects surgical decisions⁴³ and patient outcomes. These continue to expand. The appendix addresses several of these indications. Each indication contains a description of the modalities typically used, the rationale for their application and a description of supporting evidence, followed by a reference list.

The following descriptions and references are kept short for the readers' convenience and are not meant to be exhaustive. Readers are referred to the clinical and scientific literature for additional material.

⁴² Delitis, V; Sala, F. (2008), 'Intraoperative neurophysiological monitoring of the spinal cord during spinal cord and spine surgery: A review focus on the corticospinal tracts', *Clinical Neurophysiology* **119**(2), 248-264.

⁴³ Wiedemayer, H.; Fauser, B.; Sandalcioglu, I. E.; Schäfer, H. & Stolke, D. (2002), 'The impact of neurophysiological intraoperative monitoring on surgical decisions: a critical analysis of 423 cases.', *J Neurosurg* **96**(2), 255--262.

Spinal Surgeries:

Decompression of the spinal cord where function of the spinal cord is at risk

Typical Modalities Used:

Primary: SSEP

Secondary : TceMEP

Rationale:

Monitoring spinal cord function is indicated in any surgery in which the blood supply to the spinal cord may be compromised, or during which it is manipulated. When the spinal cord is compressed or its baseline function is compromised, margins for error within the surgical procedure are slim. At these times IONM adds functional to anatomical guidance and improves outcomes.

Evidence for Use:

The most cited article reporting efficacy in spinal surgery, including scoliosis surgery, is a 1995 paper by Nuwer et al¹ in which SSEP monitoring of spinal surgeries was examined by serial survey in 153 spinal surgeons performing 97,586 spinal surgeries of which 53% were monitored. This series is most often quoted as supporting scoliosis monitoring, however, only 60% of the patients had scoliosis; 7.5% had fractures, 6.5% kyphosis and 5.5% spondylolysis. In this diverse group, united by spinal cord compromise or expected manipulation, patients from surgeries monitored by experienced SSEP monitoring teams had fewer than one-half as many post operative neurologic deficits as those monitored by teams with little or no experience.

Norcross-Nechay² reported retrospective results in 1999 on 70 patients monitored for chronic lumbar stenosis undergoing decompression and recommended “monitoring SEPs during surgery in all patients undergoing invasive lumbar surgery”.

Several other examples of clinical indicators for monitoring in this group of patients has existed since the 1970s^{3, 4}. A more recent 2005 assessment by the McGill University Health Center Technology Assessment Unit on the use of IONM during spinal surgery found that on the basis of 11 case series studies cited, there is sufficient evidence to support the conclusion that intraoperative spinal monitoring using SSEPs and MEPs during spinal procedures that involve risk of spinal cord injury is an effective procedure that is capable of substantially diminishing this risk⁵. They further note that IOM monitoring of spinal cord injury during surgery generally comprises both motor and sensory pathways so that using both SSEP and TceMEP monitoring in parallel acted as a safeguard should one of these monitoring techniques fail.

References

- ¹ Nuwer, M. R.; Dawson, E. G.; Carlson, L. G.; Kanim, L. E. & Sherman, J. E. (1995), 'Somatosensory evoked potential spinal cord monitoring reduces neurologic deficits after scoliosis surgery: results of a large multicenter survey.', *Electroencephalogr Clin Neurophysiol* **96**(1), 6--11.
- ² Norcross-Nechay, K.; Mathew, T.; Simmons, J. W. & Hadjipavlou, A. (1999), 'Intraoperative somatosensory evoked potential findings in acute and chronic spinal canal compromise.', *Spine* **24**(10), 1029--1033.
- ³ Nash, C. L.; Lorig, R. A.; Schatzinger, L. A. & Brown, R. H. (1977), 'Spinal cord monitoring during operative treatment of the spine.', *Clin Orthop Relat Res*(126), 100--105.
- ⁴ Nash, C. L. & Brown, R. H. (1989), 'Spinal cord monitoring.', *J Bone Joint Surg Am* **71**(4), 627--630.
- ⁵ Erickson, L;Costa, V. M. M. (2005), 'USE OF INTRAOPERATIVE NEUROPHYSIOLOGICAL MONITORING DURING SPINAL SURGERY', *McGill Technology Assessment Unit*(20), 1-39.
see (http://www.mcgill.ca/files/tau/SPINAL_MONITORING_Final.pdf)

Spinal Monitoring for Pedicle Screw Placement

Typical Modalities Used:

Primary: T-EMG

Secondary : S-EMG

Rationale:

Placement of pedicle screws during surgery for lumbosacral instrumentation presents significant potential for cauda equina and nerve root injury (1-6%) due to incorrect placement^{1,2}. Stimulating the awl, hole or screw at different thresholds of intensity (mA) during placement and recording T-EMG and S-EMG from the associated myotome identifies screws placed close to or through the pedicle edge that allow current to pass to the nerve root and activate the myotome at lower than expected thresholds. This allows preventative repositioning.

Evidence for Use:

Pedicle screw testing was first described by Calancie in 1992³ and has since become widely used for instrumented spine surgeries requiring screw placement below T6 level.

Clements found pedicle screw breach to accurately correlate with stimulation thresholds and to be more accurate than plain x-ray⁴. Several series including prospective ones support its use in the absence of neuromuscular blockade⁵. Glassman found the technique to identify mal-positioning of screws in 9% of 512 screws placed⁶. Tolekis et al. found in their series of 3,409 pedicle screws that 3.9% required inspection due to low thresholds and that this was “an easy, inexpensive, and quick method to reliably assess screw placements and protecting neurological function”⁷. Danesh-Clough found with 91 screw placements that the technique had a sensitivity of 94% and a specificity of 90% in their hands⁸. Owen found the technique to be both effective in reducing injury and cost effective⁹.

The technique appears accurate in the lower thoracic region at different threshold levels¹⁰ and possibly cervical levels¹¹ as well.

T-EMG is typically used in conjunction with S-EMG to detect ongoing abnormal discharges and improve sensitivity¹².

References:

¹ Thalgott, J. S.; LaRocca, H.; Aebi, M.; Dwyer, A. P. & Razza, B. E. (1989), 'Reconstruction of the lumbar spine using AO DCP plate internal fixation.', *Spine* **14**(1), 91--95.

