# 5th ISIN CONGRESS & EDUCATIONAL COURSE

**NOVEMBER, 09th - 14th 2015**
WINDSOR ATLÂNTICA HOTEL
COPACABANA - RIO DE JANEIRO - BRAZIL

**INTERNATIONAL SOCIETY OF INTRAOPERATIVE NEUROPHYSIOLOGY**

## SCIENTIFIC PROGRAM

5th ISIN CONGRESS & EDUCATIONAL COURSE

INTERNATIONAL SOCIETY OF INTRAOPERATIVE NEUROPHYSIOLOGY

# FACULTY ISIN RIO 2015

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# Welcome


Ricardo Ferreira


Francisco Soto

Welcome dear participants!

We will be delighted to be your hosts during this event, held by the only scientific international society dedicated exclusively to intraoperative neurophysiology. We are celebrating the 10th anniversary of the ISIN and organizing its 5th Congress. That for the first time is held here in our Latin America! What a pride for us! We will now be definitely inserted in the IOM World Map.

We thank the unconditional support of the ISIN Board members who elected Latin America and who have in all ways helped us making this event a reality. We want especially to thank the encouragement of our current President Francesco Sala, of ex-President Jay Shils and our colleagues Karl Kothbauer - Chair of the Scientific Committee and Charles Dong - Chair of Educational Committee. The help of the members of these two committees made it possible to prepare a comprehensive scientific program, plenty of space for discussions, where the exchanges of experiences will certainly happen.

The great majority of the members of our faculty belong to the most renowned universities in the world and many of them are authors of the most important articles, chapters and books in the field. We hope to provide a relaxed atmosphere where you feel encouraged to move closer to the members of the faculty, to ask your questions, discuss with them any specific technique and even discuss some case of your daily practice. This is the reason for these events, to be able to return home with increased knowledge, knowledge that may already be put in practice as soon as the next OR case arises.

This year the theme of the educational course will be Brain Surgery, which is in fact the Part II of the Second Cycle of the ISIN courses.

As you all know, the official language of the event is English. We decided however to provide more comfort to our audience, hiring for the first time the simultaneous translation English-Portuguese-English and English-Spanish-English. During the discussion, the questions may be also made in Portuguese or Spanish, with the simultaneous translation of the answer.

Our scenario is Rio de Janeiro. What to say about a city that is called Marvelous? Therefore, we also prepared some sightseeing tours and two dinners that will certainly remain in your memories. Don't forget to book in advance, since the numbers of participants is restricted.

Well, enjoy the meeting!  We will be available here to support you.

A Big Hug!

Your hosts,
Ricardo Ferreira and Francisco Soto

Dear Colleagues and Friends,

Francesco Sala

It is a great honor and a privilege to welcome you to Rio de Janeiro for the 5th Biannual Congress of the International Society of Intraoperative Neurophysiology (ISIN).

This is the 10th anniversary since the foundation of our Society and, therefore, a very special occasion for all of us. Looking backward, I take pride in saying that ISIN has grown tremendously over the past decade, together with the interest for intraoperative neurophysiological monitoring (IOM) worldwide.

From Lucerne (Switzerland) to Dubrovnik (Croatia), from Barcelona (Spain) to Cape Town (South Africa) we have enjoyed the development of our discipline through the outstanding contributions of many of you who are moving this field forward. The number of IOM related articles in the neurophysiological and neurosurgical literature is growing exponentially. More recently, ISIN has adopted Clinical Neurophysiology as its official journal and this is, we hope, just the first step of a strong liaison with the International Federation of Clinical Neurophysiology.

Over the past two years, ISIN has significantly reinforced the relationship with neurosurgical societies such as the American Association of Neurological Surgeons (AANS), the European Association of Neurosurgical Societies (EANS) and the World Federation of Neurosurgical Societies (WFNS) through the organization of joint events at international conferences.

But, undoubtedly, one of the major achievement for ISIN has been the establishment of the Educational Courses in IOM. We have entered the Second Cycle last year in Istanbul and the participation to these training courses is constantly increasing. Yet we are also realizing that these courses do not suffice, as many colleagues have no or little chance to travel long distances in order to attend our courses in different geographical areas of the world. For this reason, we are considering to run “ad hoc” courses in some of these countries in the spirit of our commitment that “nobody should be left behind”.

I would like to thank Ricardo Ferreira and Francisco Soto for their spectacular work in supporting and organizing the Educational Course and Congress here in Rio. Together with the Scientific Committee, chaired by Karl Kothbauer, they have worked very hard to shape a remarkable scientific program, which reflects ISIN's attitude towards technological innovation, original research, rigorous scientific methodology, open mindedness, and a translational approach to neurophysiology.

Last but not least, Rio de Janeiro is among the top-ranked destinations in the world, and will offer a unique setting to share professional experience, meet old friends, and new colleagues. Our hosts have prepared social events that you will never forget, and I encourage all of you to spare time, during your visit, to explore this wonderful city.

Finally, approaching the end of my Presidency, I take this opportunity to thank all board members as well as all of you for the great support to our Society and for your enthusiasm in promoting the development of IOM around the world.

Looking forward to meeting you in Rio,

Francesco Sala
President of the ISIN

**Ricardo Ferreira, MD**
Chair, ISIN 2015 Congress

**Francisco Soto, MD**
Co-Chair, ISIN 2015 Congress

**Francesco Sala, MD**
President, ISIN

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Kathleen Seidel, MD - Switzerland

# ISIN EDUCATIONAL COURSE
## BRAIN SURGERY
## Cycle II - PART II

INTERNATIONAL SOCIETY OF
INTRAOPERATIVE NEUROPHYSIOLOGY

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## Scientific Program

### Educational Course IOM in Brain Surgery
### Day 1 - Monday, November 9

| | |
|---|---|
| 14h00 - 14h15 | **Welcome and Introduction**<br>Chair: Ricardo Ferreira — Co-Chair: Francisco Soto<br>ISIN President: Francesco Sala — Educational Committee Chair: Charles Dong |
| | **Introductory Course Part I**<br>Chair: Jay Shils<br>Co-Chair: Kathleen Seidel |
| 14h15 - 14h45 | **Basic Principles of electrophysiology**<br>David B. MacDonald |
| 14h45 - 15h15 | **The operating room environment: Safety, troubleshooting and communication**<br>Jay Shils |
| 15h15 - 15h45 | **Mapping techniques**<br>Isabel Fernández-Conejero |
| 15h45 - 16h15 | **Somatosensory Evoked Potentials - SEPs**<br>Armando Tello |
| 16h15 - 16h45 | **Motor Evoked Potentials - MEPs**<br>Elif Ilgaz |
| 16h45 - 17h00 | **Discussion: Previous speakers** |
| 17h00 - 17h30 | **Coffee Break** |
| | **Introductory Course Part II**<br>Chair: Francesco Sala<br>Co-Chair: Armando Tello |
| 17h30 - 18h00 | **BAERs**<br>Charles Dong |
| 18h00 - 18h30 | **Cranial Nerve Monitoring**<br>Isabel Fernández-Conejero |
| 18h30 - 19h00 | **Anesthesia for Neuromonitoring**<br>Antoun Koht |
| 19h00 - 19h15 | **Discussion: Previous speakers** |
| 19h15 - 20h00 | **Magistral Lecture**<br>Chair: Vedran Deletis<br>**New developments in Systems Neuroscience that relate to Neurosurgery**<br>Aage R. Møller |
| 20h00 | **Welcome Cocktail and Adjourn** |

# Scientific Program

## Educational Course IOM in Brain Surgery
### Day 2 - Tuesday, November 10

| | |
|---|---|
| | **Breakfast Session A**<br>Chair: Luiz Henrique Cuzziol<br>Co-Chair: Ileana Escobar |
| 07h00 - 07h45 | **A) SEPs Practical Issues**<br>David B. MacDonald<br>**B) BAERs Practical Issues**<br>Aage R. Møller<br>**C) TcMEPs Practical Issues**<br>Karl Kothbauer<br>**D) EMG Free Run and Trigger Practical Issues**<br>Jay Shils<br>**E) OR Theater Practical Issues**<br>Konstantinos Papadopoulos |

| | |
|---|---|
| **08h00 - 12h00** | **Session I:**<br>**Why do we need IOM in brain tumor surgery?**<br>Chair: Andrea Szelenyi<br>Co-Chair : Silvia Verst |
| 08h00 - 08h30 | **Functional neuroanatomy of the brain (cortex and tracts)**<br>Feres Chaddad |
| 08h30 - 09h00 | **Surgery for brain tumors in motor areas**<br>Francesco Sala |
| 09h00 - 09h30 | **Surgery for insular and deep-seated tumors**<br>Karl Kothbauer |
| 09h30 - 10h00 | **Coffee Break** |
| 10h00 - 10h30 | **Awake surgery for brain tumors in cognitive areas (language and more)**<br>Lorenzo Bello |
| 10h30 - 11h00 | **Brain surgery in children**<br>Sergio Cavalheiro |
| 11h00 - 11h30 | **Does IOM impact on brain tumor surgery? Accumulating evidence**<br>Lorenzo Bello |
| 11h30 - 12h00 | **Discussion: Previous speakers** |

12h00 - 13h30 **Lunch**

**13h30 - 18h00 Session II**
**How do we perform IOM in brain tumor surgery**
Chair: Karl Kothbauer
Co-Chair: Carlo Marrone

13h30 - 14h00 **EEG and Ecog**
David B. MacDonald

14h00 - 14h30 **Technical aspects of cortical and transcranial electrical stimulation**
Louis Journee

14h30 - 15h00 **Cortical mapping and Phase reversal**
Andrea Szelenyi

15h00 - 15h30 **Language mapping in asleep patients**
Vedran Deletis

15h30 - 16h00 **Coffee Break**

16h00 - 16h30 **Subcortical mapping**
Kathleen Seidel

16h30 - 17h00 **MEP monitoring**
Francesco Sala

17h00 - 17h30 **Monitoring and mapping visual pathways**
Kunihiko Kodama

17h30 - 18h00 **Discussion: Previous speakers**

**18h00 - 19h30 Session III:**
Chair: Charles Dong
Co-Chair: Martin Segura
**The real life part I: Illustrative cases on brain tumor surgery**
Karl Kothbauer, Lorenzo Bello, Andrea Szelenyi, Francesco Sala, Kathleen Seidel, Sergio Cavalheiro, Kunihiko Kodama, Isabel Fernandez-Conejero, Vedran Deletis

20h30 - 23h30 **Educational Course Dinner**

# Scientific Program

## Educational Course IOM in Brain Surgery
### Day 3 - Wednesday, November 11

| | |
|---|---|
| | **Breakfast Session B**<br>Chair: Carlos Eduardo Barbieri<br>Co-Chair: Oscar Herrera |
| 07h00 - 07h45 | **A) Cortical Mapping Practical Issues**<br>Andrea Szelenyi<br>**B) Subcortical Mapping Practical Issues**<br>Kathleen Seidel<br>**C) Awake craniotomy Practical Issues**<br>Lorenzo Bello<br>**D) Anesthesiology in Intracranial Surgery Practical Issues**<br>Antoun Koht<br>**E) Cranial Nerve Mapping and Monitoring Practical Issues**<br>Isabel Fernandez-Conejero |
| **08h00 - 10h00** | **Session IV:**<br>**Why do we need IOM in cranial vascular neurosurgery and epilepsy surgery?**<br>Chair: Francesco Sala<br>Co-Chair: Rachel Boy de Lanna |
| 08h00 - 08h25 | **Vascular neuroanatomy of the brain: vessels and territories**<br>Feres Chaddad |
| 08h25 - 08h50 | **Aneurysm and AVM surgery**<br>Feres Chaddad |
| 08h50 - 09h15 | **Carotid Endarterectomy**<br>Jay Shils |
| 09h15 - 09h40 | **Epilepsy surgery**<br>Arthur Cukiert |
| 09h40 - 10h00 | **Discussion: Previous speakers** |
| 10h00 - 10h30 | **Coffee Break** |
| **10h30 - 12h30** | **Session V:**<br>**How do we perform IOM in cranial vascular neurosurgery and epilepsy surgery?**<br>Chair: Jay Shils<br>Co-Chair: Alfredo Torres Castellon |
| 10h30 - 10h55 | **Monitoring during carotid endarterectomy: SEPs? EEG? MEPs? Current evidence for best practice**<br>Michael J. Malcharek |

10h55 - 11h20 **Monitoring during aneurysm surgery**
Andrea Szelenyi

11h20 - 11h45 **Monitoring during endovascular procedures**
Sedat Ulkatan

11h45 - 12h10 **Monitoring during epilepsy surgery**
David B. MacDonald

12h10 - 12h30 **Discussion: Previous speakers**

12h30 - 14h00 **Lunch**

14h00 - 15h00 **IOM industries State of the Art**
Chair: Jay Shils

**15h00 - 17h00 Session VI:**
Chair: Charles Dong
Co-Chair: Armando Tello
**The real life part II: Illustrative cases on vascular neurosurgery and epilepsy surgery**
Andrea Szelenyi, Kunihiko Kodama, Sedat Ulkatan, David B. MacDonald, Vedran Deletis, Kathleen Siedel, Jaime Lopez

17h00 - 17h30 **Coffee break**

17h30 - 18h00 **Course evaluation and adjourn**

# Invited Faculty Abstracts

## Day 9 - Introductory Course Part I: 14h15 - 17h30

### Basic principles of intraoperative electrophysiology

David B. MacDonald, MD, FRCP(C), ABCN
King Faisal Specialist Hospital & Research Center
Riyadh, Saudi Arabia

**Objectives**

After attending the lecture and reading this abstract, the participant should be able to:

- Describe the goals of intraoperative electrophysiology.
- Compare intraoperative and diagnostic laboratory testing.
- Describe the role and responsibility of the interpreter.

**Introduction**

Surgeons and neurophysiologists have applied intraoperative electrophysiology since the early 1900's. Beginning with electrocorticography for epilepsy surgery, methodology and indications have expanded to embody a true discipline with specialized practitioners, guidelines and professional societies. This overview summarizes goals, differences from diagnostic neurophysiology, and interpreter responsibility.

**Goals**

The fundamental goals of intraoperative electrophysiology are to a) optimize surgical results and b) preserve neurologic function. These are accomplished by providing real-time information about the functional role and integrity of critical neurologic structures during surgery through mapping and monitoring.

***Mapping***

Mapping techniques apply mainly to neurosurgery and some ENT procedures. One typically uses them to localize selected structures, such as motor cortex, cranial nerves or the corticospinal tract (CST). This is particularly important when pathology near functional tissue distorts anatomy. The results help to define safe margins, which can allow a total resection that may otherwise not have been done for fear of a deficit, or decide a subtotal resection limit that does not produce a deficit. Negative mapping results are as important as positive ones because they demonstrate the absence of functional structures within tissue to be resected.

Guiding neuromodulatory electrode placement is another mapping application. Examples include accurately implanting epidural electrodes over the motor cortex, deep brain stimulation electrodes within the basal nuclei, or spinal electrodes over the dorsal columns. Finally, one occasionally maps pathologic rather than functional tissue, such as using electrocorticography to delineate an epileptic focus.

Most often mapping is intermittent, being done early and at later strategic times. However, there are also nearly continuous 'dynamic mapping' techniques. Examples include stimulation through dissection tools during acoustic neuroma or brain tumor resection to provide early warnings of cranial nerve or CST infringement.

***Monitoring***

Monitoring consists of nearly continuous recordings assessing the ongoing functional integrity of at-risk neurological structures or pathways and is applicable to a wide variety of surgeries. Typically, one employs 'multimodal' combinations of EEG, BAEP, SEP, MEP and EMG methods strategically selected according to the surgical circumstances. Stable results provide confidence to continue, while deteriorating signals can prompt intervention to restore potentials and avoid injury, or decide a surgical stopping point.

**Comparison to diagnostic neurophysiology**

There are important differences between intraoperative electrophysiology and the diagnostic laboratory. In the lab, one compares a single recording to normative control data to diagnose and localize relatively static abnormalities. The environment is electrically quiet, the signal-to-noise (SNR) ratio and acquisition time are not critical and technical parameters must be standardized for valid comparisons. Lab recordings are relatively safe, normally requiring simple standard precautions. Interpretation is done after recording and can always be reevaluated.

In the operating room, one tracks dynamic changes in a series of recordings to quickly detect acute neuronal or axonal failures and reliably differentiate them from systemic or technical confounding factors. Effective monitoring requires rapid signal acquisition that depends on high SNR. The SNR is challenged by anesthetic signal reduction as well as the electrically noisy environment and EMG, ECG and EEG noise. Measures to maximize SNR include favorable anesthesia, low impedances, tight braiding of recording leads, selecting short inter-electrode distance recording derivations optimized to individual patient physiology, omitting noisy recording sites (e.g., frontal scalp, Erb's point, neck), omitting inherently low-SNR signals (e.g., subcortical SEPs), as well as judiciously restricted filter settings and troubleshooting extrinsic electromagnetic noise sources. High stimulus frequencies can also speed acquisition (e.g., 49.1 Hz for BAEPs). Since patients serve as their own controls, technical optimization can and should be done to individually maximize acquisition speed. There are additional safety concerns that require specific precautions to avoid shock, fire, electrical burns, hazardous stimulator output, invasive electrode complications, seizures, bite injury, movement-related injury, infection, needle-stick complications and essential performance failures. Finally, interpretation is immediate and has irrevocable consequences.

## The interpreter

Interpretation is the action of explaining meaning and for intraoperative electrophysiology, extends to guiding intervention when appropriate. Technical-level personnel can set up recordings, troubleshoot, acquire signals and recognize possibly adverse changes, but do not have the background needed for interpretation that requires a professional-level practitioner with broad in-depth expertise from extensive training and experience.

It is not enough to simply call an alarm because most surgeons do not know what it means or what to do about it. Instead, the interpreter decides and conveys the most likely cause of signal deterioration, and corrects confounding factors or suggests appropriate intervention accordingly. Thus, the interpreter shares responsibility for intraoperative diagnosis and management.

To optimize surgical results while avoiding neurologic deficits, one has to minimize both false positives that can interfere with surgery and false negatives that can miss neurologic injury. Thus, the interpreter carefully incorporates criteria that are neither overly sensitive nor specific for the particular surgical circumstances.

## Future directions

There is presently a great deal of research and development that will expand and improve the field. Training, credentialing and efficacy measures are some currently outstanding issues that need to be addressed.

## Conclusions

The goals of intraoperative electrophysiology are to optimize surgical results and avoid neurologic deficits. Effective intraoperative recordings include individual technical adjustments to optimize signal acquisition and specific measures to enhance safety. Immediate interpretation has irrevocable consequences and requires a professional-level practitioner able to assume clinical responsibility for intraoperative diagnosis and management considering both surgical and neurological outcome.

### Selected references


- Hussain AM, editor. A practical approach to neurophysiologic intraoperative monitoring. 1st ed. New York: Demos; 2008.
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## Safety Issues in the Operating Room

Jay L. Shils, PhD,
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USA

### Objectives

Safety for the intra-operative monitoring individual/team can be divided into three concerns: (A) the patient – outside of the monitoring goals; (B) the operating room personnel; (C) the IOM and operating room equipment. It is the goal of this lecture to describe each of these areas.

The patient:
IOM includes the placement of invasive recording and stimulating transducers that have the potential to inflict injury by either poor electronic isolation, improper connection to the patient potentially causing erroneous data, or a change in the medical status of the patient (i.e. infection, lacerations, burns …). Poor electronic isolation can potentially expose the patient to higher than normal currents in either the IOM electrodes touching the patient, or even other electrical conduits touching the patient such as from the cautery system. Proper electrical safety checks, even having the IOM recommend equipment checks for other system in the OR if a failure is suspected. The most likely cause of these electrical failures are: (1) stimulation or even recording isolation devices to fail allowing a direct pathway from the outlet power to the patient; (2) isolation failures that can cause ground loops to generate unwanted signals at the patient that have the potential to cause burns at high stimulation levels; (3) multiple grounds on the patient that can set-up unwanted ground loops causing similar issues; (4) ground failures in other IOM equipment connected to the patient that can cause unwanted energy to enter the IOM equipment.
Simple impedance test only tell you whether or not an electrode is in contact with the patient, not whether or not it is in the correct place. Improper returns can cause erroneous data by picking up large signals that can obscure the real signals. Finally, placing low signal level recording electrodes, wires, or amplifiers near equipment that can generate noise in frequency bands other than line noise, or even line noise, can obscure signals,even placing a masking signal that may mistakenly be interpreted as a real signal. Constant vigilance in the OR is necessary to minimize these affects because these change throughout the course of a case.
The operating room personnel:
The two biggest issues with the safety of the operating room personnel are the wires that go from the patient to the IOM equipment and the needles that many groups use for recording. A third, less common safety issue, but is an issue for the data is the potential for electrode wires to be knocked about or even disconnected by the surgeon or assistants. All wires, whether going from the amp and stimulation boxes to the IOM machine, or electrode wires should be neatly hidden under the patient or OR table or run in a neat way, trying to follow areas that are hard to walk over. The stimulator and the amplifier cables should be run in separate areas. OR personnel should be made aware of the cables and also the needles. If needles are placed prior to positioning or any time the patient is going to be moved with needles in place the OR team involved in that moving need to be informed of the needles.

IOM and operating room equipment:
In the United States all equipment that is brought into an operating room requires electrical isolation testing and ground safety checks. Some centers even require that any equipment removed from the hospital be checked every time it comes back to the hospital. This helps to minimize the potential for issues stated above. In addition all equipment needs to be cleaned at the end of every case even if no visible contaminates are noticed. Equipment should be visually inspected, especially boxes placed on the OR table or near the patient for any points where fluid may enter the electronics. Any fluid entering the device my cause a device failure by causing a short circuit in the system. Also, many of the newer devices have complex circuitry in the boxes that are placed near the patient so overheating if the device is covered for a long time can occur.

### Conclusion

Better isolation and failure detection circuitry have helped to minimize the serious electrical failures, but they have not eliminated them thus it is critical for the IOM team to be as vigilant to safety of the equipment and OR staff as they are to the protection of the patient.

#### Key references


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## Neurophysiological Mapping in Neurosurgery

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### Objective

To define and describe the different electrophysiological techniques of mapping in neurosurgery.

### Recent Clinical and Research Developments

The most direct way that intraoperative neurophysiological recordings can guide the surgeon in an operation is in identifying a specific neural structure. The methodology for the rapid anatomical identification of these neural structures by electrical stimulation is known as mapping.

Neurophysiological mapping is used in many types of surgeries and provides reliable information about the location of different neural tissues. It can be applied in brain, brainstem, posterior fossa, spinal cord and peripheral nerve surgeries. In most of those pathologies it is necessary the combination of "mapping" and "monitoring" techniques since mapping does not offer information on real-time about the functional integrity of the neural structures involved in the surgical procedure. If the surgeon needs to identify neural tissue, he/she is going to stop what is doing to stimulate over the surgical field. Therefore it is needed the use of monitoring techniques which provides real time information through the whole surgery.

### *Bipolar vs Monopolar Stimulating Electrodes*

The use of bipolar stimulating electrode will result in a greater selectivity but a bipolar stimulating electrode is more difficult to use and its ability to stimulate a neural structure depends on its orientation. In short, a bipolar stimulating electrode is preferable if the purpose is to identify each one of two closely located nerves that are clearly visible, but a bipolar stimulating electrode is not suitable for searching for the location of a neural tissue. In this case it will be preferable a monopolar stimulator.

### *Mapping techniques in Neurosurgery*

BRAIN SURGERY IN THE CENTRAL REGION AND ALONG SUBCORTICAL MOTOR PATHWAYS:

a) Phase reversal

   This technique is useful to point out the location of the central sulcus. The classic triphasic negative-positive-negative configuration of the early components of median nerve SEPs with N20 over the sensory cortex changes shape into a mirror image with N20 becoming P25 over the motor cortex.

b) Direct cortical and subcortical mapping (with the "60Hz" or the multipulse technique)

   In 1937 W. Penfield described a method for the anatomical identification of functional areas in the motor cortex (mapping of cortical motor areas). It is used a bipolar stimulation, 60 Hz repetition rate and the stimulus is kept for a couple of seconds over the cortex. The response is a tonic movement of the muscle or group of muscles represented in the stimulated area. The main limit In 1993 M. Taniguchi describe another method to stimulate the motor cortex. It is used a monopolar stimulation, and consists in a short train of stimuli, ISI 4 ms.The response is a motor evoked potential. This method has several advantages over the Penfield technique; first it produces less epileptic seizures (up to 5% in asleep patients) and second it allows to continuously monitoring the functional integrity of the corticospinal tract (CT) during the surgery.

   Both methods are also used for subcortical mapping. The objective of the subcortical mapping is to have a feedback about the proximity to the CT during the tumor resection.

BRAIN SURGERY IN SPEECH AREAS

a) Direct cortical mapping

   a. Awake (see table 1)

   b. Asleep (see table 2)

Table 1.

| MAPPING OF ELOQUENT AREAS OF THE BRAIN IN AWAKE PATIENTS | | |
|---|---|---|
| Area | Penfield | Short Train of stimuli |
| MOTOR | TONIC MOVEMENT | MEP |
| SENSORY | PARESTHESIAS | Non applicable |
| LANGUAGE | Speech arrest, paraphasias, slow peech | Speech arrest+LLR* |

*LLR: long latency response identified in phonatory muscles

Table 2.

| MAPPING OF ELOQUENT AREAS OF THE BRAIN IN ASLEEP PATIENTS | | |
|---|---|---|
| Area | Penfield | Short Train of stimuli |
| MOTOR | TONIC MOVEMENT | MEP |
| SENSORY | Non applicable | Non applicable |
| LANGUAGE | Non applicable | LLR |

POSTERIOR FOSSAAND BRAINSTEM SURGERY

a) Direct mapping of motor nuclei of the cranial nerves in the floor of the fourth ventricle

Brainstem mapping (BSM) is an intraoperative neurophysiological method to localize cranial motor nuclei (CMN) on the floor of the fourth ventricle.

BSM enables the neurosurgeon to understand functional anatomy on the distorted floor of the fourth ventricle; thus, it is emerging as an indispensable tool for challenging brainstem surgery.

b) Direct mapping of the CT within the cerebral peduncle

The objective is to have a feedback about the proximity to the CT during the tumor resection. It is used a monopolar stimulator with a reference electrode in the cervical muscles or in the surgical field.

c) Direct mapping cranial nerves

As described in the introduction can be used monopolar or bipolar stimulation. It will preferable to use bipolar stimulator if the nerve is visible and we want to be selective in stimulation and monopolar stimulator if we are searching for the nerve.

SPINAL CORD SURGERY

a) Dorsal column mapping

In order to be able to offer guidance to surgeons in performing myelotomy in the midline, it is attempted to identify neurophysiological features on the exposed dorsal cord surface using conducted potentials. Prior to mielotomy the surgeon placed a miniature multielectrode on the exposed dorsal cord surface approximately at the midline and according to available anatomical landmarks. This multielectrode is highly selective for recording spinal SEPs from the dorsal surface of the exposed spinal cord (figure 1).

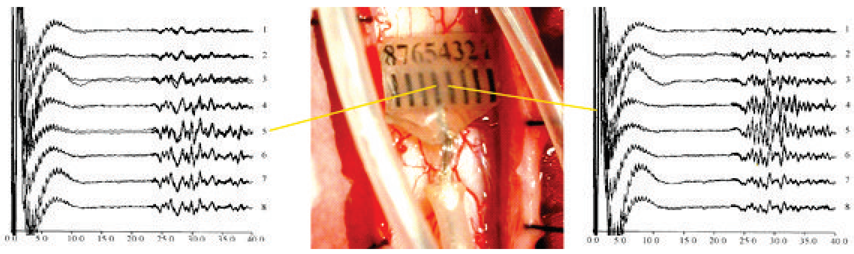


Figure 1. Dorsal column mapping in a patient with syringomyelic cyst between C2 and C7 segments of the spinal cord. The pictures shows placement of miniature electrode over surgically exposed dorsal column. SEPs after stimulation of the left and right tibial nerves showing maximum aplitude between recording sites 4 and 5 (left and right). These data strongly indicate that midline of spinal cord is between these two sites.

CONUS-CAUDA EQUINA

a) Pudendal roots mapping

b) Motor roots mapping

RHIZOTOMY FOR RELIEF OF SPASTICITY

a) Pudendal Dorsal Roots Action Potentials (DRAP) mapping

In the treatment of spasticity, the sacral roots are increasingly being included during rizhotomy procedures. In order to spare sacral function, it is important to identify those sacral dorsal roots that are carrying afferents from pudendal nerves. To do this it is used the DRAPs. The electrical stimulation is applied over the clitoris or penile nerves and the DRAPs are recorded by a hand-held sterile bipolar hooked electrode placed on dorsal sacral roots.

b) Motor roots mapping

PERIPHERAL NERVE

a) Nerve to nerve conduction

Intraoperative recordings of compound nerve action potentials (CNAPs) can provide quick, reliable information on the status of peripheral nerves at the time of surgery. The surgeon confronted by a neuroma in continuity has difficult decisions to make. He must determine the status of the nerve and judge its potential to recover at the time of the surgery. The CNAP has been found useful tool towards this goal.

b) Fascicular mapping of the nerve

It is used as a guiding method to select the nerve branch or fascicles for transfer. Nerve transfer, sometimes termed "neurotization", refers to the use of all or portion of a functioning nerve to restore crucial missing function by transfer to a specific motor or sensory target nerve.

**Conclusion and "take home message"**

1- Mapping techniques allow a rapid anatomical identification of neural structures

2- The optimal strategy for intraoperative neuromonitoring in neurosurgery consists in the combination of mapping and monitoring techniques.

**Key References and Recommended Reading**


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# Motor evoked potentials

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## Objectives

The corticospinal tract consists of a bundle of descending fibers that connects the cerebral cortex to the spinal motor neurons and its destruction produces permanent weakness. Motor evoked potentials (MEPs) are electrical signals recorded from neural tissue or muscle following activation of central motor pathways.

## Brief historical review and methodology

The use of intraoperative neurophysiological monitoring to reduce the risk of neurological function is based on the knowledge that the functions of the nervous system is changing in a measurable way before nonreversible damage occur. Therefore reversing the surgical manipulation will aid to recover, whereas if not any intervention is taken, there will be a risk of a permanent postoperative neurological deficit.

Although the origin of muscle MEPs monitoring dates to the 1870's, Taniguchi et al. made a major breakthrough in 1993, by discovering that brief pulse train direct cortical stimulation (DCS) evokes muscle MEPs under anesthesia, thus allowing motor cortex mapping and monitoring during brain surgery.

A single-pulse stimulating technique elicits corticospinal tract activity by a single pulse stimulation of the motor cortex while descending volley of the corticospinal tract is recorded over the spinal cord as *D wave*. The *D wave* reflects the direct activation of the pyramidal cell axons arising from the cortex and following volleys, also called Indirect waves or *I waves reflects* activation of these pyramidal neurons by synaptic transmission from activated cortical interneurons (1).

A multipulse stimulating technique involves a short train applied over the motor cortex while muscle MEPs from limb muscles in the form of compound muscle action potentials (CMAPs) are recorded (2). This train stimulation is widely applied as 5 to 7 stimuli with an interstimulus interval of 2 to 4 ms (equal to 500-250 Hz) and 0,5 ms duration. The basic mechanism of muscle MEPs generation is temporal and spatial summation of lower motor neuron excitatory postsynaptic potentials.

Monitoring the central motor pathways directly is mostly accomplished using transcranial electrical stimulation (TES) of the brain and recording of evoked neural or myogenic activity caudal to the area that is at risk during surgery. If the craniotomy permits direct stimulation of the motor cortex by using a probe or strip electrodes, direct cortical stimulation (DCS) can also be used to elicit muscle MEPs. Constant voltage stimulation is commonly used, although controlled current is preferable being less dependent on impedance (3).

The electrode placement on the scull is based on the international 10-20 EEG system. Spiral" corkscrew" needles are commonly used for TES because of their secure placement and low impedance One array is C3, C1, C2, C4, Cz-1cm and Cz+6cm (4). Anodal stimulation of the MEPs gives better results when applied on the scalp and cortex, whereas cathodal stimulation are preferred during subcortical stimulation (5).

Inter-hemispheric montages are C1/C2 and C3/C4 and they evoke arm, leg and sphincter MEPs but are not suggested in monitoring facial MEPs because of confounding facial nerve excitation (6). Direct cortical and subcortical stimuli are most commonly applied with a monopolar electrode and a reference electrode is placed on the scalp (5). When TES is applied to intracranial surgery, widely spaced stimulating electrodes and unnecessary high intensity promoting deep activation should be avoided. To avoid this problem DCS through subdural strip electrodes has been advocated (7).

Recording MEPs from the muscles is widely done with subdermal needle or hookwire electrodes(4). Bite injuries are the most common pulse train complication and should be avoided with bite block in the mouth. Electrical stimulation of the brain can trigger seizures. However many conditions such as epilepsy, elevated intracranial pressure, cerebral lesions are not considered as contraindication for TES and patients with similar underlying conditions had uneventful neuromonitoring (8)

D wave preservation during surgery provides good evidence that the corticospinal tract is intact. The warning criteria for intramedullary spinal tumor surgery is 50% peak to peak amplitude reduction of the D wave. Patients in whom D waves are lost or attenuated by more than 50% during intramedullary spinal cord tumor surgery generally suffer permanent weakness (9).The amplitude reduction, due to intrinsic variability of the M waves, is usually not an appropriate alarm criterion as it would cause too many false positive alarms (10)

In spine surgery presence or disappearance (all or nothing) of MEP criteria is commonly accepted. In cervical and intramedullary surgery additional information can be obtained by recording D waves from the epidural spinal compartment. Other alarm criteria have been used during M wave monitoring including an increase in threshold stimulus intensity (11).

### Conclusions

The methodology for monitoring the functional integrity of the corticospinal tract came out as a reliable, fast and a simple tool. Multipulse-train and single-pulse MEP monitoring techniques provide reliable data which highly correlate with neurological outcome postoperatively.

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## Day 9 - Introductory Course Part II: 17h30 - 19h15

# Auditory Evoked Potentials and their Application in Monitoring of the Auditory Pathways

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### Objectives

This presentation is to give an overview of the neural substrates and neurophysiological bases of auditory evoked potentials and provide an introduction of using these auditory potentials to monitor the function of the auditory pathways during surgery.

### Introduction

Auditory evoked potentials (AEPs) are electrical manifestations of activation of the auditory system in response to transient sound stimuli. Among them, Brainstem Auditory Evoked Potentials (BAEPs) and Auditory Nerve Compound Action Potentials (AN-CAPs) are commonly used in the clinical laboratory and the operating theatre.
Following the first report on BAEPs by Sohmer and Feinmesser[1], Jewett and colleagues[2] clearly described the waveform of human BAEPs and correctly interpreted the late waves of BAEPs as arising from the brainstem structures in the early 1970's. The clinical application of BAEPs came along shortly after. In 1975, Starr and Achor[3] were among the first to demonstrate the relationship between BAEP abnormalities and neurological disorders. In the late 1970's, techniques of BAEPs were taken into the operating theatre aimed at improving hearing preservation during surgical removal of vestibular schwannomas[4]. In 1983, Moller and Jannetta[5] recorded CAPs directly from the exposed cranial nerve VIII during cerebellopontine (CP) angle surgery. Available evidence supports the conclusion that AEP monitoring improves hearing preservation during CP angle procedures for resection of vestibular schwannomas and microvascular decompression of cranial nerves[6,7].

### Description of Auditory Evoked Potentials

*BAEP:* The BAEP is a series of electrical waves generated in the auditory nerve and the ascending auditory brainstem pathway in response to transient acoustic stimuli (e.g. clicks). It is recorded from an electrode at the vertex referenced to the mastoid or the ear lobe. In normal subjects, it consists of 5 - 7 vertex positive peaks designated with the Roman numerals, and falls within 10 milliseconds after the stimulus (Fig. 1). Among these peaks, waves I, III and V are most stable and prominent and therefore are usually measured for clinical use.

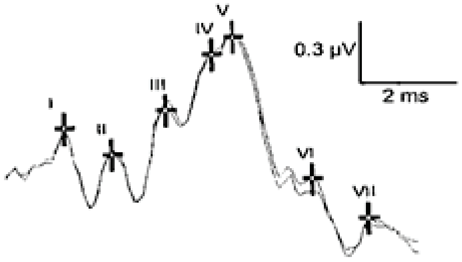


Fig. 1 A BAEP waveform recorded from a normal subject after averaging of 3000 individual trials. Stimuli: clicks of 70 dB HL; Recording montage: ipsilateral earlobe Ai (-) – vertex Cz (+).

*AN-CAP:* The AN-CAP is exclusively recorded intraoperatively from the electrode placed on or in close vicinity to the exposed proximal auditory nerve. It is a measure of signal conduction along the auditory nerve and usually has a triphasic waveform (Fig. 2). The depolarization front of the nerve generates the P1 potential and the large negative N1 is produced when the depolarization passes under the recording electrode.

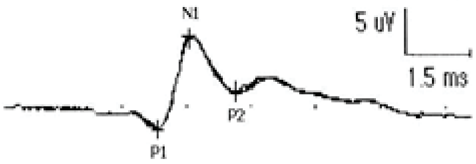


Fig. 2 Auditory nerve CAP recorded directly from the intracranial portion of cranial nerve VIII. Note the high-amplitude response which was obtained after averaging of 50 trials.

To better understand auditory evoked potentials and their application in neuromonitoring, knowledge of the anatomy of the ascending auditory pathway and the neural generators of these potentials is essential.

**Anatomy of the Ascending Auditory Pathway and Neural Generators of BAEPs**

The ascending auditory pathway begins with auditory nerve fibers leaving the cochlea, passing through the spiral ganglion and forming a nerve bundle in the internal acoustic canal (IAC) where it merges with the vestibular nerve to become the eighth cranial nerve. Together with the facial nerve, the eighth nerve exits the IAC through the porus acousticus and transverses the subarachnoidal space in the CP angle to enter the brainstem at the pontomedullary junction.

Neural elements in the ascending auditory brainstem pathway include the cochlear nucleus (CN), the superior olivary complex (SOC), the lateral lemniscus (LL) tracts and nuclei, and the inferior colliculus (IC), which are arranged in a "hierarchical" order (Fig. 3). Obviously, the auditory brainstem pathway is bilateral with connections of nuclei between two sides at almost all levels and incorporates complex parallel processing. These features make it unlikely that there is a one-to-one relationship between the brainstem structures and individual BAEP waves. In fact, all but the earliest waves (i.e. waves I and II) in the BAEP arise as a composite of electrical activities from multiple sources.

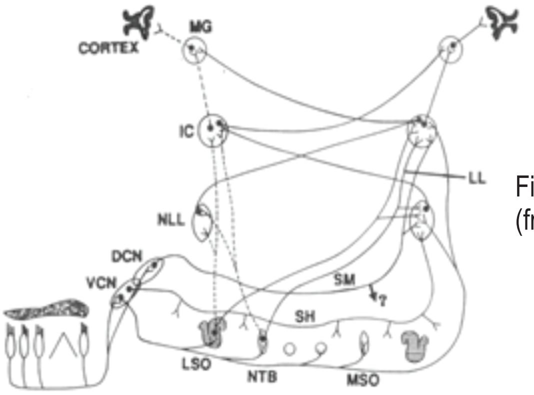


Fig. 3 Schematic drawing of the ascending auditory pathway (from Moller 1983)

Waves I and II are generated in the distal and proximal auditory nerve, respectively. Wave III is generated in the CN and the SOC in the lower pons. Less is known about Wave IV, but bilateral SOC and LL are among its contributors. Wave V also has multiple sources and is believed to be generated in the LL and the IC of both sides.

**Clinical Utility of BAEPs**

Interpretation of BAEPs in a clinical lab usually involves measuring the absolute latency of waves I, III and V, their interpeak latencies (i.e. IPL I-III, IPL I-V, and IPL III-V) and interaural differences, and comparing them with normative data. Although BAEPs have long been used to investigate patients with possible multiple sclerosis and other neurological disorders, and lesions of the CP angle and the brainstem, their diagnostic roles have gradually been replaced by the development of neuroimaging techniques (e.g. MRI). Owing to their properties of being objective and minimally affected by anaesthetics or the state of consciousness, however, BAEPs have found their utility in the operating room as a monitor of the ascending auditory pathway and in the intensive care unit as a prognostic indicator.

**Monitoring of Auditory Evoked Potentials**

Surgical procedures involving the CP angle and other areas of the posterior fossa pose risks of injury to the auditory nerve and sometimes brainstem structures, resulting in postoperative hearing loss and other associated neurological deficits. AEPs provide objective methods to monitor the function of the auditory nerve and brainstem auditory pathways, and have been used during these surgical procedures to help preserve hearing and minimize the risk of postoperative neurological deficits[4,5,6].

During surgery, many factors can cause AEP changes, which include technical, systemic and surgical. Only after confounding factors are excluded, can changes of AEPs be attributed to surgical manipulations. Consequences of surgical manipulation that can compromise the auditory pathway and lead to intraoperative AEP changes include direct mechanical or thermal injury and ischemia. Although some AEP changes resulting from mechanical trauma or thermal injury of the auditory pathway are rapid and irreversible, detection of these changes can potentially prevent more damage to the surrounding neural tissues. In the case of compression, traction or ischemia of the auditory pathway, the resulted AEP changes are usually gradual and reversible. Early detection of these changes and subsequent application of corrective measures may restore the normal function to the neural structures affected, leading to improved outcome.

Commonly used warning criteria include 50% amplitude decrease and/or 10% prolongation of latency of wave V. However, since the BAEP is relatively insensitive to alterations of anaesthesia, any consistent changes exceeding normal variability should be given serious consideration. On the basis of our current understanding of the neural generators of BAEPs and the pattern of BAEP changes, the locus or loci of dysfunction in the auditory pathway may be roughly inferred.

The primary goal of AEP monitoring is to detect functional changes of the auditory pathways and provide early warning to the surgeon before they become irreversible. Each AEP technique has its own advantages and limitations. Their intraoperative application depends on the status of preoperative hearing, the pathology, and the location/size of the lesion. When deemed suitable, the BAEP alone or combined with the AN-CAP can be monitored during surgery to provide timely and accurate information about the function of the auditory pathways and improve postoperative outcome.

## Summary

It is crucial to understand the anatomy and neurophysiology of AEPs in order to appreciate their clinical and intraoperative applications. Although their value in the assessment of certain neurological disorders has faded away due to the advances in neuroimaging techniques, AEPs have found their utility in the operating room. During monitoring, examination of the pattern of AEP changes, investigation of possible contributory factors and correlation of the changes with surgical maneuvers can help determine the underlying causes and provide the correct interpretation.