² Matsuzaki, H.; Tokuhashi, Y.; Matsumoto, F.; Hoshino, M.; Kiuchi, T. & Toriyama, S. (1990), 'Problems and solutions of pedicle screw plate fixation of lumbar spine.', *Spine* **15**(11), 1159--1165.

³ Calancie, B.; Lebowhl, N.; Madsen, P. & Klose, K. J. (1992), 'Intraoperative evoked EMG monitoring in an animal model. A new technique for evaluating pedicle screw placement.', *Spine* **17**(10), 1229--1235.

⁴ Clements, D. H.; Morledge, D. E.; Martin, W. H. & Betz, R. R. (1996), 'Evoked and spontaneous electromyography to evaluate lumbosacral pedicle screw placement.', *Spine* **21**(5), 600--604.

⁵ Minahan, R. E.; Riley, L. H.; Lukaczyk, T.; Cohen, D. B. & Kostuik, J. P. (2000), 'The effect of neuromuscular blockade on pedicle screw stimulation thresholds.', *Spine* **25**(19), 2526--2530.

⁶ Glassman, S. D.; Dimar, J. R.; Puno, R. M.; Johnson, J. R.; Shields, C. B. & Linden, R. D. (1995), 'A prospective analysis of intraoperative electromyographic monitoring of pedicle screw placement with computed tomographic scan confirmation.', *Spine* **20**(12), 1375--1379.

⁷ Toleikis, J. R.; Skelly, J. P.; Carlvn, A. O.; Toleikis, S. C.; Bernard, T. N.; Burkus, J. K.; Burr, M. E.; Dorchak, J. D.; Goldman, M. S. & Walsh, T. R. (2000), 'The usefulness of electrical stimulation for assessing pedicle screw placements.', *J Spinal Disord* **13**(4), 283--289.

⁸ Danesh-Clough, T.; Taylor, P.; Hodgson, B. & Walton, M. (2001), 'The use of evoked EMG in detecting misplaced thoracolumbar pedicle screws.', *Spine* **26**(12), 1313--1316.

⁹ Owen, J. (1999), *Adjuncts of Surgery: Intraoperative Electromyographic Monitoring*, Churchill Livingstone (January 15, 1999), chapter 95, pp. 1259-1264.

¹⁰ Raynor, B. L.; Lenke, L. G.; Kim, Y.; Hanson, D. S.; Wilson-Holden, T. J.; Bridwell, K. H. & Padberg, A. M. (2002), 'Can triggered electromyograph thresholds predict safe thoracic pedicle screw placement?', *Spine* **27**(18), 2030--2035.

¹¹ Djurasovic, M.; Dimar, J. R.; Glassman, S. D.; Edmonds, H. L. & Carreon, L. Y. (2005), 'A prospective analysis of intraoperative electromyographic monitoring of posterior cervical screw fixation.', *J Spinal Disord Tech* **18**(6), 515--518.

¹² Bose, B.; Wierzbowski, L. R. & Sestokas, A. K. (2002), 'Neurophysiologic monitoring of spinal nerve root function during instrumented posterior lumbar spine surgery.', *Spine* **27**(13), 1444--1450.

Excision of Intramedullary Spinal Cord Tumors

Typical Modalities Used:

Primary: TceMEP and D wave recordings

Secondary: SSEP

TceMEP and D wave recordings are typically used in conjunction with SSEP monitoring. Together these provide ascending as well as descending spinal cord tract coverage, monitor for positioning effects and help predict outcome.

Rationale:

Intramedullary spinal cord tumors present a surgical challenge with a high risk of possible injury to the spinal cord¹ due to proximity of ascending and descending tracts. The spinal cord is often expanded and remaining neural tissue compressed and at risk.

Evidence for Use:

SSEP monitoring for spinal cord tumors has been carried out for almost 20 years^{2, 3, 4, 5}. More recently it has been recognized that TceMEP and D wave monitoring is highly useful^{6, 7}. When used in combination with SSEPs and TceMEPs, D waves appear to be able to predict expected recovery time for episodes of waveform change based upon degree of amplitude change, clearly indicating their clinical efficacy^{8, 9, 10} (Table 2). The monitoring of corticospinal tracts during spinal surgery including intramedullary tumors is comprehensively reviewed by Delitis and Sala (2008- in press)¹¹.

D wave	Muscle MEP*	Motor status (postoperatively)
Unchanged or 30–50% decrease	Preserved	Unchanged
Unchanged or 30–50% decrease	Lost uni- or bilaterally	Transient motor deficit
>50% Decrease	Lost bilaterally	Long term motor deficit

* In the tibial anterior muscle(s).

Table 2 - Principles of MEP interpretation (reproduced from Delitis, 1999)

References:

¹ Kothbauer, K. F. (2007), 'Neurosurgical management of intramedullary spinal cord tumors in children.', *Pediatr Neurosurg* **43**(3), 222--235.

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- ⁴ Koyanagi, I.; Iwasaki, Y.; Isu, T.; Abe, H.; Akino, M. & Kuroda, S. (1993), 'Spinal cord evoked potential monitoring after spinal cord stimulation during surgery of spinal cord tumors.', *Neurosurgery* **33**(3), 451--9; discussion 459-60.
- ⁵ Kothbauer, K.; Delitis, V. & Epstein, F. J. (1997), 'Intraoperative spinal cord monitoring for intramedullary surgery: an essential adjunct.', *Pediatr Neurosurg* **26**(5), 247--254.
- ⁶ Fujiki, M.; Furukawa, Y.; Kamida, T.; Anan, M.; Inoue, R.; Abe, T. & Kobayashi, H. (2006), 'Intraoperative corticomuscular motor evoked potentials for evaluation of motor function: a comparison with corticospinal D and I waves.', *J Neurosurg* **104**(1), 85--92.
- ⁷ Jellinek, D.; Jewkes, D. & Symon, L. (1991), 'Noninvasive intraoperative monitoring of motor evoked potentials under propofol anesthesia: effects of spinal surgery on the amplitude and latency of motor evoked potentials.', *Neurosurgery* **29**(4), 551--557.
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- ¹⁰ Sala, F.; Palandri, G.; Basso, E.; Lanteri, P.; Delitis, V.; Faccioli, F. & Bricolo, A. (2006), 'Motor evoked potential monitoring improves outcome after surgery for intramedullary spinal cord tumors: a historical control study.', *Neurosurgery* **58**(6), 1129--43; discussion 1129-43.
- ¹¹ Delitis, V.; Sala, F. (2008), 'Intraoperative neurophysiological monitoring of the spinal cord during spinal cord and spine surgery: A review focus on the corticospinal tracts', *Clinical Neurophysiology* **119**(2), 248-264.