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**Recommended Reading**

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## Cranial Nerve Monitoring: Corticobulbar Motor Evoked Potentials

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### Objective

To describe the methodology for monitoring the functional integrity of the corticobulbar tract for the different cranial motor nerves.

### Recent Clinical and Research Developments

Historically, the first intraoperative neurophysiologic methodology for the study of cranial motor nerves (CMN) was intraoperative identification of these nerves by electrical stimulation with a hand held probe (mapping). This method was first applied for mapping the facial nerve because of the high incidence of loss of facial function in operations for acoustic neurinoma. These techniques came into general use in operations in the cerebellopontine angle during 1980's. Subsequently methods for intraoperative monitoring of several other CMN were introduced.

Despite advantages in preventing injury by intraoperative mapping the CMN, this methodology can only be used if the nerves are exposed, or if surgery is performed around the nerves' anatomical location. Furthermore, mapping can be performed intermittently and cannot be used for continuous monitoring.

In order to overcome the mapping technique shortcomings in CMN, a methodology has been developed to continuously monitor the functional integrity of the CMN by eliciting corticobulbar motor evoked potentials (CoMEPs) in the cranial motor nerves innervated muscles. Dong et al. were the first to describe a methodology for continuously monitor the corticobulbar tract (CBT) for the facial nerve by eliciting facial motor evoked potentials with transcranial stimulation during skull base surgery (Dong et al., 2005). Deletis et al., 2009 described methodology for continuous monitoring of CBT for vagal nerves. The method for intraoperative monitoring CBT for other CMN has not been yet described.

In its anatomical definition, the CBT is formed by axons that are homologous to corticospinal fibers, but terminate in the motor nuclei of the cranial nerves in the brain stem (e.g., nuclei V, VII, IX, X, XI and XII). Thus, they are the axons of the upper motor neurons that synapse on the lower motor neurons of the cranial nerves. The corticobulbar fibers accompany the corticospinal axons through the internal capsule and cerebral peduncle and then gradually leave the corticospinal tract to enter the tegmentum of the pons and medulla to terminate in the different CMN nuclei.

### Methodology

Previous experience with transcranial electrical stimulation (TES) in anesthetized patients has shown that temporal summation of multiple descending volleys is necessary to activate lower motor neurons (Taniguchi et al. 1993). Therefore it is necessary to use a short train of electrical stimuli to activate CBT and to record CoMEPs from the innervated muscles by each CMN.

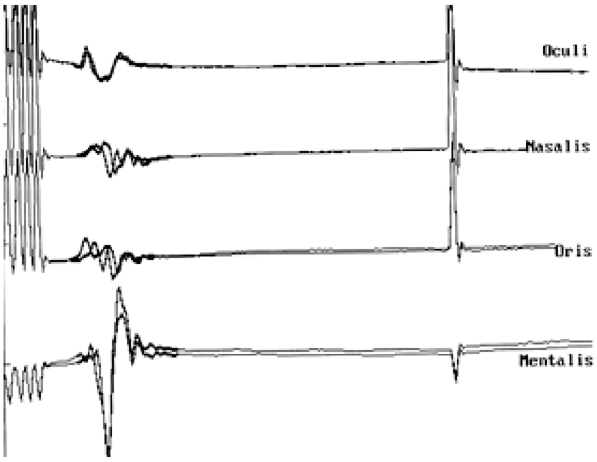
a) Stimulation Parameters

It was used transcranial electrical stimulation consisting of a short train consisting of 3 to 5 stimuli with 0.5 ms duration each. These stimuli are separated by 2 ms interstimulus interval, with a train repetition rate of 2 Hz and an intensity of up to 120 mA. The montage is C3 (+) vs. Cz (-) for left hemispheric stimulation and C4 (+) vs. Cz (-) for right hemispheric stimulation. Ninety milliseconds after the train we delivered a single stimulus over the same stimulating montage. The rational for this kind of stimulation is the fact that in most patients under general anesthesia only a short train of stimuli can elicit “central” responses generated by the motor cortex or subcortical part of CBT. If a single stimulus elicits a response, this should be considered a “peripheral” response that activates the CN directly (Dong et al., 2005; Ulkatan et al., 2007). Electrical stimuli are delivered through subcutaneously placed corkscrew electrodes over the scalp (CS electrode, Viasys Healthcare WI, MA, USA). The intensity of TES is determined when CoMEPs that appear in the muscles are equal to or 10 to 20 mA higher than the set threshold for eliciting MEPs in the contralateral abductor pollicis brevis muscle.

b) Recording Parameters

To record CoMEPs from the different muscles we use two hook wire electrodes and each consisted of a teflon coated wire 76 μm in diameter passing through 27 gauge needles (hook wire electrode, specially modified, Viasys Healthcare WI, MA). The recording wires have stripped 2 mm from Teflon isolation at the tip and are curved to form the hook to anchor them in the muscle after the needle is withdrawn. The impedance of electrodes was below 20 Kohl. When the patient is intubated, two electrodes are inserted in each muscle. After inserting the wire electrodes in the muscles, wires are twisted and needles are withdrawn and covered in order to protect the patient from a possible accidental injury. The intensity of TES was adjusted at the level of maximal amplitude of CoMEPs (suprathreshold intensity). Depend of specific surgeries; recordings are performed from the following muscles:

- V CN (Trigeminal): Masseter muscle.
- VII CN (Facial): Frontalis, Orbicularis Oculi, Nasalis, Orbicularis Oris, Mentalis muscles. (see figure 1)
- IX CN (Glossopharyngeal): Posterior wall of oropharynx.
- X CN (Vagal): Vocal cord or cricothyroid muscle.
- XI CN (Accesori spinal): Trapezius muscle.
- XII CN (Hypoglossal): Lateral side of the tongue.



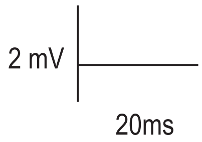




***Figure 1.*** *Example of CoMEPs for the facial nerve. The responses were obtained after the train of stimuli but not after single stimuli from each muscle innervated by different branches of the facial nerve.*

The methodology for eliciting and recording CoMEPs allows for continuous monitoring of the functional integrity of the corticobulbar tract from the motor cortex to the neuromuscular junction. Furthermore recording from the different muscles innervated by the CMN can be used in the different types of surgeries where, either the upper motor neuron (CBT) or the lower motor neuron, including the motor cranial nerve nuclei, the cranial nerves and the muscles innervated by them, could be damaged during the procedure. It is therefore that CoMEPs monitoring can be used in supratentorial surgery, skull base, brain stem, and face and neck surgeries. In our ongoing study the monitorability rate is 100%.

**Future Questions and Directions**

It is a difficult task to establish criteria for predicting the clinical outcome for these patients. In our experience we have observed that if CoMEPs are preserved through the surgery till the end, no motor deficit will exist, while if CoMEPs decrease in amplitude more than 50% compared with the baseline recordings the patient could have slight motor deficit, in most of the cases transient. When CoMEPs are lost at the end of the surgery the outcome is a severe or complete motor deficit for the particular cranial nerve. In few occasions after an intense surgical manipulation of the cranial nerves the CoMEPs might temporarily disappeared. We have observed that many times parameters of the responses come back to normal before the surgery ended. A temporary axonal block might explain this phenomenon after the nerve manipulation and this is the reason why CoMEPs monitoring should be done until the end of surgery, in order to avoid false positive results.

**Conclusion**

To conclude, the corticobulbar tract monitoring offers on line information about the functional integrity of the upper and lower motor neuron for cranial nerves and can predict their outcome with sufficient accuracy.

**Key References and Recommended Reading**

**(See Recent Literature and "Neurophysiology and Neurosurgery" a Modern Intraoperative Approach, edited by Vedran Deletis and Jay L. Shils. )**

**Take home message**

The corticobulbar tract monitoring for the different cranial motor nerves offers on line information about the functional integrity of the upper and lower motor neuron for cranial nerves and can predict their outcome with sufficient accuracy. The optimal strategy for intraoperative neuromonitoring the cranial nerves in neurosurgery consists in the combination of mapping and monitoring techniques.

**Modern Literature**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## Anaesthesia for Neurophysiological Monitoring

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**Objectives**

To review an overview of the anesthetic effects on neurophysiological monitoring modalities during varieties of surgical procedure.

**Brief historical review**

Early on, during the introduction of early monitoring modalities, it was obvious, what works in the laboratory did not work well in the operating room, which required the involvement of anesthesiologists to modify the anesthetic techniques and enable monitoring.(1)

**Summary of recent developments and/or future directions**

The basic requirements of anesthesia during surgery are; analgesia, amnesia, loss of conscious and immobility. Different anesthetics influence basic requirements differently. Different patients require different anesthetics and different surgeries involve different plans. Optimal anesthesia during IOM is a balance among these factors.

Patient's nervous system evolves overtime and the anesthetic effects vary from stage to another. While the immature nervous system, during childhood, is influenced by anesthetics such as inhalation agents, mature vibrant adults with a strong nervous system can tolerate the use of such agents that cannot be used in very young children. At later stages of life, especially if compound with medical systemic problems, the nervous system is influenced, again, by many anesthetics agents, especially inhalation agents. Therefore such agents should be chosen wisely to minimize their effects on neurophysiological monitoring. Patients at all ages who have narcotic dependency may require very large doses of narcotics which may require modifications in anesthesia during monitoring and the need to use adjunct medications that may have antinociceptive effects. (2-4)

Neuronal functions are set by varieties of circuits run by numerous receptors which are influenced differently by medications. (5) Some receptors such as GABA influence unconscious and amnesia while others such as opioid receptors affect analgesia and other receptors affect immobility such as the glycine receptors.

Surgeons require a still unmoving target to perform surgery, patients' wants surgery to be done free of pain and without knowledge of what is happening while the neurophysiologist wishes for anesthetics that do not interfere with monitoring. To achieve these goals the anesthesiologist has to strike a balance between all of such needs. Also, the anesthesiologist's challenges are widened to include; type of surgery, position of the patient, age of the patient in addition to the limitation of each drug. Therefore there is a need to optimize anesthesia, balance of differences while keeping the safety of the patient at the forefront.

To reach such goals, anesthesiologist needs to optimize anesthesia by utilizing multiple medications while minimizing side effects. Since there is no single medication can achieve all anesthetic goals, a combination of medications is needed. The combined medications may be associated with additive or synergistic effects and need to be taken in considerations when such agents are added.

Narcotics can achieve one of the main goals of anesthesia, namely analgesia. Narcotics does have synergistic effects with other agents used during anesthesia such as propofol therefore the amount of medications should be observed and calculated carefully. Higher doses of narcotics will lower the need for other agents. Bolus injections may affect IOM and need to be avoided in favor of continuous infusion. The use of infusions of the short acting narcotic agents will have the advantage of early wake up time and easier wake up testing.

The use of inhalation agents should be limited to half MAC and avoided in certain patients at extreme ages and/or with multiple systemic medical problems which may have affected neuronal functions. The use of inhalation agents in such low concentration provides amnesia, support immobility and provide a safety backup in case of interruption of intravenous medication by dislodge of the cannula or kinking of the intravenous line.

Anesthesiologist's contribution to IOM is not limited to provide optimal anesthesia, but extends to contribute to differential diagnosis during episodes of IOM changes and to support neuronal function during such time of neuronal stress by preserving tissue oxygenation. Tissue preservation is optimized by oxygenation, ventilation and circulation through raising blood pressure and adjusting other parameters.

### Conclusions

Knowledgeable anaesthesiologist and continuous interaction with members of the IOM team during neurophysiological monitoring is essential to optimize conditions that may lead to the desired outcome during monitoring of surgical patients.

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## New Developments in Neuroscience that relate to Neurosurgery

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Research regarding organization and function of the spinal cord and the brain continue to unveil fascinating aspects that were not imagined just a few decades ago. Many of these new developments have directly or indirectly implications for how surgical operations are performed and for intraoperative neuroscience. Many developments in basic neuroscience have their roots in neurosurgery and observations done during performing neurosurgical operations have provided information about both normal and pathological functions of the central nervous system. Research that is made possible during neurosurgical operations has contributed to basic neuroscience.

The main purpose of this presentation is to describe some important new developments in neuroscience. The presentation also provides a brief history of the development of neuroscience. I will discuss the implications and importance of recent finding for understanding some of the normal functions of the brain and how brain functions are altered in some diseases where the symptoms are generated in the brain.

The human brain is the most complex structure known to man. The complexity of the brain can only compete with that of the universe. The brain is a giant information processor that can extract useful features in many forms of sensory signals. The brain is also a controller of complex motor systems and the site of human creativity and consciousness. It has enormous memory capacities, estimated to be in the size of 2.5 petabytes (2,500 terabytes).

Neuroscience, the study of the brain and other parts of the nervous system, developed first slowly and then at a rapid pace. Similar to research in many other areas, research in neuroscience was driven by people's curiosity and ingenuity from its beginning; not until relatively recently have the results of neuroscience studies found practical use in developing methods for treatment of people with disorder of the nervous system.

That era of neuroscience more or less started with the work of Francis Bacon (1561-1626) who is credited for having introduced experiments in studies of biology. He advocated a critical view on old science. Of other important discoveries it is worth mentioning that Francois Magendie (1783-1855), discovered that sensory information enters in dorsal spinal roots while motor information exits in ventral roots. Later the Russian physiologist Ivan Sechenov (1829-1905) discovered inhibitory synapses. More recently, experimental work by Charles Sherrington (1857-1952) provided a major increase in knowledge concerning many basic functions of the CNS. Sherrington is often regarded to be the father of modern neurophysiology. Specifically, he studied spinal reflexes and described the action of the synapse. He also emphasized the importance of how different cortical areas of the brain interact with each other. The Hungarian anatomist J. Szentágothai (1912-1994), made use of the then newly developed electron microscope to describe the structure of the synapse. Later the Australian neurophysiologist John Eccles, (1903-1997) and the American neurophysiologist Eric Kandel (1929-) studied some of the basic functions of synapses including the role of synapses in memory storage.

Modern neuroscience may be regarded as having two main parts, one that study how systems in the brain are organized, work and interact, known as systems neuroscience. The other branch is the study of the biochemistry (molecular biology) of nerve cells and other cells in the central nervous system.

Recent development in systems neuroscience includes new methods for studies the anatomy of connections (axons between cells in different structures) as well as the functions of these anatomical connections with regards to the strength of the connections. The function of the connections that axons make depends on the efficacy of the synapses that connect the axons from one nerve cell to another. Newly developed technologies have made it possible to identify which anatomical connections are functional and to what degree. Anatomical connections have been studied for many years but studies of functional connections have only been possible recently when new techniques were developed.

The techniques for studying the neuroanatomy of the central nervous system used earlier were limited to histological staining and light microscopy. These techniques produced just a two-dimensional view. A recently introduced method, diffusion magnetic resonance imaging (MRI), makes it possible to study the structural organization and connectivity of the human brain in more detail. Diffusion MRI and new tractography techniques, in particular, have been used to probe the architecture of both white matter (nerve fiber tracts) and gray matter (clusters of nerve cells) in three dimensions. Tractography offers 3-D modeling that can be used to visually represent neural tracts using data collected by diffusion tensor imaging (DTI) a special techniques that uses MRI, together with computer-based image analysis.

Understanding of some of the complex functions of the central nervous system has enriched many people's lives and continues to do so. Leonardo da Vinci stated: "The noblest pleasure is the joy of understanding." New hypotheses and serendipitous observations have contributed to many important discoveries. We now have prospects of tangible public benefits from research on the central nervous system. The increased knowledge and understanding of the functions of the central nervous system acquired has already been beneficial to many people through development of new treatments of various diseases; it has made it possible to improve surgical procedures and in particular to reduce the risk of neurological deficits from intraoperative injuries.

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## Day 10 - Session I: 08h00 - 12h00
## Why do we need IOM in brain tumor surgery?

### Functional Neuroanatomy of the Brain (Cortex and Tracts)

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The brain is remarkably beautiful and a delicate structure. The main target of the study of microsurgical anatomy is to perform gentle, precise and accurate neurosurgery and to be able to navigate safely around ando through the cortex and the tracts whithin white matter.
Although the traditional topographic neuroanatomy is essential for neurosurgical technique performance, its functional interrelationship is crucial for mantaining patient`s function of eloquent brain areas, even if it would be necessary to be surgically approached.
Nevertheless, thoroughly knowlegde of the cortex areas and the tracts, which should be used by neurosurgeons as surgical pathways, makes the difference between failure and success applied to our patients.

# Why Do We Need Intraoperative Neurophysiology in Brain Tumor Surgery in Motor Areas?

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With the increasing strive for complete resections of supra-tentorial low (LGG) or high-grade gliomas (HGG) the necessity for intraoperative electrical stimulation methods to map and monitor functional important cortical or subcortical brain areas increased. While many brain functions can be assessed during awake surgery and electrical stimulation mapping, motor function can be mapped and monitored in the asleep patient.

While for LGG years ago a defensive “watch and wait” strategy was often adopted, data accumulated supporting early maximum resection to improve quality of life and oncological prognosis (Capelle 2013, Jakola 2012, Smith 2008). An aggressive surgical therapy using supra-marginal resections and re-resections of recurrent tumors is nowadays followed by an increasing number of centers (Martino 2009, Yordanova 2011). Similarly, for HGG current literature data promote a maximum possible resection to improve overall survival. Resection limits are controlled by postoperative MRI and even small remnants are potentially re-operated (Sanai 2011, Stummer 2008). Furthermore, re-operations for recurrent HGG are increasingly supported by an improved survival (Bloch 2012, Quick 2014).

However, in the pursuit of a maximum resection, patient neurological outcome and the resulting quality of life needs to remain in focus leading to the aim of safety. This is challenged in tumors were functionally important structures, so called eloquent brain areas, are reached and a resection would carry the surgeon to these areas with impending neurological deficits by ischemia or direct surgical damage. Moreover, the dogmatic assumption that tumoral tissue could not retain function has been repeatedly questioned by neurophysiologic and functional magnetic resonance imaging studies, especially when dealing with LGG (Ojemann 1996, Skirboll 1996).

Therefore, intraoperative electrophysiological techniques to map and monitor critical brain functions have been developed, which aim to guide tumor resection to a maximum without hampering patients´ neurological functions.

Although intraoperative electrophysiological stimulation gains increasing interest and the majority of tumor surgeons are convinced of its indispensable value, criticisms remain as whether intraoperative electrical stimulation mapping and monitoring would identify not only essential functional areas but also non-essential areas. Thereby, tumor resection might be confined within non-necessary preserved tissue, thus sacrificing oncological benefit for the sake of extensive non-necessary functional mapping. Since no prospective randomized trial is available and would be ethically justified comparing glioma resection with vs without intraoperative stimulation mapping and monitoring, other comparable data is at hand which assessed oncological and neurological outcome in the context of intraoperative electrical stimulation.

In a publication comparing a historical cohort of patients resected for a glioma without electrical stimulation mapping to a more recent cohort resected with electrical stimulation mapping the rate of significant neurological morbidity and mortality was 17% and 2% without mapping vs 6.5% and 0% with mapping, respectively. The rate of complete resections was increased by stimulation mapping from 6% to 25% and of subtotal resections from 37% to 51% (Duffau 2003). Certainly, the study design used is prone to methodological problems but with the inherent limitations a neurological and oncological benefit has been shown. In a more recent meta-analysis (De Witt 2012), 90 reports with a total number of 8,091 patients who had resections for supra-tentorial gliomas with or without electrical stimulation mapping were assessed. Early post-operatively new neurological deficits were higher in the mapping group (36.0%) compared to the non-mapping group (11.3%). However, the late severe neurological deficits were lower in the mapping group (3.4%) compared to the non-mapping group (8.3%). The extent of resection was higher in the group of patients resected with stimulation mapping (74.8%) compared to the patients operated on without the use of electrical stimulation (58.3%). This nicely demonstrates, that intraoperative mapping allows for a more aggressive resective approach within functional boundaries with the calculated risk of higher immediate deficits due to closer resection to functional borders than resection without mapping. However, most severe early deficits are temporary and the permanent deficit rate is reduced by mapping.

Likewise, it has also been shown that presumed eloquent location of LGGs, i.e. tumors potentially eloquently located not verified by electrical stimulation, which were resected, had a worse progression-free and overall survival than tumors in eloquent anatomical location but identified as non-eloquent upon stimulation mapping (Chang 2011).

The issue of “calculated risk” is critical when discussing the role of intraoperative neurophysiology in oncological neurosurgery. Whether we are dealing with intramedullary spinal cord tumors or brain gliomas, neurophysiological warning criteria to alarm the surgeon of an impending injury to the nervous system should always be tailored considering the oncological implications of more strict or loose criteria.

The ultimate goal of intraoperative neurophysiology is to establish warning criteria (such as safe threshold for subcortical mapping or critical values of amplitude drop in cortical MEPs) which warrant long-term motor recovery in spite of transient deficits, while improving tumor removal rates. And yet, the discussion remains open when dealing with low vs. high grade tumors, because even transient deficit might not be acceptable when life expectancy is short.

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**Note**: This summary has been excerpted and modified from *Ringel F, Sala F: Intraoperative Mapping and Monitoring in Supratentorial Tumor Surgery. J Neurosurg Sci 2015; 59: 129-39.*

# Surgery for Insular and Deep Seated Tumors

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## Objective

Insular gliomas are a significant tumor entity and their resection requires applications of surgical technology as well as intraoperative neurophysiological techniques for mapping and monitoring. This overview intends to highlight the surgical considerations, the diagnostic aspects of insular glioma surgery, as well as the need for and application of neurophysiological methods.

## Brief historical review

The insula plays an important role in visceral sensorimotor processing, somatosensory input and pain processing, swallowing; as well as gustatory, auditive, vestibular, emotional, and cognitive functions. Insular gliomas come from the white matter under the insular cortex. Since the insula is part of the mesocortex, the initial growth of insular gliomas appears to involve other mesocortical areas suchas the temporal pole, the caudal orbitofrontal cortex, and cingular and parahippocampal gyri. About 1 in 4 low grade gliomas arise here, as well as about 10% of glioblastomas. The anatomical structure of the insula makes it an area difficult to access because the involuted architecture of the insular cortex with the overlaying opercula. Furthermore the distal branching of the middle cerebral artery occurs here. Therefore microsurgical resection as described by Yaşargil in 1992 and later perfected by many groups, most importantly by Berger is designed to respect the essential vasculature and to maximize resection in between the MCA branches.

## Summary of recent developments and/or future directions

The slowly increasing evidence that resection of low grade glioma improves survival and probably postpones the advent of malignant transformation puts emphasis on the surgical goal to maximize resection of all low grade gliomas. Due to their anatomical property in the insular and opercular region these tumors are more difficult to access and resect than those in more favorable locations. Microsurgical manipulation of the passing MCA-branches, which serve the motor cortex cannot rarely lead to vasospasm and vascular compromise which may well lead to cortical ischemia which in turn can be detected using both sensory and motor evoked potentials. Intraoperative Neurophysiology therefore in this entity serves at least three objectives. First: Mapping of the cerebral cortex in order to obtain safe entry into the tumor area if it involves the opercula, particularly the frontal operculum and more particularly on the language dominant side. Second: Coninuous monitoring of SEPs and MEPs from cortical stimulation provides a continuous monitoring concept for early detection of corticual ischemia due to vascular compromise of MCA-branches. Third: continous monitoring of both MEPs and repeated monitoring with local direct stimulation provides feedback as to the proximity of resection to the internal capsule.

## Conclusions

Insular and other deep seated low grade gliomas should be aggressively resected to optimize long term survival and prevent malignant transformation. At the same time it is essential to preserve neurological function as neurological deficits result in a loss of any survival benefit aggressive resection may provide. Intraoperative neurophysiological techniques provide an essential tool to mapping the motor cortex, particularly in language associated areas, and continuous monitoring to detect cortical ischemia as well as proximity to deep motor pathways in the case of deep seated tumors which may result in surgical injury to the deep corticospinal tract.

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# Awake Surgery for Brain Tumors in Cognitive areas (language and more)

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## Objectives

Surgical resection of intrinsic tumors located within or close to cognitive areas requires the identification at surgery of cortical and subcortical sites involved in these functions. Cognitive functions generally mapped during surgery include language, working memory, and mentalization. In this talk we will explore the basic principles of cortical and subcortical cognitive mapping during brain tumor surgery.

## Basic principles

Cognitive functions in the brain, such as any other brain function, depend on the activity of bilateral networks. The organization of such networks in the human brain is partially known, and varies among functions (more known for language, less for mentalization and memory) and individuals (education, social background, gender). Language is composed of three main components, the semantic, the phonemic and the articulatory (speech production). In fact, it is divided between pure language components (semantic, phonemic) and speech (articulation). The actual model of language organization includes both psycholinguistic and motor control tradition. According to this comprehensive view, language starts at the level of the temporal and occipital lobes, where the concept is generated and taken out from the internal repository, and mixed with visual experiences. Then it is sent anteriorly to the frontal areas thorough the ventral stream as a semantic attribute,and the dorsal stream as a phonemic attribute. The phonemic attribute is then transformed in speech (word) at the level of the ventral premotor (vPM) and primary motor cortices. This network, mainly present in the dominant side, but also evident in the non dominant one, is composed of several fascicles, such as the inferior fronto occipital (semantic) and the inferior longitudinalis (verbal), the arcuatus and the superior longitudinalis (phonemic), the uncinatus (proper name retrieval), the middle longitudinalis fascicle (category), and the vPM and M1 connection (speech production). The presence and continuous growth of an intrinsic brain tumor within the network may progressively alter its bilateral functioning, increasing its reorganization, enhancing the activity of contralateral portions. The anatomical size of fascicle may also influence the level of such organization. Among the various components of memory, working memory is one of the most frequently evaluated in brain tumor patients, due to its particular relevance in the quality of life of brain tumor patients. While the circuits subserving long term memory are basically known, such for working memory are less. The role of parieto frontal connectivity has been recently raised in this topic. The study of mentalization is very recent in brain tumor patients, but of particular importance, because psycho oncology testing shows that emotions and decision making activities are frequently impaired and strongly affecting the ability to perform a normal work and globally the quality of life. The anatomo functional networks subserving these functions are only partially known, and the role of the inferior fronto occipital fascicle in the non dominant hemisphere, and of the cingular and anterior frontal short connecting tracts has been recently suggested. More studies are going on on this topic.

## Operative setting

The location of the main tracts involved in language and other cognitive functions and their relationship with the tumor mass can be studied pre operatively by Diffusion tensor imaging. The role of fMRI in depicting language functions is not clear; generally the presence of areas of activation within or in close vicinity of the tumor mass does not prevent surgical excision. Pre operatively, the patient is submitted to extensive neuropsychological and psycho oncological evaluation, from which the tests to be used intraoperatively are extracted, according to the patient social background, education and needs.

Intraoperative mapping is generally performed with low frequency (LF, 50-60 Hz) technique, delivered by a bipolar probe (ball tips, 5 or 10 mm distance) looking at the beginning for the working current, generally established on the vPM as the lowest current producing a speech arrest, or as the current that produce a speech arrest just below that which induces an afterdischarge; in this case, the use of ECoG is recommended. This working current is then used during the all cortical and subcortical mapping. A site is considered positive when three different stimulations at that site interfered with the given task. HF frequency stimulation (Train of Five), delivered by a monopolar probe, can be also used to interfere with cognitive task; in this case, the repetition rate is increased to 3 Hz. HF stimulation is associated with a reduced incidence of intraoperative seizures.

The patient cooperation and the occurrence of intraoperative seizures during mapping,are the major factors which limit the ability to reach an effective cognitive mapping. Various strategies could be adopted to overcome to these factors and will be discussed.

## Future directions

The implementation of mentalization tasks will be of particular relevance to keep full patient integrity and maintaining a high level of quality of life.

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## Does IOM impact on brain tumor surgery? Accumulating evidence

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### Objectives

The modern neurooncological approach combines maximal tumor removal and maintenance of full patient functional integrity. This aim is reachable by the intraoperative use of brain mapping techniques (IOM). The role of IOM in influencing brain tumor surgery is discussed in the setting of low and high grade gliomas. Basic principles and finding in low grade gliomas. Low grade gliomas are a heterogenesous group of intrinsic brain tumors, which develop in young adults, continuously growing and causing medically refractory epilepsy, and invariably progressing toward a malignant phenotype. The location of these tumors is generally close or within the most eloquent areas of the brain. Surgical treatment in the past was generally postponed, due to the high post operative morbidity associated to it. Surgery is nowadays the main therapeutic strategy. Surgery is aimed at total and whenever feasible to supratotal resection. The surgical strategy is based to find functional boundaries, with the aid of intraoperative neurophysiology and neuropsychology. This surgical attitude is associated with a high rate of post operative deficits, but a low rate of permanent one. Functional recovery takes place within the first 3--4 months after surgery. This paradigm shift from imaging to physiology has significantly changed the clinical attitude toward these tumors, increasing the number of low grade glioma patients who benefit from surgery, increasing the Extent of Resection (EOR), and decreasing the percentage of permanent morbidity. This results in a change in the natural history of the tumor, postponing the time of malignant transformation, impacting also on the progression free survival and overall survival. This is associated with an improvement of the quality of life. Basic principles in high grade glioma surgery: High grade gliomas are intrinsic brain tumors originating from glioma cancer stem cells. The goal of surgery is to perform histological and molecular diagnosis, to relief symptoms due to mass effect and seizures. Surgery in the setting of high grade gliomas has the goal to resect at least 95% of contrast enhancement areas seen in post GD MR images and to maintain full patient functional integrity. Patient performance status is one of the main critical parameters influencing the response to therapies and patient survival, stronger than EOR. The use of brain mapping techniques in this setting is important for reaching a safe and effective resection. The strategy in the high grade glioma setting are different to those generally.
Used in the low grade one and usually not aimed at an extreme functional boundaries identification, because high grade glioma patients do not have the time to recover after surgery, being started one month after surgery with adjuvant therapies. In this context, the mantainance of a high performance status is the main goal asked to IOM.

### Future directions

The implementation of intraoperative neurophysiological protocols, particularly in the low grade glioma setting, aimed to increase the number of patients who are going to benefit from an effective and safe surgery.

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## Day 10 - Session II: 13h30 - 18h00
## How do we perform IOM in brain tumor surgery

### Electroencephalography and electrocorticography

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**Objectives**

After attending the lecture and reading this abstract, the participant should be able to:

- Define electroencephalogram (EEG), electrocorticogram (ECoG) and electroencephalography.
- State the physiologic basis.
- Describe the intraoperative methodology.
- List the main intraoperative applications.

**Introduction**

Hans Berger developed human electroencephalography in the 1920's. It evolved into a rich diagnostic specialty applicable to epilepsy, disorders of consciousness, dementia, cerebrovascular and structural brain disease and to a limited extent, psychiatric disorders. In addition, it was quickly adapted to intraoperative use for epilepsy surgery and later on became a useful tool for intensive care unit or intraoperative cerebral monitoring.

**Definitions**

An EEG is a multi-channel recording of spontaneously fluctuating scalp potentials. An ECoG is a similar recording made directly from cortex. Electroencephalography is the discipline of analyzing and interpreting these recordings, usually in a clinical context.

**Physiologic basis**

Fluctuating postsynaptic potentials of a cerebral neuron generate extracellular currents that volume conduct through tissue, but decline in strength with the square of distance. Consequently, single neuron activity recordable very near the cell is too weak to register farther away. However, synchronous extracellular currents from many neurons can spatiotemporally summate to generate aggregate potentials strong enough to record on the cortex or even the scalp.

The uniform radial geometry of cortical pyramidal neurons enables spatiotemporal summation, while potentials of other more randomly oriented neurons cancel out. Thus, EEG selectively records synchronous potentials of pyramidal neuron populations. Subcortical–cortical synaptic circuit modulation contributes to rhythmic waveforms traditionally classified as delta (< 4 Hz), theta (4 to < 8 Hz), alpha (8–13 Hz), and beta (> 13 Hz). More recently described infra-slow (< 0.1 Hz or DC shifts) and high-frequency oscillations (80–500 Hz) may be relevant for epilepsy.

Large pyramidal neuron populations — about 5–6 $cm^2$ cortical surface area — must be synchronously active to generate scalp EEG signals. The potentials diffuse and attenuate through the skull and other intervening tissues, thereby forming wide low-voltage scalp fields characterized by a peak surrounded by declining voltage, like a hill. Dipolar scalp fields have a negative and positive peak with voltage gradients around them, like a hill and valley. Localizing EEG signals involves analyzing their fields as sampled by all scalp electrodes in order to estimate the cortical source.

Smaller pyramidal neuron populations generate more focal and higher voltage ECoG signals: a large potential at one electrode can be absent a centimeter away. Localization considers each electrode separately and the activity of unrecorded cortex is unknown. The difference between EEG and ECoG can be likened to viewing a forest vs. viewing a sample of individual trees.

Individual epileptic neurons exhibit abnormal 'paroxysmal depolarizing shift' discharges. Synchronous discharges in a large enough pyramidal neuron population generate ECoG or EEG 'spikes' that demarcate the interictal 'irritative zone'. Ictal transformation produces a seizure pattern characterized by various combinations of attenuation, rhythmic, or epileptiform discharges that evolve in frequency, amplitude, and distribution over time. The cortical seizure onset region helps demarcate the 'epileptogenic zone' that is usually smaller than the irritative zone.

## Intraoperative methodology

For intraoperative EEG, collodion-fixed cup or needle electrodes are applied to 10–20 system coordinates. Modified locations may be needed to accommodate craniotomy. Gold-standard ≥ 16 channel montages are preferable because of their wide coverage and enhanced localization. However, truncated 4–8 channel montages may be needed to free channels for other modalities, or for intracranial procedures. Two channels are sufficient for anesthesia pattern tracking. Tight lead braiding, < 2 kΩ impedance and bipolar montages reduce extraneous electromagnetic interference.

For intraoperative ECoG, referential recordings are made from subdural strip or grid arrays, or from an ECoG headset. When mapping an irritative zone, a 16–64 electrode array should extend beyond the putative epileptogenic zone and the montage should be anatomically logical to enhance localization. When used only for afterdischarge detection, a smaller array of 4–16 electrodes around cortical stimulation sites may be sufficient.

To avoid aliasing, the minimum analog-to-digital sampling rate should be > 2 × the highest frequency of interest: 200 Hz for standard frequencies of up to 70 Hz; 2000 Hz for high-frequency oscillations. A 1–70 Hz bandwidth is appropriate for traditional frequencies, but would be adjusted for infra-slow activity or high-frequency oscillations. Display sensitivity is adjusted to utilize dynamic range without trace overlap. Sweeps of 10–20 s are appropriate for epileptiform discharge or anesthesia pattern assessment; compressed 20–600 s sweeps enhance visualizing ischemic changes or infra-slow activity; and expanded 1–10 s sweeps would be needed to see high-frequency oscillations.

Processed EEG spectra displays can help summarize frequency content changes over time, but include potentially misleading artifacts, so are an adjunct but not a replacement for expert raw signal analysis.

## Intraoperative applications

Intraoperative EEG is mainly used for cerebral ischemia detection during carotid endarterectomy, intracranial vascular procedures, or open heart surgery. Ischemic changes consist of reduced alpha/beta amplitude, followed by increased delta/theta amplitude, and then suppression. They are reversible when perfusion is restored before infarction. Anesthesia pattern tracking is another application that can assist evoked potential interpretation. For example, evolution from continuous waveforms to burst–suppression or suppression can implicate deepening anesthesia as an explanation for declining somatosensory or motor evoked potential amplitudes.

Intraoperative ECoG is mainly used for irritative zone mapping and afterdischarge detection. Thus, epilepsy surgery is a longstanding application, but there are significant limitations addressed in “Monitoring during epilepsy surgery”. Afterdischarges are seizure patterns induced by direct cortical stimulation. By spreading to adjacent and distant cortex, they can produce clinical signs or evolve into generalized seizures. Their detection with ECoG is mandatory during 'Penfield technique' stimulation (50–60 Hz pulse trains lasting 1–5 s) to avoid false localization and major seizures. ECoG is optional for the brief high-frequency pulse train MEP technique because the short-latency transient responses are not subject to afterdischarge false localization and because of a lower incidence of seizure induction.

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## Technical aspects of cortical and transcranial stimulation

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### Objectives

To give insights in and practical information on

1. The controversy why in direct cortical stimulation (DCS) and transcranial electrical stimulation (TES) the anode is the active electrode and anywhere else in the body the cathode and what this implies in some applications in monitoring and cortical mapping
2. Technical aspects of stimulators, bio-electric interface, electrode and segmental head impedances

This abstract is restricted to a part of subjects addressed by the title and considered in the presentation.

### Historical review

In the centuries long history of neurophysiology, it almost came to a functional logon, -a lemma-, that the negative stimulation electrode, the cathode is always and everywhere in the body the active electrode with the lowest stimulation thresholds for activation of axons. In 1954, it may have felt like a shocking experience to the older neurophysiologists when Patton and Amassian first described D-waves from DCS in monkeys and discovered that for corticospinal axons the positive electrode, the anode, is the active electrode with lowest threshold. In addition, in 1980 when Merton and Morton introduced TES to generate muscular evoked potentials in conscious man, again the anode appeared to be the active electrode.

At first glance, this consistent exception of anodal stimulation of corticospinal axons impresses as a paradox, since the characteristics and anatomic architecture of the myelinated axons in the corticospinal tract are not different from any other axons in the spinal cord and peripheral nerves. Further research was done by modeling electrical fields around and currents through axon hillocks of upper motor neurons at the entry and course of corticospinal axons by Amassian and co-workers. Later, computer models of electrical fields from stimulation and activation of axons were introduced (Rattay 1986, 1987, Stecker (2005), Manola et al 2005, 2007). These studies gave information to the key-answer of the anode-cathode paradox: *the difference is based on the orientation of axons to the electrode.* Corticofugal axons with inclusion of CS-axons depart “vertical” from the “horizontal” oriented cortex, while all other axons in the body are oriented more or less parallel to the body surface.

*Visualization of the anode-cathode paradox*

Activation functions (AF) result from specific computations on the voltage distribution along an axon. AFs express where along their course axons are activated (depolarize) or inhibited (hyperpolarized) in an electrical field. The activation value depends on its orientation relative to the stimulation electrode. Figure 1 explains the anode-cathode paradox showing horizontal (left) and vertical (right: corticospinal axons) orientations of myelinated axons near an anode in a simple electrical field (homogeneous volume conductor) with the course of the potential and AFs. Largest AF values are noticed on closest distances to the anode with hyperpolarization (negative AF peak) for horizontal and depolarization (positive AF peak) for vertical axons. Conversely at a cathode maximum activation is encountered at the horizontal axon. A polar plot of the activation function (PAF) at the center point P on a distance R from the anode is given in figure 2. The crossings of a line through P with the PAF contour PAF depicts whether axons with the line orientation will depolarize or hyperpolarize at the center point. The spirals crossing P depict axonal trajectories with always zero activation. When pointed to the anode, a PAF can be used as template depicting depolarization or hyperpolarization at a considered location of an axon.

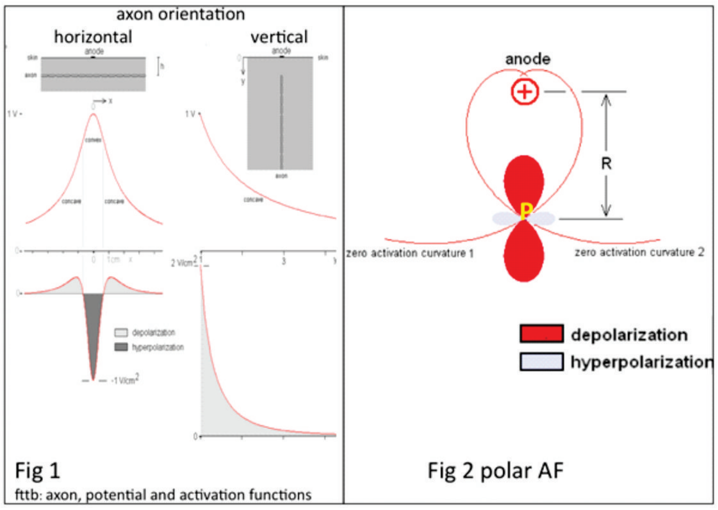


Fig 1
fttb: axon, potential and activation functions

Fig 2 polar AF

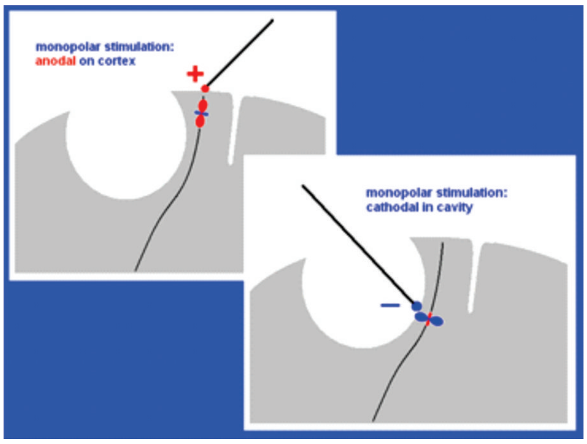


Figure 3 shows an example of a PAF template application predicting activation of CS axons by a monopolar probe active as anode when placed on the cortex and active as cathode when placed in the cavity wall after tumor resection.

**Practical aspects of TES**

The TES electrode impedance $R_{TES}$ is the series connection of two local electrode impedances $R_L$ and the segmental head impedance $R_{segm}$. $R_L$ depends fully on the dimensions of the electrode. Small needle electrodes show high electrical field gradients, which imply a relative great voltage drop, have inherent high impedances and surge most of the administered electrical energy. This should be taken into account in consideration of electrical safety. The local field expands rapidly and adapts to the geometrical conductive tissue compounds of the scalp, skull layers, CSF and brain. The outer boundaries of the local electrical fields enclose a segment of the head. $R_{segm}$ is independent of the type of electrode and reflects the electrical properties of the enclosed tissue components. In fact, the stimulation is primarily aimed at the enclosed segment, whereas the local impedances should not play a role. However $R_{segm}$ is significant lower than $R_{TES}$. In our studies $R_{segm}$ = 90-200 Ω, while $R_{TES}$ of regular used electrode types are according to (Berends et al, 2015): large needles 245±19Ω, corkscrews 423±36 Ω and small needles 477±70 Ω (mean±SD). Current stimulation thresholds are independent on $R_L$ and best reflect conditions of $R_{segm}$. $R_L$ dominates the linear relationship of TES voltage threshold with $R_{TES}$. One should be aware of the degrading effects of the relative high values of high $R_L$s on voltage stimulator characteristics when interpreting voltage threshold values. Closest approximation can be expected with large contact surface electrodes (Journée et al, 2004) when assuming a neglectable low internal resistance of the voltage stimulator. When studying the course of the threshold current, voltage and impedance during stepwise stimulation from the skin surface to the human cortex, the results of Szeleny et al (2012) indicate that most of the supplied current is shunted through the scalp and CSF layers. In contrast to voltage thresholds, current thresholds are significantly more sensitive to changes in conductivity of the scalp. For IOM, this is in favor of voltage stimulation. However, the degrading effects of $R_L$ introduces sensitivity to scalp conductivity changes as well.

**Conclusion**

Out of the few technical aspects of DCS and TES that are considered one can expect that models of the electrical-biological interface are useful to explain observations, practical limitations of stimulator and electrodes and offer features for designing set-up protocols.

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## Cortical mapping and Phase reversal

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### Objectives

Intraoperative neurophysiology in brain tumor surgery should be tailored to the surgical needs and thus the cortical and subcortical areas at potential risks. To optimize surgical resection and preserve neurological status, localization should be performed with high spatial resolution. Real time monitoring is mandatory.

### Basic Principles

The intraoperative localization of primary motor cortex and the corticospinal tract is performed with direct cortical and subcortical stimulation. Somatosensory evoked potentials (SEPs) are used to localize the postcentral gyrus and determine the central sulcus ("phase reversal").

### Brief historical review and technical aspects of direct cortical electric stimulation

The 60-Hz-technique was introduced for mapping of cortical "function" in awake procedures by Penfield in 1937[1]. The technique is still used for mapping of cortical areas related to motor, language and cognitive function in awake brain tumor surgery. For spatial and temporal summation of the descending activity of the fast conducting pyramidal axons at the alpha-motoneuron a high frequency (200 – 500 Hz) cortical stimulation is needed. The fast conducting pyramidal axons are essential for voluntary movement and need to be preserved. As commonly applied with a pulse series of five pulses, this was coined "train-of-five-technique". It is very robust during anesthesia, but can also be applied in alert patients in awake craniotomies.

Briefly, the comparison between the 60-Hz and train-of-five techniques shows that the first is more seizurogenic[2] and as being performed with a bipolar probe has a more focal spatial resolution, which might be felt as disadvantageous in detecting subcortical pathways. Further, the method is limited to mapping.

### Practical approach to mapping of the motor cortex

The application of the train-of-five technique for direct cortical stimulation (DCS) follows the same settings as for MEPs elicited by transcranial electric stimulation except the limitation to a maximum stimulation intensity to 25 mA (exceptions might apply in children or pre-existing neurological deficits).

First, the central sulcus is determined with the "phase reversal" – a direct cortical recording of SEPs. The SEP amplitude inverses when recorded above the precentral gyrus, thus pre- and postcentral gyrus can be determined[3]. The phase reversal can be deteriorated or provide inconclusive results in case of underlying tumor masses or pre-existing somatosensory deficits[4].

The results have to be confirmed by mapping. Such, to follow direct cortical stimulation of the precentral gyrus (i.e. motor cortex, location of reversed SEP amplitude) is performed. For this, MEPs are elicited with a monopolar stimulation probe. The stimulation is applied in an anodal polarity. The return electrode is placed frontal and should not overly the motor cortex (if not exposed).

For MEP recording muscles being represented at the cortical area of interest are chosen. The motor cortex is determined by the lowest stimulation intensities (motor thresholds) necessary to elicit MEPs. Those motor thresholds at the "motor hot-spots" are reference for re-mapping during the surgery and subsequent continuous stimulation via a strip electrode. Ideally, this strip electrode would be placed parallel over the precentral gyrus with the medial located contacts covering the leg area and lateral positioned over arm, hand and face motor areas [5]. Electrodes not being used for stimulation might be used for electrocorticography or recording of cortical SEPs.

### Future developments

In the aim of maximal tumor resection, precise mapping, determination of motor hot-spots and high spatial resolution is critical. Such, the use of different probes or even bipolar concentric probes might have to be assessed.

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**Recommended Readings:**
Vedran Deletis and J.Shils: Neurophysiology in Neurosurgery: A modern intraoperative approach (Academic Press, New York, 2001).
Aage R. Møller: Intraoperative Neurophsiological Monitoring, (Humana Press, 2006)
Marc R. Nuwer: Intraoperative Monitoring of Neural Function (Handbook of Clinical Neurophysiology, Vol. 8; 2008)


## Language mapping in asleep patient

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### Introduction
The larynx is the final common organ for speech, therefore it receives delicate programming codes for speech execution. After artificially stimulating selective cortical motor speech areas by electric current we try to decode distinctive markers as synchronized time locked electric events from the cricothyroid muscles.

### Method
Ten right handed healthy subjects underwent navigated transcranial magnetic stimulation and eighteen patients underwent direct cortical stimulation over the left hemisphere, while recording neurophysiologic markers; short latency response (SLR) and long latency response (LLR) from cricothyroid muscle. Both healthy subjects and patients were engaged in the visual object naming task. In healthy subjects the stimulation was time locked at 10-300 ms after picture presentation while in the patients it was at zero time ( Figure 1)

### Results
The latency of SLR in healthy subjects was 12.66±1.09 ms and in patients 12.67±1.23 ms. The latency.of LLR in healthy subjects was 58.5 ± 5.9 ms, while in patients 54.25±3.69 ms (1). SLR elicited by stimulation of M1 for laryngeal muscles corresponded to induced dysarthria, while LLR elicited by stimulation of the premotor cortex in the caudal opercular part of inferior frontal gyrus, recorded from laryngeal muscle corresponded to speech arrest in patients and speech arrest and/or language disturbances in healthy subjects (2).

### Conclusion
SLR elicited by stimulation of M1 for laryngeal muscles corresponded to induced dysarthria, while LLR elicited by stimulation of the premotor cortex in the caudal opercular part of inferior frontal gyrus, recorded from laryngeal muscle corresponded to speech arrest in patients and speech arrest and/or language disturbances in healthy subjects.

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## Subcortical motor mapping and motor evoked potential monitoring in brain tumor surgery

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### Objective

In modern neuro-oncology two main concepts are maximizing the extent of tumor resection to improve survival and avoiding postoperative deficits to improve quality of life., Therefore tumor resection should be based on function of the nervous system rather than anatomy alone.,,,,,

### Modern literature review

To achieve functional guidance during tumor resection two main intraoperative neurophysiological techniques are available. Continuous monitoring of MEPs enables real time assessment of the functional integrity of the cortico-spinal tract (CST). ,,,,,, Subcortical stimulation with a handheld probe (called mapping) is used to localize motor tracts in deep white matter structures at different stages of tumor resection.,,,,,,

### Recent clinical and research developments

The gold standard for electrical cortical and subcortical stimulation is the classical Penfield technique (bipolar probe, 50-60 Hz).,, Later the short train stimulation (3-5 stimuli, 0.5 msec pulse duration, ISI 4 msec) has been introduced.,, The temporal summation of multiple descending volleys in high frequent short train stimulation finally triggers a time-locked MEP response which has a defined latency and which amplitude is easy to quantify.,, The radiant current by monopolar (referential) stimulation enters distant structures perpendicular and therefore is most effective in stimulation.27

An imminent question during tumor removal is how distant the resection cavity is at a certain point to the CST. Recently several important studies were done to correlate the stimulation site to the distance of the CST and most of them came up with to the "rule-of-thumb" of 1 mA would correspond to 1 mm.,,,, Yet comparing those different studies the applied number of stimuli, pulse duration, polarity and especially charge might be of important value. Therefore we would recommend for motor mapping to keep a constant number of stimuli and pulse duration and to apply constant current cathodal subcortical stimulation.,,

We had recently analyzed what would be a reasonable lowest mapping threshold (MT in mA) to stop tumor resection. We had demonstrated that 1) mapping MTs correlate with the risk of CST injury, 2) there is safe mapping corridor between the first (high) and critical (low) MTs and 3) the critical (low) mapping MTs are lower than previously thought., In this context, we had shown that mapping thresholds of 1-3 mA might be safe provided that DSC-MEP monitoring remains stable at the same time.,

Therefore mapping should not been applied intermittently but continuously with the highest temporal coverage and directly at the site of tumor removal. This is absolutely necessary at very low mapping thresholds of 1-3 mA in close proximity to the CST. Therefore we had described recently a new mapping protocol.21 By integrating a monopolar stimulation tip to a classical suction device, stimulation is possible during the whole process of tumor removal at the site of tumor removal. This technique allows that mapping is achieving the same temporal coverage as monitoring but being able to give spatial information of the CST at the same time., This is especially achieved by adopting the simulation current to the estimated distance to the CST.,

It is important to highlight that mapping provides only information of the stimulation site and distal to this point. If feedback of the whole integrity of the motor system is needed MEP monitoring is indicated.,, Remote vascular injury can only be detected that way,, and should be therefore always combined with mapping techniques. As long as direct cortical stimulated (DCS) MEP are preserved, there is a very low risk for postoperative change in motor function.,,,,,, The downside is that DCS MEP changes often occur abruptly and are irreversible in around 40% of cases.,,

### Future questions and direction

Still the exact distance in mm of a stimulation site to the CST remains unclear., Even more the reliability of different stimulation paradigms to recognize essential motor fibres might depend on the clinical context (infiltrative versus non-infiltrative tumors, prior radiation).1 Whether any mapping strategy may help to improve long term survival has to been shown in future studies.4

## Conclusion

The combined approach of DCS MEP monitoring for remote vascular injury and continuous dynamic mapping with high spatial and temporal solution by stimulation over a modified suction device enables real-time functional feedback during motor eloquent tumor surgery.

**Key references, recommended reading:**


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# Intraoperative Neurophysiology of the Motor System: From *Mapping* to *Monitoring* in Brain Tumor Surgery

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While subcortical stimulation mapping allows for localization of the subcortical corticospinal tract (CT) and for identification of the functional integrity from the point of stimulation distally, it does not reflect the functional integrity of the complete corticospinal tract, i.e. the part proximal to the point of subcortical stimulation. Therefore, during the resection of deep seated lesions close to the subcortical corticospinal tract, like insular gliomas, subcortical stimulation might always elicit muscle motor responses while an ischemic event could lead to an undetected damage of the corticospinal tract proximal to the resection cavity and point of subcortical stimulation. For this reason an additional technique to evaluate the functional integrity of the complete CT is necessary, which is motor evoked potential (MEP) monitoring (Taniguchi 1993, Sala 2003, Kombos 2009, Seidel 2013).

MEP monitoring can be performed either by transcranial electrical stimulation (TES) using electrodes at the C1 and C2 or C3 and C4 scalp sites -according to the 10-20 International Electroencephalography System - or by direct cortical stimulation using a grid electrode over the precentral gyrus. The advantage of the TES is the needlessness of exposure of the central region i.e. the precentral gyrus. However, depending on the stimulation intensity, TES can penetrate deep into the brain leading to MEP stimulation at brain stem levels and, therefore, expose to the risk of false negative results. In contrast, in direct cortical stimulation by a strip electrode current flow is more restricted and allows for a more focal stimulation including a limited pool of motoneurons of selected areas of the homunculus, depending on electrode position. By placing the strip electrode directly over the precentral gyrus different muscles can be stimulated independently. While an exposure of the precentral gyrus makes electrode placement easily achievable, for insular tumors where the motor cortex is not exposed by the craniotomy, a strip electrode can still be gently inserted into the subdural space to overlap the motor cortex, under continuous irrigation. Phase reversal and/or direct cortical stimulation can be used to identify the electrode with the lowest threshold to elicit muscle MEPs.

The warning criteria for changes in muscle MEPs that warrant a prompt feedback to the surgeon because of an impending injury to the motor system are still a matter of debate. In spinal cord tumor surgery, a "presence/absence" of muscle MEPs criterion has been adopted by some authors, based on the observation that –as long as a D-wave is monitorable and stable – a drop in the MEP amplitude is not of major concern because it correlates only with transient deficit, if any (Kothbauer 1998).

Vice versa, several studies have shown that in brain tumor surgery a significant drop in the MEP amplitude at the end of the surgery as compared to baseline values may predict a persistent motor deficit (Kombos 2001, Neuloh 2004 and 2007). Sometimes, even transient disappearance of mMEPs may be indicative of some degree of post-operative motor impairment. What is a "significant" drop in MEP amplitude is still controversial. Some authors suggest 50% as a critical threshold; others consider significant only a 80% drop (Krieg 2012, Szelenyi 2010, Nossek 2011, Neuloh 2004). As expected, the adoption of these two different thresholds exposes to a higher risk of false positive and false negative results, respectively. Vice versa, irreversible complete loss of muscle MEPs consistently correlates with a long-term new or worsen motor deficit in the affected muscle/s.

A persistent increase in the threshold to elicit muscle MEPs or a persistent drop in muscle MEP amplitude, despite stable systemic blood pressure, anesthesia, and body temperature, represents a warning sign. However, it should be noted that muscle MEPs are easily affected by muscle relaxants and high concentrations of volatile (and other) anesthetics such that wide variation in muscle MEP amplitude and latency can be observed. Due to this variability, the multisynaptic nature of the pathways involved in the generation of muscle MEPs, and the nonlinear relationship between stimulus intensity and the amplitude of muscle MEPs, the correlation between intraoperative changes in muscle MEPs (amplitude and/or latency) and the motor outcome is not linear. Further clinical investigation is needed to clarify sensitive and specific neurophysiologic warning criteria for MEP monitoring in brain surgery.

The value of MEP monitoring has been questioned several times, and it has suggested that MEP may have a merely predictive, rather than preventive, role with regards to post-operative motor deficit. This is certainly true for a subset of MEP monitoring courses, where a sudden loss of MEP amplitude occurs, which does not recover despite a halt of resection, vasoactive warm irrigation and blood pressure optimization. These cases of MEP loss after exclusion of technical causes are highly predictive for permanent significant new motor deficits. However, about 65% of MEP changes are reversible after adequate reactions of the surgeon to reverse the amplitude decrease. Corrective measures include temporarily halting any surgical maneuver, warm irrigation of the surgical field, correction of low blood pressure, improvement of perfusion pressure by local instillation of papaverine.

MEP monitoring was also blamed for false negative results, i.e. patients with new motor deficits despite stable MEP monitoring. However, when these cases were reviewed (Neuloh 2009), it appeared that there was always an explanation for motor deficits despite stable MEPs. In facts, these cases fall in to the following categories: i) resections within the supplementary motor area - which typically result in a motor deficit slowly recovering after surgery – that are associated with a completely intact primary motor system and, therefore, cannot be detected by MEP-monitoring; ii) secondary events as hemorrhages, ischemia or significant brain edema occurring after discontinuation of monitoring and before arousal of the patient; iii) technical problems. True false negative monitoring results occurring despite these reasons have not been identified, with the exception of distal activation of the corticospinal tracts due to high intensity TES.

In conclusion, MEP monitoring is a reliable technique in brain tumor surgery. However, robust criteria for their interpretation and for correlation with the post-operative short- and long-term motor outcome are still lacking. Ideally, monitoring of the D-wave would provide the most reliable prognostic data (Fujiki 2006) but, for brain surgery, requires the percutaneous insertion of an epidural electrode at the cervical level, and this has been considered too invasive in western countries.

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# Intraoperative monitoring and mapping of visual pathways

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Japan

## Objective

Neurosurgical procedures for treatment of tumors or vascular lesions along the visual pathways carry a risk of visual dysfunction. This applies mostly to parasellar tumors and aneurysms, but also to temporal and occipital lobe tumors and intraorbital lesions. An already impaired visual pathway is particularly at risk in patients with parasellar lesions, such as tuberculum sellae meningiomas, craniopharyngiomas and internal carotid paraclinoid aneurysms. A reliable method for real time visual function monitoring assists in intraoperative decision making regarding radicality of excision and intermittent maneuvers near the optic apparatus.

In this lecture you will leran the indication, purpose, measurement method and waveform evaluation of VEP, and systematic review of intraoperative visual function monitoring.

## Historical review

It was difficult to obtain stable visual evoked potential (VEP) in real time intraoperative monitoring because of interruption by anesthesia, in addition to insufficient and unstable stimuli delivery. However, VEP has recently been established for use in intraoperative visual function monitoring [1-3]. VEP has been utilized for evaluation of visual function. Two types of stimulation are used in routine VEP monitoring: flash and pattern reversal stimulations. Pattern reversal stimulation is frequently used in routine VEP examination; however, it is impossible to perform under general anesthesia because the patient cannot gaze at an object. Only flash stimulation can be adopted as intraoperative VEP. The waveform in flash VEP is generally unstable even in the same patient and under the same conditions. Intraoperative flash VEP monitoring has been reported to be useful [1-3] or unreliable [4, 5]. Recently brighter stimulator is developed for intraoperative stimulation and stable and “reliable” VEP waveforms recording under general anesthesia VEP monitoring is established [1, 2].

## Recent clinical and research developments and future directions

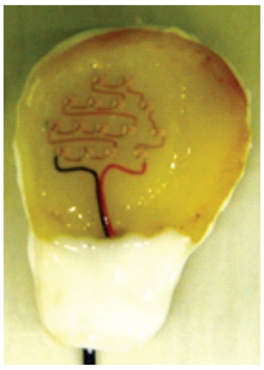
Usefulness of intraoperative VEP using flash stimulation has been reported [1-3].

We present our experience of intraoperative flash VEP monitoring.

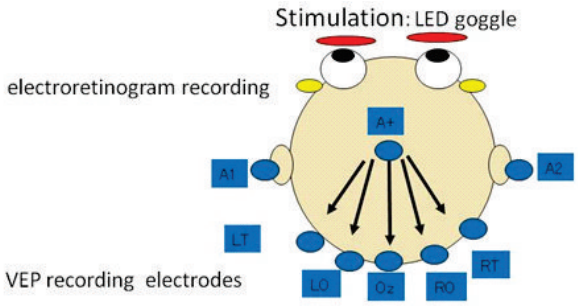
**1) Indications for intraoperative VEP monitoring:** The indication for VEP monitoring is to avoid postoperative worsening of visual function. Intraoperative electrophysiological monitoring is an important alarm for keeping the patient's neurological condition intact. Cooperation between the surgeon and staff responsible for monitoring is essential in this field. It is recommended to use VEP monitoring in removal of intraorbital lesions, parasellar lesions and cortical lesions adjacent to the optic pathways. Especially it is essential to use VEP monitoring in surgeries for parasellar tumors and aneurysms.

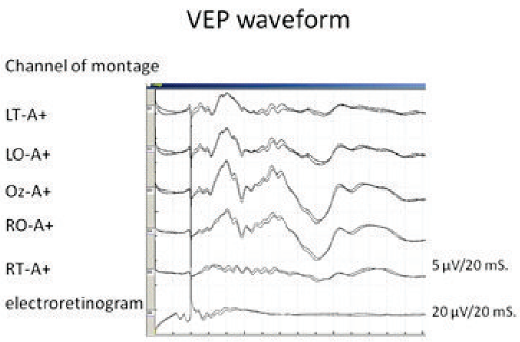
**2) Anesthesia:** Under total intravenous anesthesia (TIVA), the VEP shows larger amplitude with less variability and latency [1-3]. We request that the anesthesiologist not use inhaled anesthetic gas, and there have been no problems in over 100 cases in our 8 years of experience. The concentration of propofol, fentanyl, or remifentanil may be unrelated to evaluate the VEP monitoring. Nitrous oxide does not cause changes in the waveform. On the other hand, inhaled anesthetics, such as sevoflurane and isoflurane, markedly decrease the amplitude. Body temperature and depth of general anesthesia may also not be important for evaluating VEP monitoring.

**3) Stimulation:** Flash VEP and ERG are recorded with a Neuropack evoked potential measuring system (Nihon Kohden Corporation, Tokyo, Japan). The bandpass is from 10 to 1000Hz and averaging is 100 times. Preconditioning of flash stimulation before starting averaging should be done to obtain a steady VEP waveform. As the retina shows a greater reaction to the initial period of flash light stimulation, it is necessary to wait at least 1 minute to obtain a steady reaction after commencement of flash stimulation. The stimulation intensity is decided by the supramaximal stimulation to the retina. As the evoked ERG is easy to record and the waveform is stable, it is utilized for checking the supramaximal value. Routine ERG has an amplitude of 5 μV and 4 or 5 peaks from 30 to 70 ms. If VEP attenuation is suspected, the ERG amplitude should be checked. If the baseline amplitude of ERG is not obtained, the attenuation is caused by inappropriate stimulation, usually inadequate stimulation to retina due to stimulator dislocation. Figure 1 shows standard set up for VEP stimulation.




**4) VEP Recording:** Reference electrodes are set at A1 and A2, and these are electrically connected. Recording electrodes are set near Oz, O1, and O2. Five recording electrodes are routinely placed. Even in the event of unexpected dislodgement during an operation, it is difficult to set new electrodes. Thus, stable and secured setting of the recording electrode is essential, because reducing the noise by stable setting can decrease the number of averagings. Diagram below demonstrates VEP set up and typical waveforms.




**5) Optic nerve action potential:** In the cases of parasellar lesions such as craniopharyngiomas and giant aneyrysms, optic nerves, chiasm and tracts are sometimes streched around the lesion. And, it is difficult to identify the location of the optic apparatus. In these situations, flash stimulation is deliverd as same manner as VEP, and action potentials recoeded from the operative fields facilitates to identifiy the optic apparatus.

**6) future directions:** The limitation of current method are 1) temporal resolution and 2) difficulty in repording VEP in patients with already low visual acuity. Sophisticated stimulation and recording methodology may overcome these limitation.

## Conclusions

Intraoperative flash VEP monitoring is essential method for preserving visual function. VEP can be monitored in a patient with visual acuity greater than (0.04). The flat VEP indicates postoperative severe visual disturbance (nearly blindness). Judgment of waveform change by mechanical damage is more difficult than that for ischemic compromise. Pitfalls for intraoperative VEP monitoring are: preoperative severe visual dysfunction, low amplitude of control VEP may interfere intraoperative VEP monitoring in this method. Visual field defect without decrease in the visual acuity may not be predicted by VEP monitoring. Attention should be paid for these pitfalls for reliable intraoperative VEP monitoring.

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## Day 11 - Session IV: 08h00 - 10h00
## Why do we need IOM in cranial vascular neurosurgery and epilepsy surgery?

### Vascular Neuroanatomy of the Brain: Vessels and Territories

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Chief of Vascular Neurosurgery- UNIFESP
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Cerebrovascular diseases are among the most important pathologies faced by neurosurgeons. Properly understanding of vascular neuroanatomy and parenchimal territory supplied by each vessel is crucial for planning the management of these pathologies.

The complete study of anterior circulation arteries, posterior circulation arteries, superficial draining veins, the deep system of draining veins and their primary or colateral irrigation territories is the aim ability  for neurosurgical success once treating brain aneurysms, AVMs, cavernous angiomas, strokes, moyamoya, fistulas and every other cerebrovascular diseases.

### Aneurysms and Avm: Surgery

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Cerebrovascular diseases are among the most important pathologies faced by neurosurgeons. Properly understanding of vascular neuroanatomy and natural history of is crucial for planning the management of aneurysms and AVMs.

With advances in anestesia techniques, neurosurgical microscopes, and intra-operative angiography, the risk associated to treatment has been decreasing and almost all patients could be eligible for direct surgical repair.

Thinking of cerebral AVMs or brain aneurysms, it is important to keep in mind that the treatment is most frequently aimed at preventing hemorrhage in the future. In this context, the surgical success is essential for keeping the best quality of life to our patients.

## Carotid Endarterectomy Procedures

Jay L. Shils, PhD, D.ABNM, FASNM, FACNS
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USA

**Objectives**

To gain a basic understanding of the anatomy and neurophysiologic methods for monitoring these procedures with a focus on EEG.

**Historical Review**

There are multiple techniques that can be used to monitor the status of the brain during CEA procedures. These techniques include: (1) performing the procedure awake; (2) Transcranial Doppler; (3) Stump pressure monitoring; (4) Electroencephalography; (5) Somatosensory evoked potentials; (6) Motor Evoked Potentials; (6) Near infrared spectroscopy. Each technique has its advantages and benefits which are related to speed of acquisition, resolution of cortical volume monitored, effects of anesthesia on the resulting data needed for interpretation, and the lack of ability to localize emboli or even the overabundance of emboli detection and not understanding what it actually means. Other than the complexity of interpretation, which for CEA is minimal, the EEG seems to be least affected by all of these short comings given its speed of data for interpretation and cortical resolution if enough channels are monitored.

**Conclusions**

This lecture is a basic educational lecture on the anatomy of, basic methodology of, and EEG interpretation of CEA procedures with examples.

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## Results of surgery for refractory epilepsy: Highlights from a series of 1696 patients submitted to surgery.

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**Rationale**:

This paper reviewed a series of epileptic patients submitted to surgery in the MR era.

**Methods**:

1696 patients submitted to epilepsy surgery from 1996 to 2012 were studied. Mean age at surgery was 16 years and follow-up period was 6. 6 years. 919 patients were submitted to temporal lobe, 187 to frontal, 70 to rolandic, 69 to posterior quadrant, 26 to parietal, 12 to occipital and 6 to insular cortical resection. 92 patients were submitted to hemispherectomy and 190 patients to callosotomy; 109 patients were submitted to VNS and 37 to DBS.

**Results**:

Overall, 81% of the patients submitted to temporal lobe resection were seizure-free after surgery, as did 82% of the patients submitted to hemispherectomy. 72% of the patients with frontal lobe have been rendered seizure-free. Patients submitted to occipital, parietal and insular resections were seizure-free in 85%, 80% and 100% of them, respectively. Eighty-three percent of the patients submitted to posterior quadrant resections were seizure-free postoperatively. There has been an 88% reduction in the generalized seizure frequency in those patients with Lennox-Gastaut syndrome submitted to callosotomy. Overall, 51% of the patients submitted to VNS had at least a 50% reduction in seizure frequency; best results were obtained in kids with Lennox-Gastaut syndrome. Among the DBS patients, although targeted for different syndromes, the best results were obtained with hippocampal stimulation.

**Conclusions**:

Patients with MRI-defined lesions had better seizure-outcome. There is a clearcut trend towards operating at a younger age, and discontinuing the use electrocorticography, awake-craniotomy and Wada's testing. Neuromodulation is very likely to be increasingly used in these patients.

## Monitoring during carotid endarterectomy: SEPs? EEG? MEPs? Current evidence for best practice.

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Division of Neuroanesthesia & Intraoperative Neuromonitoring
Department of Anesthesiology, Intensive Care and Pain Therapy
Germany

### Objectives

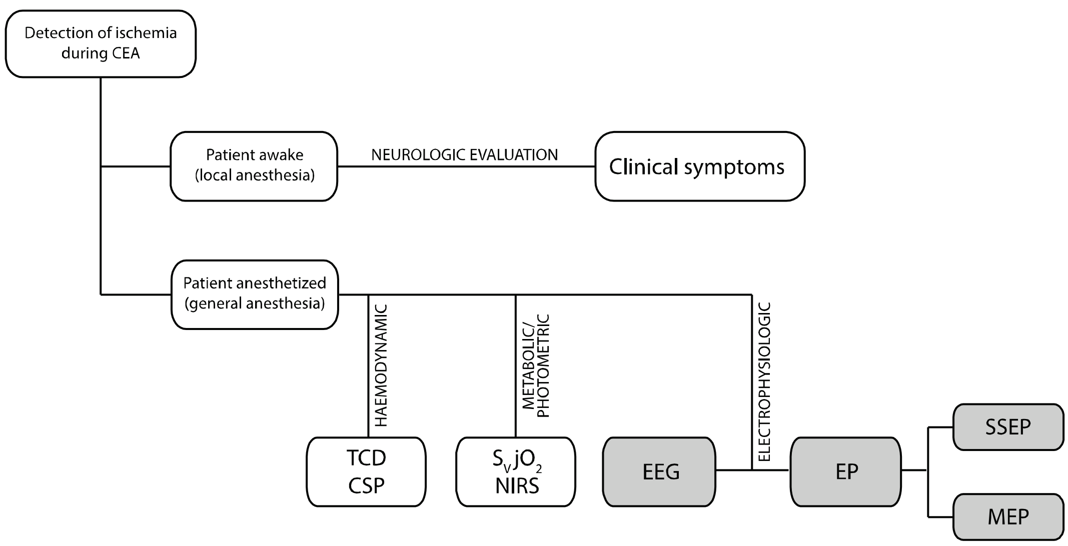
A controversy exists regarding which monitoring technique is superior in cases in which general anesthesia is necessary for carotid endarterectomy (CEA). This lecture is supposed to show some developments in the field of intraoperative neurophysiology with regard to monitoring of cerebral ischemia during internal carotid artery (ICA) cross clamping.

### Historical review

CEA is an effective intervention to prevent strokes in patients with symptomatic and asymptomatic carotid stenosis but it also has a potential risk of perioperative stroke. Ischemia related to ICA cross clamping and arterial embolism are the most common intraoperative causes of stroke. Therefore, selective shunt application based on different criteria evaluating the patient while awake or anesthetized has been shown to be sufficient in reducing the rate of perioperative stroke (e.g. Woodworth et al. 2007).

Figure 1 shows neurophysiologic monitoring methods in the context of neuromonitoring techniques used for CEA.

**Techniques of monitoring of cerebral ischemia during CEA**



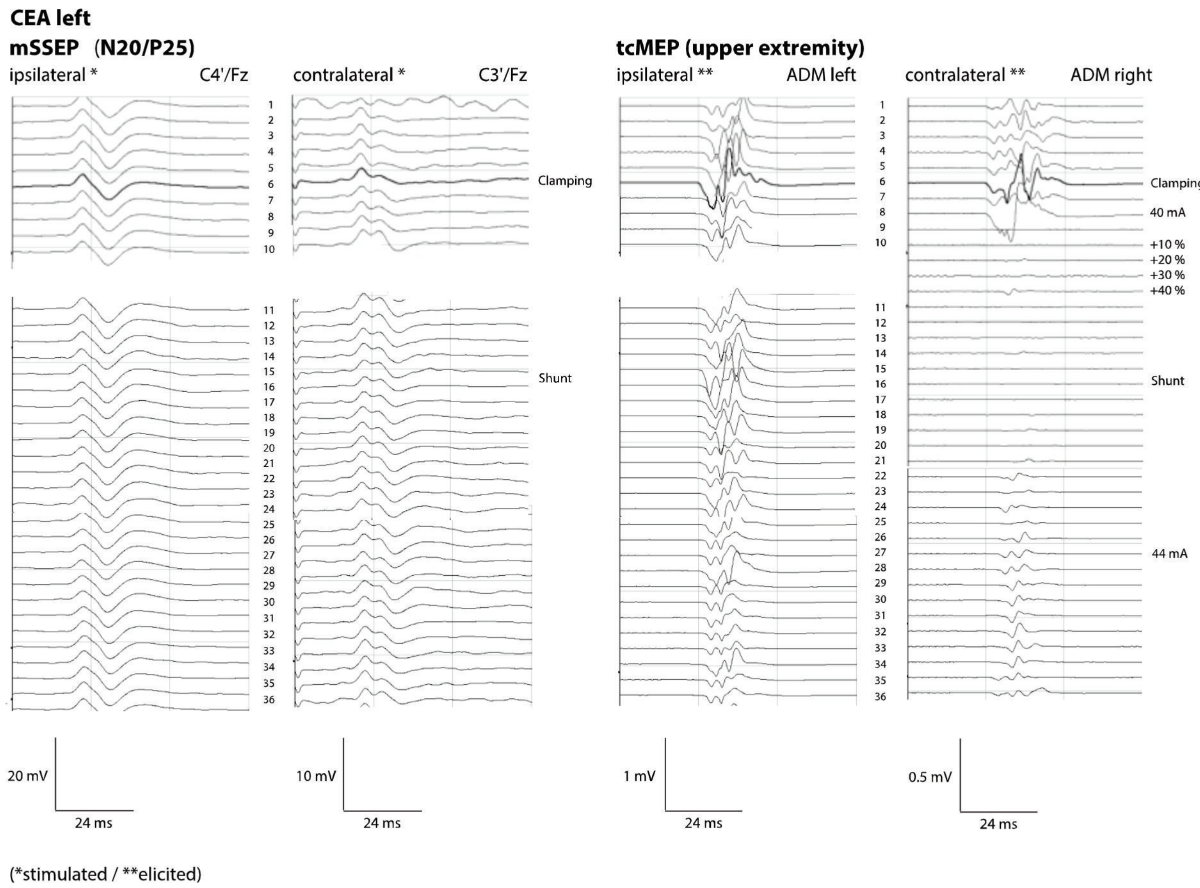

*(**Fig. 1:** Scheme of various neuromonitoring methods during CEA. TCD – transcranial doppler; CSP – carotid stump pressure; $S_VjO_2$ – jugular venous oxygen saturation; NIRS – near infrared spectroscopy; EEG – electroencephalogram; EP – evoked potentials; SSEP – somatosensory evoked potentials; MEP – motor evoked potentials)*

With regard to neurophysiologic methods meanwhile SSEP recording after stimulating the median nerve seems to be the gold standard monitoring technique during CEA in many institutions. However, EEG monitoring, essentially more channel EEG, was officially recommended in US in 1993 (Nuwer et. al 1993). In contrast to SSEP monitoring under

general anesthesia during CEA EEG has some potential limitations, such as the low specificity in patients with preexisting EEG-changes, e.g. history of stroke (Blume et al. 1986) and the comparably strong dependency of the EEG criteria for ischemia on anesthesia regime. In addition animal experiments showed SSEP alteration at lower levels of cerebral blood flow, whereas significant EEG changes occurred earlier at higher levels. Thus, shunt rates may be higher under EEG monitoring. However, both EEG and SSEP are indirect predictors for cerebral ischemia providing more or less information about global ischemic events. Even though the high sensitivity and specificity of SSEP monitoring false negative results with regard to the outcome of motor function after CEA have been described in up to 3.5% (Schwartz et al. 1996, Prokop et al. 1996).
Similar to results from cerebral aneurysm surgery false negative SSEP rates suggest differences of global cortical CBF and focal subcortical perfusion of the corticospinal tract (CST) (Szelényi et al. 2006, Neuloh and Schramm 2004). Since MEP monitoring provides direct information about the integrity of the CST it was successfully implemented in aneurysm surgery a decade ago. However, pathophysiology during CEA can be similar - Why not using MEP monitoring to detect subcortical ischemia of the CST during ICA cross clamping in carotid surgery?

**Summary of recent developments**

A multicenter trial including 600 patients undergoing CEA under general anesthesia showed evidence that MEP recording was technical wise feasible in this particular cohort comparable to SSEP results (Malcharek et al. 2013). Secondly, there was found an isolated MEP loss in 1.5%. The time from MEP loss until intervention was significantly related to the postoperative outcome of motor function. The longer the delay until shunt application the higher the probability of postoperative motor deficit. Figure 2 illustrates a case of isolated MEP loss during ICA cross clamping suggesting subcortical focal ischemia of the CST.




*(**Fig. 2**: Exemplarily case of isolated unilateral MEP loss during ICA cross clamping)*

Further single center studies supported the useful implementation of MEP method in addition to SSEP recording (multimodal EP monitoring) during CEA (Malcharek et al. 2015a, Alcantara et al. 2013).
Furthermore the technical stability of the multimodal EP concept in patients under general anesthesia was recently compared to the feasibility of awake neurologic evaluation in patients undergoing CEA under local anesthesia

(Malcharek et al. 2015b). Multimodal EP monitoring failed significantly less than awake monitoring of the patients (1% vs. 5.4%). Even though a historical control (awake patients) was used and the power of the study is limited, the trial points out that the combination of SSEP and MEP monitoring under general anesthesia should be considered as effective alternative to awake evaluation of patients during CEA.

## Conclusions

Recent developments in intraoperative neurophysiologic monitoring during CEA suggest an effective combination of SSEP and MEP monitoring to reduce false negative results. Hereby the differentiation between cortical and subcortical ischemia seems pathophysiological wise essential - similar to cerebral aneurysm surgery. However, prospective investigations including a control group without MEP monitoring would be necessary to provide clear evidence. Since the above described retrospective trials showed some usefulness of MEP monitoring in a small group of patients, and according to pathophysiologic considerations, a control group would probably be unethically.

**Key references and recommended readings**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## Intraoperative neurophysiological monitoring in aneurysm surgery

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### Objective

An overview about the most commonly applied methods and their safe utilization - with special regard to microsurgical dissection - will be given. The advantage of the use of multiple modalities will be supported by current literature review.

### Brief historical review

Since the early 80ies the use of intraoperative neuromonitoring, first with auditory evoked potentials (AEP) and somatosensory evoked potentials (SEP), later with motor evoked potentials (MEP) were reported. Whereas the technique of SEP is well established and is performed according to diagnostic neurophysiological standards [1]. The intraoperative application of MEPs was focus of research during recent years.

### Summary of recent developments

Neuloh et al. [2] reported that those surgical steps, which were deemed very critical by the surgeon, were often related to EP alteration: in 100% of perforating vessel manipulation, in 80% of brain retraction and in 30% of temporary intentional vessel occlusion. Vascular injury relates to the involved vascular territory. During the surgical procedure, neuromonitoring methods should cover vascular territories related to main arterial branches and subcortical, perforating arteries causing subcortical ischemia. The strong correlation between SEPs and the cerebral blood flow hallmarks SEPs for an indicator for imminent cortical ischemia [3]. Thus SEPs are sensitive in predicting cortical ischemia involving the primary somatosensory cortex. MEPs on the other hand are generated in the white/grey matter border or the white matter. The descending conduction along the corticospinal tract is sensitive towards subcortical ischemia. The relation between MEP alteration and subcortical ischemia affecting the corticospinal tract has been shown in many studies (see overview in Guo[4]).
This is supported by the analysis of subcortical ischemia affecting the corticospinal tract related to MEP alteration during the course of tumor resection[5].
Studies have demonstrated the strong correlation between intraoperative MEP alteration and postoperative motor outcome [2;6]. In intracranial surgery, permanent MEP losses are followed by long-term motor deficits, but – in contrast to spine surgery – also MEP alterations might be followed by permanent motor deficits. Recent research confirmed that even amplitude deterioration and prolonged transient losses might be correlated to postoperative motor deficit[7].
Stimulation associated movement disturbing microdissection is of concern. The analysis of 220 aneurysm surgeries demonstrated that continuous MEP monitoring was abandoned in only 2.3% due to disturbing patients' movement. In my own experience, hemispheric stimulation electrode montage for most focal excitation and slightly suprathreshold stimulation intensity minimize unwanted patient movements during microsurgery. The revival of awake surgeries promoted even awake craniotomies for cerebral aneurysm repair. The authors reported that impairment (clumsiness) of voluntary movement preceded MEP deterioration for [8]. This is not surprising considering the complexity of voluntary movement and is supported by the known relation between MEP deterioration and impaired motor function, notably not plegia.

### Conclusion

MEPs and SEPs are essential methods for real-time monitoring of motor and somatosensory pathways. MEP loss bears a higher risk than MEP deterioration to postoperative motor deficit resulting from subcortical postoperative MR signal alteration of the corticospinal tract.

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## Monitoring during Endovascular Procedures (Brain and Brainstem)

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### Objectives

Intraoperative monitoring (IOM) has been largely used in endovascular treatment for Spinal cord procedures and has demonstrated to be of critical value for decision making via provocative tests[1,2,3]. Very recently, interest of IOM for endovascular treatment of brain and brainstem procedures has been raised too. Brainstem procedures require indeed the same level of IOM support as spinal cord procedures but brainstem procedures can be only done in highly experienced units. In the past decade, endovascular treatment of brain aneurysms has become the first option of treatment, but only very recently IOM has become an integral part of these procedures. Endovascular treatment of brain aneurysm entitles various procedural maneuvers, such as balloon occlusion, that may cause ischemia and postoperative permanent or transient neurological deficits. In these procedures Patient is under general anesthesia, neurologic assessment during the procedure is not possible. Therefore IOM has been started to use in endovascular procedures.

### Recent developments

Brain vascular pathologies were treated with endovascular procedures more than Neurosurgical approach last decade, However IOM has not utilized like in Neurosurgery. We are witnessing the increasing interest towards IOM in endovascular procedures. Therefore we should review very recently published papers to understand acceptance of IOM among the endovascular specialists. Lukui reported that in 4.8% of patients, changes in IOM triggered some procedural action in order to prevent neurological deficit. In spite of this warnings from the IOM , five patients still had postoperative neurologic deficits [4]. Similarly, Amon et al. reported that 26% of the patients showed IOM changes during endovascular procedures and in 14% of them the procedure was altered due to those changes[5]. In a large series of 873 patients of brain endovascular procedures Philliphs et al. reported IOM changes in 6% of the patients. Positive predictive value was 21%, negative predictive value was 83%, sensitivity 60% and specificity 48%[6]. Interestingly, Sala et al. in their 11 patient series did not observe any false negative results, by using lidocaine as provocative test[7]. Kinshuk et al. reported IOM changes in 3.8% of 406 patients whom underwent endovascular treatment of aneurysms. They also reported irreversible IOM changes highly correlated with postoperative neurologic deficits[8].

The IOM modalities used in brain endovascular treatments are still mainly limited to somatosensory evoked potential (SEP) and brainstem auditory evoked potentials (BAEP). Unsurprisingly, postoperative motor deficits were not detected by SEP and BAEP modalities in several studies[4,5,6,8]. However, almost all the authors of these papers agreed that motor evoked potentials (MEP) may be useful in endovascular procedures. Only one study reported that MEP would not add extra value to IOM in endovascular treatment of aneurysm[9]. This statement can be contested given the fact that the treatment of brain aneurysm by endovascular approach poses different type of risk than by open surgery. For instance, during endovascular procedures, the interventional radiologist has visual assessment of small feeders' vessels such as lenticulostriate arteries or Heubners artery, what does not happen during open surgeries where small feeders can be inadvertently clipped.

The leading concept is particularly the risk of injury during endovascular treatment of brain aneurysm is more comparable to the risk during carotid endarterectomy because embolization and ischemia can happen in both procedures. Intraoperative SEP monitoring efficacy cannot be extend to endovascular procedures. Recently In a small series of choroideal artery aneurysms, reported by Hiraishi et al., MEP changes were detected during endovascular treatment and had good correlation with postoperative transient motor deficits, even though the angiography did not reveal any abnormality. Therefore, MEP monitoring prevented permanent deficits[10]. Similarly, in carotid endarterectomy surgery, MEP monitoring has recently shown to be valuable adjunct to SEP and EEG modalities[11].