Surgery as a result of traumatic injury to the spinal cord

Typical Modalities Used:

Primary: SSEP

Secondary: TceMEP

Rationale:

Traumatic injury to the spinal column requiring surgery may result in reduced or compromised spinal cord function and / or structural spinal column change and instability. IONM helps to prevent further injury to an already compromised structure.

Evidence for Use:

Much of the evidence outlined in the section 'Decompression of the spinal cord where function of the spinal cord is at risk' applies to traumatic injuries as well, where surgery is usually prompted by spinal cord compression or spinal instability.

More specifically, experimental studies in dogs indicate that intraoperative evoked potential monitoring post injury is accurate and reliable as a predictor of prognosis¹.

In humans, Tsirikos (2004) found that SSEP monitoring in 82 patients with traumatic spinal injuries in cervical, thoracic and lumbar regions was able to predict outcome with 67% sensitivity and 81% specificity². Further, he noted that improvement in SSEP signals after an event correlated with a good outcome, suggesting that interventions after warning were effective.

References:

¹ Shen, N. & Wang, S. (1998), 'Monitoring spinal-cord injury intraoperatively and attempting prognosis by cortical somatosensory evoked potentials: experimental study.', *J Reconstr Microsurg* **14**(1), 61--66.

² Tsirikos, A. I.; Aderinto, J.; Tucker, S. K. & Noordeen, H. H. (2004), 'Spinal cord monitoring using intraoperative somatosensory evoked potentials for spinal trauma.', *J Spinal Disord Tech* **17**(5), 385--394.

Surgery for arteriovenous malformation (AVM) of the spinal cord

Typical Modalities Used:

Primary: SSEP

Secondary: TceMEP

Rationale:

Arteriovenous malformations of the spinal cord pose immediate risk of ischemic injury to the cord during resection or embolization. IONM is able to identify impending ischemia during these procedures and prevent injury. Combined SSEP and TceMEP monitoring provides coverage of both anterior and posterior spinal cord circulations. Monitoring may also be used during Amytol or Xylocaine provocative test prior to embolization.

Evidence for Use:

Spinal AVMs are infrequent but serious lesions within the spinal cord that can lead to ischemic, hemorrhagic or compressive injury to the spinal cord.

Successful resection of spinal AVMs has been reported under SSEP guidance since 1979¹. Spinal AVM surgery was included in those where IONM was recommended by The Therapeutics and Technology Subcommittee of the American Academy of Neurology in 1990².

TceMEPs were shown to correlate with angiographically confirmed catheter occlusion and vasospasm by Sala in 1999³ - both instances recovering with appropriate intervention.

More recently it has been used successfully during spinal AVM embolization coupled with provocative testing in 52 patients where it was felt to have a high NPV⁴. The use of SSEP or TceMEP alone however seems unwise, as the author also reported on 30 cases of spinal cord provocative testing monitoring in which TceMEPs and SSEPs were not simultaneously affected⁵. He concluded that "This suggests that to monitor only SEPs (SSEPs) or only mMEPs (TceMEPs) would expose the patient to the risk of neurological deficits".

References:

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Correction of Scoliosis (IS)

Typical Modalities Used:

Primary: SSEP, TceMEP

Secondary: S-EMG

Rationale:

Corrective procedures during scoliosis surgery carry a high risk of injury to the spinal cord. IONM of the spinal cord long tracts allows early recognition of impending injury allowing reversal or interruption of corrective maneuvers, thereby reducing injury.

Evidence for Use:

Monitoring of this surgery is standard of care and has robust literature support.

Far Lateral Trans-psoas Lumbar Disc Surgery

Typical Modalities Used:

Primary: T-EMG, S-EMG

Secondary: SSEP

Rationale:

The trans-psoas approach to the lumbar spine presents significant likelihood of injury to lumbar plexus components and nerves traversing the psoas muscle. Identification and monitoring of traversing nerves reduces the likelihood of injury. SSEP waveforms are often monitored simultaneously to reduce the likelihood of positioning effect.

Evidence for Use:

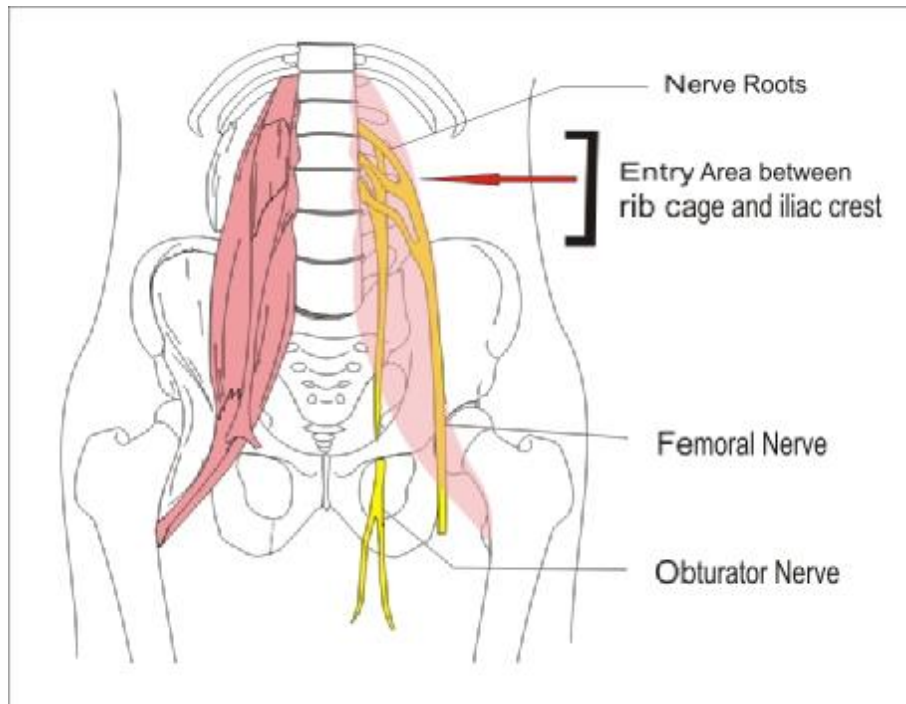


Figure 11 - Posterior Neurological Structures at Risk with Trans-Psoas Approach

The trans-psoas approach has been popularized in the last four years as a rapid access low morbidity alternative to lumbar fusion¹. Several companies now offer instrumentation for this approach, the most prominent being NuVasive². The majority of these surgeries are performed at the L4-5 level, where degenerative change is most prominent. Clinical and anatomical studies show that there is significant risk of femoral nerve or lumbosacral plexus injury during the surgery³ that can be ameliorated by monitoring nerve function. NuVasive offers an automated version of this; however intraoperative monitoring professionals are apprehensive of its use in the absence of a trained neuromonitoring professional⁴.