Brain vascular malformations are comparable to spinal vascular malformations regarding the endovascular approach and require MEP monitoring for similar reasons. In our experience, during endovascular treatment of brain vascular malformations, MEP as well as SEP is an indispensable methods of IOM because provocative testing with lidocaine and amytal are systematically used. IOM for brain endovascular procedures should be multimodal. Particularly, aneurysms and vascular malformations located at the brainstem require much comprehensive IOM methods. Unfortunately, there is not big series published about the utility of multimodal IOM and so far studies are few with also little number of cases. Only personal communications of highly expert institutes state that multimodal IOM should be used in brain and brainstem endovascular procedures. The predictive value of the provocative tests should be expected to be the same for spinal endovascular procedures as for brain endovascular procedures.

## Conclusions

Endovascular procedures of brain vascular malformations have become a significant part of vascular neurosurgical treatments and IOM should become an integral part of these procedures. Larger case series are necessary to establish the level of value of multimodal IOM in brain endovascular procedures.

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## Monitoring during epilepsy surgery

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### Objectives

After attending the lecture and reading this abstract, the participant should be able to:

- State the goals of monitoring epilepsy surgery.
- Describe intraoperative epileptic focus mapping and its limitations.
- Outline functional mapping and monitoring relevant to epilepsy surgery.

### Introduction

The legendary epilepsy surgeon Wilder Penfield and his neurologist colleague Herbert Jasper developed intraoperative neurophysiology for epilepsy surgery beginning in the 1930's. Their basic approach is still in use — although modified by subsequent advances. In particular, modern preoperative imaging, functional testing and monitoring combined with intraoperative neuronavigation dramatically enhance the design and safety of resective epilepsy surgery. However, preoperative tests and images may not fully match visible anatomy after craniotomy and cannot evaluate intraoperative neural integrity. Thus, direct neurophysiologic assessment of exposed brain tissue remains valuable and complimentary.

### Goals of monitoring epilepsy surgery

Surgical decisions in epilepsy consider multiple investigations seeking *congruent* evidence for an epileptic focus that could be safely resected to achieve seizure freedom or worthwhile reduction. Neurophysiologic results are one part of this holistic process. Thus, the goals of monitoring epilepsy surgery are to *help* optimize epileptic tissue resection while avoiding neurological deficits. Achieving these goals may involve mapping the epileptic focus as well as mapping and monitoring functionally critical brain structures.

### Epileptic focus mapping

Epilepsy surgery aims to resect the epileptogenic lesion identified by imaging along with its associated 'epileptogenic zone' defined as the seizure-generating cortex that has to be removed for seizure freedom. Electrocorticography (ECoG) is a method for estimating the epileptogenic zone. Epileptic neurons manifest abnormal paroxysmal depolarizing shifts that when arising synchronously in a large enough neuronal population summate as 'spike' discharges. The cortical region exhibiting interictal spikes is the 'irritative zone' that may offer some guide to the epileptogenic zone, but can be much larger. The 'seizure onset zone' is the cortical region where an ECoG seizure pattern first begins. It is usually a subregion of the irritative zone and better estimates the epileptogenic zone, subject to electrode coverage.

Intraoperative ECoG has serious limitations because it only briefly maps the irritative zone and may be influenced by anesthetic agents that can suppress, mimic or provoke spikes. Nevertheless, resecting a small congruent irritative zone along with the lesion seems reasonable because it is likely to contain the epileptogenic zone. On the other hand, resecting a large or incongruous irritative zone may be inappropriate. Furthermore, post-excision ECoG often shows activation of new spikes due to the acute surgical injury, but having no significance for seizure recurrence. While methods to differentiate significant from insignificant pre- and post-resection spikes have been suggested, there is no generally confirmed way of doing so. Consequently, the value of intraoperative ECoG for tailoring epilepsy surgery remains controversial after decades of clinical experience.

Extraoperative ECoG monitoring with implanted intracranial electrodes has fewer limitations. It enables thorough irritative zone assessment without anesthetic influence and also maps the seizure onset zone by capturing seizures. This is the method of choice for epilepsy surgery candidates needing detailed epileptic focus mapping.

Thus, the use of intraoperative ECoG for epileptic focus mapping is declining. Some programs incorporate it for straightforward cases, while others omit it with no apparent detrimental effect on outcome. Most programs use extraoperative ECoG for complex patients, thus removing the need for intraoperative epileptic focus estimation.

### Functional mapping and monitoring

Functional mapping and monitoring are not needed for epilepsy resections away from vital cerebral structures. However, they are important for resections near sensorimotor, language, or visual cortex. In these circumstances, mapping can permit a complete resection that might otherwise not be done for fear of a deficit, or help decide a safe subtotal resection limit. Intraoperative mapping is particularly important for patients who have not had preoperative mapping, but may also be done to confirm or modify preoperative results. Stable intraoperative monitoring results build confidence to complete the resection, while deteriorating signals can prompt restorative intervention to avoid injury, or help decide a surgical stopping point.

The traditional Penfield intraoperative mapping technique consists of direct cortical stimulation with 50-60 Hz biphasic pulse trains lasting 1–5 seconds while observing the awake patient for responses. Primary motor cortex stimulation produces localized contralateral tonic muscle contractions; primary sensory cortex stimulation produces localized contralateral somatosensory experiences; language cortex stimulation produces aphasia or dysphasia; and primary visual cortex stimulation produces phosphenes. The technique is not feasible for patients unable to collaborate with awake craniotomy, forgoes monitoring, and often induces afterdischarges — seizure patterns in adjacent or distant cortex induced by and outlasting the stimulus. Afterdischarges risk false localization because they can produce clinical signs from unstimulated cortex, and build to clinical seizures in 5–15% of patients. Thus, concurrent ECoG monitoring is mandatory: one ignores patient responses with an afterdischarge, and tries to keep stimulus intensity below afterdischarge threshold.

Modern intraoperative sensory evoked potential (SEP), motor evoked potential (MEP), and possibly visual evoked potential (VEP) methods enable mapping *and* monitoring, and are applicable to all patients because they are done under general anesthesia. In addition, concurrent ECoG is not needed for SEPs or VEPs, and is optional for direct cortical stimulation MEPs because these short-latency transient responses are not subject to false localization from afterdischarges, and because the technique induces fewer seizures. SEPs and MEPs are gradually replacing traditional sensory and motor functional testing, and recent evidence suggests similar value for VEPs.

There are also preliminary efforts towards developing language mapping under anesthesia. One possible method consists of cortico–cortical potentials with language cortex stimulation and recording. Another consists of pulse train stimulation of premotor cortex near Broca's area with long-latency laryngeal muscle MEP recording. For the time being, however, accurate language mapping still requires the traditional awake Penfield technique.

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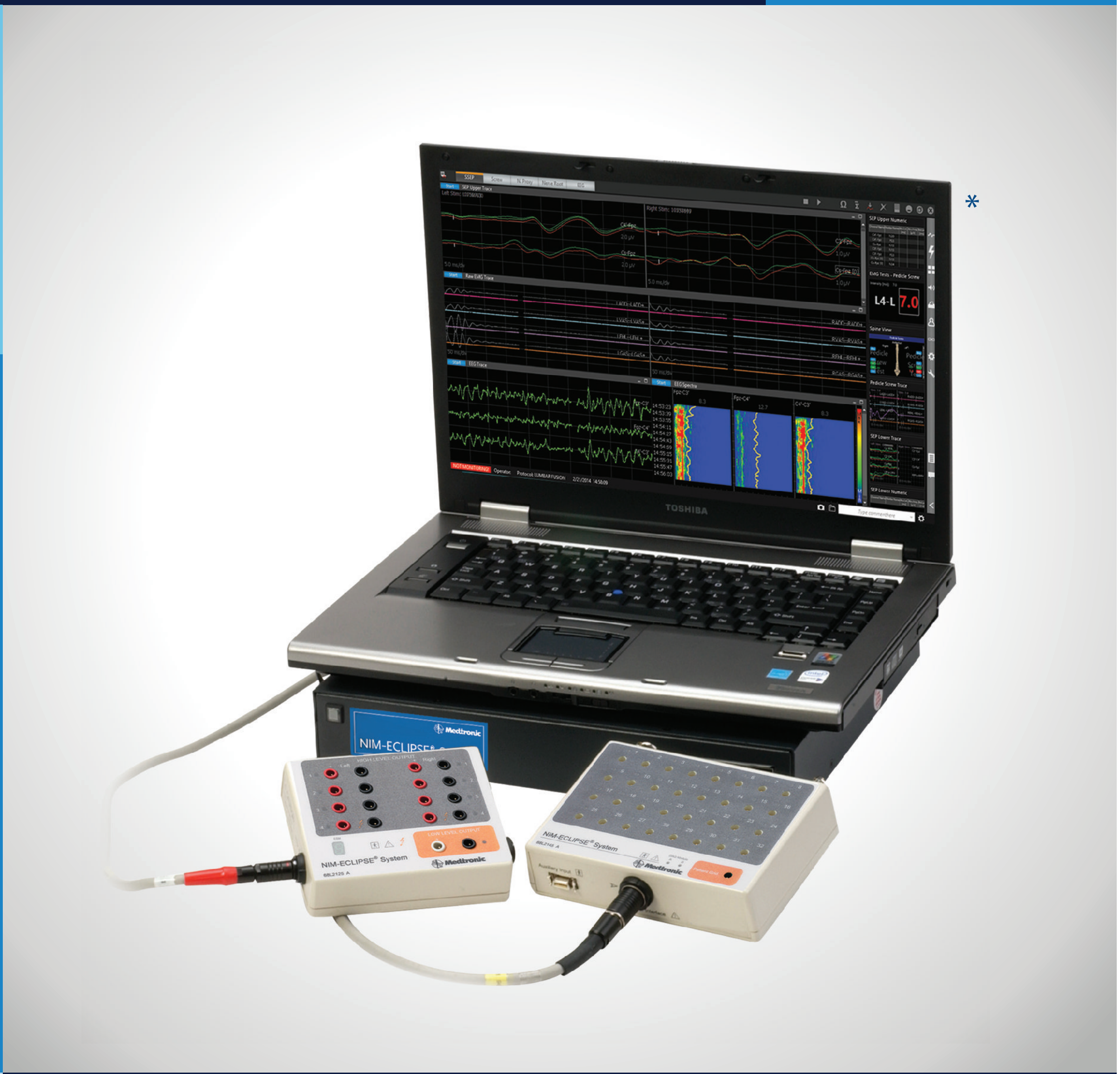


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# Scientific Program

## Day 1 - Thursday, November 12

07h30 - 08h15 **Registration**

08h15 - 08h30 **Opening Remarks**
Chair: Ricardo Ferreira    Co-Chair: Francisco Soto
ISIN President: Francesco Sala    Scientific Committee Chair: Karl Kothbauer

**08h30 - 10h30 Session I:**
**Warning Criteria for MEP monitoring**
Chair: Vedran Deletis
Co-Chair: Jaime Lopez

08h30 - 08h50 **Overview on criteria for MEP monitoring**
David B. Mac Donald

08h50 - 09h10 **MEP monitoring: The threshold-level method**
Blair Calancie

09h10 - 09h30 **The percentage of amplitude decrease Warning Criteria**
Louis Journee

09h30 - 09h50 **The All or Nothing Warning Criteria in Myogenic Responses**
Karl Kothbauer

09h50 - 10h10 **Multiparametric alarm criterion for MEP during spine deformity surgery**
Martín Segura

10h10 - 10h30 **Discussion: Previous Speakers - Tailoring MEP warning criteria**

10h30 - 11h00 **Coffee Break**

11h00 - 12h00 **Mary Menniti Stecker Memorial Lecture**

11h00 - 11h05 **Introduction**
Chair: Karl Kothbauer

11h05 - 12h00 **New development on neurophysiology of the corticospinal tract**
Roger Lemon

12h00 - 13h00 **Free Papers Session I MEPs ( 4 Oral Presentations )**
Chair: Karl Kothbauer
Co-Chair: Louis Journee

13h00 - 14h00 **Lunch Plus Poster Session I**
Chair: Vedran Deletis
Co-Chair: Mirela Simon

| | |
|---|---|
| **14h00 - 15h20** | **Session II:**<br>**Monitoring in Vascular Surgery**<br>Chair: Andrea Szelenyi<br>Co-Chair: Kunihiko Kodama |
| 14h00 - 14h20 | **Introduction Cerebral Aneurysms Surgery**<br>Feres Chaddad |
| 14h20 - 14h40 | **Aneurysms Endovascular Monitoring**<br>Jaime Lopez |
| 14h40 - 15h00 | **Monitoring in Aortic Aneurysms**<br>Mirela Simon |
| 15h00 - 15h20 | **Discussion: Previous speakers** |
| 15h20 - 15h50 | **Coffee Break** |
| **15h50 - 17h30** | **Session III:**<br>**Thoracic Pedicle Screws**<br>Chair: Ricardo Ferreira<br>Co-Chair: Maria Lucia F. de Mendonça |
| 15h50 - 16h10 | **Introduction and Free Hand Technique**<br>Paulo Tadeu Maia Cavali |
| 16h10 - 16h40 | **Experimental models and translation to OR**<br>Gema de Blas Beorlegui |
| 16h40 - 17h10 | **Neuromonitoring using train pulse in thoracic pedicles screws**<br>Blair Calancie |
| 17h10 - 17h30 | **Discussion: Previous speakers** |
| **17h30 - 18h30** | **Session IV:**<br>**IONM World Vision - ISIN Educational Challenge**<br>Chair: Francisco Soto<br>Co-Chair: Francesco Sala |
| 17h30 - 17h45 | **IONM in Underdeveloped countries**<br>Francisco Soto |
| 17h45 - 17h55 | **IONM in Africa** |
| 17h55 - 18h05 | **IONM in China**<br>Xianzeng Liu |
| 18h05 - 18h15 | **IONM in India**<br>Ashok Jaryal |
| 18h15 - 18h30 | **Discussion : Previous speakers** |
| 18h30 - 19h30 | **Free Papers Session II ( 4 Oral Presentations )**<br>Chair:  David B. MacDonald<br>Co-Chair: Gema de Blas Beorlegui |
| 19h30 | **Welcome Cocktail and Adjourn** |

# Scientific Program

## Day 2 - Friday, November 13

**Breakfast Session C**
Chair: Luciana Taricco
Co-Chair: Carolina Nuñez

07h00 - 07h45 **A) Anesthesia and Intraoperative Monitoring**
Antoun Koht
**B) Neurophysiology at the ICU**
Mirella Simon
**C) Monitoring of posterior fossa surgery**
Isabel Fernández-Conejero
**D) Monitoring of conus and cauda equina**
Sedat Ulkatan
**E) Monitoring for Spinal Cord Surgery**
Karl Kothbauer
**F) Deep Brain Stimulation**
Kendall Lee and Kevin Bennet

**08h00 - 08h50** **Session V:**
Chair: Vedran Deletis

08h00 - 08h50 **Development of the corticospinal tract in children: Implications for cortical mapping and MEP monitoring**
Janet Eyre

08h50 - 09h50 **Fred Epstein Memorial Lecture**
Chair: Francesco Sala

09h00 - 09h50 **Monitoring and mapping during brain surgery in children**
James Rutka

**08:00 - 10:00** Workshop Techs :
CNIM BOARD PREP.
Chair: Rebecca Clark-Bash

Local: Floor -1

09h50 - 10h20 **Coffee Break**

**10h20 - 12h10** **Session VI:**
**Motor Mapping**
Chair: Isabel Fernandez-Conejero
Co-Chair: Kathleen Seidel

10h20 - 10h50 **High versus low frequency motor mapping: A tailored approach in glioma surgery**
Lorenzo Bello

10h50 - 11h20 **Optimizing the extent of resection in eloquently located gliomas**
Andrea Szelenyi

11h20 - 11h50 **What to expect if there is a postop motor deficit**
Janet Eyre

11h50 - 12h10 **Discussion: Previous speakers**

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|---|---|
| 12h10 - 13h10 | **Free Papers Session III ( 4 Oral Presentations)**<br>Chair: Andrea Szelenyi<br>Co-Chair: David B. MacDonald |
| 13h10 - 14h10 | **Lunch Plus Posters Session II**<br>Chair: Jay Shils<br>Co-Chair: Jaime Lopez |
| 14h10 - 14h30 | **Presidential Address**<br>Francesco Sala |
| 14h30 - 14h35 | **Invited Lecture: The Journal of Neurosurgery - View**<br>Chair: Karl Kothbauer |
| 14h35 - 15h10 | **Is IOM relevant for neurosurgical journals?**<br>James Rutka |
| **15h10 - 16h20** | **Session VII:**<br>**Peripheral Nerves**<br>Chair: Elif Ilgaz<br>Co-Chair: Maria Rufina Barros |
| 15h10 - 15h30 | **Tethered Cord Neurosurgical Vision**<br>Gabriel Mufarrej |
| 15h30 - 15h50 | **Brachial Plexopathy**<br>Jaime Lopez |
| 15h50 - 16h10 | **Pudendal Monitoring: what is missing?**<br>Vedran Deletis |
| 16h10 - 16h20 | **Discussion: Previous speakers** |
| 16h20 - 16h45 | **Coffee Break** |
| 16h45 - 17h45 | **Free Papers Session IV ( 4 Oral Presentations )**<br>Chair: Karl Kothbauer<br>Co-Chair: Charles Dong |
| 17h45 - 17h50 | **Invited Lecture**<br>Chair: Ricardo Ferreira |
| 17h50 - 18h40 | **The art of Navigation and Science of Planning**<br>Amyr Klink |
| 18h40 - 19h00 | **2017 Bi-annual Meeting Announcement** |
| 19h00 - 19h30 | **General Assembly** |
| 20h30 - 23h30 | **5th Congress Dinner in Rio de Janeiro** |

# Scientific Program

## Day 3 - Saturday, November 14

**Breakfast Session D**
Chair: Lais Miller Reis Rodrigues
Co-Chair: Silvia Heredia de Luqui

07h00 - 07h45 **A) D-wave physiology and spinal cord mapping**
Vedran Deletis
**B) EEG Monitoring**
Mirela Simon
**C) Deep Brain Stimulation**
Jay Shils
**D) MEP Monitoring for supratentorial surgery**
Andrea Szelenyi
**E) Cranial Nerve Monitoring**
Isabel Fernandez-Conejero

**08h00 - 10h00 Session VIII:**
**Intraoperative Neurophysiology of the injured spinal cord: From bench to bedside**
Chair: Antonio Santos de Araujo Junior
Co-Chair: Francesco Sala

08h00 - 08h30 **Spinal cord injury: Plasticity**
Roger Lemon

08h30 - 09h00 **IOM during the acute phase of SCI**
Paolo Costa

09h00 - 09h40 **Restorative neurology of the injured spinal cord**
Milan Dimitrijevic

09h40 - 10h00 **Discussion: Previous speakers**

10h00 - 10h30 **Coffee Break**

10h30 - 11h30 **Free Papers Session V ( 4 Oral Presentations )**
Chair: Klaus Novak
Co-Chair: Konstantinos Papadopoulos

## 11h30 - 13h20 Session IX: Deep Brain Stimulation - DBS

Chair: Jay Shils
Co-Chair: Martin Segura

11h30 - 12h00 **Introduction and future perspectives**
Jay Shils

12h00 - 12h30 **Current and Future application of Neuromodulation surgery**
Kendall Lee and Kevin Bennet

12h30 - 13h00 **Neural Engineering next generation of DBS technology**
Kendall Lee and Kevin Bennet

13h00 - 13h20 **Discussion: Previous speakers**

13h20 - 13h40 **Award Ceremony:**
Best Free Paper presentation Karl Kothbauer

13h40 - 14h00 **Closing Remarks, Acknowledgements**
Chair: Ricardo Ferreira — Co-Chair: Francisco Soto
ISIN President: Francesco Sala — ISIN President elected: Andrea Szelenyi

# Invited Faculty Abstracts

## Day 12 - Session I: 08h30 - 10h30
## Warning Criteria for MEP monitoring

### Overview on criteria for MEP monitoring

David B. MacDonald, MD, FRCP(C), ABCN
King Faisal Specialist Hospital & Research Center
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**Objectives**

After attending the lecture and reading this abstract, the participant should be able to:

- Describe motor evoked potential (MEP) properties that influence warning criteria.
- State the theoretical basis for different criteria.
- Describe the rationale for tailoring criteria to surgical circumstances.

**Introduction**

D-waves have straightforward warning criteria but limited indications, while muscle MEPs have many indications but unsettled warning criteria, which this session explores. The emphasis will be on spinal cord monitoring for which criteria were first developed, but the tailoring of criteria for other circumstances will also be introduced.

**MEP properties influencing criteria**

*D-waves*

D-waves are compound volleys of corticospinal axon action potentials. They are *non-synaptic*, so resist anesthesia and neuromuscular blockade (NMB). They are *linear*, meaning that their amplitudes are proportional to the number of conducting axons. They are *stable*, exhibiting < 10% trial-to-trial amplitude variability. These properties support amplitude reduction warning criteria.

*Muscle MEPs*

Muscle MEPs are compound motor unit potentials generated by lower motor neuron (LMN) temporal summation of multiple corticospinal excitatory postsynaptic potentials. They are *polysynaptic*, so are sensitive to anesthesia, NMB and fade — gradually falling amplitudes and rising thresholds. They are *non-linear*, meaning that disproportionately large decrements follow small reductions of conducting corticospinal axons or LMN excitability, resulting in high sensitivity to central motor compromise. They are *unstable*, exhibiting amplitude, morphology, and threshold variability. These properties challenge warning criteria.

**D-wave criteria**

The D-wave amplitude criterion for intramedullary spinal cord tumor (IMSCT) surgery is 50% reduction and the criterion for peri-Rolandic brain surgery (direct cortical stimulation with cervical epidural recording) is 30–40% reduction. Final amplitudes below these limits predict long-term motor deficits, while preservation above them predicts long-term recovery of any early weakness. There are no established criteria for other surgical circumstances.

**Muscle MEP criteria**

The following criteria apply to responses that have been consistently present and deterioration for which there is no apparent confounding factor explanation.

*Disappearance*

Muscle MEP disappearance is *always a major criterion* because it is a strong predictor of early postoperative weakness when irreversible. It can be the first sign, or follow partial deterioration. Reversible disappearance implies successful intervention.

Disappearance has been proposed as a sole criterion for spinal cord monitoring. The theoretical basis is that pathophysiology such as compression or traction likely disturbs many of the corticospinal axons in the anatomically compact spinal cord, and ischemia rapidly disables LMNs. Thus, highly sensitive non-linear muscle MEPs often disappear. Dissection during IMSCT surgery may also disrupt other systems that support LMN excitability, causing muscle MEP loss with an intact corticospinal pathway.

There is published support for disappearance as a sufficient spinal cord monitoring criterion. However, there is also evidence for some generally mild transient motor deficits picked up by deterioration of still-present MEPs. Thus, amplitude or threshold might be *minor* or *moderate* spinal cord criteria, but could increase false positives.

Disappearance is clearly not a sufficient sole criterion in other surgical circumstances, for which other criteria must be incorporated.

*Amplitude reduction*

Amplitude reduction criteria have been proposed for all surgical circumstances. The theoretical basis is that partial reduction of conducting corticospinal axons or responding motor units could result in appreciable amplitude deterioration of still-present responses. Muscle MEP properties present obstacles to this approach. In particular, they could risk false alarms that may interfere with surgery or desensitize surgeons to real deterioration.

For spinal cord monitoring, 50% is too sensitive and marked reduction is required, such as > 80% — which still results in some false positives. However, for brain, brainstem, and facial nerve monitoring, 50% is the currently recommended limit. Decrements should be visually obvious and clearly exceed spontaneous variability.

*Threshold elevation*

Threshold elevation criteria have been proposed for spinal cord and brain monitoring. The theoretical basis is that the largest corticospinal axons have lowest threshold and greatest susceptibility to damage, so that threshold elevation could provide an early and sensitive warning. Thresholds do spontaneously vary and can gradually increase during surgery, thus risking false positives.

There is published support for a ≥ 100 V threshold elevation criterion for spinal cord monitoring. Valid application may require adherence to the reported methodology (constant voltage C3–C4 stimulation, 3–4 pulse trains, 2 ms interstimulus interval, 0.05 ms pulse duration). Three reports indicate few false positives for *acute* threshold elevation. One orthopedic surgery series reported a substantial proportion of gradually evolving benign ≥ 100 V threshold elevations attributed to fade.

There are a few reports of combining > 20 mA threshold elevation with > 50% amplitude reduction as warning criteria during peri-Rolandic brain surgery. It is difficult to separate the contributions of the two criteria.

*Morphology simplification*

A single report proposed a morphology criterion for IMSCT surgery. It consisted of transformation from polyphasic long duration to biphasic short duration potentials and was combined with ≥ 100 V threshold elevation. The results have not been replicated.

**Tailoring criteria**

It is advisable to consider anatomy when selecting criteria. For example, in contrast to the compact spinal cord, the cerebral corticospinal system is a large structure consisting of motor cortex and fanned-out corona radiata axons. Consequently, partial muscle MEP amplitude deterioration (> 50%) due to localized compromise is probably more likely. As another example, the facial nerve is the only supply for facial muscles and the injury site is distal to LMNs. Thus, partial facial MEP amplitude deterioration (> 50%) due to partial motor axon failure might be expected.

Surgical goals are also important. For example, IMSCT surgery seeks complete tumor removal without permanent deficits, but temporary deficits may be acceptable. Thus, major warnings based on sensitive criteria could interfere with successful treatment. As another example, scoliosis surgery seeks satisfactory curve correction without any deficit. Thus, one might consider moderate warnings based on sensitive criteria while keeping their propensity to false positives in mind.

**Key references**


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## MEP monitoring: The Threshold-Level method

Blair Calancie, PhD
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### Objectives

Describe the threshold-level alarm criteria for monitoring transcranial MEPs
Examine the physiologic basis for this method
Review data comparing 'Threshold-Level' with 'All-or-None' alarm criteria for predicting post operative motor deficit
Examine this method's advantages and limitations

### History

Testing with intraoperative MEPs from repetitive transcranial electric stimulation (rTES) of motor cortex has been in regular use in the United States since 2002, when the FDA approved the first stimulator – the Digitimer D185 – designed for this purpose. That approval was based upon clinical data generated by my laboratory from 1995 through 2001 (Investigational Device Exemption G890040). These data were comprised of MEP responses from 903 subjects tested during surgery, whose post-operative motor status was examined through either prospective evaluation by an investigator blinded to the intraoperative records (n = 352) or from chart review (n = 551), again by an investigator blinded to intraoperative MEP findings. In all cases, the Threshold-Level method served as the primary intraoperative measure of corticospinal tract (CST) functional integrity.

### Summary of method

Under defined and unchanging stimulation and anesthesia conditions, the stimulus voltage needed to elicit a minimal compound muscle action potential (i.e. the *threshold* voltage) from a given target muscle will remain relatively constant, even for surgical procedures lasting many hours. Deterioration in central motor conduction and/or lower motor neuron function will be reflected by a need for stronger stimulation intensity, recruiting a larger population of upper motor neurons. Hence this stimulus voltage serves as the primary outcome measure of CST function. It's important to note that *every target muscle being monitored* has its own unique threshold. Finally, the reliability of this approach is diminished significantly by utilization of halogenated agents, such as Desflurane or Sevoflurane, even at dosages well under 1.0 MAC; we've found that dexmedetomidine to also be problematic, although to a lesser extent.

### Stimulation parameters

The method requires a brief, high-frequency pulse train. We typically use a 4-pulse train with a 2 ms interpulse interval (i.e. *4@2*); this pattern is usually adequate – although not necessarily optimal – for evoking responses from both upper and lower limb muscles. Stimulation is via corkscrew electrodes placed just anterior to C3 and C4. The initial stimulus intensity is set at 100 V, and is increased by fixed increments until a response is elicited in each target muscle. The pattern of increments used is: 100 V, 125 V, 150 V, 200 V, 250 V ..... 500 V. We limit the maximum voltage to 500, which typically leads to current delivery of ~ 1000 mA. In practice, we test a particular stimulus intensity, then reverse the electrode polarity and stimulate with the same intensity, thereby testing both left- and right-side motor cortices, before incrementing the stimulus intensity.

The pattern of voltage increments described above was arrived at empirically. One could establish more precise thresholds for a given muscle by using smaller voltage increments, but at the expense of added test time. Conversely, testing could be completed in less time using larger increments in voltage, but at the expense of test sensitivity. For us, the pattern described above provides an acceptable combination of test brevity (it typically takes 30 – 60 s to complete a full measure of thresholds for a montage including 10 target muscles in both upper and lower limbs) and sensitivity.

### Results

A significant change in MEP thresholds was defined as a threshold increase of 100 V or more that could not be explained by a change in anesthesia management or CNS $O_2$ delivery (e.g. hypotension; significant blood loss). This 100 V value was arrived at empirically (1, 2).

Of the 859 subjects from whom at least one target muscle showed an MEP at baseline, there were 93 cases of new and clinically-significant weakness (manual muscle test score declined by 2 or more) in at least one target muscle during the acute post-operative period.

In every case of post-operative weakness, we found that the intraoperative rTES threshold of a least one target muscle had increased by at least 100 volts at the time the case concluded (i.e. *true positive*), with no cases of post-operative weakness in the absence of an intraoperative threshold increase (i.e. sensitivity = 1.00). There were 2 cases of significant intraoperative threshold increase of 100 volts in a target muscle for which the subject awoke without any obvious worsening of motor function (i.e. *false positive*). For both of these cases, responses in the target muscles persisted to the conclusion of the case, albeit at higher thresholds.

Our data allowed us to compare the timing of target muscle threshold changes to the timing of a complete loss of response (i.e. *presence-or-absence*) to rTES. There were many instances in which target muscle thresholds increased by significant amounts without losing the response altogether, and/or thresholds were significantly elevated for a period of time before the responses were lost altogether (3).

**Conclusions**

We found that in this cohort made up primarily of neurosurgical patients (many with spinal cord tumors), changes in target muscle thresholds for eliciting MEPs provided accurate and *earlier* indications of deterioration in central motor conduction than would often have been discerned had we relied solely upon the presence or absence of an evoked motor response to rTES. We concluded in this report that ".... a complete signal loss triggering a warning with the Presence-or-Absence approach will accurately and reliably predict a worsened clinical status after surgery, but the delay associated with providing this warning may contribute to the clinical problem, not prevent it. Unless the practitioner can be absolutely certain that CST and/or lower motoneuron function will be impacted immediately and uniformly by a particular surgical maneuver, use of the Presence-or-Absence alarm criteria for interpreting rTES-evoked motor responses should be avoided." (3).

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## The percentage of amplitude decrease warning criteria

H. Louis Journée, MD, PhD
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### Objectives

- To give insight in current alarm criteria pertaining to percentage of amplitude decrease for transcranial elicited motor potentials (MEP).
- To provide guidelines for operational methods to desensitize muscular MEPs (mMEP) for confounding factors to reduce trial-to-trial MEP variations and optimizing the relationship between impact and outcome.

### Historical review

Patton and Amassian first described D-waves from direct cortical stimulation (DCS) in monkeys, in 1954. In 1980, Merton and Morton introduced transcranial electrical stimulation (TES) to generate mMEPs in conscious man. Epidural D-waves became rapidly a valuable tool for intra-operative monitoring in spinal procedures. In 1993 Taniguchi et al introduced multipulse TES-trains to overcome the blocking effects of lower motor neurons (LMN) by anesthetics. An additional facilitation by double train stimulation (Journée et al,2004) improved the success rate of TES-mMEP.
MEPs were a welcome addition in to-dates intra-operative multimodality monitoring and comprises 2 different types of motor potentials: epidural D waves and mMEPs.
D-waves are stable within physiological variations of 8% due to the absence of synapses in the cortico spinal tract between activation and recording. They are resistant to most anesthetic agents and any neural activity acting on LMNs.
In contrast, anesthetics control absolute conditions for activation of LMNs. Guidelines for selection of anesthetics when using mMEPs are derived from dose-effect studies. Major MEP modulators are sedatives. Important additions for maintaining steady state conditions are total intravenous infusion (TIVA) administering constant volumes per unit of time or target controlled infusion (TCI) for constant blood levels. These techniques minimize dose related MEP modulation. The use of neuromuscular blocking agents during monitoring is discouraged.

### Warning Criteria

Because of the invariability of D-waves lacking many confounding factors that are encountered in muscle MEPs, it is not a surprise that strict warning criteria with consistent evidence exist. Warning criteria are defined as percentages of amplitude reduction. A reduction down to 50% predicts a good long-term motor outcome in intramedullary spinal cord tumors, whereas cervical d-waves from direct cortical stimulation (DCS) of 30-40% is a major criterion in brain surgery Fujiki et al (2006).
In contrast, the inter- and intra- individual variability of muscle MEP amplitudes is high. The complex dependence of the MEP amplitude and shape on many confounding factors complicates the interpretation of MEPs during monitoring. False negatives are scarce in expert hands and usually due to incomplete coverage of monitored muscle groups. The experience gained by a trained neuromonitoring team is of utmost value, because their clinical and neuromonitoring knowledge is the only available guideline to determine the TES-MEP criteria.
There exist several interpretive criteria. 1) Amplitude reduction, subdivided in presence-disappearance and percentage amplitude decrease, 2) threshold elevation and 3) simplification of morphology.
This presentation is restricted to percentage of amplitude reduction of TES-MEPs, ignoring other modalities.
The only criterion for which a consensus has been reached is the complete disappearance of muscle responses (100% amplitude reduction). However, this only applies to surgery for intraspinal tumors, where temporary motor deficits are accepted. In corrective surgery of the spine even a temporary postoperative motor deficit is not acceptable. Therefore, detection of impending neurological deficits at an earlier, more reversible stage is preferred before complete disappearance of responses occurs.
The criteria are based on a reduction of the baseline peak-to-peak amplitude below a predefined percentage proposed for all types of monitoring. Warning levels for spinal surgical procedures are 50 – 90% [Langeloo et al 2003, Skinner et al 2005, 2009]. False positives are inevitable in this range.
For surgery in supra tentorial regions and posterior fossa, more stringent criterions are used: 50% (Irie et al, 2010, Neuloh et al, 2004, 2008, Szelenyi et al 2006, 2010, 2011, Akagami et al, 2005, Liu et al, 2007 Fukuda et al, 2008, Matthies et al 2011), or 20-50% when the latency time is increased over 15% ( Fujiki et al, 2006).
For surgery in the fossa posterior, Dong et al (2005) used 50, 35 and 0% decrease of baseline criteria. They found a prediction of facial deficits in the cranial nerve distal from the LMN, sensitivity/ specificity of 1.0/0.88, 0.91/0.97 and 0.64/1.00.

**Recent developments and future directions**

The interpretation of mMEPs is hampered by their sensitivity to the many confounding factors.

Systematic TES parameter optimizing procedures may reduce trial-to-trial variations to improve sensitivity and selectivity of mMEP warning criteria. MEP amplitudes as function TES parameters give insight in the sensitivity to parameter changes for each muscle group. For example, one can retrieve the sensitivity to voltage from the voltage function. A steep slope (gain parameter) between threshold (THL) and supramaximal levels (SML) indicates a high sensitivity to THL changes, while mMEPs in the horizontal part of the curve at SML remains unaffected (gain=0). THL, slope and SML may differ between muscle groups. A change of THL may -for example- happen during development of scalp edema. Instead of a general involvement of muscles, MEP reductions may become only apparent in specific muscle groups. Here, knowledge of the characteristics of the voltage curve may help to reduce false positive interpretations.

Other measures for improving the accuracy of percentage criteria are adapting baseline levels to fading effects, establishing blood pressures in the middle of the horizontal part (gain=0) of spinal cord autoregulation functions, monitoring the scalp electrodes impedance to alarm for THL changes from developing scalp edema.

It is difficult to compare all outcome data from literature because of absent TES- set-up standards.

**Conclusion**

The limited selectivity/ sensitivity and positive predictive value of warning criteria of percentage of amplitude reduction possibly can be improved by developing standards for set-up procedures of TES paradigms including strategies for desensitizing mMEPs for variations of confounding parameters. The creation of such standards for set-up conditions may be valuable for comparison of outcome data of multicenter evidence based studies.

**Recommended reading:**

D.B. MacDonald, S. Skinner, J. Shils, C. Yingling. Intraoperative motor evoked potential monitoring – A position statement by the American Society of Neurophysiological Mnitoring. Clin Neurophysiol 124 (2013) 2291-2316

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## The all-or-nothing warning criteria in MEPs

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### Objective

The interpretation of motor evoked potentials is a hotly debated issue of intraoperative neurophysiology. There are several ways to do this, most of which are plausible but none is universally accepted. It is essential to recognize that this must be viewed anatomically rather than methodologically: motor evoked potentials are the same method regardless if the pathology is in the cerebral cortex, the deep areas of the cerebrum, the brainstem and posterior fossa or the spinal cord. Their interpretation depends methodologically upon the site of stimulation, i.e. the transcranial or the direct cortical stimulation technique on one hand, and on the anatomical site of the lesion and the surgery on the other. There is a great difference between MEP-interpretation in cranial and brainstem-surgery and MEP-interpretation in spinal cord surgery. The MEP-interpretation in spinal cord surgery is best understood of all, albeit our understanding is far from complete.

### Brief historical review

MEP-monitoring has been first used with a single stimulus-technique, probably insufficient anesthesia and with the assumption that decrease of signal amplitude would indicate neurological compromise. The train-stimulation technique introduced by Taniguchi has resolved the stimulation and recording problems by bringing a robust MEP-technique into the surgical environment. Since then train-stimulus or multi-pulse stimulation is the gold-standard for intraoperative muscle MEP-monitoring. The interpretation of muscle MEP amplitudes, change in stimulus thresholds, or the complete loss of muscle MEPs have been the three paradigms used.

The most convincing data published and the overwhelming experience of users appears to be that the loss of muscle MEPs during spinal cord surgery has the most serious "meaning" in terms of occurrence of postoperative neurological dysfunction. Loss of muscle MEPs most consistently correlates with clinically relevant deficits. This is not to say that decrease of muscle MEP amplitudes or elevation of stimulus thresholds should be regarded as "meaningless". These changes certainly indicate changes in the excitability and connectivity of the motor system which may both relate to local factors attributed to the surgery performed and general factors including temperature, cerebrovascular stability, anesthesia depth.

The application of muscle MEP amplitudes is limited by the significant variability of muscle MEP amplitudes over the course of an operation and between individual stimulations. Which extent of deviation from a (difficult to determine) baseline value should be used? Mostly about 50% of amplitude decrement is proposed but this seems rather haphazard and correlations to clinical changes are rare and seldom convincing. Furthermore there is a lack of standardization of recording techniques which makes comparing different results even more difficult.

### Summary of recent developments and/or future directions

At the present time the most convincing correlation of clinical deficits after spinal cord surgery is to the loss of muscle MEPs rather than other measures. While this appears to reflect the collective experience of users it is in fact insufficient for use in surgery, as one would NOT want to advance as far as muscle MEP loss which indicates a deficit, even if it may only be transient. Rather one would like to use parameters going less far as a deficit to guide spinal cord operations. Therefore and because of the scientific controversy this debate will continue until definitive data come from larger and more detailed studies about the true "meaning" of muscle MEP parameters.

### Conclusions

The best correlation of muscle MEP data to clinical deficits lies in the assessment of MEP presence and absence. Monitoring should be improved towards a better understanding of threshold and amplitudes, or other yet to be determined measures to provide intraoperative monitoring with earlier warning criteria and thus avoid even short-term motor deficits.

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# Multiparametric alarm criterion for motor evoked potential monitoring during spine deformity surgery

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**Objectives**

To compare the magnitude and time course of changes in TcMEP parameters, such as amplitude, area under the curve, duration, number of phases, and latency, for the early detection of spinal cord impairment due to spinal instrumentation or force manoeuvring (e.g. cervical traction or placing the patient in surgical position).

In addition, to analyse similar changes of an empirical ratio calculated by a combination of the above-mentioned parameters:

$$\text{Ratio} = \frac{(\text{Amplitude} + \text{Area}) \times (\text{Duration} + \text{Phases})}{\text{Latency}}$$

**Historical review**

Transcranial motor evoked potentials (TcMEP) have improved intraoperative monitoring (IOM) during surgery for spine deformities (1,2,3,4,5). Several warning criteria aimed to detect impending spinal cord damage have been proposed in recent years. These include: TcMEP absolute (6,7) or relative amplitude drop (7,8), changes in cortical thresholds (9,10), a combination of the latter with a decrease in the number of phases of the muscle response (11), and a multiphasic TcMEP pattern (12). Nevertheless, there is no general agreement regarding which of the above mentioned criteria is the most sensitive for the early detection of spinal cord injury.

Based on previous studies (6,7,8,13,14,15,16,17), it seems that the most commonly employed warning criterion is an MEP amplitude drop with cutoff points tailored to the type of surgery under monitoring. For orthopaedic spine surgery the cutoff point most often employed is an MEP amplitude drop of 70-88%. However, other MEP parameters, such as number of phases, duration, area under the curve, and latency, could also be used. Indeed, some of them, e.g. phases, duration, and stimulation thresholds, have been proposed by other authors (11).

**Summary of recent developments and/or future directions**

This presentation describes an attempt to employ multiple TcMEP parameters in order to seek an improved alarm criterion during spine surgery. The idea for this study originated from the empirical impression that when intraoperative TcMEP presents an amplitude drop, latency increases while, at the same time, its duration shortens and the number of phases as well as the area under the curve decrease.

- Methods:

We analysed the TcMEP recordings in five neurophysiological events from a selected group of four patients (32 mths to 12 yrs) with a diagnosis of neuromuscular kyphoscoliosis, idiopathic scoliosis, congenital kyphosis, and achondroplasia with cervical instability. All of them presented with significant TcMEP changes during surgical correction for spine deformities or force manoeuvring (e.g. cervical traction or placing the patient in surgical position) in the absence of any anaesthetic or haemodynamic change. In every case, TcMEP changes reverted to normal values when the surgery team interrupted the harmful manoeuvring or modified the surgical plan. The time course of changes in TcMEP parameters (amplitude, area under the curve, latency, number of phases, and duration) was analysed during each event. In addition, changes of the empirical ratio were also assessed. For analysis purposes, all variables were normalised and changes were expressed as a percentage of basal recordings.

Normal variability of TcMEP parameters and ratio were determined in three patients sampling 15 consecutive responses in the abductor pollicis brevis, tibialis anterior, and abductor hallucis under stable anaesthetic and haemodynamic conditions, and before any harmful surgical or force manoeuvring.

In every surgery, after induction, anaesthesia was sustained with a low dose of sevofluorane (MAC 0.4) plus remifentanil (0.2-0.5 ug/kg/min) or propofol (80-120 ug/kg/min) plus remifentanil (0.2-0.5 ug/kg/min) and no muscle relaxants were used after intubation.