References:

-
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Intracranial Surgeries:

Resection or Correction of cerebral vascular aneurysms

Typical Modalities Used:

Primary: SSEP, TceMEP

Secondary: EEG, BAER

Rationale:

Cerebral aneurysm surgery risks inadvertent reduction of the blood supply to the brain distal to the aneurysm through hemorrhage, occlusion or arterial spasm¹. IONM can detect these early ischemic changes and allows rapid intervention for preservation of at risk functional (motor, sensory and other) cerebral tissue and reduced morbidity. Because no one modality provides information on both motor and sensory function in an arterial distribution², more than one is typically used to improve sensitivity.

Evidence for Use:

The UHC Revised Policy states that “Clinical evidence does NOT support the use of Somatosensory evoked potential (SSEP) studies for the following: ... - Intraoperative monitoring during surgery for cerebral aneurysm.” The Network Bulletin from September 2007 however states that “Somatosensory evoked potential (SSEP) monitoring during surgery... for anterior cerebral artery aneurysm may identify opportunities to avoid intraoperative damage to the ...brain, and may lessen new postoperative neurologic deficit”. These seemingly contradictory statements are based on analysis of 4 studies^{3, 4, 5, 6} comprising 258 mixed and 58 middle cerebral aneurysm surgeries.

The above evidence fails to include several significant studies and current multimodality monitoring approaches.

Several older series of patients show at least some efficacy of SSEP monitoring in aneurysm surgery. Buchthal⁷ concluded that “appropriate SEP monitoring can make a major contribution to patient safety in aneurysm surgery”. Ducati used SSEPs to assess the feasibility of lowering MAP during aneurysm surgery⁸. Kidooka reported a series of 31 patients monitored with SSEPs in which prolongation of the central conduction time exceeding 1.2 ms or disappearance of the N20 peak adversely affected the postoperative conditions in 8 of 13 patients (62%). Mizoi compared SSEP monitoring to cerebral blood flow in 67 aneurysm resections and found significant changes in N20 amplitudes in 24 cases, all responding to recirculation with no sequelae.⁹ He also found that “The SEP N20 attenuation reflected the CBF reduction in the middle cerebral artery (MCA) territory during MCA occlusion.”

Manninen reported a series of 157 patients of which 97 had temporary occlusion of the feeding arteries¹⁰. Although the technique was more useful in carotid circulation aneurysms, and carried a 14% false negative rate, the authors felt that “Despite these limitations, we find SSEP monitoring useful during temporary occlusion in cerebral aneurysm surgery”. He followed this with a series of 70 procedures for posterior fossa aneurysm surgery in which both BAER and SSEP were used. They did not find a difference in the ability of SSEP compared with BAEP in predicting neurological deficits but did find that using a multi-modality approach reduced the incidence of false negative results from 47% and 60% respectively to only 20%.

Schramm reported a series of 134 cerebral aneurysms with SSEP monitoring alone¹¹. Although he reported a low sensitivity for events with SSEP monitoring alone (17/58 events), he also noted that SSEP monitoring allowed identification and correction of changes in 6 patients through reapplication of aneurysm clips, repositioning of retractors, or removal of temporary clips. He concluded that “Despite the limitations of SEP monitoring in certain anatomical locations, it has been found to be helpful in the operative management of some cases such as multilobed aneurysms of the middle cerebral artery, giant aneurysms, trapping procedures, and procedures requiring temporary vessel occlusion.” Schramm followed this report with a series of 60 patients monitored with both SSEP and TceMEPs¹². He found that post operative motor deficits occurring in patients in whom SSEP monitoring did not detect a change were usually accounted for by small perforator artery insults, in agreement with Holland¹³. He also reported a number of cases in which monitoring influenced surgery including kinking of a perforator artery 2-3 mm from the tip of the clip due to indirect traction from an arachnoid string. He concluded that “simultaneous monitoring using MEPs and SEPs... increased detection of motor impairment stemming from manipulation of small perforators.”

Szelenyi reported in 2006 a series of 119 patients undergoing surgery for 148 cerebral aneurysms using both retrospective and prospective data utilizing both DECS and TceMEPs. They showed no advantage of DECS, which was associated with increased incidence of subdural bleeding, lack of surgeon preference, slightly lower ability to cover the motor field of interest and need to check positioning for migration of electrode. The series did show that intraoperative loss of motor potentials “reliably predicts both severe and permanent postoperative motor deficits “. More importantly, monitoring changes occurred in 14 patients, of which 10 were reversed by intervention. If the changes were reversed within 5 minutes, no new neurological deficit occurred.

Lastly, intraoperative barbiturate protective infusions have been advocated by some surgeons requiring EEG monitoring for titration to a burst suppression pattern^{14, 15}.

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Microelectrode Recordings during Deep Brain Stimulator Implantation

Typical Modalities Used:

Primary: Micro-electrode recording

Secondary: none

Rationale:

Micro-electrode recording allows identification of characteristic firing patterns of individual neuronal groups that allow accurate placement of stimulating DBS electrodes.

Evidence for Use:

UHC has a supportive policy in place as of Dec 20, 2007 regarding coverage for DBS for severe Parkinson's disease and essential tremor. It does not specifically address the need for micro-electric recordings. It refers instead to placement under radiological guidance. None the less, in the studies quoted in constructing the policy, where method of implantation is mentioned, several include micro-electrode recordings¹. Indeed, several studies suggest that pretargeting with microelectrode recording improves efficacy in DBS electrode placement.^{2, 3, 4}

If this issue has not been addressed elsewhere, clarification would be of value.

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Microvascular decompression of cranial nerves (e.g., trigeminal, facial, auditory nerves)

Typical Modalities Used:

Primary: S-EMG, BAER

Secondary: T-EMG, SSEP

Rationale:

Monitoring of cranial nerve function during microvascular decompression (MVD) of a cranial nerve aids in prevention of injury to the operated nerve and those surrounding it. In addition, monitoring antidromic T-EMG from the facial nerve can identify abnormal muscle response (AMR)¹ across branches which disappear when decompression occurs.

Evidence for Use:

Monitoring for MVD of cranial nerves is best documented for facial (hemifacial spasm) and trigeminal nerves (trigeminal neuralgia) although it has been used for others.

Monitoring AMRs during facial microvascular decompression has been shown to be helpful. Moller demonstrated an improved success rate using this technique². A more recent series of 74 patients was described by Mooij who found the technique to have a guiding role (identifying the vessel) in 33.8% of cases and a confirming role in 52.7%. Hearing impairment was a complication in 2.7% of surgeries.

Moller also described 140 surgeries in 129 patients for microvascular decompression for hemifacial spasm, disabling vertigo and trigeminal neuralgia³ which were monitored with BAER to preserve hearing. Only one patient lost hearing during a second surgery. A more recent series of BAERs for hearing protection in 84 patients undergoing MVD for hemifacial spasm by Polo⁴ helped to define warning criteria based on waveform V latency. Sindou reviewed the role of BAERs in MVD for hemifacial spasm in 2005 finding it “of value to reduce occurrence of hearing loss”⁵.

In Trigeminal MVD, Ali reported more than seventy five percent of their series of 17 patients had significant alteration in the latencies and amplitude of BAER waveforms during surgery, and felt that “Prompt identification of these changes is critically important in reducing postoperative hearing loss as well as other neurologic deficits”.

In addition to eighth cranial nerve protection with BAERs, trigeminal SSEP responses can be recorded during MVD of the nerve⁶ although the technique is technically demanding.

References:

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Removal of cavernous sinus tumors

Typical Modalities Used:

Primary: EEG, SSEP, S-EMG

Secondary none

Rationale:

Apart from vascular structures (venous plexus, internal carotid artery) the Cavernous Sinus contains several delicate neurological structures including the third, fourth, and sixth cranial nerves. Monitoring of these structures offers guidance leading to avoidance of injury. In addition, control of the internal carotid artery usually requires occlusion during surgery, which can be guided by balloon test occlusion and intraoperative monitoring for ischemia.

Evidence for Use:

Balloon test occlusion requires intraoperative monitoring to measure cerebral ischemia (see Arteriography, during which there is a test occlusion of the carotid artery). Appropriate references are cited elsewhere.

Similarly, intraoperative occlusion of the internal carotid artery is best done under IONM guidance. (see Distal aortic procedures, where there is risk of ischemia to the spinal cord and Carotid artery surgery with selective shunting (Carotid Endarterectomy – CEA).

More specifically, Kawaguchi¹ reviewed 45 patients undergoing resection of cavernous sinus lesions receiving multimodality monitoring with EEG, SSEP and S-EMG / T-EMG to the extraocular muscles and nerves. He reported that “Intraoperative neurophysiological monitoring in the surgery of lesions involving the cavernous sinus is crucial to reduce the surgical complications”.

Sekhar² described how the advent of better radiology and multimodality IONM utilizing the balloon-occlusion test of the ICA and monitoring of the third, fourth, sixth, and seventh cranial nerves was used to assist in locating the nerves and in avoiding injury to them during cavernous sinus surgery, thus allowing a more aggressive surgical approach.

Beijani's³ series of 244 skull base surgeries which included cavernous sinus surgeries showed a high positive predictive value of SSEP monitoring for neurological outcome in cranial base tumors (100%). As one might expect from single modality monitoring, not all deficits were detected (NPV 90%).

References:

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Removal of tumors that affect cranial nerves excluding Acoustic Neuromas

Typical Modalities Used:

Primary: S-EMG, BAER

Secondary: T-EMG, TceMEP, SSEP

Rationale:

Surgeries that affect cranial nerves often occur in a complex area such as the skull base through which several cranial nerves pass. Monitoring of these nerves allows both identification and preservation of function while optimizing any required resection.

Evidence for Use:

Cranial nerve monitoring is possible for a large proportion of the 12 nerves including oculomotor (EMG), trochlear (EMG), trigeminal (motor) (EMG), abducens(EMG), facial (EMG), vestibulocochlear (BAER, ECoG) glossopharyngeal (EMG), vagus (motor)(EMG), accessory (EMG) and hypoglossal (EMG). Harper reviewed intraoperative cranial nerve monitoring in 2004 stating that “A growing body of evidence supports the utility of intraoperative monitoring of cranial nerve nerves during selected surgical procedures”¹.

References:

¹ Harper, C. M. (2004), 'Intraoperative cranial nerve monitoring.', *Muscle Nerve* 29(3), 339--351.

Removal of Acoustic Tumors

Typical Modalities Used:

Primary: S-EMG, ECoCh, BAER

Secondary: T-EMG

Rationale:

ENT surgeries for acoustic neuroma surgery occur in a complex area through which several cranial nerves pass, including the seventh (facial) and of course the eighth (auditory) cranial nerves. Monitoring these nerves during surgery allows identification and preservation of function.

Evidence for Use:

The UHC Revised Policy specifically comments on the use of BAER during acoustic neuroma surgery, citing four uncontrolled studies^{1, 2, 3, 4} with a total of 253 patients. The review overlooks the study by Matthies of 201 patients in which it was concluded that “Useful (in-time) recognition of significant waveform changes is possible and enables a change of microsurgical maneuvers to favor ABR recovery.”⁵

With regard to the study by Schlake et al. Al. it is notable that the conclusions of the UHC review are at odds with those of the paper’s authors. According to the UHC review, “Schlake et al. found electrocochleography recordings at the end of the procedure to be more sensitive than BAEP with respect to postoperative hearing preservation (37% versus 20%) and significantly correlated with hearing preservation, whereas BAEP was not.” Whereas BAER latencies had little or no predictive value, “The amplitudes of ABR waves I, III and V showed a highly significant (inverse) correlation to the degree of pre- and postoperative hearing” which were similar to those of ECoChG (P=1.0001). In fact Schlake goes on to conclude that “In combination with ABR monitoring, ECoChG proved to be a useful supplementary tool for hearing preservation in acoustic neurinoma (neuroma) surgery”. Certainly, cochlear microphonic potentials and summation potentials are more difficult to record and fail to screen for brainstem problems.