For TcMEP monitoring, either 8- or 16-channel Akonic IOM devices were employed. Muscle responses to transcranial electrical stimulation (TES) were recorded from the abductor pollicis brevis, tibialis anterior, and abductor hallucis using a band pass of 10000 to 100 Hz and an analysis time of 100 ms. Automatic measurements of every TcMEP parameter were provided online by the software, and only corrected by hand if necessary.

For TES, a constant current Akonic 2000 stimulator, delivering single or double trains of 7-9 stimuli of 200 usec duration each, with an inter-stimuli interval of 3-4 ms, and intensities between 550 and 1000 mA, was employed. Anodic stimulation, to contralateral muscles, was applied through corkscrew electrodes located at C1–C2 or C3-C4 (International system 10-20).
Significant monitoring changes should include a decrease of at least 65% in TcMEP amplitude.

- Results:

The five illustrative neurophysiological events in this presentation showed significant TcMEP changes closely related to instrumentation of the spine or force application during traction or patient positioning. Those TcMEP changes reverted to baseline values when the surgery team interrupted the harmful manoeuvring or modified the surgical plan. No confounding factors, such as hypotension or anaesthetic changes, were present during those events.
In every patient and neurophysiological event, TcMEP changes consisted of a transient decrease in amplitude (of at least -65%), area under the curve, duration, and phases while the latency value increased, finally returning to baseline values in all cases. The changes were clearly above the normal variability (up to -35%) assessed in consecutive samples obtained from three patients under stable anaesthetic and haemodynamic conditions, and before any harmful surgical or force manoeuvring.
In all cases, the drop of the area under the curve was always deeper than those of the amplitude, duration and phases, measured as a percentage of basal TcMEPs.
Finally, the empirical ratio was calculated and tested showing the earliest and greatest decrease in every event.

**Conclusions**

These observations suggest that a drop in TcMEP amplitude alone might not be the most important sign to detect impending cord damage.
Of the conventional TcMEP parameters, a decrease in the area under the curve is often the most prominent and earliest change of muscle response deterioration during a neurophysiological event.
The empirical ratio, accounting for all TcMEP parameters, seems to decrease even more than the area under the curve during a neurophysiological event, and could be a useful tool for intraoperative monitoring.
Accurate cutoff points, for the area under the curve and ratio, should be obtained through ROC analysis from a larger series of patients.

**Key references and recommended readings**

- Key references:

TcMEP monitoring alarm criterion, amplitude, area under the curve, duration, phases.

- Recommended readings:


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## Day 12 - Mary Menniti Stecker Memorial Lecture: 11h00 - 12h00

### New developments in the neurophysiology of the corticospinal tract

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In this lecture I will review some recent discoveries about the neurophysiology of the corticospinal tract which have brought new insights into its function. These are important in terms of understanding the results of interoperative monitoring of this important pathway. New findings have further emphasised the importance of the CST for skilled actions such as tool use, and indeed have underlined that these actions are particularly vulnerable to diseases such as ALS which target the most highly developed feature of the human CST: the direct, cortico-motoneuronal connection to hand muscles. Although we have learned an enormous amount about CST function from animal studies, there is no doubt that it has additional functions in humans, including a key role in bipedal locomotion. We are also learning much from tractography studies in humans, although these need to be validated. In particular, these studies need to recognise that only a tiny fraction of the white matter fibres in the subcortical white matter and internal capsule actually project into the pyramidal tract and CST.

I will suggest that we need to update our concepts of the corticospinal tract as simply a 'descending' or 'motor' pathway, which is used by the motor system to 'command' movements. The need to revise these ideas comes partly from anatomy, where new knowledge of the terminal projections of the CST suggest many different functions, not just motor control. Much of the CST probably serves to control somatosensory input and it may carry predictive signals about the proprioceptive inputs that will be generated by an upcoming movement. Recent work in the macaque monkey suggests that corticospinal neurons can show 'mirror-like' properties, being active not only when we generate a movement ourselves, but also when we observe the same movement performed by another person. Indeed, with these new findings, an important question is raised as to how we avoid self-movement during action observation (echopraxia). I shall outline some of the mechanisms that might be involved. Finally, I shall issue a humble reminder that we know very little about the great majority of fibres in the CST, most of which are small in size and very slowly conducting.

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## Day 12 - Session II: 14h00 - 15h20
## Monitoring in Vascular Urgery

### Neurophysiologic Monitoring of Endovascular Treatment of Cerebral Aneurysms

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Stanford University School of Medicine
USA

**Objectives**

1. Review the risks involved in endovascular intervention of cerebrovascular disorders.
2. Review the neuro-electrophysiologic changes seen with cerebral ischemia.
3. Describe the techniques useful in neurophysiologic monitoring of these endovascular procedures.
4. Demonstrate how IONM can alter surgical management.

The utility of IONM in the surgical treatment of cerebrovascular disorders is well established. However, its utility in the endovascular treatment of these disorders is not as widely appreciated. The purpose of this presentation is to demonstrate that the risks posed to the patient from these procedures is similar to that encountered in the surgical treatment of cerebral aneurysms. The main risk is cerebral ischemia and infarct. Neurophysiologic monitoring can accurately identify cerebral ischemia in a dynamic real-time fashion and allow for intraoperative interventions to reverse ischemic changes, thus, enhancing patient safety and neurologic outcomes. Unfortunately, the short time allocated for this presentation does not allow for a full discussion of the topic and the attendee is directed to reviews of the subject available in the literature.

**Key Reference**

- Intraoperative Neurophysiologic Monitoring, Cambridge University Press, 2010. Gloria M. Galloway, Marc R. Nuwer, Jaime R López and Khaled M. Zamel.
- Chapter 14: Intraoperative neurophysiologic monitoring of vascular disorders. Jaime R. López, MD

## The Role of Intraoperative Neurophysiology in Thoracoabdominal Aneurysms (TAA) Repair

Mirela Simon, M.D., M.Sc.
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Boston, MA

**Objectives**

1- Present the concept of spinal cord collateral arterial network (SCAN) and its impact on risk of spinal cord ischemia (SCI) associated with these procedures
2- Present critical steps of TAA repair surgery
3- Present the main roles of neuromonitoring
4- Present correlation between type of neurophysiologic changes and the underlying pathophysiology
5- Role of neuromonitoring in prevention of delayed paraplegia

TAA repair surgery has an increased risk of SCI, by some series as high as 16%, with about half of these cases resulting in devastating paraplegia.[1] The risk of SCI during TAA repair relates to clamping of the aorta and/or sacrificing critical vessels such as segmental intercostal and lumbar arteries. Twenty years ago, open repairs were done via clamp/sew technique using neuroprotective adjuncts, such as drain of cerebrospinal fluid and regional hypothermia via epidural cooling.[2] However, the latter offered limited protection as, with patient's rewarming at the end of the surgery, spinal cord was left highly vulnerable to ischemia. Additionally, practice of non-selective reimplantation of segmental arteries was contributing to an increase in the aortic clamp time, and indirectly to the morbidity and mortality associated with these procedures. Discovery of the SCAN concept[3, 4], emphasized the relative dissociation and/or a relationship hard to predict, between anatomy and perioperative spinal cord hemodynamics and thus, of the importance of real- time intraoperative neurophysiologic testing as a mean to assess the adequacy of the spinal cord perfusion pressure. While somatosensory evoked potentials (SSEPs) had been used intraoperatively for several decades to monitor the function of the spinal cord, motor evoked potentials (MEPs) developed as a far more superior monitoring tool for the motor system, and the anterior-lateral aspects of the cord and were found to be significantly more sensitive spinal cord ischemia[5,6].

Within this context, TAA repair too started benefiting from neuromonitoring with SSEPs and MEPs[7,8]. However, this new neuroprotective method, required a major shift in the surgical techniques as well as in anesthesia protocol, including a renunciation to epidural cooling and a shift to an anesthetic regimen that allowed reliable neurophysiologic recordings, such as total intravenous anesthesia with propofol and opioids, and no use of muscle relaxant beyond the incision time. Open TAA repair with distal aortic perfusion (DAP) via atrio-femoral bypass and selective segmental re-implantation replaced the classical clamp and sew technique. Detection and reversal of SCI was now relying entirely on the reliability of neurophysiologic monitoring to promptly signal SCI with aortic clamping as well as to guide the surgical and anesthesia regimen, such as titration of the distal mean arterial pressure in atrio-femoral bypass and/or selective re-implantation of segmental arteries. More so, different patterns of neurophysiologic changes, interpreted within the surgical and anesthesia contexts, could be used to determine its etiology, and to differentiate between limb, spinal cord and cerebral ischemia[9].

This major shift in TAA repair practice led to a significant reduction in cases of immediate paraplegia (i.e., detected on the first neurologic exam after emergence from anesthesia).[2, 10] However, it did little towards decreasing the risk of delayed paraplegia (i.e., occurring after an initial normal neurologic exam, within the first week post-operatively). Stable MEPs during aortic clamping do not necessarily mean stable MEPs and/or intact motor function in the post-DAP period. Delayed paraplegia is known to have a multifactorial etiology, though no one single factor has been found to reliable predict it[11]. It occurs due to an imbalance between metabolic demand and energy supply during a period of particular vulnerability of the cord to ischemia.

We found that neurophysiologic testing in the immediate post-DAP period informs post-operative hemodynamic management and decreases the risk of delayed paraplegia.

### Conclusion

Combined SSEPs/MEPs monitoring significantly reduce the risk of SCI after TAA repair. Both tests deliver useful information and contribute to reliable detection of SCI.

#### Key References


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## Day 12 - Session III: 15h50 - 17h30
## Thoracic Pedicle Screws

### Introduction and Freehand Technique

Paulo Tadeu Maia Cavali, MD, PhD
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São Paulo – Brazil

**Objective**

The objective of this issue is to describe the Freehand Technique for transpedicular stabilization in the thoracic spine and the importance of neuromonitoring.

The use of pedicle screws has become popular during the past decade, first in application involving the lumbar spine and subsequently in the thoracic spine surgery. Pedicle screws also prevent the need to place instrumentation within the spinal canal like like sublaminar wiring or hooks which create the risk of neurological injury.

Transpedicular stabilization **(TS)** has been shown to resist flexion and extension loads as well as torsional loads better than other devices. Especially in spinal deformity surgery, the use of **TS** provides better correction and maintenance than system with hooks and wires. Disadvantages of pedicle screws are related to the misplacement of pedicle screws which can lead to disastrous complications such as vascular or neural injuries. Accurate and safe placement of screw within the pedicle is a crucial step during the surgery. There are many proven techniques used to insert pedicle screws, including fluoroscopic or radiographic guidance, stereotactic guidance system based on computed tomography, direct visualization of the pedicle with the use of laminotomy, and the Freehand Technique (without intraoperative image guidance). The freehand technique use established surface landmarks and direct palpation of internal pedicle and vertebral structure.

The use of intraoperative neuromonitoring recordings with somatosensory evoked potentials (SSEP), transcranial electric motor evoked potentials (TMEP), and electromyography (EMG) will ensure the safety required for placement of the pedicle screws. The use of neuromonitoring will be shown in detail at every stage of surgery.

**Conclusion**

A Freehand Technique using neuromonitoring data is a safe and accurate method of instrumentation in the thoracic spine with pedicle screws.

**Key Reference**

1 Transpedicular Stabilization with Freehand Technique on the Thoracic Spine. Manual of Spine Surgery. Springer- Verlag Berlin Heidelberg, 2012.

# Experimental models and translation to OR

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## Objectives

To describe the new developments in the monitoring of thoracic pedicle screws and their feasibility in the clinical practice.

## Brief historical review

In recent years, the use of thoracic pedicle screw instrumentation has become a widely used technique in spinal surgery. In our experience, pedicle screws are the most frequent cause of neural injury in spine surgeries.

Thoracic screws were first used at the beginning of the 2000s, and our hospital was one of the first centres in the world using this technique. At that time, very few papers describing thoracic screw monitoring were available, and the same neurophysiologic techniques used for lumbar screw monitoring were applied for the thoracic screws.

However, the neurological risks of the thoracic screw placement are quite different from those at the lumbar segments. In the thoracic spine, the risk of root damage is rather low because of the anatomical perpendicular disposition of the thoracic roots; furthermore, a thoracic root injury has little clinical impact.

The real risk of a malpositioned screw in the thoracic spine instrumentation is a spinal cord injury, produced by the medial displacement of the screw. Moreover, in these segments the surgeons want us to asses not only about neural injury but also about the correct position of the screw within the pedicle.

With this historical background, our team started to develop a series of experimental and clinical studies trying to asses about the utility of the traditional neurophysiologic techniques for the screw monitoring, as well as to study the tolerance of the spinal cord to different potentially damaging situations.

## Summary of recent developments and/or future directions

Calancie and the Siracusa Group published a seminal article in 2008, describing a new technique using high-frequency pulse-train stimulation of the thoracic screw in order to detect medial malpositioning of the screws invading the spinal canal. This paper has significantly improved the rate of malpositioned screws detected. In our hospital we have been using this method since it was first described, however we use a lower threshold to reduce the number of false positives.

Our group has described the difference in the thresholds of screw placed at the concavity and convexity of the apex of the scoliosis curves. We have also determined by means of experimental studied the high tolerance of the spinal cord to the lateral displacement produced by the screws, and we have described that the key factor determining the screw threshold is the distance to the neural structures.

We would like to emphasize that the most sensitive technique for the detection of the screw is the stimulation of the tracks, as it was already described by Calancie in the 90s, even though it is not widely used so far.

## Conclusions

The use of thoracic pedicle screws has forced the neurophysiologist to develop refined methods to avoid neural injuries due to their malpositioning. Currently with the use of these methods the rate of medially malpositioned screws is very low.

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## Neuromonitoring using Pulse Trains for Thoracic Pedicle Screws

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**Objectives**

Review the history of pedicle screw neuromonitoring: lumbar vs thoracic spine
Describe the pulse-train method
Summarize clinical study design & results

**History**

Pedicle screws (PS) were first used for anchoring implants in the lumbosacral spine, placing nerve roots of the cauda equina at risk. We developed a neuromonitoring method to reduce the risk to lumbosacral nerve roots, by alerting the spine surgeon to breaches in the cortical wall of a pedicle *before* a screw was placed. EMG was monitored from leg muscles innervated by the nerve roots at risk. EMG responses at relatively low stimulus intensities suggested proximity between stimulus electrode and the nerve root, as might occur with a breached pedicle (1). In our hands at least, the method proved to be both simple to implement, and reliable. More recently, a number of groups have adapted this approach to monitoring PS placement in the *thoracic* spine, typically using screw stimulation to monitor thoracic-level screws, and using EMG evoked from intercostal and/or abdominal muscles as outcome measures. Even more than for lumbar PS monitoring, these studies have led to widely differing conclusions about the efficacy of thoracic PS monitoring.

It's important to point out that: 1) our original lumbosacral PS neuromonitoring method was designed to protect *nerve roots*, and not the spinal cord; and 2) our original method was developed in an era when all implants and test devices were made from stainless steel, whereas most if not all implants now in use are made from different titanium alloys.

**Summary of method**

Stimulation was with repeated pulse trains, each train comprised of 4 pulses with a 2 ms interpulse interval (i.e. *4@2*; pulse width = .2 ms; constant-current of varying intensity), delivered via a stainless steel insulated ball-tipped probe while palpating the pedicle track after cannulation with a pedicle finder/gearshift. EMG was recorded from quadriceps (Quads), tibialis anterior (TA) and abductor hallucis (AbH) bilaterally. The primary outcome measure was the minimum stimulus intensity needed to elicit small (< 50 µV) evoked EMG responses from one or more of the target muscles. For comparison to other studies, we also recorded EMG from intercostal and abdominal muscles.

If this sounds suspiciously similar to the Threshold-Level approach to monitoring transcranial MEPs, that's no coincidence: we're simply transposing the site of activation of corticospinal tract fibers from the primary motor cortex to the spinal cord.

**Study design**

In adult patients undergoing elective surgery to include implantation of thoracic pedicle screws, compare intraoperative thresholds for thoracic pedicle track testing (i.e. before screw placement) to screw position (from postoperative CT scans).

The study had 3 phases:

Phase 1: withhold all information from intraoperative testing of all pedicle tracks from the surgical team (i.e. the surgeons were *blinded*);

Phase 2: provide feedback of intraoperative pedicle track testing for 50% of the screw sites (chosen randomly);

Phase 3: deliver stimulation through an insulated pedicle finder/gearshift used to cannulate thoracic pedicles, and provide feedback of this testing for 50% of the screw sites (chosen randomly).

Hypothesis: the incidence of malplaced screws would decline from Phase 1 to Phase 2, and be lowest for screws implanted during the study's Phase 3.

Break-the-Blind: in the event that pedicle track testing resulted in a threshold to lower limb EMG of < 4 mA – suggesting direct physical contact between ball tipped probe and the spinal cord – this result was shared with the surgical team (i.e. we *broke the blind*), giving the surgeon multiple options, including revising the pedicle track before screw implantation.

**Results**

We obtained data from 71 subjects, in whom 802 thoracic pedicle screws (including the L1 level) were implanted. There were 32 instances in which the threads of a pedicle screw penetrated ≥ 2 mm into the canal space, having breached the pedicle's medial wall. Using alarm criteria ranging between 10 – 15 mA thresholds, pulse-train stimulation within the pedicle track using a ball-tipped probe and EMG from lower limb muscles correctly predicted all 32 (100%) of these medially malpositioned screws. In stark contrast, stimulation of the implanted screw at each of these sites (i.e. using the screw as the stimulating electrode) failed to elicit *any* response in roughly 1/3rd of the cases, even at stimulus intensities of 30 mA. We showed that this poor result from screw stimulation reflects – at least in part – the fact that screws were made from anodized Ti-alloys, whose conduction properties resemble those of semi-conductors (2). The combination of pedicle track stimulation and electromyogram response from leg muscles proved to be far more effective in predicting these medially malpositioned screws than was direct screw stimulation and any of the target muscles (intercostal, abdominal, or lower limb muscles) we monitored (3).

Regarding the impact of feedback to the surgical team of intraoperative neuromonitoring findings, we showed, by combining results of suspect pedicle sites in which we broke the blind with cases including planned feedback (i.e. Phase 2 of the study design), that we significantly reduced the numbers of thoracic pedicle screws with clinically relevant (≥ 2 mm) medial malpositioning (4).

Note that we never started Phase 3 of this study, due to our failure to successfully compete for renewal of NIH funding.

**Conclusions**

In this blinded and randomized study we proved that acting on neuromonitoring data generated intraoperatively by revising the direction/trajectory of the pedicle finder within the pedicle track significantly reduced the probability of placing a screw with a clinically relevant amount of encroachment upon the spinal canal. Implementation of this approach for thoracic pedicle screw placement should lead to a reduction in immediate or delayed spinal cord myelopathy caused by canal stenosis from a medially placed pedicle screw, and a lower probability that a patient will require additional surgery to revise and/or remove the offending screw(s).

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## IONM in China - The Past, Present and Future of Intraoperative Neurophysiological Monitoring

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Since 1994, the application of intraoperative neuophysiological monitoring (IOM) in China has expanded from the initial neurosurgery to orthopedics, E.N.T department, hand surgery, general surgery, etc. There are also a few hospitals applying IOM to cardiovascular surgery and gynecology and obstetrics. Operations involve epileptic surgery, resection of cerebral cortex function lesions, microelectrode recording in deep brain stimulation in movement disorders, brainstem and skull base surgery, posterior cranial fossa operation, cranial nerve microvascular decompression (MVD) surgery, head and neck surgery, carotid endarterectomy, vertebral and spinal cord operation, selective posterior rhizotomy (SPR) for cerebral palsy in children, aortic dissection closure, pelvic surgery, etc.

Though neurophysiological monitoring (NM) has been used in the prediction for prognosis in the intensive care unit (ICU) since 1991, there is still insufficient understanding of its role in the diagnosis and differential diagnosis. For electroencephalogram (EEG) recording in ICU, it is advised to place 19 electrodes according to 10-20 international electrode system rather than subhair line method or single channel recording. For an ICU patient suspected with non-convulsive seizures (NCS) or non-convulsive status epilepticus (NCSE), continuous EEG (CEEG) monitoring should be completed for at least 48 hours to avoid misdiagnosis of NCSE. Due to the huge data from CEEG, a combination analysis of the original EEG and quantitative EEG (QEEG) can be used, although there is not yet a conclusion as to which QEEG analytic method is most representative. Also, evoked potentials (EP) should be further applied in ICU.

In China, the work on NM is mainly driven by the department of neurology, which requires high-expertise and specialized personnel trained for long duration, while on the other hand, ICU is considered an independent program that lacks neuroelectrophysiological professionals. This hindered the development of NM application in ICU. Within recent years, as the technology of QEEG gradually matures, interaction and fusion of subjects, and the expansion of regarding disease as the center of the model of scientific clinical medicine, NM will develop rapidly as well.

Currently, academic organizations in China associated with neuroelectrophysiology include Chinese Society of Neurology, Chinese Neurosurgical Society, Chinese Congress of Neurological Surgeons, and China Association Against Epilepsy. These academic organizations have all made great contributions to the development of clinical neuroelectrophysiology and professional training, but somewhat limited to their own fields of study. This is to the disadvantage of training and application for other clinical departments such as orthopedics, cardiovascular surgery, E.N.T department, general surgery, obstetrics and gynecology, critical care medicine, etc. Therefore, to establish the neuroelectrophysiological society in China is critical.

## IONM in India: Current status, roadblocks and future directions

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**Objectives**

1. To provide a snapshot of current status of IONM services in India.
2. To present demand-supply mismatch in IONM services,
3. Potential for expansion of IONM services in India,
4. To identify key roadblocks that need to be addressed,
5. To suggest solutions to overcome hindrances. 6. Vision and future plans.

At present, IONM services in India are at a nascent stage of deployment. IONM services are being provided on routine basis only at a handful of hospitals across the country (government as well as private sector hospitals). There are only about 50 installations of necessary equipment across a country of 1 billion plus. These equipment are manned by personnel primarily trained as technicians, physiologists, anaesthetists or surgeons and most of them have acquired IONM skills by self-learning rather than structured training programs. Currently, there is neither any structured training programs running in India nor any regulatory body to manage/supervise the standards of IONM services. Despite this, in many centres, the range and standard of IONM techniques can match the best in the world.

Health sector in India is growing at a rapid rate with establishment of hospitals with state-of-the-art infrastructure and technology. The advancement is happening both in government as well as corporate hospitals. Even-though surgeons unanimously advocate and request IONM services but most are unable to avail the same so due to lack of trained manpower. In most institutions, the equipment is underutilized.

India has about 350 medical schools with faculty catering to different specialities in teaching, research and clinical services. One such pre-clinical speciality in all medical schools is Physiology. Except for a few, in most medical schools the primary responsibility of Physiologists is in teaching and research with very little emphasis on clinical services. After obtaining degree of MBBS, one can pursue a 3 year post-graduate degree of MD in Physiology to be eligible as faculty in Department of Physiology. There are about 3,000 registered Physiologists in India. This pool of manpower is academically competent and highly trainable for IONM services.

Lack of awareness about IONM amongst Physiologists combined with lack of explicit communication between the Surgeons (demand) and the Physiologists (potential supply) is a major roadblock. Lack of educational programs and standardised training workshops precludes involvement of Physiologists in IONM services. As of now, IONM as a career opportunity is not even considered by the Physiologists, despite the high demand. It is due to a combination of systemic inertia, lack of awareness about IONM and career opportunities, and absence of training/certification programs.

A big impetus to IONM in India can be given by initiating educational programs and training workshop across India. This has to be simultaneously supported with implementation of minimum standards and establishment of national level regulatory body. A system of registration and certification of technical and interpretive level expertise in IONM has to be established in India.

I envision development of Clinical Physiology (IONM) as a speciality in all medical schools in India that will act as feeder system to quench the increasing demand of IONM services in India keeping in line with best practices worldwide. I seek the advice, wisdom and support of all the learned members in this endeavour.

## Day 13 - Session V: 08h00 - 08h50
## Vahe E. Amassian Memorial Lecture

### Development of the corticospinal tract in children: Implications for cortical mapping and MEP monitoring.

Janet Eyre, MD
Professor of Paediatric Neuroscience at Newcastle University in the UK
England

The young human brain is highly plastic, thus brain and spinal cord lesions occurring during development interfere with the innate development of the architecture, connectivity, and mapping of functions and trigger modifications in structure, wiring, and sensorimotor representations. This lecture will describe the development of the corticospinal system from fetal life to old age, providing evidence for activity dependent shaping of the origin and termination of the corticospinal tract at difference stages during development. The implications for monitoring of corticospinal function will be discussed. In addition techniques will be described which enable investigation of these developmental changes at cortical, tract and segmental spinal levels even in newborn babies.

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## Day 13 - Fred Epstein Memorial Lecture: 08h50 - 09h50

### Intraoperative neuromonitoring and mapping during brain surgery in children

James T Rutka, MD, PhD, FRCSC,
Division of Neurosurgery, Department of Surgery, the University of Toronto
Canada

**Objectives**

The objectives of this presentation are to provide state-of-the-art information on the use of intraoperative neuromonitoring and mapping techniques during the performance of brain surgery in children.

**Summary of recent developments and/or future directions**

Pediatric neurosurgery has changed considerably over the past decade and has been advantaged by the development of numerous advances that have taken place in microneurosurgery, neuroimaging, and intraoperative neuromonitoring. One of the most important tools has been the linking of preoperative imaging data to patients in the operating room using frameless stereotaxy. This technique, known as neuronavigation, has played an enormous role in facilitating the approach to, and resection of intracranial lesions that previously were difficult to remove. Today, important functional datasets from magnetoencephalography (MEG), functional MRI (fMRI), and diffusion tensor imaging (DTI) can all be used to aid the neurosurgeon in identifying critical neural structures that must be preserved in order to maintain normal neurological function after surgery. Another major advance has come with the development of the intraoperative MRI (IoMRI) scanner which enables neurosurgeons to follow in real time how their resections are taking place. The other technique which has factored largely into the success of neurosurgical procedures has been intraoperative neuromonitoring (IONM). IONM can now be used for both spinal can cranial procedures, and can be used throughout these procedures to ensure integrity of the ascending and descending pathways in the spinal cord, the cranial nerves, the subcortical structures, and the brainstem. At the Hospital for Sick Children in Toronto, we are routinely using IONM for all cranial and spinal cases where there may be questions around safety of resection and injury of critical neural pathways. The development of the monopolar "train of 5" stimulation technique has shown considerable value in continuously sampling the corticospinal tract during surgery to avoid any undue consequences during resection. The monitoring of the transcranial somatosensory evoked potentials (SSEPs) and motor evoked potentials (MEPs) has added additional benefit during neurosurgical procedures. During this presentation, key examples will be provided from cases where IONM and mapping were used to perform maximally aggressive but safe surgery in children with both spinal and cranial conditions. Some of the lesions which will be described include arteriovenous malformations, supratentorial and infratentorial tumours, brainstem tumours, spinal tumours, and epilepsy resections, especially those around or near the Rolandic cortex or language regions.

**Conclusions**

The combination of advanced neuroimaging strategies with mapping and IOMN has led to extremely gratifying results in children with intracranial and spinal lesions. The use of these technologies requires a multidiscliplinary approach with team members including neuroradiologists, neurologists, neurosurgeons, neurophysiologists, and neuropathologists. It is hoped that these approaches will become standardized worldwide for the improvement of neurosurgery in children.

## High versus low frequency motor mapping: A tailored approach in glioma

Surgery Bello L, Pessina F, Riva M, Rossi M, Fava E, L Fornia, V Ferpozzi, G Cerri
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### Objectives

Surgical resection of tumors involving motor areas or pathways requires the identification at surgery of functional motor sites at both cortical and subcortical level. This is feasible by adopting various intraoperative neurophysiological protocols, adapting the choice to the clinical context.

### Basic principles and intraoperative findings

The motor system is organized in a hierarchical manner with many descending systems from the motor cortices to the spinal cord. Schematically the corticospinal tract is divided in a direct and indirect system. It originates from several cortical areas, both in the frontal and parietal lobes, it is composed of fibers of various diameters, and has a large termination on the spinal cord. Two neurophysiological stimulation paradigms have been developed to explore the motor system, the low frequency (50-- 60 Hz) protocol, generally delivered by a bipolar probe; and the High Frequency (Train of Five, pulse) technique, usually delivered by a monopolar probe. Both protocols are better administered when motor activity is evaluated by a multichannel EMG device. When used on the primary motor cortex, both protocols induced motor responses, and designed the well known somatotophy, letting the HF also to measure the latency of the response. In a previous work on 591 patients with gliomas involving motor pathways, both protocols were applied and the efficacy evaluated in term of Extent of resection, rate of intraoperative seizures, percentage of immediate and permanent deficits. This study showed that the best approach is to choose the stimulation protocol (LF, HF, LF+HF) and probe (monopolar and/or bipolar) match according to the clinical context, ie on the excitability of the motor system. This parameter is influenced by both patient conditions (clinical history, previous treatments, medications) and tumor features (volume, grade, infiltration of the CST). By doing this, it was possible to stratify patients in various risk group based on clinical features, describing for each of them the best stimulation and probe match in the clinical routine use. By this approach we were able to increase the number of patients who could benefit from surgery of 60%, and decrease the percentage of permanent deficits to 1.7%. Extent of resection (EOR) reached 71.4% on average. To further increase the number of patients and the EOR and keeping at the same time the functional motor integrity we developed alternative stimulation protocols, targeted to the different components of the CST. To locate M1 fibers and to operate on tumors mainly involving the primary motor cortex and originating fibers we progressively reduced the number of stimuli in the pulse techniques, and to increase focality, we delivered it by a bipolar probe. This increases the EOR to 93.6% keeping the rate of permanent deficit to 2%. To study non primary motor areas, which are mainly involved in motor cognition activities, such as grasping, bilateral motor control, or the sensory motor integration, we developed specific neurophysiological protocols and motor cognition tasks. The latter because requiring patient cooperation have to be administered in the awake setting. To afford an optimal motor control, mapping techniques have to be associated to monitoring techniques, to ensure during all the duration of surgery the integrity of the motor pathways, particularly from ischemic events. The results of the clinical application of these protocols to non primary motor areas will be also discussed and described in their clinical use.

### Future directions

The implementation of neurophysiological protocols to study the various components of the CST will increase the understanding of the motor system organization in human and at the same time increase the number of patients who are going to benefit from a safe and effective surgery.

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- Tailoring neurophysiological strategies with clinical context enhances resection and safety an expands indications in gliomas involving motor pathways.
- Bello L, Riva M, Fava E, Ferpozzi V, Castellano A, Raneri F, Pessina F, Bizzi A, Falini A, Cerri G. Neuro Oncol. 2014 Aug;16(8):1110-28

## Optimizing the extent of resection in eloquently located gliomas

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### Objective

The extent of intrinsic brain tumor resection is critical for the overall survival. This changed the approach in brain tumor surgery to the maximum resection possible with preservation of neurological function.

### Brief historical review

The introduction of the train-of five-technique with high frequency stimulation (200-500 Hz) allowed for reliable motor evoked potential (MEP) monitoring under anesthetized conditions.

### Summary of recent developments

*MEPs and motor outcome*

The high positive predictive value of intraoperative MEP alteration and postoperative motor outcome is acknowledged [1-4]. Permanent MEP losses and transient losses in combination with prolonged severe amplitude deterioration are followed by long-term motor deficits. In relating qualitative MEP alteration with motor outcome and postoperative MR-imaging, the empirical evidence that refined intraoperative MEP signal interpretation is needed was supported [5]. In a group of 29 patients only suffering MEP alteration, irreversible MEP alteration was more often associated with postoperative new signal alteration in MRI compared to reversible MEP alteration (12/14 patients vs. 5/13 patients, p =0.018). MEP loss was significantly more often associated with subcortically located new signal alteration (16/19 vs. 3/10; p = 0.006). On the contrary, MEP deterioration was significantly more often followed by new signal alterations located in the precentral gyrus (4/10 vs 1/19; p = 0.036)[6].

*Intraoperative complementary use of monitoring and mapping*

During tumor resection, mapping and monitoring are used in a cogent alternating fashion. Preferable direct cortically elicited MEPs are used to continuously assess the integrity of the fast conducting parts of the corticospinal tract (CST). This allows for the detection of imminent injury, which might be caused by manipulation of the subcortical pathways (e.g. resection, CUSA) or by the critical injury of perforating arteries causing subcortical ischemia. Comparing results of different research groups, permanent morbidity in highly eloquent brain tumor surgery decreased below 5% and was most often linked to subcortical ischemia. Such, the timely discovery of perforating arteries within the resection cavity is highly challenging. Whenever an alteration of potential occurs, mapping can confirm the distance toward the CST and determine the extent of tumor resection. This further not only allows to determine the extent of tumor resection, but also differentiates the origin of the alteration.

*Implementation into awake procedures*

The here described mapping methods can be easily implemented into awake procedures as those allow for patient independent assessment and can be continued in non-compliant patients, where awake testing fails.

*Extent of resection - How far is too far?*

There are more and more data about “safe” distance by the means of electrical stimulation and tumor removal [7;8]. With parallel continuous cortical assessment, the safe distance can be tailored by the means of stimulation parameters guiding a stepwise microsurgical resection. This approach needs a close communication between the surgical and the neuromonitoring teams. Clearly, very low subcortical stimulation intensities might result into permanent minor deficits despite unaltered MEPs[9].

## Future directions

The method of the D-wave recording in supratentorial tumor surgery has been reported [10;11]. The combination of MEPs and D-wave recordings needs more refinement. First experience show, that due to the focal direct cortical stimulation, a robust D-wave recording is only achieved with higher stimulation intensity compared to MEPs. Preliminary data analysis showed concordant behavior between D-wave amplitude alteration and MEP-alteration.

## Summary

Meticuluos mapping and monitoring of motor evoked potentials with refined stimulation and mapping techniques allow for maximum resection possible. One of the major causes of permanent neurological deficit are related to subcortical ischemia.

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## What to expect if there is a post op motor deficit

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England

It is now increasingly appreciated that the corticospinal system is capable of substantial
Reorganization after lesions even in old age and such reorganization is likely to underlie the partial recovery of function. Knowledge of the time course and processes of corticospinal system development and plasticity is essential both for a better understanding of current rehabilitation treatments and for designing new strategies for the treatment lesions acquired during surgery. Although reorganisation after lesions is steered by activity dependent mechanisms, this lecture will provide evidence for differing degrees of plasticity and patterns of reorganisation very early in development to old age, which reflect the stage of development of the corticospinal system when the lesion occurs.

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# The Journal of Neurosurgery Update: Is neuromonitoring valued in neurosurgical journals?

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Canada

**Objectives**

The objectives of this presentation are to review the recently published and new strategic plan of the Journal of Neurosurgery, and to review data which demonstrate that neuromonitoring is not only valued by neurosurgical journals, but also is essential for optimum patient outcomes after neurosurgical procedures.

**Summary of Recent Developments and/or Future Directions**

The new strategic plan for the Journal of Neurosurgery is entitled "Tradition – Transition – Transformation". In 2014, the Journal of Neurosurgery celebrated its 70th year anniversary making it the longest continuously published journal in the field. I became Editor-in-Chief of the Journal in 2013. The Journal is comprised of 3 print Journals (Journal of Neurosurgery, Journal of Neurosurgery: Spine, and Journal of Neurosurgery: Pediatrics) and one electronic Journal (Neurosurgical Focus). The mission statement of the Journal is that it is the journal of record in Neurosurgery. We have 5 strategic goals: 1) Global position, outreach and influence; 2) Innovation in presentation formats; 3) Collaboration and synergies with associative partners; 4) Enhancement of the efficiencies in the editorial office; and 5) Development of a sustainable business plan. In 2014, we launched a new cover design and article restructuring. The Journal has been producing numerous guidelines such as the "Lumbar spinal fusion" and the "Pediatric Hydrocephalus" Guidelines. I have also produced a webinar on how to publish a scientific manuscript in the Journal (www.thejns.org/). In 2015, the Impact Factor of the Journal increased to 3.74, the highest it has been in its 70 year history, and the highest amongst the neurosurgical journals in the world. The Journal continues to demonstrate the most citations of all neurosurgical journals for its published articles. In this presentation, I will also demonstrate the importance of intraoperative neuromonitoring (IONM) papers in the Journal of Neurosurgery. In the past decade, the number of important papers in this field have increased dramatically. Conditions where IONM has been used to assist with outcomes in neurosurgical procedures in articles published in the Journal include: Chiari malformation, vestibular schwannoma, intramedullary spinal cord tumours, spinal deformity correction with pedicle screw insertion, cervical spine surgery, among many others. A comparison with the results of papers published on IONM in other neurosurgical journals will also be presented.

**Conclusions**

The Journal of Neurosurgery is proud to publish highly impactful papers on IONM. The data presented indicate that the numbers of such papers is increasing steadily with expectations of even more important published works in the future.

## Day 13 - Session VII: 14h40 - 16h00
## Peripheral Nerves

### Thetered Cord Syndrome: neurosurgical vision

Gabriel Mufarrej
Pediatric neurosurgery fellow at New York University Medical Center 1991 / 1992 under direction of Dr Fred J. Epstein.
Head of division of Pediatric Neurosurgery and Epilepsy Surgery at Paulo Niemeyer State Brain Institute in Rio de Janeiro, Brazil.

The author will talk about the importance of the prophylatic approach in cases of thetered spinal cord, especially in cases of occult spinal dysraphism. In our opinion prophylaxis is still a major goal in treatment of the various tethering lesions of the spinal cord. Early operation will protect symptom-free patients against the development of neurological, urological and orthopeadic déficits.

## Intraoperative Neurophysiologic Monitoring of Brachial Plexus Surgery

Jaime R. López, MD
Associate Professor
Neurology and Neurosurgery
Stanford University School of Medicine
USA

### Objectives

1. Learn the anatomy of the brachial plexus.
2. Describe the technique used to obtain nerve action potentials.
3. Describe the techniques used to determine peripheral and central continuity of neural structures.
4. Demonstrate how IONM can alter surgical management.

The utility of IONM in the surgical treatment of peripheral nerve disorders is well established and described in the literature. The purpose of this presentation is to demonstrate the utility of IONM in identifying the different brachial plexus structures, determine areas of abnormality or injury, evaluate for peripheral nerve continuity and evaluate for possible root avulsion. Unfortunately, the short time allocated for this presentation does not allow for a full discussion of the topic and the attendee is directed to reviews of the subject available in the literature.

#### Key Reference

- Intraoperative Neurophysiologic Monitoring, Cambridge University Press, 2010. Gloria M. Galloway, Marc R. Nuwer, Jaime R López and Khaled M. Zamel.
- Chapter 12: Peripheral nerve monitoring: basics and indications. Jaime R. López, MD

## Pudendal Monitoring: what is missing?

Vedran Deletis MD, PhD
Intraoperative Neurophysiology Department in St. Luke's/Roosevelt Hospital and an Associate Professor at the Albert Einstein College of Medicine in New York.

**Objective**

To assess the effectiveness of pudendal afferent mapping as a tool to minimize the risk of postoperative bowel, bladder, and sexual dysfunction in patients undergoing selective posterior rhizotomies in whom the S2 roots are candidates for rhizotomy.

**Methods**

One-hundred fourteen children with the diagnosis of cerebral palsy and debilitating spasticity were selected to undergo selective posterior rhizotomies at New York University Medical Center during 1991 through 1995. There were 72 male and 42 female patients with a mean age of 3.8 years. At the time of surgery, none of the patients had clinically relevant bladder dysfunction. Dorsal root action potentials were recorded intraoperatively to map the distribution of pudendal afferent fibers in S1-S3 roots bilaterally before performing the rhizotomies. RESULTS Pudendal afferent mapping was successful in 105 of 114 patients. In the majority of these patients (56%), the distribution was asymmetrical. S1 roots contributed 4%, S2 roots 60.5%, and S3 roots 35.5% of the overall pudendal afferent activity. The pudendal afferent distribution was often confined to a single level in 18% of the patients or even to a single root in 7.6%. Fifty-six percent of the pathologically responding S2 roots during rhizotomy testing were preserved because of the significant afferent activity, as demonstrated during pudendal mapping. None of the 105 patients so mapped developed long-term bowel or bladder complications.

**Conclusion**

Pudendal afferent mapping identifies S2 roots that carry a significant number of fibers involved with genital sensation. The preservation of such roots during surgical procedures may be important for sexual function and may also contribute to decreasing postoperative bladder and bowel disturbances.

## Spinal cord injury: Plasticity

Roger Lemon, MD
UCL Institute of Neurology,
London UK

In this talk I want to focus on the important species differences that characterise response to partial or complete spinal cord injury (SCI). I shall examine the effects of SCI in animal models including the rodent, monkey vs the effects in humans. I also want to highlight the response to injury and the role in functional recovery of plasticity of uninjured fibres vs the concept of regeneration. Unfortunately we don't know whether all fibres exhibit plastic change and this may be very important because the long white matter tracts that are compromised by SCI may contain within them systems subserving many different functions. An obvious example would be the corticospinal tract, which has both 'motor' 'sensory' 'autonomic', trophic and other functions. The choice of animal model to investigate how best to promote recovery after SCI continues to be important. Studies *in vitro* and in rodent models have done much to illuminate the biological complexity of the post-injury spinal cord, and in particular the hostile molecular environment that confronts both injured and uninjured fibre systems. However, recent studies suggest that we may need to use the non-human primate model to understand how the spinal systems affected by SCI respond in the post-injury period, and how we could enhance these responses to improve function.

**Key References**


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- Lemon RN (2008). Descending pathways for motor control. *Annual Review Neuroscience*. 31,195-218.
- Friedli et al (2015) Pronounced species divergence in corticospinal tract reorganization and functional recovery after lateralized spinal cord injury favors primates. *Science Translational Medicine* 7, 302-312

## IOM During the Acute Phase of SCI

Paolo Costa, M.D.
Section of Clinical Neurophysiology, Città della Salute e della Scienza,
Torino, Italy

### Objective

To intraoperatively assess the spinal cord function in subjects during posterior stabilization for spinal cord trauma, by recording muscular (m-MEPs) and epidural motor evoked potentials (e-MEPs) along with cortical (c-SEPs) and epidural SEPs (e-SEPs) in an effort to identify a neurophysiologic profile of complete and incomplete spinal cord injury (SCI).