In addition, the UHC review found that “Rates of serviceable hearing preservation attributable to BAEP or BAEP in combination with other monitoring ranged from 18% to 50%, but conclusions about efficacy cannot be drawn because of the lack of control groups who did not undergo monitoring.” Such comments do not take into account reports of improving hearing preservation over time and with the with institution of monitoring^{6, 7}. Nor does it take into account Harper’s series of 90 consecutive patients compared to 90 controls which showed improved hearing preservation from 22% in controls to 37% in monitored patients⁸.

The UHC determination also does not address the marked benefits of EMG monitoring during acoustic neuroma surgery in the preservation of the the facial nerve. S-Emg is extensively documented in the literature^{9, 10} with predictive

results extending out to as much as a year after surgery^{11, 12, 13, 14, 15, 16}. Facial nerve stimulation with threshold measurement is also reported as effective^{17, 18}. These findings have recently been extended to facial TceMEPs¹⁹. Sammi emphasized the utility of facial nerve monitoring in acoustic neuromas in his series of 1000 cases²⁰.

Fisher²¹ reported as early as 1995 on comments from the Mayo clinic surgeons: "I don't think I could convince anybody at our institution with experience to give up monitoring under any circumstances". Yingling reported similar feelings from the surgical team at UCSF in 1992²². Facial nerve monitoring is routinely described with retrolabyrinthine craniotomy²³. A recent review by Ciric describes this technique²⁴.

References:

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Resection of brain tissue close to the primary motor cortex and requiring brain mapping

Typical Modalities Used:

Primary: SSEP cortical mapping

Secondary: Cortical Motor Stimulation for Mapping

Rationale:

It can be difficult to identify visually the central sulcus with certainty in surgery. This landmark can, however be easily identified functionally by using SSEPs recorded from a cortical electrode array following peripheral stimulation. The initial component of the N20 primary cortical response is generated by activation of the posterior bank of the central fissure that is recorded as a negativity post-centrally and a positivity pre-centrally. Electrical cortical stimulation may also be used to identify pre-central cortex. These techniques are typically used together to compensate for single technique technical failure and reduce events of false mapping.

Evidence for Use:

Cortical localization using SSEPs and pre-central electrical cortical stimulation is well described and extensively used during craniotomy procedures^{1, 2, 3, 4, 5}, especially where there is distortion of architecture by mass lesions or poor visualization for other reasons. In addition, it allows functional localization when somatotopic organization presents some inter-person variability^{6, 7}. It was recommended as 'safe and efficacious' by the Therapeutics and Technology Assessment Subcommittee of the American Academy of Neurology as early as 1990⁸.

Cortical stimulation to prevent undue resection of eloquent cortical tissue is considered the 'gold standard' by some authors⁹ allowing safe resection of lesions previously considered inoperable¹⁰. Duffau, for instance, describes a series of 103 patients in which functional mapping of white matter and cortex allowed the authors to "optimize the benefit/risk ratio of surgery of low-grade glioma invading eloquent regions"¹¹. Neuloh found "The rate of permanently severe new deficit appears to be greater in unmonitored cases" for insular gliomas¹². Kombos found bipolar cortical stimulation to be more accurate than monopolar stimulation¹³

Romstock describes a series of 230 patients in which SSEP mapping using N20-P20 and P25 waveforms was a "simple and reliable technique" with a success rate of 92%. He noted by contrast that "Functional neuronavigation is a desirable tool for both preoperative surgical planning and intraoperative use during surgery on perirolandic tumours, but compensation for brain shift, accuracy, and cost effectiveness are still a matter for discussion"¹⁴. Nuwer compared strip electrodes

to arrays finding the latter superior¹⁵. Even more recently Tomas commented on the “crucial role of the central cortex mapping using the SEP phase reversal method in the surgery for the tumors of the primary sensorimotor cortex” in their series of 62 patients.¹⁶

References:

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Resection of Epileptogenic brain tissue or tumor

Typical Modalities Used:

Primary: Surface Electroocortography

Secondary: Depth electrode Electroocortography

Rationale:

Resection of epileptogenic brain tissue is more accurate and can be more constricted if the epileptogenic tissue can be accurately differentiated from normal tissue using IONM.

Evidence for Use:

Depending upon the location of epileptogenic brain tissue, cortical mapping may be of value to exclude resection of eloquent tissue (see Resection of brain tissue close to the primary motor cortex and requiring brain mapping). Mass lesions like AVMs associated with seizure benefit from electrocortography and depth electrode recording (see Yeh under Intracranial AV malformations (AVM) resection or embolization).

Electrocortography is a routinely used tool in seizure surgery. Schutz described both electrocortography and stimulation induced aura to help define boundaries of resection in 31 cases, favoring electrocortography¹. Recently, Sugano² evaluated electrocortography for identifying seizure spikes to guide degree of tissue excision in intractable seizures from temporal lobe masses in 35 patients; He found it an effective technique for identifying hippocampal generators requiring further resection. Chen³ similarly found electrocortography to be helpful in the prediction of seizure outcome in patients undergoing selective amygdalohippocampectomy.

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Intracranial AV malformations (AVM) resection or embolization

Typical Modalities Used:

Primary: SSEP, MEP, EEG

Secondary: Cortical Stimulation

Rationale:

The most frequent location of the AVM's was in the temporal lobe, followed by the frontal, parietal, and occipital lobes. They may be associated with seizure and pose immediate risk of ischemic injury to brain tissue during resection or embolization. IONM is able to identify impending ischemia during these procedures and prevent injury. Combined SSEP and TceMEP monitoring provides coverage of both anterior and posterior spinal cord circulations. In some cases SSEP cortical mapping cortical stimulation mapping may be used to identify structures prior to resection (see Resection of brain tissue close to the primary motor cortex and requiring brain mapping)

Evidence for Use:

Due to their size and somewhat non-circumscribed nature, IONM for cerebral vascular malformations is in many ways similar to that of cerebral tumors. Much of the evidence applying to the latter can apply to AVMs as well (see Resection of brain tissue close to the primary motor cortex and requiring brain mapping). Additional risk is arises from aberrant blood supply which may affect adjacent tissues and require either transient vessel clamping, balloon test occlusions (see Arteriography, during which there is a test occlusion of the carotid artery), or initial embolization¹.