### Brief historical review

The prognosis of acute SCI, in particular motor outcome, represents a challenge for the involved health-care professionals. Actually the functional assessment and the magnitude of expected recovery are based on the physical examination, as tested by ASIA scoring, within 72 h to 1 month post trauma. However recent data suggest that the rate of ASIA conversion within the first year after SCI is greater than previously reported. Conventional clinical neurophysiology techniques have been extensively studied in the SCI patient, but mainly in chronic phase and in association with the clinical examination. In particular both c-SEPs and m-MEPs by transcranial magnetic stimulation in the acute phase may fail to provide a correct prognosis of recovery in approx 25% of cases. However clinical neurophysiology methods, by their intrinsic nature, can provide (semi-) quantitative information, in terms of presence/absence, latency and amplitude of components.

### Methods

Intraoperative recording of m-MEPs and e-MEPs along with cortical SEPs and e-SEPs was attempted in 55 patients (21 with a complete SCI, 14 incomplete - 6 central cord syndromes- and 20 uncompromised) during posterior stabilization for spine and spinal cord trauma.

### Results

The neurophysiologic profile of the complete SCI was the absence of both m-MEPs and e-MEPs caudally to the lesion site, associated with a lack of cortical and e-SEPs cranially to the lesion site. None of these patients recovered motor function in the follow-up. A clearly detectable caudal D wave was associated with motor recovery even in deeply paraparetic patients. In one neurologically incomplete patient a reversible deterioration of m-MEPs and e-MEPs was observed during the compression-distraction manoeuvre.

### Summary of recent developments and/or future directions

Presented data provide evidence in favour of an intraoperative testing of spinal cord function in SCI. In fact, intraoperative neurophysiologic reliable methods to predict functional integrity of the long tracts during surgical intervention to the spinal cord has been already developed and well established. This is particularly true for epidural MEPs (e-MEPs) recorded from the spinal cord in the form of D and I waves and MEPs recorded from the limb muscles. The information provided by these two techniques are complementary, being the D wave generated by the direct activation of axons of fast conducting fibres of the cortico-spinal tract, while m-MEPs depend also on the excitability of facilitatory cortical motor neurons, beyond the spinal cord conductivity and the excitability of lower motoneurons. In this series the absence of both m-MEPs and e-MEPs caudal to the lesion site associated with a lack of epidural and c-SEPs cranially to the lesion site has to be considered as a biological marker of a complete SCI. This is consistent with data in non-primate and primate animal models of experimental SCI. By contrast, a clearly detectable caudal D wave is the pre-requisite of motor recovery even in deeply paraparetic patients. In fact, the D wave is a direct measure of the number of functioning fast-conducting fibers in the corticospinal tracts. Many reports show that if the D wave is lost during the removal of an intramedullary spinal cord tumour, the patient will suffer from profound, persistent motor deficit. Recently has been reported that the possibility of recording intraoperatively evoked m-MEPs in sublesional muscles of an SCI patient correlates with a good motor outcome. However in this series the absence of muscle MEPs below the lesion site does not correlate 'per se'' with persistent loss of ambulatory capacity. In other words, the recording of m-MEPs alone may not be sufficient for a prognostic evaluation. Indeed, m-MEPs are, at times, completely lost during surgery for intramedullary spinal cord tumours but, if the D-wave amplitude is either stable or decreased by less 50%, the patient will present additional transient motor deficit postoperatively but motor strength recovery after surgery, with a delay of hours or days. This phenomenon ('transient paraplegia') is probably due to the surgically induced temporary inactivation of non-corticospinal descending tracts and propriospinal system, while fast-conducting corticospinal fibers are mostly preserved. The speculative mechanism of transient paraplegia has at least some similarity to the current hypothesis about the 'spinal shock' phenomenon. In theory, a similar phenomenon could be present in SCI and, therefore, the intraoperative recording of the D wave could be a potential predictive index of recovery. An experimental study reported that as few as 10% of the corticospinal fibres were sufficient to support locomotion. Finally, although this study is mainly focused on MEPs, SEPs retain a great value in assessing dorsal column function, such as proprioception, which is of paramount importance even for locomotion.

**Conclusions**

These data created a neurophysiologic profile of the SCI patients concerning conduction system of the spinal cord, as a background for a further expansion of neurophysiologic testing to the grey matter of the spinal cord (processing system) and further categorization, intervention and rehabilitation strategies.

**Key references and recommended readings**.

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## Restorative Neurology of the injured spinal cord

Milan R. Dimitrijevic,
Houston, Texas

### Restorative Neurology

Restorative Neurology was defined during a symposium on upper motor neuron dysfunction (1982) as the branch of neurological sciences which applies active procedures to improve functions of the impaired nervous system through selective structural and functional modification of altered neurocontrol according to underlying mechanisms. Thus, a new sub specialty was formed that sought out clinically unrecognized, altered neural functions and developed tools that made use of afferents and other biological modalities to access those surviving neural circuits to modify their output and improve clinical function. (1)

The human CNS has the ability to conduct neural impulses as spikes, carrying information from inside and outside the body to form and between hierarchically placed nuclei of the brain and spinal cord that process this information to produce appropriate sensory perception and motor output. The conducting pathways are made up of multi parallel axons of different diameters conduction velocities and lengths reaching neural processors that are of different sizes and shapes, located within the gray matter and constructed from populations of interneuron's, with short axons. These two basic functional features of the CNS, to conduct and to process provide sensory perception, cognition and a wide variety of movements, from locomotion to skillful movement and speech.

### Intraoperative Neurophysiology

Intraoperative neurophysiology presents twofold significance in supporting intraoperative intervention treatment of CNS disorders, including spinal cord as a part of CNS.

A widely established approach is to protect the non injured spinal cord from surgical intervention such as in scoliosis, as well as in other structural spinal cord disorders.

Second and currently under development is the introduction of intraoperative neurophysiology monitoring. This conversion of neurophysiological monitoring to intervention for modification of injury establishing new anatomy and tailoring a redesign in the neurocontrol spinal cord sensory and motor functions.

In the lecture we shall review the present status of neurophysiology in sensoy motor processes involved in motor control, when fully deprived from brain motor control, partially deprived and fully integrated human lumbar cord. We shall provide evidence that the human lumbar cord isolated from brain control can respond to external sustained spinal cord stimulation with variety of tonic and rhythmic activity resembling "***brain at the human lumbar cord***" or in other words ***"spinal brain"***


Figure 1. Testing Rexed anatomy of segmental network by mono, di and poly synaptic reflex activity

**The conducting and processing capabilities of the human lumbar cord network and "spinal brain" can respond to the afferent input with a variety of features of motor activity.**

We shall illustrate that isolated lumbar cord network can generate definite motor control:

A. Regular and stochastic motor responses.
B. Spinal cord stimulation can evoke consistently different functional movement.
C. Stimulus locked responses with additional state-dependent modulation.

**After showing those "spinal brain"processing capabilities, we shall discuss how spinal brain capabilities can be used in the practice of restorative neurology of the injured spinal cord. We shall present neurophysiological intervention for the enhancement of neurocontrol in movement.**

Neurophysiological studies of motor control of spinal cord injury at first benefited from proprioceptive and exteroceptive reflex activity. Excessive reflex activity in patients with chronic spinal cord injury was shown, and the level of reflex responsiveness can be modified by habituation and dishabituation processes intrinsic to the spinal cord. Moreover, the finding that there are large variations in reflex responses and their behavior in clinically similar chronic injuries, led us to recognize that the brain facilitatory and supressive influence on segmental inter-neural networks can be present below the level of the clinically complete lesion.

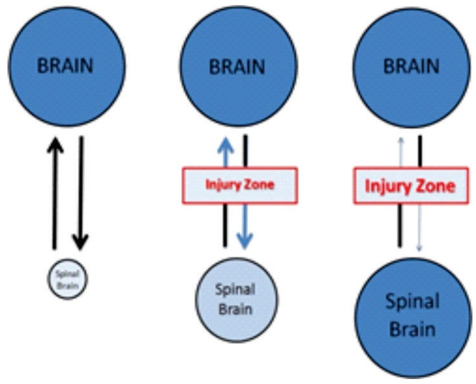




Figure 2. From historic illustration of spinal cord network to conceptual modeling of evolution of spinal brain by severity of lesion

There are inverse functional capacities between brain/spinal cord preserved connectivity.

The main message n this lecture is that reflex activity elicited by single stimulus response has significantly different motor behavior than if the stimulation is applied repetitively. The isolated lumbosacral spinal cord has the capacity to respond with a variety of pattern of motor activity. Some of the evoked patterns can be functional (e.g., rhythmic activities with co active bursts across all muscle groups). Furthermore, motor behavior evoked by repetitive elicitation of spinal cord reflexes also depends on the central state of excitability and clinical and subclinical residual brain motor control.

The spinal cord possesses various control capabilities even after chronic motor complete spinal cord injury. Yet when disconnected from supra-spinal control, it is not able to initiate any movement. With non-patterned repetitive input from still intact, afferent structures, the spinal cord networks below the level of the lesion can be configured to perform various movements. In incomplete spinal cord injury where brain control is partially preserved, spinal cord stimulation induced activity can be modified, controlled, and integrated. Thus, paretic and paralyzed movements in patients with chronic spinal cord injury due to upper motor neuron dysfunction have characteristic alteration of neurocontrol of afferent input as well by residual suprasegmental brain control. (2)

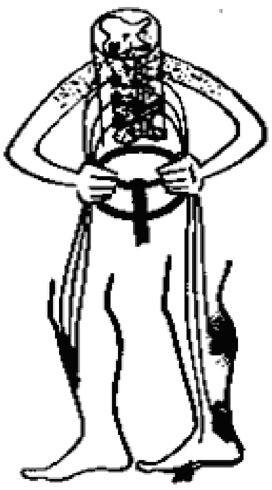
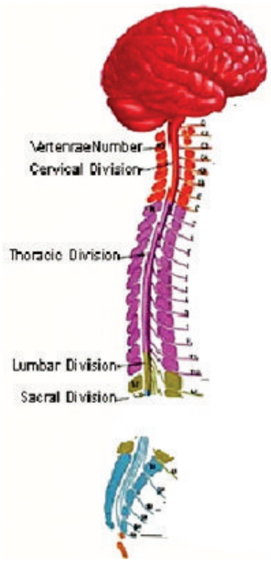


Fig. 3.





**Key References**

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## Day 14 - Session IX: 11h30 - 13h20
## Deep Brain Stimulation - DBS

### Neuromodulation Therapy
### Current and Future Applications of Neuromodulation Surgery

Kendall H. Lee, M.D., Ph.D.
Mayo Clinic, Rochester, MN, USA; Department of Neurologic Surgery
Deakin University,
Melbourne, Australia

**Objectives**

1. **Understand the history and current usage of neuromodulation surgery**
2. **Understand current medical, engineering, and ethical challenges facing surgeons using neuromodulation therapy**
3. **Understand technologies under development to address current problems and improve the delivery of neuromodulation therapy**

**Brief Historical Review**

Neuromodulation surgery involves the electrical stimulation of neural targets via implanted electrodes. This technique includes deep brain stimulation (DBS, the most common procedure) as well as cerebral cortex stimulation and spinal cord stimulation. The earliest work in the modern field of neuromodulation dates back to the 1960s, when Spanish physician Jose Delgado reviewed the implantation of intracranial electrodes in humans and presented his theories about their potential use as diagnostic and therapeutic tools. American neurosurgeon Irving Cooper, another pioneer in the field, was able to demonstrate in 1980 that chronic electrical stimulation could produce effects similar to the more permanent and damaging technique of surgical ablation or lesioning of sites in the brain for treatment of movement disorders. These techniques reached their logical conclusion in 1987, when a team consisting of French neurosurgeon Alim-Louis Benabid and neurologist Pierre Pollack at Grenoble University, demonstrated that electrical stimulation could safely mimic surgical ablation for the treatment of tremor.

**Summary of Recent Developments**

We know that neuromodulation therapy (DBS) is clinically effective for movement disorders, including Parkinson's disease, dystonia, and essential tremor. Its effectiveness for the treatment of movement disorders has led to its application for psychiatric disorders such as obsessive compulsive disorder and Tourette's syndrome where it has shown great promise. DBS is currently being tested as a treatment for depression, addiction, schizophrenia, anxiety disorders, and memory loss due to Alzheimer's disease.

The current major obstacles to expanding neuromodulation therapy are twofold. First, the mechanism of action by which electrical stimulation modulates brain function and disease symptoms remains unknown. Continued research into the different mechanisms of action of neuromodulation therapy is still needed, including the mapping of circuitry activated by the stimulation of different brain areas, understanding the interconnected role of different neural and glial cell types, and understanding the precise roles played by the various neurotransmitter systems. Second, existing neuromodulation devices are 'open loop,' requiring regular reprogramming, as current devices maintain a single set of stimulation parameters independent and unreactive to any physiological parameters or changes in the implanted patient. A key goal for neuromodulation device development, particularly for deep brain stimulation, is for an implantable closed-loop system that self-regulates stimulation based on changes in neural activity to optimize patient outcome.

Several issues remain to be addressed before a closed-loop neuromodulation device will become feasible. First, existing electrodes used for stimulation and recording see a substantial degradation in condition and sensitivity in the electroactive environment of the central nervous system. Current microelectrodes are made of carbon fiber and simply do not have the longevity necessary for chronic implantation. Second, we have not yet defined the most effective biomarkers to determine modulation changes in a closed-loop system. Can an effective feedback control system be designed based on electrophysiology recordings alone? Can real-time monitoring of neurotransmitter release using electrochemical recordings provide effective feedback control? Will some combination of physiologic parameters provide the best control? This issue is complicated by the variety of anatomical sites targeted for stimulation to treat various disorders, since each brain target and neural disorder may require a different feedback algorithm.

### Conclusions and Future Directions

The field of neuromodulation therapy is advancing rapidly. DBS is now being used routinely for the treatment of movement disorders and is also being applied to a variety of neuropsychiatric conditions. Electrophysiologic recordings, real time measurement of neurotransmitter release, and the imaging of brain activity using BOLD-fMRI can now all be used on human patients undergoing the surgical implantation of DBS electrodes offering unprecedented opportunities for the study of human brain function and behavior.

#### Key References and Recommended Reading


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- Chang SY, et al. Development of theMayoInvestigational Neuromodulation Control System: toward a closed-loop electrochemical feedback system for deep brain stimulation. J Neurosurg. 119:1556-1565 (2013).
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## Neural Engineering Next Generation of DBS Technology

Kevin E. Bennet, BSChE, MBA,
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Melbourne, Australia

### Objectives

1. **Understand the issues in neurotransmitter detection electrode composition and usage**
2. **Understand current state of the art neurochemical detection system**
3. **Understand the value of combining stimulator with detection system**
4. **Understand option for targeting area of activity for feedback**

### Brief Historical Review

In the few years since DBS systems have become available (FDA approval 2002), there have been approximately 110,000 implantations, primarily for debilitating neurologic disorders such as essential tremor and Parkinson's disease. While DBS is believed to regulate neurochemical release, the stimulation effect is not known.

A variety of brain characteristics have been proposed for providing a feedback mechanism to allow the extension of DBS to a variety of disease states including psychological issues such as depression, obsessive compulsive disorder and Tourette's among others. Feedback mechanisms include electrophysiology, amperometery and fast scan cyclic voltammetry (FSCV).

We, at the Mayo Clinic have developed WINCS (Wireless Instantaneous Neurochemical Concentration Sensing), MINCS (Mayo Investigational Neuromodulation Control System) and Harmoni ( the combination of WINCS and MINCS) as a staged approach in the design and building of closed loop DBS based upon FSCV electrochemical detection. The monitoring system utilizes a real time, wireless, in vivo neurochemical detection process which is capable of monitoring and reporting in real time the release in neurochemicals during DBS surgery. By imposing a voltage waveform that ramps through potentials allowing oxidation and reduction of chemical species of interest, detection and measurement of chemical changes can be determined by monitoring the nanoampere amount of electrical current flowing at specific voltages.

The carbon fiber microelectrode, long the mainstay of FSCV, erodes with the normally imposed voltage waveform. It appears that carbon is oxidized to carbon dioxide which dissolves in the interstitial fluid and is dispersed to the body. This issue prevents the use of CFM for any permanently implanted device.

### Summary of Recent Developments/Future Directions

The goal of our current research is to develop a closed-loop DBS device that incorporates sensing of neurotransmitters as the feedback to control stimulation parameters of amplitude and frequency.

The integration of WINCS with our neurochemical sensing microelectrode and a feedback control algorithm being developed in our laboratory serves as the foundation for chronically implantable closed loop device. The system must remain electrochemically stable over the lifetime of the patient.

Boron doped diamond electrodes in FSCV demonstrate excellent electrochemical properties, including a wide potential window, low baseline current and excellent stability. These characteristics lead us to continue development of our acute electrode to a chronically implantable one.

As we compared results of CFMs to boron-doped diamond, both electrodes demonstrate good sensitivity detecting neurochemicals in vitro and in vivo, the diamond based electrodes have increased longevity and mechanical strength, much needed for long term implantation. After 5.2 million cycles, the diamond based electrode continues to provide adequate information.

### Conclusions

We anticipate that coupling the developed, multichannel neurotransmitter detection device with the interleaved stimulation pulse subsystem and diamond sensing electrode, will provide the means for the long term detection of neurotransmitters. This combination is expected to provide the required information needed for a DBS control algorithm allowing intervention in a greater number of debilitating neurologic disorders.

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# Oral Presentations

## Day 1 - Thursday, November 12

Free Papers Session I MEPs / 12h00 - 13h00

### 1 - Neurophysiological Mechanism of Confounding Peripheral Activation of The Facial Nerve During Corticobulbar Tract Monitoring

*Ulkatan Sedan*

**Clinical Study**

**Introduction**

Corticobulbar motor-evoked potential (CoMEP) monitoring of facial nerve activation evoked by transcranial electrical stimulation (TES) is a known technique to monitor the functional integrity of corticobulbar tract. Moderate intensity TES can leak to the facial nerve itself and generating confounding peripheral responses (CMAP).

Methodologically, it is accepted that the facial responses elicited by TES are true CoMEPs when the responses are evoked by short trains and that confounding peripheral activation can be ruled out when no responses are observed following single stimuli.

We hypothesized that current leaked TES at sub- or near-threshold intensity to the facial nerve might elicit a confounding CMAP after a short train while not eliciting a response after a single stimulus. In other words, the short train of TES might change the excitability of the facial nerve such that the leaking current at sub- or near-threshold intensity might evoke a confounding CMAP that cannot be recognized with the current methodology.

**Methods**

We applied a single stimulus and a short train of electrical stimuli directly to the extra cranial portion of the facial nerve. We compared the CMAP of the facial nerve to the responses elicited by TES during intraoperative monitoring of the corticobulbar tract.

**Results**

A single stimulus applied directly to the facial nerve at sub-threshold intensities, did not evoke a CMAP, whereas short trains of sub-threshold stimuli repeatedly evoked CMAPs. This is due to the phenomenon of sub- or near-threshold super excitability of the cranial nerve described by Bostock et al. (2005) and Trevillion et al. (2010).

**Conclusion**

The facial responses evoked by short train of TES, when the leaked current reaches the facial nerve at sub- or near-threshold intensity, could lead to false interpretation. Our results revealed a potential pitfall in the current methodology for facial corticobulbar monitoring.

## 2 - Preoperative Motor Function Predicts Ability to Record Muscle Motor Evoked Potentials

*LanJun Guo[1], Li Yano[3], LingZhong Meng[2], Han Ruquan[3], Adrian W Gelb[2]*
1 - Neurophysiological Monitoring Service; 2 - Department of Anesthesiology and Perioperative Care, University of California, San Francisco, USA. 3 - Department of Anesthesiology, Beijing TianTan hospital, Beijing, China.

**Background**

Motor evoked potentials (MEPs) have been routinely used during surgery for spinal cord tumor resection. However, it can be difficult to record reliable MEPs from the muscles of lower extremities during surgery on patients with weakness due to spinal cord compression. In this study, motor function of patients' lower extremities and their association with intraoperative MEP recording were compared.

**Method**

89 patients underwent thoracic spinal cord tumor resection. Patients' motor function was checked immediately before the surgical procedure. MEP responses were recorded from the tibialis anterior and extensor digital muscles from 178 lower limbs of the 89 patients, and as also from hand muscles as control. Electrical current was delivered through two corkscrews placed on C3 and C4 sites with train of eight pulses, 200 to 500 volts. Anesthesia was maintained by total intravenous anesthesia (TIVA) using a combination of propofol and a remifentanil after induction with intravenous propofol, remifentanil, and rocuronium. Rocuronium was not repeated. Bispectral Index was maintained between 40 to 50.

**Results**

From the 178 lower limbs of 89 patients, muscle MEPs could be recorded from 100% (105/105) of the patients with 5 out of 5 motor strength in lower extremity; 90% (36/40) from the patients with 4/5 motor strength; only 25 % (5/20) with 3/5; and 12.5% (1/8) with 2/5 motor strength; None (0/5) were able to be recorded if the motor strength was 1/5.

**Summary**

Recordable muscle MEPs are closely associated with the patient's motor function. They are difficult to measure if motor function is 3/5 of motor strength in the lower extremity. They are almost impossible to record if motor function is worse than 3/5.

### 3 - Intraoperative Direct Cortical Stimulation Motor Evoked Potentials: Optimal Pulse Train Parameters Based on Rheobase and Chronaxie

*MacDonald DB, Abalkhail T, Al Thubaiti I, Al Otaibi F, Stigsby B, Mokeem A, Al Homoud I.*
**Department of Neurosciences, King Faisal Specialist Hospital, Riyadh, Saudi Arabia**

**Introduction**

Rheobase is threshold current at infinite pulse duration (D) and chronaxie is D with 2 x rheobase threshold. They might be used to optimize pulse train parameters for direct cortical stimulation (DCS) motor evoked potentials (MEPs) because the interstimulus interval (ISI) producing lowest rheobase and D at the chronaxie would minimize the stimulus energy needed to evoke responses.

**Methods**

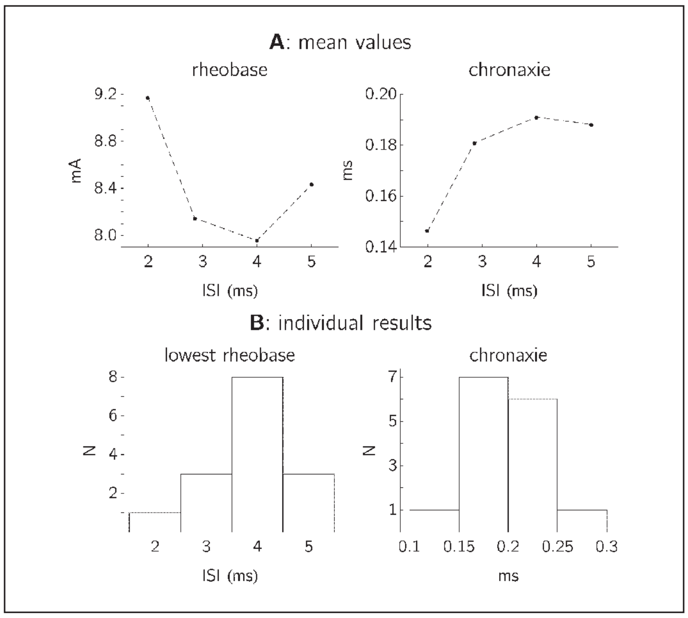
The rheobase and chronaxie of 5-pulse DCS thenar MEPs were derived from thresholds at 0.05, 0.1, 0.2, 0.5 and 1-ms D for ISIs of 2, 3, 4 and 5-ms in 15 patients under propofol and remifentanyl anesthesia omitting neuromuscular blockade.

**Results**

Fig. 1A plots sample mean values: the lowest mean rheobase at 4-ms ISI was significantly lower ($p<0.05$) than at 2 or 5, but not 3-ms ISI; mean chronaxie was statistically equal at about 0.18–0.19 ms for 3–5 ms ISIs and slightly shorter with a 2-ms ISI ($P<0.05$). Fig. 1B shows the distribution of individual results: lowest rheobase occurred most often with a 4-ms but sometimes other ISIs and chronaxie was usually near 0.2-ms but occasionally closer to 0.1 or 0.3-ms.

**Conclusions**

A 4-ms ISI and 0.2-ms D are near optimal for most patients and individual optimization based on rheobase and chronaxie is possible.



## 4 - Warning Thresholds for Motor Evoked Potential Monitoring During Surgery in Brain Motor Areas: Correlation with Neurological Outcome

*C.Parisi, V. Tramontano, G. Bulgarelli A. Pasqualin, M. Meglio, G. Pinna, F. Sala*
**Institute of Neurosurgery, University Hospital, Verona, Italy.**

**Introduction**
Different warning criteria for muscle motor evoked potentials (mMEP) are used during brain tumor surgery. The aim of our study was to analyze the early neurological outcome and the correlation with IONM in order to assess the value of different IONM criteria.

**Materials and Methods**
Clinical data of 120 patients who underwent IONM assisted surgery for brain tumors in the motor areas, between January 2012 and April 2015, were collected prospectively in 37 patients and retrospectively in 84. Motor status on admission, early after surgery, at discharge and at follow-up (3-5 months) was evaluated according to the Medical Research Council scale. IONM consisted of monitoring mMEPs elicited by transcranial electrical and/or direct cortical stimulation (DCS) of the motor cortex. Correlations between mMEPs after DCS and motor outcome were analyzed post hoc considering thresholds for significant amplitude decline set at 50% or at 80%.

**Results**
Post-operatively 40% of patients (n=48) showed a worsening of neurological function. This rate dropped to 22% (n=27) at discharge and 13% (n=13) at the follow-up. Monitorable mMEP following DCS were present in 85,3% of the procedures (n=103). The rate of false positive results was 8,8% when threshold was set at 50% and 1% when set at 80%. Vice versa, the rate of false negative was 9,8% using a 50% threshold and 13,5% using a 80% threshold. When the lesion was located in the pre-motor areas there was an increased number of false negative results, likely reflecting a supplementary motor area syndrome.

**Conclusions**
IONM reliably predicted motor outcome at discharge from hospital and especially at the follow-up. For cortical mMEPs, an amplitude decline criterion of 80% increases the rate of false negative results but minimizes the risk of false positive results, while a 50% drop criterion seems to be little specific.

The authors declare no conflict of interests

## Day 1 - Thursday, November 12

Free Papers Session II MEPs / 18h30 - 19h30

### 5 - TMS-Induced Phosphene Maps in Patients with Arteriovenous Malformations (AVMs)

*Pridgeon, M. Hopper, A. Manohar, R. Barbarisi, M. Byrne, T. Farah, J. Eldridge, P.*

**Introduction**

Although transcranial magnetic stimulation (TMS) has been validated against direct electrical stimulation of the brain for motor and language mapping (Picht et al 2012, Krieg et al 2012), the visual system – using induced phospenes - has not. This is a particular issue with AVMs undergoing surgical resection as in such cases fMRI mapping is less reliable (Gallagher et al 2013).

**Methods**

Seven patients with occipital or parietal AVM were mapped pre-operatively, and between stages of pre-operative embolisation using TMS induced phosphenes.
The visual evoked response (VER) was measured using flash stimulus delivered by LED stimulators placed over the patient's eyelid, recording between a reference and the visual cortex. The optimum position chosen for monitoring was by the surgeon identifying the site with maximum P100 amplitude by trial and error, but with the knowledge of the predicted site from both TMS and fMRI. All patients underwent visual field testing.

**Results**

In all cases phospenes were elicited in areas predicted to overly primary visual cortex. In one case – negative to fMRI phospenes were not obtained prior to pre-surgical embolization of the AVM, but did appear after this procedure. In all cases the pre-operative induced phosphene maps were used to identify the optimal site for intra-operative VER monitoring, though this differed in location from the TMS point.

**Conclusion**

Post-operatively there were no new visual field deficits. TMS- maps were found to be a reliable technique for the identification of the optimal site for intra-operative VER. The difference in TMS and VER maxima is likely to be due to the deep seated position of the calcarine fissure.

## 6 - Monophasic High Frequency Stimulation of Dorsal Column Axons: Potential Underlying Mechanism of Paresthesia-Free Neuropathic Pain Relief

*Jeff E. Arle, MD, PhD, Jay L. Shils, PhD, Longzhi Mei, MS, Kris Carlson*

J.E. Arle has received grant support from Boston Scientific.

This research was supported with a generous grant from the Sydney Foundation

**Objective**

Spinal cord stimulation (SCS) treats neuropathic pain through retrograde stimulation of dorsal column axons and their inhibitory effects on wide dynamic range (WDR) neurons. Typical SCS uses frequencies from 50 - 100 Hz. Newer stimulation paradigms use high frequency stimulation (HFS) up to 10 kHz and produce pain relief but without paresthesiae. Our hypothesis is that HFS preferentially blocks larger diameter axons (12-15 µm) based on dynamics of ion channel gates and the electric potential gradient seen along the axon, resulting in inhibition of WDR cells without paresthesiae.

**Methods**

We created a 70 mm active axon model with ion channel subcomponents for fiber diameters 5 - 20 µm and simulated dynamics on a 0.001 ms time scale.

*Results:* Action potential (AP) blockade occurs as hypothesized, preferentially in larger over smaller diameters at frequencies above approximately 3 kHz, with blockade in most medium and large diameters occurring between 4.5 -10 kHz. Simulations show both ion channel gate and virtual anode dynamics are necessary.

**Conclusion**

At clinical HFS frequencies and pulse widths, HFS preferentially blocks larger-diameter fibers and concomitantly recruits medium and smaller fibers within certain parameter ranges. These effects are a result of interaction between ion gate dynamics and the activating function (AF). The larger fibers that cause paresthesia in LFS are blocked, while medium and smaller fibers are recruited, leading to paresthesia-free neuropathic pain relief by inhibiting WDR cells.

**Significance**

This finding suggests a putative mechanism for HFS to mitigate neuropathic pain without paresthesiae and may suggest further refinements of SCS in general.

## 7 - Model of Vagus Nerve Stimulation as a Paradigm for Selective Fiber Activation or Blocking in Peripheral Nerves

*JE Arle, KW Carlson, LZ Mei*

**Introduction**

Vagus Nerve Stimulation, used in increasingly diverse therapies including the treatment of epilepsy, depression and heart failure, often uses a helical electrode wrapped around the nerve. Given the parameter space used therapeutically in epilepsy therapy, we analyzed which fiber diameters are likely activated or blocked.

**Methods**

Using FEM techniques (COMSOL, Burlington MA), geometry was created to account for thickness and conductivity of thin layers (e.g. perineurium, scar tissue) which are set programmatically, as are electrical ground and insulation. We identified possible locations of fascicles implicated in VNS from photographs of the cat vagus nerve and replicated those in our finite element model. We then calculated:

1) The estimated number of fibers in what are likely the key fascicles involved in vagus nerve stimulation
2) The estimated number of fibers at the location of the stimulator, just above the recurrent laryngeal branch point and below the superior laryngeal and two cardiac nerve branch points.

**Results**

a) Two Aβ groups are recruited with electrode amplitude between 0.3 – 0.75 mA and have no therapeutic effect
b) A fast B group ~5 μm diameter is recruited next, with electrode amplitude between 0.75 and 2.25 mA. This groups seems to likely produce efficacy (for seizure control).
c) Above 2.25 mA amplitude VNS produces side effects such as hoarseness likely to arise from over-driving the Aβ groups associated with the recurrent laryngeal branch, possibly from recruiting a slow B group of P2ry1 pulmonary fibers, and other groups. The fast B group is still active and driven more strongly.

**Conclusions**

Computational analysis of VNS has identified parameter ranges wherein selective fiber diameters, and thus likely function, can potentially be used therapeutically (activated and/or blocked) for desired therapy, in VNS and possibly in other peripheral nerve stimulation approaches.

This study was partially funded by a grant from Cyberonics Corporation and the Sydney Family Foundation. The authors otherwise have no COI's to report.

## 8 - Prospective Study of Continuous Dynamic Mapping of the Corticospinal Tract during Surgery of Motor Eloquent Intra-axial Brain Tumors

*Kathleen Seidel, Jürgen Beck, Philippe Schucht, Andreas Raabe*
**Department of Neurosurgery, Inselspital, Bern University Hospital, Bern, Switzerland**

### Introduction

A mapping technique comparable to a "cortico-spinal tract (CST) radar" was applied to overcome the temporal and spatial limitations of classical subcortical mapping. The feasibility and safety of continuous dynamic subcortical motor mapping (at the site of and synchronized with tissue resection) was evaluated in patients with intra-axial brain tumors.

### Methods

We prospectively studied 182 patients who underwent surgery of intra-axial brain tumors adjacent to the CST (defined as <1 cm distance using diffusion tension imaging fiber tracking) with simultaneous subcortical monopolar motor mapping (cathodal stimulation, train of 5 stimuli, inter-stimulus interval 4.0 ms, pulse duration 0.5 ms) and a new acoustic motor evoked potential alarm. Temporal and spatial coverage was technically realized by integrating the mapping probe at the tip of a new suction device. Motor function was assessed using MRC scale for muscle strength one day after surgery, at discharge, and at 3 months.

### Results

All procedures were technically successful. Lowest individual motor thresholds were as follows (MT, number of patients): >20 mA, n=21; 11-20 mA, n=35; 6-10 mA, n=31; 4-5 mA, n=37; 1-3 mA, n=58. At 3 months, 6 patients (3%) had persisting postoperative motor deficits, 3 of them were caused by vascular injury, 2 by mechanical injury of the CST and one was unclear. MRCS grades deficits at 3 months caused by vascular injury were 0.5, 1 and 3, by mechanical injury 0.5 and 2 and in the unclear case 1.

### Conclusion

Continuous dynamic mapping was found to be a feasible and ergonomic technique for localizing the distance of the CST. The acoustic feedback and the ability to continuously stimulate the tissue exactly at the site of tissue removal improves the accuracy of mapping, especially at low (<5 mA) stimulation intensities. This new technique may increase the safety of motor eloquent tumor surgery.

## Day 2 - Friday, November 13

Free Papers Session III MEPs / 12h10 - 13h10

### 9 - Intraoperative Monitoring of Visual Pathway with Intracranial Recording Electrodes in Patients with Brain Tumors

*Hans Lindehammar[1], Peter Milos[2], Cecilia Gustafsson[3]*

**1 Dept of Clinical Neurophysiology 2 Patrick Vigren Dept of Neurosurgery 3 Axel Johansson Dept of Clinical Neurophysiology Linköping University, Sweden**

**Introduction**

Hemianopsia is a common postoperative deficit after brain tumor surgery causing considerable problems for patients. Preservation of visual function is therefore important during surgery. Neurophysiological monitoring of visual evoked potentials (VEP) has traditionally been performed using flash stimulation and extracranial recording electrodes. This method can be used in pre-chiasmatic lesions but is inaccurate for monitoring post-chiasmatic visual tracts. We therefore used intracranial recording from the visual cortex in order to preserve the visual field.

**Methods**

Intraoperative monitoring was performed in 9 patients with gliomas near the post-chiasmatic visual tract (parietal, temporal, occipital). Six were low grade gliomas and three were high grade gliomas. Six patients were asleep during surgery and three were awake. Flash stimulation with LED goggles was done intermittently during resection. VEP was recorded with subdural strip electrodes placed over the visual cortex. Visual function postoperatively was evaluated with Donder's test.

**Results**

Clear VEPs were recorded in 8 patients. The responses were stable, polyphasic and of high amplitude. In one patient no reproducible response was obtained. The reason was difficulties in placing the strip electrode correctly over the visual cortex. In 7 patients the VEP was unchanged during surgery and they had no visual field defect postoperatively. In one patient the VEP was completely lost during surgery with hemianopsia after surgery. In one patient the VEP was temporarily lost and then recovered. This patient had no visual field defect postoperatively.

**Conclusions**

Continuous monitoring is possible in anesthetized patients. In awake patients the monitoring may be used during part of the resection without side effects. Intraoperative monitoring of post-chiasmatic visual tracts during brain tumor surgery is feasible and useful, preventing postoperative visual field defects.

## 10 - Monopolar High Frequency Stimulation in Language Mapping

*Marco Riva[1] M.D., Enrica Fava[1] M.D., Marcello Gallucci[2] Ph.D., Alessandro Comi[1] Ph.D., Alessandra Casarotti[1] Ph.D., Tommaso Alfiero[1] M.D., Fabio A. Raneri[1] M.D., Federico Pessina[1] M.D., Lorenzo Bello[1] M.D.*

**1 Neurosurgery, Dept of Medical Biotechnology and Translational Medicine, Università degli Studi di Milano, via Manzoni 56, 20089 Rozzano-Milano, ITALY. 2 Faculty of Psychology, Università di Milano Bicocca, Piazza dell'Ateneo Nuovo 1, 20126, Milan, ITALY**

**Introduction**.

The High-Frequency train-of-5 stimulation, delivered by a monopolar probe (HF-MP), was applied for language mapping during awake surgery. The performance was compared with the traditional low-frequency bipolar stimulation (LF-BP).

**Methods**.

59 patients were included. A constant current stimulator was used. EMG responses from perioral muscles were collected by ISIS IOM system (Inomed, Germany). HF stimulation unit was a train of 5 square pulses. 0.5 ms duration, 2 ms ISI (total train duration 3.3 ms), applied with a monopolar probe; LF-BP stimulation was applied by a bipolar probe and delivered biphasic square pulses, 1 ms duration, 60 Hz rate (ISI 16.66 ms), in trains lasting 1-4 s.

Three types of errors were considered: articulatory disturbance, anomias, paraphasias.

**Results**.

HF-MP stimulation at 1 Hz induced *speech arrest* during stimulation of the ventral motor/premotor regions at cortical and subcortical level, but no interference with the naming tasks.

A MEP was detected from the perioral muscles during speech arrest.

HF-MP stimulation determined a *language interference during the naming tasks* (anomias, phonemic and semantic paraphasias ) when the repetition rate was increased to 3 Hz, at cortical and subcortical level. No MEP was observed from the perioral muscles.

The current intensity of the HF-MP stimulation was higher than with LF-BP, with a linear relationship ($r^2$=0.515); on average, double the intensity than LF-BP is required with HF-MP.

Error rate determined by both modalities differed from baseline ($p<0.001$), but not between them ($p=0.06$). The error rate across the three types of errors (articulatory, anomia, paraphasia) did not differ between the two stimulation methods ($p=0.279$).

**Conclusion**

With proper setting adjustments, HF-MP stimulation is a safe and effective technique for language mapping and it is able to interfere with the more complex components of language.

## 11 - The site of activation of the human corticospinal tract to follow transcranial electric stimulation: new evidence

*Andrea Szelényi, MD PhD, Marcel Kamp, MD, Michael Sabel, MD PhD, Philip Slotty MD, Jan Vesper MDPhD, Marion Rapp, MD*

**Department of Neurosurgery, University Clinic and Medical Faculty, Heinrich Heine University, Duesseldorf, Germany**

### Introduction

Type, intensity and electrode montage of transcranial electric stimulation (TES) determines the site of excitation of descending corticospinal axons (CT), which might occur at brainstem level when using high voltage intensities.
The site of CT-activation was studied in comparing latencies of descending corticospinal volleys (D-wave) evoked by anodal constant current (cc) TES, direct cortical (DCS) and subcortical stimulation (SubCxS).

### Methods

In 5 patients (61±10 years, 4f) undergoing surgery of central region tumors, D-waves were recorded with epidural electrodes at cervico-thoracic level. TES electrode montages were: hemispheric (C3/Cz resp. C4/Cz, Hem), medial (C1/C2 resp. C2/C1, $InHem_{med}$) and lateral interhemispheric (C3/C4 resp. C4/C3, $InHem_{lat}$). Monopolar anodal DCS and cathodal SubCxS (all .5 ms pulse width) were performed at hot-spots eliciting hand muscle motor evoked potentials. Stimulation intensity was categorized into motor threshold (MT), moderate ($TES_{mod}$: 90–150mA; $DCS_{mod}$: 10–15mA) and high ($TES_{max}$: 200–250mA, $DCS_{max}$: 20–25mA).

### Results

In all patients, only single peak D-waves were recorded. D-wave latency differences ($\Delta D_{lat}$) with $TES_{max}$ at $InHem_{med}$ vs. $InHem_{lat}$ were 0.22±0.1ms; at $InHem_{lat}$ vs. Hem 0.3±0.01ms and at $InHem_{med}$ vs. Hem 0.1±0.1ms. D-wave latencies evoked by $InHem_{lat}$ were shortest. $\Delta D_{lat}$ between $TES_{mod}$ and $DCS_{mod}$ was 0.17±0.17ms resp. 0.13±0.1ms for $TES_{max}$ vs. $DCS_{max}$. D-wave latency decreased with stepwise deeper SubCxS. $\Delta D_{lat}$ between $TES_{max}$ at $InHem_{med}$ and $subCxS_{MT}$ at 20-25mm was 0.05±0.02ms. D-wave latency decreased in 0.27ms at 42mm $SubCxS_{MT}$ compared to $TES_{max}$ at $InHem_{lat}$ (one patient).

### Conclusion

Data confirms that $TES_{max}$ at $InHem_{med}$ and $DCS_{MT}$ activate the CT within superficial subcortical white matter. $TES_{max}$ at $InHem_{lat}$ activates the CT deeper within the white matter (approximately 40mm). This supports study results that $TES_{mod}$ and DCS are of comparable sensitivity indicating subcortical ischemia affecting CT. CT-activation at the level of the brainstem seems to be unlikely when stimulating with cc $TES_{max}$.

## 12 - Reorganization of Cortical Motor Areas after Tumor Resection: a longitudinal nTMS Study

*Marie-Therese Forster, Anne Barz, Anika Noack, Christian Senft, Volker Seifert*

**Department of Neurosurgery, Goethe University, Schleusenweg 2-16, 60528 Frankfurt am Main, Germany**

### Introduction

During the last decade evidence for brain plasticity after resection of low grade gliomas in mainly speech relevant areas has been obtained. Thus, our aim was to evaluate motor cortex reorganization after tumor resection non-invasively by navigated transcranial magnetic stimulation (nTMS).

### Methods

Mapping of the motor cortex by nTMS was performed pre- and postoperatively in 14 patients (5 females, aged mean 35.4, range 15 – 52.3 years), separated by 21.4 ± 21.3 months. Moreover, 8 patients underwent a third nTMS mapping 27.6 ± 10.3 months after their second motor cortex evaluation, resulting in a follow-up period of 40.4 ± 20.2 months. Centers of gravity (CoGs) were calculated for every muscle representation area, and Euclidian distances (EDs) between CoGs over time were defined. Results were compared with data from 12 healthy patients, whose motor cortex had been examined by nTMS in two sessions at an interval of 10.3 ± 9.6 days.