There are multiple reports in the literature of the utility of IONM for cerebral AVM treatment, both endovascular and during resection. Kato described a series of 17 cases of resection of AVMs involving the sensorimotor cortex in which they used motor evoked potentials to help identify motor cortex². Eighty eight percent of these patients showed clinical improvement, leading them to say that "AVMs in eloquent areas can be treated successfully when the surgery is well-designed and well-oriented with the combined use of diagnostic imaging and monitoring".

Rohde described TceMEPs in 10 patients undergoing AVM embolization in which two patients had changes, both of which resulted in transient neurological deficits³. Zentner⁴ describes a similar experience.

Neuloh reports in his large mixed series of 400 cerebral resections that included tumors, vascular malformations and aneurysms that motor evoked potential monitoring was "a useful aid in brain surgery with which to avoid a new motor deficit without compromise to the surgical result"⁵.

Yeh⁶ described a series of 27 patients with seizure disorders secondary to AVMs that underwent resection electrocortocography to aid in defining epileptogenic

brain area. Eighteen patients required resection of surrounding epileptogenic brain tissue as a result of monitoring.

Neuloh⁷ describes monitoring over 30 AVMs and comments that “With many vascularly induced changes, reversibility can be achieved. Therefore, monitoring in patients with vascular pathologies appears to be particularly helpful”.

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ENT Procedures for Non-Tumorous Hearing loss and Vertigo:

Endolymphatic shunt for Meniere's disease

Oval or round window graft

Vestibular section for vertigo

Typical Modalities Used:

Primary: ECoG, S-EMG, T-EMG

Secondary: BAER

Rationale:

Electocochleography is a useful test in diagnosing Meniere's disease or endolymphatic hydrops. Monitoring this modality during surgery gives immediate feedback and allows the surgeon to gauge effectiveness of an endolymphatic shunting procedure by comparing the summation potential to action potential ratio to baseline. For intractable vertigo selective vestibular section surgery may be undertaken via a retrosigmoidal approach. The latter approach benefits from facial nerve monitoring.

Evidence for Use:

Surgeons who utilize endolymphatic shunting have reported utilizing ECoG monitoring during surgery to gauge effectiveness of shunting during the operation^{1, 2}. McDaniel reported BAER recordings as "sensitive detection of trauma to the auditory system" during vestibular neurectomy and a benefit to their patients³. Since many of these surgeries share similar approaches as for acoustic neuroma removal, they may also benefit from facial nerve monitoring (see Removal of Acoustic Tumors).

Hausler reported on multimodality monitoring (BAER, ECoG and Facial EMG) for vestibular neurectomy allowing them to better identify completeness of vestibular neurectomy and obtain 100% vertigo free results with 86% hearing preservation and 100% facial nerve preservation in 14 patients⁴.

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Vascular Surgeries:

Circulatory arrest with hypothermia (does not include surgeries performed under circulatory bypass such as CABG, and ventricular aneurysms)

Typical Modalities Used:

Primary: SSEP

Secondary: EEG

Rationale:

The goal of hypothermic arrest is to reduce metabolic activity to sufficiently low levels that tissue injury, especially neural tissue, is avoided or ameliorated during circulatory arrest for surgical intervention. In order to implement this, cooling must precede circulatory arrest and some method of monitoring neural tissue metabolism is required. The latter can be indirectly ascertained by measuring reactivity to standardized electrophysiological testing.

Evidence for Use:

Guerti¹ described 20 patients undergoing hypothermic circulatory arrest for ascending thoracic aneurysm repair, and found that no deficit was seen in those in which disappearance of the P14 waveform was used as criterion to induce arrest, so long as arrest time was kept at a minimum. The same author later noted a significant correlation between the duration of the circulatory arrest and the delay of N20 and P14 reappearance on rewarming² again suggesting both the need for sufficient hypothermia and short arrest times. A third study involving 32 patients demonstrated good outcomes for patients in whom the P14 (brainstem) waveform was used as criteria for inducing cardiac arrest in contrast to using the N20 cortical response. All surviving patients in whom cortical SSEPs disappeared at higher temperatures presented neurological sequelae.

Ghariani described a retrospective study of SSEP monitoring during hypothermic cardiac arrest in 62 consecutive patients³ (both P14 and N20 disappearance). He concluded "The use of SEP monitoring to determine the optimal level of hypothermia efficiently prevents neurological sequelae of CA. It helps in monitoring the degree of cerebral protection during cooling (flap effect), and rewarming."

The more selective usefulness of brainstem SSEP responses over cortical responses helps to explain the apparent failure of purely cortical waveforms such as EEG to adequately offer protection in other surgeries involving hypothermic arrest, especially if burst suppression and not isoelectric activity is chosen as the end point⁴. Nonetheless, EEG is typically recorded simultaneously as it provides a useful backup in the case of technical issues and aids in confirming cortical suppression.

Stecker⁵ also found that recovery times in SSEP and EEG potentials correlated with circulatory arrest times during a series of 109 patients undergoing aortic surgery. "No trend toward shortened recovery times or improved neurologic outcome was noted with lower temperatures at circulatory arrest, indicating that the process of cooling to electrocerebral silence produced a relatively uniform degree of cerebral protection, independent of the actual nasopharyngeal temperature."

More recently Kotch⁶ described the relationship between time of SSEP waveform disappearance and occurrence of spinal cord ischemia in surgery for descending thoracic or thoracoabdominal aneurysms and found a highly linear relationship between amplitude and arrest time in all five patients monitored (see also Distal aortic procedures, where there is risk of ischemia to the spinal cord). He suggested that SSEP monitoring during descending thoracic aortic surgery requiring circulatory arrest is of potential value of estimating safe arrest times.

References:

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Distal aortic procedures, where there is risk of ischemia to the spinal cord

Typical Modalities Used:

Primary: TceMEP

Secondary: SSEP

Rationale:

The lower spinal cord often receives a large proportion of its blood supply from a single radicular artery, the Artery of Adamkowitz, usually arising on the left side of the aorta between T9-L2. Inadvertent occlusion of this artery during aortic surgery may result in spinal cord ischemia and myelopathy.