### Results

Histopathological examination revealed glioma grade I and IV each in one patient, grade II in five and grade III in 7 patients. In healthy subjects, CoGs of upper and lower limb muscle representation areas over both hemispheres differed 5.41 ± 2.76 mm over sessions. In patients, pre- and postoperatively pooled nTMS data did not differ significantly, whereas a reorganization of the leg motor cortex was observed during the further postoperative follow-up period (p=0.005 for the tibial anterior muscle; p=0.007 for the abductor hallucis muscle). In detail, a significant shift of their motor representation areas was identified in 2 patients between their second and third nTMS mapping.

### Conclusion

nTMS allows for a non-invasive and reliable evaluation of motor cortex reorganization after brain tumor removal and thus might encourage repeated tumor resection in case of residual tumor or tumor recurrence.

## Day 2 - Friday, November 13

Free Papers Session IV MEPs / 16h30 - 17h30

### 13 - The Anatomical Distribution of EMG Responses during SDR

*Volter, Simone*

**Introduction**

In treating spastic syndrome by means of SDR (selective dorsal rhizotomy), a partial deafferentation of sensory nerve roots (L1-S2) was performed. IOM (intraoperative monitoring) was used to assess EMG responses and classify them into specific grades in order to decide which rootlets of a nerve root to transect. The aim of the study was to investigate the frequency distribution of the assessed grades per level and side of the body.

**Methods**

SDR was performed on 146 children, and a total of 7017 rootlets were tested using IOM. For every rootlet of a nerve root, a 50Hz response was graded according to defined criteria of Phillips&Park, ranging from Grade0 (no abnormalities) to 4+ (highly abnormal). The respective frequency of the Grades was analyzed in a retrospective evaluation, with prior permission from the local ethics committee. Statistics: Non-parametric analysis of variance (ANOVA) with repeated measurements.

**Results**

Within the current total sample, 1327 rootlets showed Grades3+4 responses, 2855 Grade1+2, and 2835 Grade0. These grades were not distributed homogeneously over the levels L2-S1; instead, significant differences ($p<0.001$) were observed. Side played no role in the distribution of hyperactive responses of Grades3+4, and only minimal differences of no statistical significance ($p=0.067$) were observed. However, significant lateral bias ($p<0.001$) reappeared in the patients with higher Grade3+4 prevalence.

**Conclusion**

Far from being homogeneous, the distribution of Grades was found to vary widely from level to level. In view of this, IOM should remain an integral part of this microsurgical intervention. A significant side difference was only observed in connection with high Grade3+4. Thus we can expect left-biased asymmetry to occur primarily in children with conspicuous hyperactivity.

## 14 - How precise is Virtuality? – Pre- and postoperative Fiber Tracking evaluated by Subcortical Mapping and iMRI.

*Marie-Therese Forster[1], Timo Münnich[1], Anika Noack[1], Volker Seifert[1], Jan, Klein[2], Christian Senft[1]*

**1 Department of Neurosurgery, Goethe University, Schleusenweg 2-16, 60528 Frankfurt am Main, Germany**

**2 Fraunhofer MEVIS, Institute for Medical Image Computing, Universitaetsallee 29, 28359 Bremen, Germany**

### Introduction

Fiber tracking is a popular tool for visualizing the corticospinal tract. However, results may be influenced by the selection of regions of interests (ROI), the chosen tracking algorithm and the presence of peritumoral edema. Moreover, intraoperative brain shift may lead to inaccurate results. To overcome these limitations, functional MRI (fMRI) and navigated transcranial magnetic stimulation (nTMS) data were combined with deterministic and probabilistic fiber tracking, whereas brain shift was limited by the use of intraoperative MRI (iMRI).

### Methods

Eleven patients (age 55.2 ± 17.9 years, four women) suffering from perirolandic lesions underwent iMRI-guided surgery. Pre- and postoperatively, patients underwent diffusion tensor magnetic resonance imaging (DTI), and fMRI and nTMS were performed for motor cortex definition, serving as regions of interest for fiber tracking. Data from intraoperative subcortical mapping were related to their distances of these tracks.

### Results

Correlating stimulation intensities with distances to fiber tracts, significant differences were found for applied algorithms (probabilistic vs. deterministic), methods (nTMS vs. fMRI vs. motor cortex segmentation), somatotopy (arm vs. leg fibers) and the time of tractography (pre- vs. postoperatively). However, due to high inter-individual differences, no significant superiority of a single subgroup parameter over another was found.

### Conclusion

Fiber tracking results using different parameters and algorithms may differ significantly. Therefore, cortical and subcortical mapping is indispensable.

## 15 - How Reliable are To-date Transcranial Constant Voltage stimulators? In-vivo and In-vitro Observations of the Medtronic-Eclipse fast-charge Transcranial Stimulator.

*H. L. Journée, A. Stadhouder*

### Introduction

Transcranial electrical stimulation (TES) for motor function monitoring originally started with stand alone constant voltage stimulators (CVS). The accuracy of stimulus parameters addresses issues on quality and safety. CVS became later integrated in commercial equipment. However, important characteristics are poorly specified. Objective of the study is to determine the accuracy of TES-pulse parameters in-vivo and in-vitro with a representative example of to-date's equipment.

### Methods

CVS output voltage and current measurements over a shunt resistor by a battery powered digital oscilloscope were performed along with the set-up procedure for optimizing TES in-vivo in 3 patients undergoing scoliosis correction and in-vitro with equivalent load resistors. The CVS was part of the NIM-Eclipse® E4 NS, Medtronic ,Florida. The data were obtained from MEP-amplitude functions of independent variables: voltage, #pulses/train, interpulse interval (ipi) and intertrain interval (iti). Pulse width:0.075ms. The load resistance added another independent variable. The accuracy was determined of pulse shapes, width and timing parameters, delivered voltages and currents read from the oscilloscope and monitoring device.

### Results

In-vitro measurements agreed reasonable with in-vivo. Repeated measurements were reproducible within 3%. Pulse-timing parameters were accurate within 2%. Mono- or biphasic voltage and current pulse showed -sometimes slightly distorted (ringing effects)- rectangular shapes. Current readings showed changes of maximal: +40% from ipi=1 to 10ms; -30% from 1 to 8 pulses/train Output voltage drop: 11-34% at load impedances of 241-783 Ohm (range of TES electrode types). The estimated internal impedances of 100-220 Ohm increased stepwise by 70-110 Ohm at a voltage setting transition from 190 to 200V.

### Conclusion

The high reproducibility of stimulation parameters is important for the quality of monitoring. However, the relative high internal impedance, sensitivity to TES electrode impedances and stimulation parameters degrade the characteristics of a CVS and preclude accurate quantification of TES-parameters based descriptives like motor threshold voltage.

### 16 - Intraoperative Neurophysiological Monitoring Guided Surgery for Spinal Cord Ependymomas: Results from a Consecutive Series of 77 Cases.

*B. Skrap, V. Tramontano, C. Arcaro, F. Basaldella, G. Squintani, G. Pinna, M. Meglio, F. Sala*

**Introduction**:

Surgery for intramedullary spinal cord tumors (ISCT) has remarkably evolved following the advent of intraoperative neurophysiological monitoring (IONM). The published series in the literature often span across a very large time frame, lacking homogeneity in terms of IONM use and techniques. We present a consecutive series of intramedullary ependymomas treated over a 12-year period (2002-2014) all under the guidance of IONM.

**Material and Methods**

We operated on 77 patients (40 males, 37 females) with a mean age of 42 years. Transcranial muscle motor evoked potentials (mMEPs) were elicited using a short train of 5-7 stimuli, 4.1 ISI, 0.5 ms duration and intensity up to 220 mA. Bilateral upper and lower extremity muscles were monitored. In addition spinal MEPs (D-wave) monitoring (single stimulus, 0.5 msec duration, intensity up to 220 mA) caudal to the lesion was attempted for all tumors rostral to the T10-T11 spinal levels. Neurological outcome was assessed two weeks post-op, and at the follow-up using the McCormick Grade (MCG)

**Results**

Table 1 summarizes the MCG pre- and post-operatively. We achieved total removal in 90% of the cases.. Overall, 70% of patients were unchanged or improved with respect to their preoperative status. D-wave was monitorable in 71% of patients and its preservation (>50% baseline amplitude) warranted good long-term motor outcome in all except two cases who had post-operative complications.

**Conclusions**

In the era of IONM, surgery for intramedullary spinal cord ependymomas, guided by a stop-and-go strategy, allows total removal of the tumor in over 90% of the cases and good functional outcome, although long-term neurological impairment is not negligible. The predictive value of D-wave for long term motor outcome is confirmed in this homogeneous series. An ongoing limit remains the lack of standard criteria for the analysis of the correlation between intraoperative IONM data and post-operative outcome.

## Day 3 - Saturday, November 14

Free Papers Session V MEPs / 10h30 - 11h30

### 17 – Comparison of Intraoperative Neurophysiological Findings between Piezosurgery and Rotating Drills in Acoustic Neuroma Surgery

*Johannes Herta, Sebastian Schubert, Stefan Reitbauer, Matthias Millesi, Georg Widhalm, Christian Matula, Engelbert Knosp, Klaus Novak*

**Introduction**

Internal auditory canal (IAC) opening plays a key role during acoustic neuroma (AN) surgery. Due to heat and mechanical impact during posterior wall opening of the IAC by rotating drills, nerve tissue is considered at risk. Piezosurgery might be a safe solution during this crucial surgical step. This study evaluates piezosurgery against rotating drills by neurophysiological assessment of facial and acoustic nerve function.

**Methods**

60 patients with acoustic neuroma were operated by two experienced neurosurgeons and divided in two groups. In group-one (29 patients) piezosurgery was applied while in group-two (31 patients) a standard rotating drill was used to open the posterior wall of the IAC. Intraoperative neurophysiological monitoring starting and closing baselines for auditory evoked potentials (AEP) as well as facial nerve motor evoked potentials (MEP) were carried out before and after opening of the IAC. Therefore preservation of AEP and facial nerve MEP could be compared between the two techniques.

**Results**

There were no significant differences between both groups regarding age, sex and tumor grading. After IAC exposure AEP were recordable in 20 patients in group-one compared to 14 patients in group-two ($p=0.06$). Before drilling at least one branch of the facial nerve could be monitored in 27 patients of group-one compared to 28 patients in group-two ($p=0.523$). After opening of the IAC no change in facial MEP between both groups were recorded. AEP were never lost during the opening process. Postoperatively, both groups showed an equal distribution in extent of resection, newly developed symptoms and complications.

**Conclusion**

Safety of piezosurgery was compared with rotating drills in acoustic neuroma surgery. Functional integrity of the facial nerve as well as auditory function was assessed by comparing MEP and AEP before and after opening of the IAC. No difference was found between the two techniques.

*Conflict of Interest Disclosure:* Research was not funded or receiving any research grants. All authors are working for the General Hospital of Vienna or studying at the Medical University of Vienna and have no financial interest in promoting piezosurgery.

## 18 - Intraoperative Monopolar Cortical/Subcortical Motor Mapping: the Impact of the Return Electrode Position.

*D. Kefalas, M. Sabel, M. Rapp, A. Szelényi*
**Department of Neurosurgery, Heinrich-Heine-University, Düsseldorf, Germany**

### Introduction

Cortical mapping is performed by monopolar stimulation to localize the motor cortex, while motor threshold (MT) of subcortical stimulation provides information about the proximity to the motor tracts. Commonly Fpz is used as "return" (anode/cathode), but its position is not standardized. This study investigates whether the position of the return-electrode does have an impact on the MT.

### Methods

In 33 patients (55.7±12.4 y.o., 10 females) epidural (EpS) and/or cortical (CS), subcortical (SbS) stimulation was performed before/after (CSb/CSa) brain tumor resection. Stimulation was performed with a train-of-five pulses (max. 30 mA; pulse width 0.5 ms; interpulse interval 4 ms; intertrain interval 2 s). The lowest MTs of representative contralateral hemibody muscles were determined. MTs were measured for six different positions of the return: Fpz, Cz, Oz, T3, T4 and ipsilateral gluteus muscle (iGm). The MTs for each return's position were compared to Fpz. The stimulation site to return's position distance (SRD) was measured via the neuronavigation system or estimated by the MRI images in 31 patients.

### Results

The mean values of the MTs for each return position are shown in the table. In all cases there was no significant difference ($p>0.1$, paired t-test) of the MTs. There was significant difference ($p<0.05$, paired t-test) between SRD for Fpz and Cz.

The maximum individual MT differences ranged between 0-9 mA. Differences of more than 3 mA were mainly observed in MTs higher than 10 mA. In some patients (9%-40%) responses from different or multiple muscles were observed.

| Stim. Site | Number of Patients | MT(mA) Fz mean ±SD | MT(mA) Oz mean ±SD | MT(mA) Ti * mean ±SD | MT(mA) Tc * mean ±SD | MT(mA) Cz mean ±SD | MT(mA) iGm mean ±SD | min/max MT (mA) | Individual MT difference range (mA) |
|---|---|---|---|---|---|---|---|---|---|
| EpS | 10 | 17.5±4.1 | 16.6±3.1 | 17.7±3.6 | 16.4±4.1 | 16.9±3.5 | 16.7±3.7 | 11-25 | 1-9 |
| CSb | 18 | 13.6±5.5 | 13.6±5.4 | 14.2±6.1 | 13.1±5.2 | 13.2±5.2 | 13.2±5.1 | 4-23 | 0-8 |
| SbS | 27 | 8.0±5.6 | 7.6±5.2 | 8.0±5.6 | 7.9±5.1 | 7.9±5.2 | 7.9±5.3 | 1-23 | 0-6 |
| CSa | 23 | 14.0±6.1 | 14.3±6.1 | 14.3±6.0 | 12.8±5.0 | 13.1±5.4 | 14.5±6.2 | 3-30 | 0-8 |

* Ti, Tc ipsilateral/contralateral temporal electrode (T3 or T4)

### Conclusions

No significant effect of the return position on the MTs was revealed. However, in high stimulation intensities, remarkable MT differences were observed. The MT did not appear to be associated with the SRD. In most patients one muscle only was activated stimulating with the lowest MT.

## 19 - Epidural monopolar stimulation for localization of cortical motor areas - a useful tool for tailored dura opening?

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### Introduction

Epidural stimulation (EDS) for tailored dura opening was introduced to minimize unnecessary exposure of primary cortical motor areas. EDS requires higher stimulation intensities to elicit motor evoked potentials (MEP), which might facilitate current spreading resulting in spatial inaccuracy. EDS and direct cortical stimulation (DCS) were compared for spatial distribution of motor responses and their respective motor thresholds.

### Methods

22 patients (60±10.5 years; 15male) with subject to craniotomy exposing the motor cortex were studied. A bone-cement template of the craniotomy's size with grid-like burr holes was made for point-to-point EDS and DCS. Anodal train-of-5 stimulation was performed with a monopolar probe (maximum 30mA). Motor threshold was established for each point. MEPs were recorded from contralateral representative muscles.

### Results

DCS elicited MEPs in 164/299 stimulation points (55%) and EDS in 163/194 stimulation points (99%). EDS was not successful (false negatives) in 21/164 DCS positive stimulation points (13%). In 11/21 of those false negative stimulation points (52%), EDS elicited MEPs in the close neighborhood (i.e. maximum distance of 2cm or two point distances). On the other hand, in 20/135 DCS negative stimulation points (15%) EDS elicited MEPs (false positives). The results yield a sensitivity of 0.87 and specificity of 0.85. EDS elicited MEPs with an intensity of 15.5±5mA and DCS with 14±6.4mA. In case of not successful EDS, DCS required an increased stimulation intensity of 21.8±6mA.

### Discussion

In the majority of the stimulation points, EDS allowed for point-to-point epidural location of motor cortex and thus is useful for tailored dura opening. False negative results were related to higher DCS intensities compared to congruent EDS-DCS-points. This can be explained by the limited maximum stimulation intensity and unpredictable current spreading towards areas of lower resistance.

## 20 - Scalp-recorded Somatosensory Evoked Potentials in Swine are Reliable for Studying Cerebral Ischemic Injury and Recovery Following Cardiac Arrest

*Joshua Mergos[1, 2], Nicole L. Werner[3], Nick Chulski[1], Christy Villa[1], William Stacey[1, 4], Alvaro Rojas[5], Robert W. Neumar[5]*

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### Introduction

Swine have been employed as a model for studying cardiac arrest and resuscitation. Additionally, various neurophysiological techniques have been tested on swine to study traumatic brain and spinal cord injury. Here, we use somatosensory evoked potentials (SSEPs) to develop a swine model for monitoring neurologic function following cardiac arrest.

### Methods

SSEPs were recorded from 15 Yorkshire pigs following supramaximal stimulation of the right forelimb using standard stimulation parameters. Subdermal needle electrodes were placed for stimulation and recording at the distal forelimb and brachial plexus, respectively. Corkscrew electrodes were placed on the scalp and behind the neck to record cortical and subcortical potentials. Inhalational anesthetics were discontinued after induction and total intravenous anesthesia was used to obtain optimal SSEP recordings. Cardiac arrest (CA) was induced at least once in each pig, with a second CA induced if return of spontaneous circulation (ROSC) was achieved and accompanied by a return of the cortical signal to >50% of baseline.

### Results

Cortical and subcortical SSEPs were successfully recorded in 15/15 pigs. The cortical response had an average latency and amplitude of 19.94 ± 1.28msec and 1.35 ± 0.56uV, respectively, and was recorded from the lateral aspect of the skull contralateral to the site of stimulation as either a negativity (11/15) or a positivity (4/15). The cortical response was completely lost within three minutes of CA though subcortical and peripheral responses varied in rate and degree of loss. ROSC was achieved in 6/18 studies. Cortical responses returned to at least 39% of baseline amplitude following ROSC though the rate and degree of return varied.

### Conclusion

SSEPs appear to be a reliable biomarker of neurological function in this swine model of CA. This study demonstrates the utility of SSEPs in swine as a reliable model for studying neurological damage and recovery following CA.

# Poster Presentations

## Day 1 - Thursday, November 12

### 1 - Intraoperative Triggered and Free Running EMG for Percutaneous Pedicle Screw Placement: An Unreliable Adjunct to Fluoroscopy

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**Introduction**
Fluoroscopy is considered the golden standard for accurate pedicle screw placement,6 but intraoperative monitoring is commonly employed to with the intention of improving patient safety. We investigated the quantitative predictive value of intraoperative monitoring in patients undergoing percutaneous pedicle screw placement.

**Methods**
Patient Selection and Characteristics:
A retrospective analysis was performed of 24 consecutive patients undergoing minimally invasive thoracolumbar fusion surgery with percutaneous pedicle screws. Intraoperative monitoring in conjunction with fluoroscopy was utilized during percutaneous pedicle screws placement.

Neuromonitoring technique
Intraoperative monitoring consisted of free running EMG and triggered EMG using an electrified Jamshidi needle. All patients were placed under general anesthesia, and no long-acting neuromuscular blocking medications were used.

A threshold of 8mA was selected for malposition detection. Values below 8mA were interpreted to suggest medial breech and were considered 'abnormal' EMG findings.

**Results**
A total of 129 screws were placed in 24 patients under fluoroscopic guidance and IOM. The EMG values were normal in 33% (8/24) patients during pedicle cannulation and screw insertion. 1 patient from this group developed a drop foot that corresponded with a medial wall breach of the L5 pedicle on CT imaging. The remaining 67% (16/24) patients exhibited abnormal triggered EMG values in at least one or more pedicles. Only 1 patient in this group developed iatrogenic sequela. The final malposition rate was 1.6% per pedicle screw, with a calculated sensitivity of 57.3% and a specificity of 25.0% per pedicle screw.

**Conclusion**
Triggered EMG values are not usefully sensitive or specific to medial wall breech, and may result in unnecessary trajectory adjustments. Unless and until steps are taken to refine an intraoperative monitoring technique with adequate sensitivity and specificity, intraoperative fluoroscopy will remain the gold standard for confirming percutaneous pedicle screw placement.

## 2 - Intraoperative neurophysiological monitoring to prevent new neurological deficits in spinal deformity surgery

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**[1] Department of Neurology, Acibadem University School of Medicine, Istanbul, Turkey [2] Department of Orthopaedics and Traumatology, Acibadem University School of Medicine, Istanbul, Turkey**

**Introduction**
Intraoperative neuromonitoring is commonly used during surgery for scoliosis and spinal deformity. The aim of this study is to early detect iatrogenic insults to the central and peripheral nervous systems early in procedures involving decompression and instrumentation of the cervical, thoracic and lumbosacral spine. Pedicle screws improve deformity correction but may cause injury to the spinal cord, nerve roots and vascular structures.

**Methods**
A total of 52 – 17 male and, 35 female – patients in our center, ; between the ages of 1 and 79 (mean 24,2 ) were operated on diagnoses of different types of spinal deformity, scoliosis (n: 42), kyphosis (n:6), post-traumatic deformity (n:4) and spondilolysthesis (n:2) were evaluated. All of our cases were monitored with somatosensory evoked potentials (SEP), muscular motor evoked potentials (MEP), and free run electromiyography. In 35 cases 656 pedicle screws were stimulated with a monopolar ball tipped probe. Thoracal screws below T5 level were stimulated. A constant current stimulus of 200 microseconds was delivered to record treshold stimulus. Pulse-train stimulation was delivered in one case to check medial wall malpositioning.

**Results**
Temporary MEP loss of the four limbs was seen in 4; temporary MEP plus SEP loss was seen in 2 cases, but restored after blood transfusion and blood pressure elevation. Permanent MEP loss of one lower extremity was seen in one case during halo femoral traction, who not worsened in her neurological function after surgery. Pedicle screws with a stimulation treshold of 10 mA were inspected under scopy and with a pedicle feeler probe. An inferior breach of the pedicle wall was found in 8 (1,21%) screws, with a stimulation treshold below 6 mA. A medial wall breach was detected in 3 (0,45%) screws with pulse train stimulation. Five (0,76%) screws were taken out and three of them replaced with a hook. Six (0,91%) screws were repositioned. All of our cases postoperatively showed normal neurological functions.

**Conclusions**
We concluded that at a stimulation treshold of 6 mA and above, a positive EMG response was associated with no inferior wall breach. High frequency pulse stimulation trains may help to detect medial wall breaches and should be administered more often. Additional prospective study of these recordings is recommended to specify the relationship of electrophysiolgical findings to clinical outcome.

## 3 - Asymptomatic internal carotid artery stenosis in cardiothoracic surgery – intraoperative cerebral perfusion monitoring.

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**Background**

Prophylactic carotid endarterectomy (CEA) of asymptomatic internal carotid artery (ICA)stenosis in cardiothotacic surgery has no clear benefit in reduction of perioperative ischaemic stroke. Median somatosensory evoked potentials (SEP) amplitude is good marker of cerebral perfusion.

**Goal of the study**

Set reliability and effectiveness of median SEP in prevention of perioperative ischaemic stroke.

**Material a Methods**

40 patients, 31 males (77.5%), mean age 71.3 ± 6.85 years (56-84) underwent cardiothoracic procedure on-pump and intraoperative SEP, BAEP and near infrared spectroscopy (NIRS) monitoring in the period: January 2013 - April 2015.
Inclusion criteria: asymptomatic ICA stenosis ≥ 50%, at least 6 months.
Significant changes: amplitude decrease by > 50% in SEP (N20/P25) and/or in BAEP (V-wave); $rSO_2$ decrease by 20% and/or < 40 in NIRS.

**Results**

Unilateral ICA stenosis in 19 (47.5%), bilateral 16 (40.0%), occlusion and stenosis 5 (12.5%).
Procedures: Myocardial revascularization 35 (87.5%), aortal and mitral valve replacement 15 (37.5%), 7 (17.5%) respecively.
SEP amplitude decreased in 9 (22.5%), unilateral in 8, (7 ipsilateral to higher ICA stenosis).
No changes in BAEPs.
rSO2 decreased in 5 (12.5%), always bilateral (1 without SEP changes).
Effective management: combination of hypercapnia, blood pressure (BP) and extracorporeal calculated blood flow increase 7; additional red blood cell 1; only BP increase 1.
SEP recovered fully (to ≥ 50% baseline) in 5 (55.6%), partial in 4 (44.4%).
Clinical outcome: Temporary deficit developed in 2 (5.0%). Both resolved within 3 days.
Mortality: 7 day: 3 (7.5%) (ileus 1, circulatory failure 1, SIRS 1); 30 day: 5 (12.5%).

**Conclusion**

SEP amplitude decreased in 22% of procedures. BP increase seems to be important in cerebral blood flow preservation. Significant changes corresponding to cerebral hypoperfusion appeared in SEPs more often than in NIRS. No permanent neurological deficit developed. No false negatives in SEPs were recorded.

## 4 - Difference in muscle MEP and clinical outcome between cervical and thoracic OPLL surgery

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**Department of Neurology, Seoul National University Bundang Hospital**

**Introduction**
The risk of neurological complications during surgery for thoracic ossification of posterior longitudinal ligament(OPLL) is known to high. Information on change of muscle motor evoked potential(mMEP) between cervical and thoracic OPLL surgery is lacking. Thus, we exploited mMEP in abductor hallucses(AH) muscle and post-operation motor deficit, and evaluated the predictive value of mMEP in individual leg muscles for OPLL surgery monitoring.

**Method**
A retrospective study of 111 patients who underwent cervical or thoracic spine OPLL surgery between 2000 and 2014 with intraoperative mMEP monitoring in the bilateral AH muscles. mMEP in the AH muscle that reflect corticospinal tract divided right and left, respectively. So, data were obtained 216 limbs excluded no potential of mMEP in the AH muscle from the onset. Lowest mMEP at during surgery and surgery terminal mMEP compared to baseline, its relationship with postoperative motor deficit, and sensitivity and specificity were analyzed.

**Result**
The post-op motor deficit/mMEP change were more frequent in the thoracic spine(8.3%/20.8%) than cervical spine(2.6%/7.3%). In area under the receiver operating characteristic curve(AUC-ROC) of cervical and thoracic OPLL were higher in lowest mMEP at during surgery(0.948) than in terminal mMEP(0.907). At cervical spine, AUC were over 0.90 in lowest mMEP during surgery and terminal. At thoracic spine, the AUC were 0.864 in terminal while no significant in during surgery mMEP(0.716, p=0.14). The cut-off value were higher in thoracic spine(35%) than cervical spine(11%). In mMEP at terminal surgery, sensitivity was 100% in cervical and thoracic spine. However, specificity was higher in cervical spine than thoracic spine.

**Conclusion**
This study showed thoracic OPLL surgery is more vulnerable to motor deficit than cervical spine. Therefore, in thoracic OPLL surgery, we suggest that alarm criteria setting would be 60% decrement.

## 5 - IONM Research, Historical Review, Current Status and Future Perspective

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**[1] Clinical Neurophysiology Department, King Abdullah Medical City, Makkah, Saudi Arabia [2] Intraoperative Neuro Monitoring Department, Rush University Medical Center, Chicago, USA**

**Introduction**

IONM has been frequently attacked for having weak evidence to support its capacity in preventing neural morbidity during surgery. This seriously hinders it from being a standard of care in a wide range of surgical procedures. Even, in surgeries like scoliosis correction & spinal tumors resection where IONM has a more powerful evidence, better monitoring techniques with faster response to injury and more sensitive and objective monitoring parameters are required. Improving evidence by looking at outcomes, methodologies, and guidelines will help reaching IONM's potential as a proactive and predict tool in detecting iatrogenic injuries to prevent neural morbidity.

**Methods**

PubMed based research study using query that included all possible key words related to IONM and looked backward with no time limit.

**Results**

Analysis of the resulting 9449 titles starting from early 1960s proved the diversity in which the IONM literature is. Authors were a mix of at least 8 medical specialties with surgeons taking the lead followed by neurologists and anesthesiologists. These titles distributed among more than 500 journals worldwide with “spine” journal coming on top of the list follow by neurosurgery and anesthesia journals. Most of these publications were in English but German, Japanese and at least another 10 languages contributed to the IONM literature. This study also revealed that 16.3% of the publications were case reports and 12.9% were reviews that left only two thirds of total number to clinical research that had relatively few numbers of randomized controlled trials and evidence based guidelines.

**Conclusion**

Understanding the type and quality of IONM literature can provide a better handle on where gaps are and where we should focus our energies. It should be noted that each geographic location may need different data for there governments and insurance suppliers, but the field needs to make sure that it focuses on quality and outcome.

## 6 - Clinical Utility and Yield of Pharmacologic Provocative Testing During "High" and "Low" Risk Spinal Endovascular Procedures

*Joshua Mergos[1, 3], Vikas Singh[1], Daniela Minecan[1], Aditya S. Pandey[2]*

**[1]Department of Neurology, University of Michigan, Ann Arbor [2]Department of Neurosurgery, University of Michigan, Ann Arbor [3]School of Kinesiology, University of Michigan, Ann Arbor**

### Introduction

Neuroendovascular embolization is increasingly performed for the treatment of arteriovenous malformations or fistulae (AVM / AVF) of the spinal cord as well as to treat hyper-vascular metastatic lesions to the spine.

Pharmacological provocative testing (PPT) using continuous intraoperative neurophysiological monitoring (IONM) in patients under general anesthesia for the treatment of spinal AVM/AVF has been reported in the literature, but has not included its application to other conditions in the spine.

### Methods

We conducted a retrospective chart review of all patients who had IONM-based PPT performed during therapeutic spinal embolization for AVM/AVF, or pre-surgical or palliative embolization of spinal vessels of hyper-vascular lesions from December 2009 to May 2014.

All procedures were performed under general anesthesia with transcranial electric motor evoked potentials (Tce-MEPs) and somatosensory evoked potentials (SSEPs). PPT was performed using injection of Brevital and Lidocaine in a sequential manner through a micro-catheter super-selectively placed in the feeding vessel.

Standard SSEP thresholds were used (>50% amplitude decrease or >10% increase in latency) to consider a PPT as positive. Tce-MEP changes were considered positive if compound muscle action potential amplitudes in any significant limb (below the site of embolization) decreased by more than 50%. Embolization was altered or foregone in the case of positive PT.

### Results

57 procedures utilizing pharmacological PT were performed on 32 patients. Eighteen procedures were performed on patients as a pre-operative measure for surgical resection of metastatic spinal lesions, fifteen for AVF/AVM embolization, and four were performed for embolization as palliative treatment. There were six positive PPT results which resulted in modification of surgical maneuvers. No new focal neurological deficits were reported on postoperative neurological examination and immediate follow-up clinic visit.

### Conclusion

IONM-based PPT may prevent long term morbidity in patients with a variety of spinal vascular lesions not limited to AVM/AVF.

## 7 - Recording of motor cranial nerves during brain stem or cerebello pontine angle surgeries focusing on facial nerve latencies and long latencies components found during these recordings.

*Kosac, Sergio*

### Introduction

The intraoperative control of the cortico bulbar pathway during cerebello pontine angle or brainstem surgeries has gained dramatic relevance over the last decade. This is due to two facts: the improvement of new surgical techniques and, on the other hand, the generalized improvement of monitoring methods and techniques. This methodology improves morbility for cranial nerves injuries, and also, prevents global brainstem injuries, controlling brainstem functions.

The main goal of these techniques is to reduce potential facial nerves injuries, and other nerves in potential risk of being injured, to the minimum.

In this paper two main results of these procedures are highlighted:

1. Recording of cranial nerves responses to cortical stimulation, especially of the facial nerve, showing mean and standard deviation.
2. Replicated long latencies components, mainly in the lower cranial nerves, were identified during these procedures.

### Methods

In this work, recording of 20 IOM data during , mainly , cerebellar pontine angle surgeries, and, during some of intrinsic brainstem lesion surgeries.

Cranial nerves Vth, VIIth, IXth, and XIth, were recorded, with needle electrodes.

The masseter muscle was recorded for the Vth cranial nerve, the orbicular oris muscle for the VIIth, and the cricothyroid juncture was recorded for the Xth , and finally the trapezius muscle for the XIth as well, which allows to record the spinal cord component.

The corticospinal pathway was recorded by the abductor pollicis muscle in the homolateral side to the recorded side.

Stimulation electrodes were placed according to the international 10-20 measuring system with this montage: Cz, C3-4 montage , depending on which side the pathology was located, being C3 or C4 contralateral to the recorded side. Except in some cases when the pathology was intrinsic and medial in the brainstem. In these cases montage was C3-4.

Stimulation: Trains of stimuli between 3 and 4 pulses, with an ISI of 1 or 1.3 ms were applied, with a duration of 50 microsec.

The intensity applied was variable, depending on which maneuver was made at a determinate time, (i.e.: during the dura opening, intensity was taken as basal, and during tumor resection, intensity usually had to be raised significantly), ranging from 150 V to 350 or even 400 V.

Analysis time was 50 ms, and, in some surgeries, it was extended to 80 or 100 ms.

This variation permitted to identify some long latencies recordings for lower cranial nerves.

Correlation was made between preservation or deterioration of cranial nerves recordings and outcome, immediately after surgery and one week later.

### Comments

Long latenciy components were identified in few recordings in lower cranial nerves, and could be interesting complementary data to evaluate in future works. These recordings could be compared with the F wave, as a proposal. The facial nerves latencies measurements performed in this work intend to be a modest contribution to establish universal patterns for these specific measurements. Also, corticobulbar recordings via TcMEP demonstrated to be an essential tool for this way of monitoring.

## 8 - Anterolateral S1 Screw Malpositioning Detected with Intraoperative Neurophysiological Monitoring during Posterior Lumbosacral Fusion Surgery

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**Department of Neurosurgery, Hospital Clínico Regional de Concepción, Concepción, Chile.**

### Introduction

Intraoperative neurophysiological monitoring (IOM) is standard of care during posterior lumbosacral fusion surgery. IOM is an excellent tool to rule out screw misplacement into foramen or spinal canal. Foraminal misplacement can be easily detectable with screws stimulation recording from lower limbs muscles, and spinal canal adding anal sphincter monitoring. However, anterior or lateral S1 screw malpositioning could not be detected by IOM.

### Objective

Demonstrate usefulness of IOM detecting anterolateral S1 screw malpositioning during posterior lumbosacral fusion.

### Material and Methods

Prospective collected and retrospectively reviewed study since January 2013 to August 2015. During posterior lumbosacral fusion surgeries, screw stimulation were performed using warning threshold <12 mA, recording from lower limbs muscles with anal sphincter. TcMEP and SSEP were assessed, and computed tomography (CT) scan was done first day postoperatively.

### Results

In 54 patients, 106 S1 screws were placed (52 bilateral and 2 unilateral). In 6 patients (11.1%), 7 screws (6.6%) were advertised for low threshold obtained. In 1 patient, postoperative CT scan shows external malpositioning without any IOM warning criteria. During S1 misplaced screws stimulation, the most sensitive muscle was anterior tibialis. TcMEP and SSEP did not change during all these surgeries and no patient developed a new neurological deficit. Sensitivity of this method 87.5%, Specificity 97.9%, Positive predictive value 77.8%, and Negative predictive value 98.9%.

### Conclusion

Anterolateral S1 screw malpositioning can be detected with IOM stimulating screws, and could be corrected turning back the screw or changing trayectory more medial, in order to avoid contact with extravertebral neural tissue.

## 9 - Our preliminary monitoring results in the spinal surgery

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### Introduction

İntraoperative neurophysiologic monitoring (IONM) is monitoring of functional compositions of critical neural structures during the operation by the electrophsiological methods. Multimodality is a combination of different neurophysiological methods to maximize diagnostic efficacy and provide a safety margin for improved spinal surgery outcomes.
Our aim is to share our preliminary experiences about neurophsysiologic methods and monitoring practiced in the operated spinal cord surgery cases with high risk between 2013 September and 2015 January.

### Methods

Twenty six cases were included. Lesion localizations of the patients, surgery and electrophysiological findings intraoperatively and neurologic findings postoperatively were documanted.

### Results

The combination of motor evoked potential (MEP), somatosensorial evoked potential (SSEP), free-run and trigger electromyography (EMG) according to lesion localization were performed. MEP and SSEP in 22 patients, MEP with triggered EMG technic were recorded in 3 patients. Optimum recordings were not be able to obtaine because of technical problems in only one patient. MEP changes in the 12 patients and SSEP changes in the 3 patients were recorded. Postoperatively neurological deficiency were seen in 2 patients. These were transient in one and permanent in the other. It was pointed out that electrophysiologically MEP responses increased or MEP which was not obtained before, appeared at the end of the spinal tumour resections. The surgery was ended in one patient with C7-T2 intramedullary tumour after right distal MEP response disappeared.

### Conclusion

Multimodal IONM is the more important technic for especially intramedullary spinal cord lesion surgery. It provides effectively safety margin for these surgeries.
Key Words: spinal cord surgery, evoked potentials, multimodalite, intraoperative monitoring

## 10 - Utilization Neurophysiological Characteristics of Pyramidal Signs for Spinal Cord Function Monitoring when Transcranial MEPs Cannot Be Elicited. A case report.

*H.L.Journée, H.I.Berends[1] A.Stadhouder[1]*

**Departments of [1]Orthopedics, VUMC Amsterdam and [2]Neurosurgery UMCG Groningen; the Netherlands**

### Introduction

A compromised spinal cord or supraspinal lesions may result in pyramidal signs related to hyperactive spinal circuits. Muscular potentials (MEP) evoked by transcranial electrical stimulation (TES) may be severely attenuated or absent. In contrast, spinal circuits may be highly sensitivity to peripheral inputs resulting in hyperactive reflex activity spreading out widely over many root levels even reaching other limbs.

### Objective

To utilize pathological characteristics of the spinal cord for monitoring of the motor and sensory functions alternate to TES-MEP shown in a case report.

### Methods

10y male CP patient, referred for scoliosis correction over Th3-S1 levels under traction, mental age: 4 months, SMA-2, anxiety, progressive epileptic seizures, spastic quadriparesis treated by baclofen and dystonia. Symptoms developed after hypoxic ischemic lesion at birth. *Clinical examination:* doubtful voluntary lower limb muscle control. Patellar reflexes: widespread clonus above and below the knee, Babinski's sign. *Anesthetics*: propofol, remifentanil, low dose Ketanest, no muscle relaxants.

*IONM modalities*: continuous EMG. TES-MEPs: not elicitable in spite of an extended double train parameter optimizing protocol. Hyperactive spinal circuits were mobilized with bilateral double train stimulation in the popliteal fossa to generate bursts patterns.

### Results

The intertrain interval (iti) at facilitation peaks of popliteal intertrain interval curves of upper limb extensors agreed with the time interval of about 300 ms between subsequent elicited EMG bursts. At this iti, burst patterns were recordable in all muscle groups with various onset times. Their RMS values were monitored throughout the surgical procedure. No events occurred and the clinical condition of the patient remained unchanged after surgery.

### Conclusion

When no transcranial MEPs can be elicited in a compromised spinal cord or at supra spinal lesions, the characteristics of hyperactive spinal circuits with a wide segmental cross-talk may offer an alternative modality for monitoring the spinal cord covering the surgical exposed area.

## 11 - Intraoperative Neuromonitoring During Corrective Spine Surgery Using Traction

*H.I. Berends, A.A. Gouw, A. Stadhouder, H.L. Journée*

### Introduction

During corrective spine surgery, traction is used to improve the overall spinal correction and balance. However, the applied forces may cause stretching of the spinal cord and its vascular supply. We present our experience using traction during spine surgery.

### Methods

26 Idiopathic (n=16) and neuromuscular (NM) scoliosis patients are operated using halofemoral traction. Neurophysiological monitoring was done stimulating biphasically at C3C4 and measuring the motor evoked potentials (MEPs) of the extensor carpi radialis, rectus abdominis, quadriceps femoris, anterior tibial, gastrocnemius and abductor halluces muscles bilaterally. Mean arterial blood pressure (MAP) was maintained above 60mmHg. The neurophysiological events and consecutive actions are described and discussed.

### Preliminary results

6 Patients (n=3 idiopathic scoliosis) showed significant decreased MEP amplitudes in one (n=1) or both (n=5) legs.
In 1 patient, MEPs disappeared 15 minutes after traction, before incision. After removal of the weights, MEP amplitudes instantly recovered to baseline. Possible cause of the event is stretching of the anterior spinal artery and spinal cord.
In 1 patient MEPs disappeared during exposure of the spine, and in 1 patient during facetectomy. The release of muscles and joints might have caused a higher traction on the spinal column, and possibly on the spinal cord and spinal arteries, making the spinal cord more vulnerable to ischemia or mechanical manipulations. All events resolved immediately after removal of the weights.
In 3 patients the MEP amplitudes decreased after release of traction after correcting the spine. Withdrawal of pain, and an autonomous response of the nerve system or vascular system might be related to this decrease. None of the MEPs totally disappeared and all of them recovered to baseline.
There were no clinical consequences.

### Conclusion

The neurophysiological events caused by traction of the spinal cord can occur at any time during surgery, but are easily reversed without clinical consequences.

## 12 - Differences Between Transcranial Stimulation Electrodes for Motor MEP Monitoring In Corrective Spinal Cord Surgery

*H.I. Berends, A. Stadhouder, H.L. Journée*

### Introduction

Different kinds of electrodes are used to induce motor evoked potentials (MEPs) by transcranial electrical stimulation (TES). These electrode types have different sizes, shapes and contact surfaces. In this study we examine differences between voltage motor thresholds (VMT) when using long needles, corkscrews and short needle electrodes.

### Methods

5 Idiopathic scoliosis patients were included. All stimulation electrodes were placed with their centers at C3 and C4 or C3' and C4'. MEPs were measured over the muscle belly of the musculus abductor pollicis brevis (APB) and musculus tibialis anterior (TA) using 2 bipolar Ag/AgCl surface monitoring electrodes (3M®). Impedances were measured and VMT was determined using single train stimulation with interpulse interval of 1.1ms, 5 pulses and 100µs pulse width. Differences of the $VMT_{APB}$ and $VMT_{TA}$ when using different electrodes were analyzed using a MANOVA. $p<0.05$ is considered significant.

### Results

A significant interaction was found between electrode and $VMT_{APB}$ ($p<0.000$) and $VMT_{TA}$ ($p<0.000$). Additionally, a significant interaction was found between electrode and impedance ($p<0.000$).

Post-hoc analysis using an ANOVA showed a significant difference of the $VMT_{APB}$ and $VMT_{TA}$ between large needle electrodes ($VMT_{APB}$: 30±6.6 $VMT_{TA}$: 46±5.0) and both corkscrews ($VMT_{APB}$: 69±14 $VMT_{TA}$: 87±18) and small needle electrodes ($VMT_{APB}$: 69±15 $VMT_{TA}$: 92±13).