Evidence for Use:

Postoperative paraplegia is one of the most dreaded complications after descending thoracic and thoracoabdominal aneurysm surgery. Various strategies have been adopted to try to reduce the incidence of this including cytoprotective drugs, retrograde aortic perfusion, cooling and cold perfusion, CSF drainage and revascularizing segmental arteries. Nonetheless, rates of paraparesis or paraplegia remained as high as 9-10%^{1,2}. IOM with SSEP and MEP monitoring allows identification of functional interruption of sensory and motor function due to ischemia during surgical repair and has also been reported with endovascular aortic repair³ and aortic balloon test occlusions⁴.

Several studies show that TceMEPs and to a lesser extent SSEPs can detect ischemic changes, that the changes can be reversed by reimplanting segmental arteries or increasing blood flow or blood pressure, and that this technique appears to reduce the incidence of post operative neurological deficits^{5,2,6,7,8} and influences surgical strategy^{9,10}. TceMEPs changes have been shown to correlate with post operative CSF S-100 protein, confirming their prediction of tissue injury¹¹.

Kunihara¹² describes their multi part approach to spinal cord protection in 84 patients undergoing thoracoabdominal aneurysm repair in a recent article which includes IONM with selective reimplantation of segmental arteries.

References:

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Surgery of the aortic arch, its branch vessels, or thoracic aorta, when there is risk of cerebral ischemia.

Typical Modalities Used:

Primary: EEG, SSEP

Secondary: TCD

Rationale:

Surgery of the aortic arch can induce cerebral ischemia due to clamping, occlusion or embolic events. Monitoring cerebral function during these surgeries allows detection and intervention. It can also measure hypothermic effects during hypothermic arrest (see Circulatory arrest with hypothermia (does not include surgeries performed under circulatory bypass such as CABG, and ventricular aneurysms)).

Evidence for Use:

The prevalence of central nervous system injury is greater after operations on the aortic arch than after other types of aortic or cardiac surgery and such injuries are the frequent cause of perioperative death¹.

Guérit described the usefulness of median SSEP measurements during hypothermic arrest for aortic arch surgery in 1990².

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Carotid artery surgery with selective shunting (Carotid Endarterectomy – CEA)

Typical Modalities Used:

Primary: EEG

Secondary: SSEP

Rationale:

Selective shunting for CEA requires a method to sensitively measure cerebral perfusion of the clamped side to detect if collateral supply is insufficient, thus requiring shunting to restore adequate flow.

Evidence for Use:

Selective shunting has been used since the 1980's and is utilized in many of the studies showing efficacy of CEA for stroke prophylaxis. Several methods have been suggested for predicting inadequate flow including stump pressure, awake surgery¹, cerebral oxymetry, Transcranial Doppler (TCD), EEG^{2,3,4,5,6} and SSEPs^{7,8,9,10,11,12,13,14,15}. Comparison of sensitivity, the main goal of these techniques, suggests that stump pressure is the least sensitive¹⁶, cerebral oxymetry^{17,18} and TCD¹⁹ next, and EEG in both qualitative and quantitative forms²⁰ similar to SSEPs²¹. Since 70 percent of blood flow from the internal carotid artery runs through the middle cerebral artery, measurement of median SSEP waveforms that arise from the supplied area are usually done, however there is a report of some usefulness of posterior tibial waveforms as well²².

EEG and SSEP recordings are often used together, since instances of individual cases where only one or the other modality shows changes occur²⁶ (see attached case report).

Although previous studies have been equivocal about the utility of selective shunting in general, more recent reports from prospective trials suggest that monitoring is able to predict stroke after surgery^{23,24} (Rowed 2004, 156 consecutive CEAs, Ballotta 79 CEAs) and correlates with degree of contralateral carotid stenosis²⁵. Fisher's meta-analysis of the literature including over 3,000 CEA cases suggested that EEG and SSEP monitoring correlated well with critical reductions of cerebral blood flow and was effective in predicting need for shunting²⁶.

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Arteriography, during which there is a test occlusion of the carotid artery

Typical Modalities Used:

Primary: EEG, SSEP

Secondary: TCD, TceMEP

Rationale:

Test occlusion of the carotid artery allows identification of inadequate collateral blood flow to support cortical activities when monitored for changes using electrophysiological techniques.

Evidence for Use:

The underlying principles of ischemia detection using electrophysiological techniques are similar to those applied during selective shunting for CEA and many of the same references apply. (See Carotid artery surgery with selective shunting (Carotid Endarterectomy – CEA)).

More specifically, Morioka found the monitoring of EEG (via compressed spectral Array) useful for detecting changes in brain function due to inadequate collateral flow in 22 patients where it predicted good outcome in 6 of the 9 patients subsequently occluded, all of which were felt to be due to thromboembolic events rather than collateral circulation insufficiency.¹

TCD has also been of value in measuring the varying impact of internal and common carotid test occlusion hemodynamics² and has been used in conjunction with other modalities during test occlusion procedures³.

Multimodality monitoring with TceMEPs SSEPs and TCD was reported effective in four patients requiring resection or occlusion of the carotid artery by Dietz⁴.

EEG monitoring alone in 16 patients was reported as useful in planning surgeries by Herkes⁵. Nayak reported using test occlusions utilizing EEG (all) and single-photon emission computed tomographic scanning in 18 patients with malignancy and found it to “provide a valuable assessment of contralateral cerebral blood flow”.

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About the Author

American Neuromonitoring Associates, P.C. (“ANA”) is a physician PC providing intraoperative neurophysiologic monitoring oversight in multiple states. ANA, in association with Impulse Monitoring, Inc., provides intraoperative monitoring to hospital patients. A monitoring technologist collects neurophysiological data in the OR under the supervision of a dedicated monitoring physician who interprets the results. Like most providers of this service today, ANA and IMI use a real time web based oversight method.

Dr. O'Brien gained his MD in 1982 from the University of Western Ontario and has been active in clinical neurology since 1990. He holds board certifications from the Royal College of Physicians and Surgeons of Canada in Internal Medicine and Neurology, as well as an MBA from Simon Fraser University. He has over 16 years of clinical experience in electromyography and several years of experience in IONM. He is a member of the American Society of Neurophysiologic Monitoring.