Impedances of large needles (245±19) are significantly lower compared to corkscrews (423±36) and small needles (477±70) ($p<0.000$). Impedances of corkscrews are significantly lower compared to small needles ($p=0.023$). A significant correlation is found between impedance and $VMT_{APB}$ ($p<0.000$, $r=0.811$), and impedance and $VMT_{TA}$ ($p<0.000$, $r=0.88$).

### Conclusion

The type of electrode, and its impedance influences the VMT of transcranial electrical stimulation. A large needle electrode and a low impedance are related to a low VMT.

## 13 - Scoliosis In Numbers; A Comprehensive Data Review Of Over 150 Consecutive Patients With Relevant Intra-operative Neurophysiology Modalities.

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**National Neurosciences Institute(NNI), King Fahad Medical City(KFMC) Riyadh Saudi Arabia**

**Introduction**

Latrogenic paraplegia resulting from surgical intervention of the spine is the most feared and devastating complication. Preventing such complications during scoliosis procedures is extremely important and Intra-operative neurophysiology(IOM) serves to help such patients/surgeons with successful surgeries and better post-op outcome.

**Methods**

At the (NNI),KFMC we aimed to analyze data from 153 such patients who underwent scoliosis correction surgeries using following IOM modalities.
1.SomatosensoryEvokedPotentials(SSEPs)2.TranscranialMotorEvokedPotentials(TcMEPs)3.Electromyograms(EMGs)4.TriggeredElectromyograms(TEMGs). We observed anesthetic effects i.e.,drop in hemoglobin(hb),hematocrit(ht),mean arterial pressure(MAP) and positioning effects. A 4 channel Electroencephalogram(EEG) was monitored to gauge the depth of anesthesia before documenting any change.

**Results**

153 patients (n=104females,n=49males) with mean age of 17 at the time of surgery while the cob-angle ranged between 40-140 degrees. TcMEP changes were noticed in 56 patients, n=56,36.6%.TcMEP change resulting from surgical maneuvers n=43,28.10%. Within this group, TcMEP changes resulted from direct injury to the cord with immediate drop n=16,10.45%.while mechanical intervention,i.e.,decompression/hemivertebrectomy/correction n=15,9.80% and mal-positioned screws n=12,7.83%. Patients within this group, n=9,5.8% presented with both SSEP and TcMEP change. Changes in TcMEP due to anesthesia n=10,6.53%.Positional changes n=5,3.26%. Within this group, TcMEP changes n=3 1.96%;Ssep=2,1.3%.Isolated SSEP ONLY changes in lower limbs n=0.EMG irritation lasting >15 seconds in lumbar roots, n=14,9.15%. Within this group, TcMEPs drop noticed in 4 patients suggesting a 25% predictability. TEMG changes in n=81,52.9% with at least 1 screw <9mA; with n=39,25.4% between 7-9mA.However,n=42,27.4% <6mA. TcMEP change, n=12,7.83% fell under this group with a 35% probability. 3018 screws were placed in 153 patients. On average,19.73 screws/patient. 331.9 screws,10.99% <9mA in moderate category while 89% tested above threshold. Amongst 331.9, 89 screws 2.94% tested in severe category of <6mA. The probability of 2.16 screws tested below threshold/patient was 9%.

**Conclusion**

Our data highlights the need for multimodality monitoring comprehensively. A post-op clinical co-relation with patient follow-up is needed to further evaluate each modality.

## 14 - Tailored Corrective Measures Following Motor Evoked Potential Changes in a Case of Intramedullary Spinal Cord Astrocytoma

*Arcaro C., Tramontano V., Meglio M., Squintani G., Sala F.*

### Introduction

A 24-year old male patient was operated on for a relapsing intramedullary astrocytoma of the conus. On admission, the neurological examination showed right leg hyposthenia (3-/5 MRC scale), right quadriceps hypotrophy, and a right foot dorsiflexion deficit (3/5), with a steppage gait. Proper sphincters contraction.

### Methods

Muscle motor evoked potentials (mMEPs) were recorded following transcranial electrical stimulation through C1/C2 or Cz-/C6cm electrode montage. The muscles recorded were bilateral quadriceps, gastrocnemius, anterior tibial and abductor hallucis. Somatosensory evoked potentials (SSEPs) were recorded following posterior tibial nerve stimulation. The bulbocavernosus reflex (BCR) was recorded from bilateral anal sphincters following stimulation of pudendal nerves. D-wave was unmonitorable due to the low thoracic level. Totally intravenous anesthesia was used.

### Results

At baselines, right side mMEPs were present only with max. stimulation intensity (180-200 mA), versus 150 mA threshold for left side mMEPs. After opening of the dura, while removing the tumor, the right side mMEPs dropped while left side was still present. The train of stimuli was increased to 7 and the Cz-/C6cm montage appeared to be more effective. Corrective measures such as irrigation with warm saline and waiting for MEPs recover were adopted. In spite of all corrective measures, mMEP on the right side were all progressively lost but stimulation intensity was not increased above 220 mA for safety reasons. Left side mMEPs remained stable, as well as the BCR and therefore the decision was taken to continue tumor removal as long as an existing cleavage plain was visible.

Post-operatively the patient presented a partial worsening of the right leg paresis: leg extension 3-/5, foot dorsiflexion 2/5. Left side was undamaged. Within a few weeks post-op. he recovered to the pre-operative status.

### Conclusions

Neuromonitoring based decision-making during spinal cord tumor surgery may be challenging, especially when baseline mMEPs are already compromised and stimulating thresholds elevated. The affected limb can easily become unmonitorable during the early steps of surgery. Even in the lack of D-wave monitoring, contra-lateral mMEP and BCR recording can assist in the attempt to maximize tumor resection and minimize permanent morbidity.

## 15 - TES during lumbar discectomy in a patient using a pacemaker

*Silvia Mazzali-Verst, Andreya Cardoso Cavalcanti, Andrea Sucena Caivano, Ricardo Ferreira Silva, Luis Roberto Mathias Junior, Tatiana Peres Vilasboas Alves, Daniel de Andrade Gripp, Natally Saturnino Santiago, Marcos Vinicius Serra, Marcos Vinicius Calfat Maldaun, Paulo Henrique Pires de Aguiar*

**Introduction**

Since the late 90's, motor evoked potentials have been used in the operating room with multi-pulse 250-500 Hz technique in order to evaluate the descending motor tract. The electrical charge applied is a result of the intensity *versus* the duration of the stimulus and can reach as high as 1000V or 200 mA. Such a high electrical charge can damage a pacemaker, so the use of this technique is usually not indicated for pacemaker patients.

The pacemaker circuit amplifies, filters and identifies the cardiac potentials, correcting bradycardia and tachycardia. External electrical interferences can lead to dysfunction, due to inhibition, assincronic reversion or inappropriate defibrillation. A strong electrical charge could damage its components or over heat the electrode-myocardia junction without possible repair. So electrical bisturi, thermocautery, MRI, radiotherapy, radiofrequency, diathermia, and TES are normally avoided.

Several protection mechanisms have been created in order to avoid continuous current to enter the pacemaker or to short cut high intensity currents before they damage it. Such mechanisms are bipolar electrodes, electronic filtering, spectral detection. Under a skilled specialist the pacemaker program can be modified during a specific procedure to stand a hostile situation.

**Method**

We performed TES in 83 years old woman, going through a L3-L5 lumbar stenosis decompression. We stimulated C3-C4 with a train of 6 pulses, 0,5 ms duration, 4 ms interpulse interval, 300 V. We registered a baseline and stimulated several times during the decompression maneuver. The patient had a bicameral pacemaker due to total AV blockage. Immediate after the positioning of the patient, the cardiologist turned the pacemaker to an assincronic function, stimulating the ventricle with 6,5 V, 1 ms duration and 80 bpm. In an assincronic function the pacemaker is not influenced for an external electrical source, such as we can see in figure 1.

**Results**

There was no interference of the TES on the pacemaker function throughout the entire IOM.

**Conclusion**

In surgeries that require IOM in patients with a pacemaker, TES can be safely performed under proper cardiologist supervision.

# Poster Presentations

## Day 2 - Friday, November 13

### 16 - A Multimodal Approach to Neurophysiological Intraoperative Mapping for Dorsal Root Entry Zone (DREZ) Lesioning for Brachial Plexus Avulsion Injury Pain

*Pridgeon, M. Haworth, B. Manohar, R. Barbarisi, M.  Bryne, T. Farah, J. Eldridge, P.*

**Introduction**

Intractable pain after brachial plexus avulsion injuries is distressing and occurs in 70% of patients with 20% developing chronic medically intractable pain. Response to spinal cord stimulation – especially when the limb is completely anaesthetic is rarely successful for managing the pain. Dorsal root entry zone (DREZ) lesioning has shown long lasting satisfactory pain relief (Sindou et al, 2005, Ellenbogen et al, 2013). However, the success and safety of this method depends on how accurately the DREZ is localised. Difficulties in identifying the DREZ in cases with scarred distorted spinal cords lacking the landmark of the entry of the dorsal roots due to their avulsion led us to develop a neurophysiological technique to identify the DREZ.

**Methods**

A multimodal approach was developed over a total series of 17 patients and used in its final form to localise the DREZ in three patients, and to monitor treatment for any problem with cortico-spinal tracts. The method consisted of spinal cord evoked potentials, spinal cord somatosensory evoked potentials with peripheral nerve stimulation and spinal cord motor evoked potentials. The integrity of spinal cord ascending and descending pathways was monitored during thermo-coagulation lesioning with transcranial motor evoked potentials and somatosensory evoked potentials.

**Results**

Immediately after surgery all patients reported significant pain relief or were pain free. There were no long term complications but there were transient lower limb weakness with a reduction in mobility, and increased ataxia – presumably reflecting dorsal column involvement.

**Conclusion**

A multimodal Neurophysiological approach improves the accuracy of localising the dorsal root entry zone for thermo-coagulation lesioning in the treatment of intractable pain in patients with brachial plexus avulsion injuries. The patients all were pain free though with transient weakness; this continuous monitoring provides the additional security needed to create adequate lesions reflected by these good results.

## 17 - Comparison of Navigated Transcranial Magnetic Stimulation and Functional Magnetic Resonance Imaging for Preoperative Motor Mapping in Cortical Motor Areas Surgery

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**Introduction**

Intraoperative direct cortical stimulation (DCS) is considered the gold standard method for neurosurgical motor mapping in rolandic tumor surgery. The most commonly used toll for preoperative localization of motor areas is the fMRI. Navigated transcranial magnetic stimulation (nTMS) is a new tool for preoperative detection of motor cortical areas.

The aim of this study was to compare the agreement between the results of motor mapping with nTMS and fMRI in comparison with DCS.

**Patients and methods**

In prospective clinical study, nine consecutive patients (mean age 48 years, range 32-62 years) harbouring a tumor in rolandic areas were enrolled in this study. Etiologies of tumors were LGG (n=4), HGG (n =3) and melanoma (n=2). All patients underwent a preoperative fMRI and nTMS and peroperative DCS.

The localizations of the hand motor cortical areas using different preoperative methods were compared with the results of peroperative stimulation via the neuronavigation system. The differences in distance between nTMS vs. DCS and between fMRI vs. DCS were measured. The results were statistically analyzed.

**Results**

Using nTMS likewise fMRI, a preoperative localization of hand motor areas was possible in all patients. The positive motor responses were located at the primary motor cortex (nTMS: n=9, fMRI: n=5, DCS: n=9), central sulcus (nTMS: n=7, fMRI: n=9, DCS: n=0) and adjacent gyrus - precentral (nTMS: n=7, fMRI: n=0, DCS: n=0) and post central (nTMS: n=2, fMRI: n=7, DCS: n=0). The nTMS vs. DCS responses differed 0-7 mm (mean difference = 2, 2 mm) and fMRI vs. DCS differed 1-18 mm (mean difference= 6, 9 mm). There are statistically no differences between nTMS vs. DCS and fMRI vs. DCS (p=0,109).

**Conclusion**

The nTMS as fMRI appears to be clinically equally effective tool in preoperative motor mapping.

This study was supported by the Charles University Research Fund (project number P36).

## 18 - Presence of Lower Extremity Motor Evoked Potentials in Infants Undergoing Tethered Cord Surgery: Is It the Rule or the Exception?

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**Introduction**

Monitoring of motor evoked potential in very young patients may be impaired by the incomplete maturation of motor pathways during infancy.

**Methods**

We have studied the quality of lower extremity motor evoked potentials in pediatric patients undergoing surgery for tethered spinal cord. From the group of pediatric patients, twelve patients below the age of twelve months (mean age, 6 months; range, 3.8 to 8.1 months) undergoing surgery under general anesthesia were selected for the study. Motor evoked potential monitoring of lower extremities was used in combination with upper extremity and anal sphincter motor evoked potential monitoring, and with monitoring of bulbocavernosus reflex and somatosensory evoked potentials. Motor evoked potentials were elicited by transcranial electrical stimuli applied via needle electrodes placed in the scalp. Short trains of five to nine electrical stimuli with an interstimulus interval of 4.0 ms were used. Responses were recorded without averaging from needle electrodes placed in lower extremity limb muscles.

**Results**

In nine of twelve patients under the age of one year motor evoked potentials could be recorded from both lower extremities during general anesthesia. The youngest patient with preserved motor evoked potentials from lower extremities throughout surgery was 116 days old.

**Conclusion**

The application of motor evoked potential monitoring using transcranial electrical stimulation is feasible in infants undergoing spinal cord surgery. Although maturation of corticospinal tract is incomplete motor evoked potentials can be generated in the majority of infants. Monitoring of lower extremity motor evoked potentials can be used to improve the safety of surgery for tethered spinal cord even in patients under the age of six months.

## 19 - Intraoperative Neuromonitoring During Tethered Cord Surgery in Young Children

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**[1] T.C. İstanbul Bilim University, Sisli Florence Nightingale Hospital, Spina Bifida Center**

**Introduction**
The operations of children with spina bifida are now routinely being monitored with motor evoked potentials and electromyography with mapping techniques in our institution. The results of sixteen monitoring of tethered cord syndrome were presented in this paper.

**Methods**
Seventeen children aged between 1.5 month - 8 years were monitored during tethered cord surgery in Spina Bifida Center. Motor evoked potentials (MEP), continuous electromyography (EMG) and mapping with direct stimulation were used to intraoperative neuromonitoring. For MEP, transcranial stimulation was applied at C3/C4 and lower extremity muscles (quadriceps, tibialis anterior, gastrocnemius and anal sphincter) were monitored. EMG were recorded continuously from same muscles. Any repeated EMG activity were reported to neurosurgeon. Monopolar probe was used to stimulate and identify functional nerves and find out possible functional nerve fiber in filum. Since the current spreads to close nerves above 5 mA, we preferred to increase the stimulation intensity not more than 5 mA.

**Results**
In 17 patients MEP was recorded and in 15 of them we could elicited MEP response at least one myotome successfully. In two infants that we couldn't get MEP response, were 1.5 months and 3.5 months aged. In 9 patient MEP responses from anal sphincter were elicited. Since the responses were fluctuating in amplitudes during the surgery, we preferred to use all or nothing criteria as our warning thresholds. No MEP change (loss) was observed and no new or worsen postoperative neurological deficit was occurred.

**Conclusion**
As we know from the literature, MEP has a low success in very young children due to incomplete neural maturation. According to our experience, MEP can be recorded safely and successfully in children older than 6 months. Mapping with direct stimulation assists surgeon for a safer detethering.

## 20 - Intraoperative Stimulation Of Roots And Neural Placode During Myelomeningocele Repair

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**[1] T.C. İstanbul Bilim University, Sisli Florence Nightingale Hospital, Spina Bifida Center**

### Introduction

The aim of our study was to evaluate the functions of roots and neural placode by intraoperative direct electrical stimulation during myelomeningocele repair and provide information to neurosurgeon for a safer surgery. Roots and neural placode were stimulated in 15 infants with myelomeningocele (7 lumbosacral, 5 thoracolumbar, 1 thoracic and 2 lumber levels) together with continuous electromyography.

### Methods and Results

Muscle responses were elicited with monopolar cathodal root stimulation, intensities between 0.2 mA -2 mA, for placode stimulation intensities between 0.4-3 mA. In 2 infants with distal muscle weakness, both proximal (quadriceps, tibialis) and distal (gastrocnemius, anal sphincter) muscle responses were obtained with stimulation of roots and placode. In 3 infants with severe weakness at proximal muscles and plegia at distal muscles, muscle responses elicited with stimulation of roots but in one, the amplitudes were lower (10-15µV). No response was obtained from distal muscles with stimulation of placode. In one of the neurologically intact infants we couldn't get any response while in other we could get a response only with a high intensity (4 mA) during placode stimulation and we related those results to non-functional tissue covering the placode. In 1 infant, stimulation of right distal region of placode induced right muscle responses however when we moved the probe proximally on placode we observed left side muscle responses.

### Conclusion

In all patients we could obtain responses with stimulation of roots which shows that roots were functional in all MMC patients. Stimulation of placode is a more difficult method because of the non-functional tissue blocking the current to pass to neural tissue in some cases. Infants with MMC may have a different spinal neuroanatomy due to neural migration disorder and this is crucial for surgical manipulations during closure of the defect. Intraoperative mapping can guide neurosurgeon, increases the safety of surgery and contribute to the pathophysiology of neurological defects in those infants.

**Key words:** myelomeningocele, intraoperative neurophysiology, root stimulation

## 21 - Differences in Intraoperative Neurophysiological Monitoring between Spinal Intramedullary Ependymoma and Hemangioblastoma

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### Introduction

Intraoperative neurophysiological monitoring (INM) using transcranial muscle motor evoked potentials (MEPs) and somatosensory evoked potentials (SSEPs) is an established method for detecting perioperative neural damage in intramedullary spinal cord tumor (IMSCT) surgery. Ependymomas and hemangioblastomas arise in different anatomical locations, and require different surgical techniques. However, previous studies on INM during IMSCT surgery have not taken into account tumor pathology. Therefore, the aim of our study was to assess differences in INM findings between ependymoma and hemangioblastoma.

### Methods

Fifty-six limbs from 16 patients diagnosed with ependymoma, and 18 limbs from six hemangioblastoma patients were included. The alarm criterion for MEPs was a 50% decrease in amplitude, while for SSEPs it was a 50% decrease in amplitude, and/or a 10% delay in latency.

### Results

We found that 14 out of the 56 ependymoma limbs (25.9%), and 8 out of the 18 hemangioblastoma limbs (44.4%) showed MEPs decrement during surgery. Eight limbs of ependymoma patients (57.1%), and one limb of a hemangioblastoma patient (12.5%) did not show MEPs recovery at the end of surgery. Among those that showed MEPs recovery, six ependymoma (10.7%) and six hemangioblastoma (33.3%) limbs did not show postoperative motor deficits ($p$ = 0.04). Finally, 11 limbs of ependymoma patients, and one limb of a hemangioblastoma patient showed postoperative weakness.

### Conclusions

In our study, the incidence of transient changes in MEPs was higher in hemangioblastoma than in ependymoma. Our data suggest that it may be necessary to consider tumor features and the type of surgical technique used, particularly when interpreting intraoperative neurophysiologic monitoring profiles of intramedullary spinal cord tumors such as ependymoma and hemangioblastoma.

## 22 - Predictive Value of Intraoperative Bulbocavernosus Reflex during untethering surgery for post-operative voluntary voiding.

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### Introduction

Neurogenic bladder is one of the major disabilities in tethered cord syndrome. Intraoperative monitoring of bulbocavernosus reflex (BCR) is known to be helpful to predict and prevent bladder dysfunction after untethering surgery. However, its predictive value for post-operative voiding function has not been confirmed in children with spinal dysraphism

### Methods

We performed a retrospective review of 114 pediatric patients who underwent untethering surgery between January 2013 and May 2015. We excluded 8 patients whose diagnosis was not spinal dysraphism, 12 patients in whom BCR was not performed, and 30 patients whose BCR at baseline was not obtained. Finally, 64 patients were enrolled and classified based on whether BCR was preserved or lost during surgery. As a functional outcome, voluntary voiding without need of assistive technique (such as intermittent catheterization or Valsalva maneuver) was checked at admission, at discharge, 2 months, 6 to 12 months after surgery.

### Results

Among the 64 patients, BCR was lost during surgery in 12 and preserved in 52. The positive predictive value of intraoperative BCR (failure to void / loss of BCR) was 58.3%, 50%, and 44.4% at discharge, 2 months, and 6 – 12 months after surgery, respectively. The negative predictive value (independent voiding / preservation of BCR) was 67.3%, 76.9%, and 91.7% at the same time points. The sensitivity and specificity of BCR was 29.2%, 87.5% at discharge, 33.3%, 87.0% at 2 months, and 57.1%, 86.8% at 6 - 12 months.

### Conclusion

Intraoperative BCR during untethering surgery in children with spinal dysraphism can predict long-term bladder function with high specificity (86.8%) and moderate sensitivity (57.1%). It indicates that when BCR is preserved, voluntary voiding function can be reliably expected after surgery.

## 23 - Intraoperative Neurophysiologic Monitoring During Cervical Selective Dorsal Rhizotomy (SDR) to Relieve Spasticity Secondary to Stroke.

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**Introduction**

The SDR is a functional surgical treatment of intractable disabling spasticity. Lumbosacral SDR using intraoperative neurophysiological monitoring (IONM) was performed in children with cerebral palsy with favorable results. The aim of the surgery was to selectively lesion roots/rootlets contributing in maintaining the spasticity. The surgery for cervical SDR is indicated after other unsuccessful treatments of spastic hemiplegia.

**Material And Methods**

We present a 58 yo woman with left spastic hemiplegia secondary to stroke (5 years duration). Pharmacological treatments were unsuccessful. During SDR multimodal IONM included somatosensory evoked potentials and motor evoked potentials from upper limbs. The selection of roots/rootlets for lesioning was done by stimulation of left dorsal C5-C8 roots/rootlets with bipolar hook electrode and recorded responses bilaterally in: trapezius, deltoid, biceps brachii, triceps brachii, flexor carpi radialis, extensor digitorum communis and abductor digiti mimimi muscles. The responses were analysed after stimulation with a single stimulus, followed by 50-Hz stimulation.
Criteria for SDR were: 50-Hz tetanic stimulation elicited sustained responses outside of innervated myotomes, or even spreading to contralateral limb.

**Results**

Following 50-Hz stimulation of 26 rootlets, 12 rootlets were cut (46%). The spasticity assessment on postoperatively days 1, 5 and 9 showed progressive increase of the amplitude-range of motion to the passive extension of elbow and fingers with decreased spasticity.

**Conclusion**

Patients with disabling and pharmacologically resistant spasticity of the upper limb, could benefit of SDR combine with IONM. This could result in a good postoperative outcome and improve the quality of life of these patients. In patients with preserved sensitivity it is important to preserve sensory afferents. We suggest the use of IONM during cervical SDR to offer greater confidence for selection of roots/rootlets to be lesioned.

## 24 - Benefits of IONM in Neurointerventional Surgery

*E.Ejaz*

Neurointerventional surgery is a rapidly evolving and advancing subspecialty in the treatment for cerebrovascular diseases, which can benefit substantially from greater implementation of intraoperative neuromonitoring (IONM). While the use of IONM is common in the treatment of cerebral aneurysms by open surgical clipping, IONM can be extremely valuable not only in the endovascular treatment of aneurysms by coil embolization but also in mechanical thrombectomy in acute ischemic stroke and other neurointerventional procedures. IONM provides a more accurate real-time indicator of neurological function than the more derivative techniques of measuring blood flow velocity, arterial pressure, or estimated oxygen saturation. To illustrate this point, I will review two neurointerventional case examples where IONM was instrumental, including embolization of a cerebral aneurysm and mechanical thrombectomy of a large vessel occlusion in an acute ischemic stroke.

During the elective coil embolization of a cerebral aneurysm, in the middle of deployment of a coil, IONM registered an abrupt reduction of functional sensory evoked potential (SSEP) amplitude and change in EEG frequency pattern, and thereby provided immediate detection of perforation of the aneurysm wall, even before there was angiographic evidence or other clinical signs. After confirming the perforation angiographically, the coil was appropriately deployed and the aneurysm successfully secured. By the end of the embolization, SSEP amplitudes had recovered to baseline.

During a mechanical thrombectomy for a large vessel occlusion in an acute ischemic stroke in a patient presenting with left-sided hemiparesis a sensory loss, the MEP on the left side was absent at baseline. After successful retrieval of the thromboembolus and complete recanalization of the right middle cerebral artery, there was rapid recovery of the MEP.

This presentation will make clear the benefits of IONM to the neurointerventional surgeon and their patients.

## 25 - Utility of Intraoperative Mapping of Brain Function in Neurosurgeries

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### Introduction

Functional brain mapping, despite being the standard of care for high risk epilepsy and brain tumor surgeries, is underused in the developing world, the main reason being lack of qualified personnel and infrastructure to perform these procedures. We present here a case series to report our experience with the outcome of brain surgeries performed under neuromonitoring cover in the last six months (i.e. since the inception of this service) in our institute.

### Methods

A total of 13 cases required functional brain mapping in the study period (6 intractable epilepsy, 5 glioma, 1 posterior frontal cavernoma and 1 fourth ventricular ependymoma). In all epilepsy surgeries, techniques namely central sulcus localization by SSEP phase reversal, eloquent motor cortex mapping and electrocortigraphy (ECoG) for assessing epileptic activity were carried out. Among the 6 cases of glioma and cavernoma, motor cortex mapping was done in all, whereas central sulcus localization by SSEP phase reversal was done in 3 cases. In case of fourth ventricular ependymoma, brainstem mapping was carried out.

### Results

Among 9 cases in which central sulcus localization was carried out by SSEP phase reversal, in 8 cases neuronavigation was also used. In all these cases, central sulcus located by SSEP phase reversal and neuronavigation matched. Among the 12 cases in which eloquent motor cortex mapping was done, no patient developed new neurological deficit after surgery. In case of fourth ventricular ependymoma, tumor was approached posteriorly and bilateral facial nuclei were correctly identified; patient did not develop facial palsy post-op. In all epilepsy surgeries, ECoG served to guide the extent of resection.

### Conclusion

A wide range of techniques are available for functional brain mapping. When used appropriately, they are effective in averting neurological damage in high-risk epilepsy and brain tumor surgeries.

### Keywords

functional brain mapping – epilepsy surgeries – brain tumor surgeries

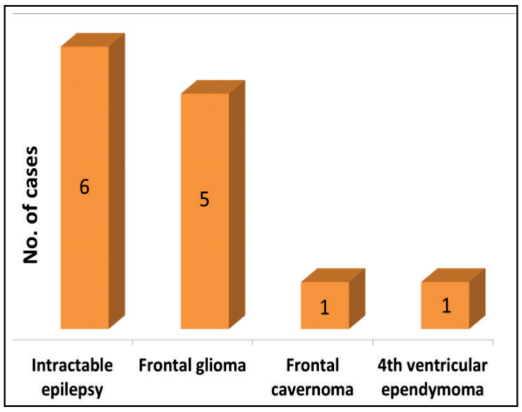


Fig.1: Cases by diagnosis

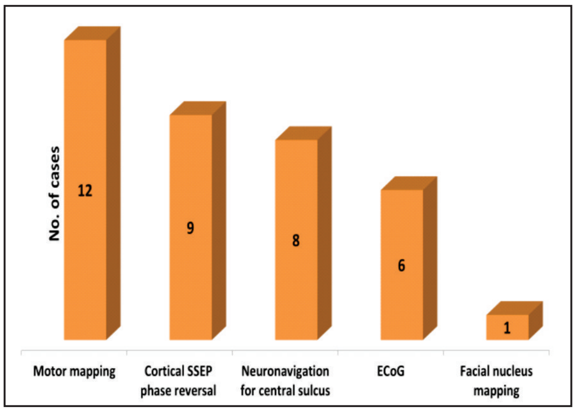


Fig.2: Cases by techniques

## 26 - Image-guided mini-invasive tailored approach for the removal of tumours near the motor cortex: a preliminary experience with the intraoperative aid of ultrasound sonography and neurophysiological monitoring.

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**Introduction**

Tumours in spatial proximity with eloquent areas represent a major challenge for neurosurgeons. The aim is maximal tumour removal while preserving the patients' quality of life. Uploading MRI and fMRI scans into neuro-navigation systems along with neurophysiological monitoring should be considered mandatory for the planning and execution of these procedures. However, neuro-navigations are based on imaging acquired pre-operatively. Thus, their accuracy decreases during the surgery due to the brain shift. Amongst the methods to gain intraoperative information on brain shift, the value of intraoperative ultrasound sonography (iUS) is improving. The combination of intraoperative neurophysiological monitoring and iUS might be pivotal in limiting the incidence of post-op neurological deficits and increasing the amount of gross total resection. This study describes our experience of tumours resection achieved with the combination of neurophysiological monitoring and iUS.

**Methods**

Tumours close to the motor cortex were removed with image-guided mini-invasive approach and neurophysiological monitoring. The motor cortex was exposed partially, limiting the electrophysiological mapping that was used to search for negative spots. Monopolar subcortical stimulation, somatosensory and motor evoked potentials were used to monitoring the cortico-spinal tract. iUS guided the tumour removal. Clinical motor scores and the extent of resection (EOR) were investigated.

**Results**

Motor scores decreased in 8% of the patients (3 months follow-up). The mean EOR was 90% (range 60-100%), although it was ≥ 90% in 75% of the patients

**Conclusions**

The intraoperative combination of neurophysiological monitoring and iUS is promising in terms of clinical motor scores and EOR. iUS allowed to correct brain shift during the procedure helping the search of radicalness, while neurophysiology allowed to constantly monitor the motor functions lessening the morbidity. This strategy represents an alternative approach to the treatment of eloquent areas tumours, although further studies are necessary to confirm the long-term efficacy of this procedure.

***Conflict of interest statement:***

*The authors declare that the article content was composed in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.*

## 27 - Intraoperative Mapping of Language Function in Awake Craniotomy for Frontal Lobe Tumor Surgeries

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**Institute of Neurosciences, SRM Institute of Medical Sciences (SIMS), Chennai, India.**

### Introduction

Intraoperative mapping of language function assumes importance in patients undergoing resection of tumors in proximity to Broca's area. Optimal stimulation protocol for effecting a speech arrest is challenging because of the risk of seizure due to high frequency, long duration electrical stimulation in awake subjects. We report a case series to present our experience with an improvised protocol for direct cortical electrical stimulation for language mapping.

### Methods

A total of 3 cases of language mapping have been carried out since the inception (i.e. about 1 month) of neurophysiological monitoring services in our institute. All the patients (2 female & 1 male) had tumors close to the anatomical Broca's area as determined by preoperative MRI. In one patient, a functional MRI confirmed the same. All were right-handed. Baseline assessment of language function revealed deficits in all the patients. Awake craniotomy was carried out under neuronavigation guidance. Verbal fluency and object recognition tasks were carried out. Stimulation protocol consisted of 1000 millisecond duration electrical pulse of biphasic polarity presented at 60 Hz for 7 seconds, repeated intermittently.

### Results

All patients had language area in the left cerebral hemisphere. Using this stimulation protocol, a current as small as 5 mA caused speech arrest and defined the expressive language area. No patient developed intraoperative seizure; nor did anyone develop new language deficit post-surgery.

### Conclusion

Our limited experience suggests that our language mapping stimulation protocol has been effective in causing speech arrest without inducing seizures during awake craniotomy for frontal lobe surgeries. Intraoperative language mapping should be considered as standard of care in such surgeries.

### Keywords

language mapping – frontal lobe tumor – awake craniotomy

## 28 - Detection of Abnormal Free-Running EMG Pattern Following Acoustic Neuroma Surgery Revealing Iatrogenic Neurovascular Conflict

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**Division of Neurology * and Neurosurgery°, University Hospital, Verona, Italy**

**Introduction**
Free running EMG is a standard procedure to monitor the facial nerve during surgery for vestibular schwannomas. It is not unusual in Intra-Operative Neurophysiological Monitoring (IONM) to stop monitoring soon after the end of tumor removal. We present the case of a 60-year old man who underwent surgery for a right vestibular schwannoma under IONM surveillance. Suspicious neurotonic discharges on the free-running EMG from the Orbicular Oris (OR) ipsilateral to the lesion occurred after tumor removal, during the hemostasis, warranting further investigation.

**Methods**
Transcranial Corticobulbar Motor Evoked Potentials (TCB-MEPs), for the evaluation of corticobulbar tract for the VII cranial nerve, were elicited by electrodes placed on C3, C4 and Cz according to EEG 10-20 International System using a train of 4 stimuli (0.5ms duration each, 2ms ISI at 1 Hz frequency). Twisted needle recording electrodes were placed on the Orbicular Oculi muscle (OO) ipsilateral to the lesion, and on Orbicular Oris muscle (OR) bilaterally. Free-running EMG evaluation was performed from the same muscles throughout the surgery.

**Results**
After tumor removal, during hemostasis but before dura closure, free-running EMG from the right OR revealed an unusual pattern characterized by neurotonic discharges which were synchronous with the heart rate, in particular with the systolic peak. The TCB-MEPs were unchanged. Requested upon investigation, the surgeon noticed that, after tumor removal, the antero-inferior cerebellar artery (AICA) was collapsed on the VII cranial nerve creating a neurovascular conflict. Following separation of the AICA from the facial nerve, the EMG activity promptly subsided. No hemifacial spasm was detected post-operatively.

**Conclusion**
During surgery for vestibular schwannomas, it is advisable to extend facial nerve monitoring behind the end of tumor removal as pathological activity may occur during closure and should be investigated.
The authors declare no conflict of interest

## 29 - 25 awake surgeries with language testing using 60 Hz and 250-500 Hz stimulation protocol

*Silvia Mazzali-Verst, Andreya Cardoso Cavalcanti, Andrea Sucena Caivano, Luis Roberto Mathias Junior, Tatiana Peres Vilasboas Alves, Daniel de Andrade Gripp, Natally Saturnino Santiago, Marcos Vinicius Serra, Paulo Henrique Pires de Aguiar, Marcos Vinicius Calfat Maldaun*

**Introduction**

The most used assembly for language mapping is Penfield/ Ojeman 60 Hz bipolar stimulation, during 3 to 4 minutes on each point. It is expected to occur more seizures with this technique than with 250-500 Hz stimulation. Since the late 90's, motor evoked potentials have been used in the operating room with multi-pulse 250-500 Hz technique and it is considered now to be a gold standard for motor tracts identification. Still there are doubts if it can be as effective for language mapping.

**Methods**

25 patients were operated between 2007 and 2015 by the same surgeon (MVCM), using language mapping with 60 Hz bipolar (6 cases) or 250-500 Hz monopolar (21 patients) technique – 2 of them were mapped by both techniques. During the stimulation patients were tested with figures, numbers and words in order to recognize and name them, build sentences and words, and talk about their daily living and families.

**Results**

There were 17 men and 8 women, ranging from 25 to 79 years old. Biopsies results revealed 16 cases of HGG, 8 LGG and 1 anaplasic astrocytoma. We achieved 10 gross tumor resection and 15 subtotal tumor resection. Mapping showed up to be positive in 21 patients and negative in 4. The negative mapping occurred in 3 patients with 250-500 Hz group and 1 patient from 60Hz group. None presented new deficits. Seizures occurred only in 4 patients from 250-500Hz group. Immediately after the surgery, 7 patients had worsening of the previous symptoms – 6 of these patients were in the 250-500 Hz group. Most of them had HGG (6) and achieved only subtotal resection (5). This may mean that these cases were already more severe. The 250-500 Hz technique showed to evoke speech and naming alterations in 18 tests of 21

**Conclusion**

We believe 250-500 Hz is effective for language mapping, since we could observe speech arrest, reverberation, mistakes in nomination and mathematics adding and subtraction, color and numbers identification and singing.

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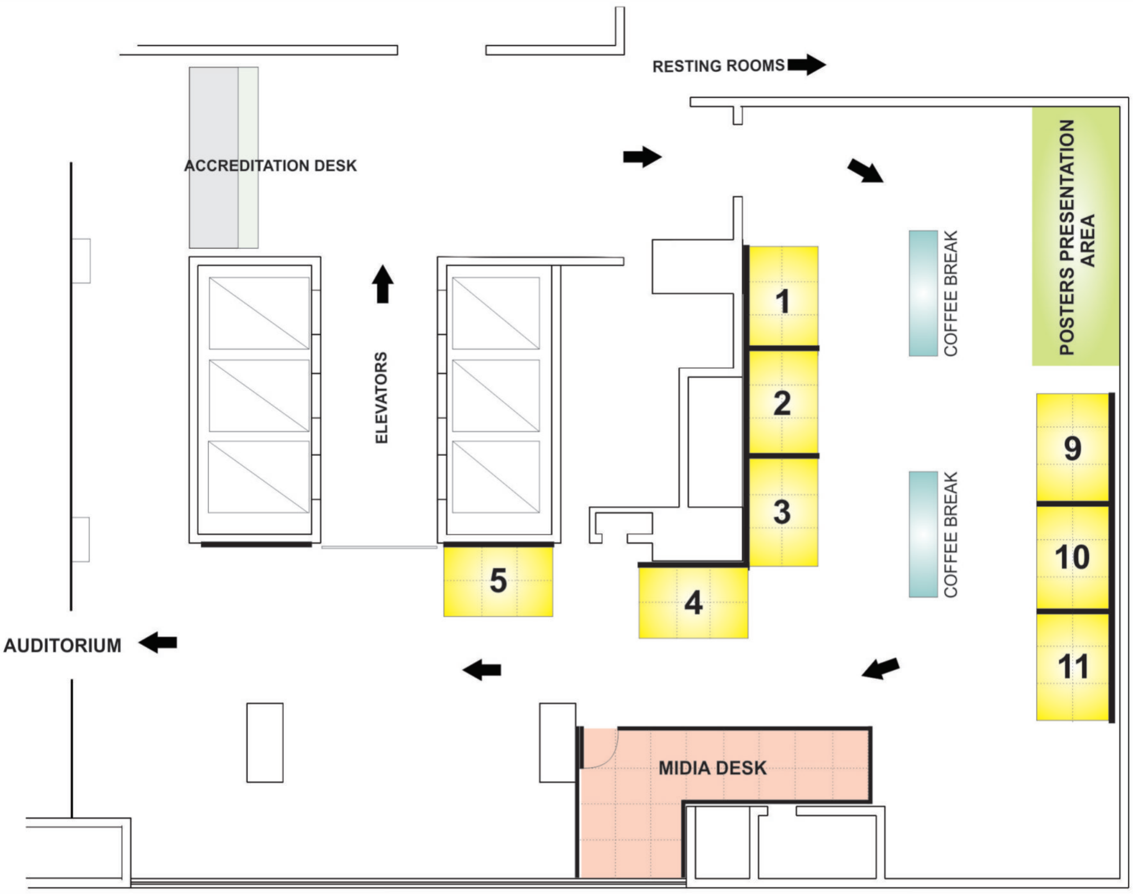
## ISIN RIO 2015

Windsor Atlântico Hotel - Copacabana - Rio de Janeiro
November 9 to 14,2015




Plant designed on October 20, 2015

**Stands:**

1 e 2.....Medtronic
3.....Neurosoft
4.....Ad-Tech
5.....Cadwell
9 e 10.....Inomed /Surgical Line
11.....Pharma Brasil

# General Information

**Accreditation and Information Desk**
Foyer - 2nd Floor

**OPERATING TIMES**

**ISIN Course**
Monday, Nov 9th - 10h00 -20h30
Tuesday, Nov 10th - 06h45 -19h30
Wednesday, Nov 11th - 06h45 -18h30

**ISIN Congress**
Thursday, Nov 12th - 07h30 -20h30
Friday, Nov 13th - 06h45 -19h30
Saturday, Nov 14th - 06h45 -14h30

**Breakfasts with Faculties**
-1 Floor (underground)

**OPERATING TIMES**

**ISIN Course**
Tuesday, Nov 10th - 07h00 -07h45
Wednesday, Nov 11th - 07h00 -07h45

**ISIN Congress**
Friday, Nov 13th - 07h00 -07h45
Saturday, Nov 14th - 07h00 -07h45

**Auditorium "Fred J. Epstein & Vahe E. Amassian"**
2nd floor

**Security**
We urge delegates to take care of their personal possessions and exhibitors to be particularly aware during periods of exhibitions build-up and breakdown. Name badges must be displayed at all times for security reasons, as well as when attending congress social events.

**Midia Desk**
Located at the Foyer - 2nd floor.
Speakers presenting on the first day of the Course and Congress need to upload their presentations at least two hours prior to their presentation. Speakers on remaining days to kindly hand in their presentations at least 24h before they are due to present. The support technicians will check fonts, formats, videos and sound to make sure your presentations is correctly formatted.

**Coffee Breaks**
Will be served in the Exhibition Hall and Foyer (2nd floor)

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The Organizing Committee, the Congress Organiser and ISIN accept lo liability for any damages, injuries and/or losses of whatever nature incurred by participants and/or accompanying persons.

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- All hotels and conference venues are non-smoking;
- Please keep cell phones on silent mode during sessions;
- Respect the starting times for all sessions as these will be strictly adhered to;

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# Congress Venue

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# Social Events

The following social events will take place during the 5th ISIN Educational Course and Congress:

**ISIN Educational Course Welcome Cocktail**
Monday, Nov 9th
Time: 20h00 to 21h00
Venue: Foyer – 2nd floor
Dress: Smart Casual

**ISIN Educational Course Dinner**
Tuesday, Nov 10th
Time: 20h30 to 23h30
Venue: Churrascaria Porcão Rios
Dress: Smart Casual

Transport: Shuttles will depart from the Windsor Atlântica Hotel at 20h15
Shuttles will return at 23h00 and 23h30

Cost: US$100 per person (last day to book: Nov 9)

Note: The first shuttle will not leave until is full

**ISIN 5th Congress Welcome Cocktail**
Thursday, Nov 12th
Time: 20h00 to 21h00
Venue: Foyer – 2nd floor
Dress: Smart Casual

**ISIN 5th Congress Dinner**
Friday, Nov 13t
Time: 20h30 to 23h30
Venue: Rio Scenarium
Dress: Casual

Transport: Shuttles will depart from the Windsor Atlântica Hotel at 20h15
Shuttles will return at 23h00 and 23h30

Cost: US$100 per person (last day to book: Nov 12)

Note: The first shuttle will not leave until is full

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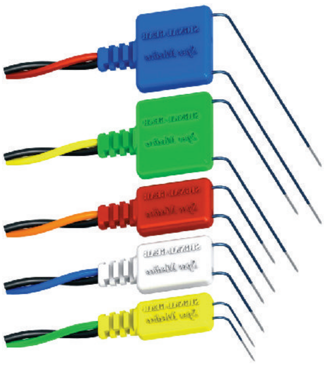
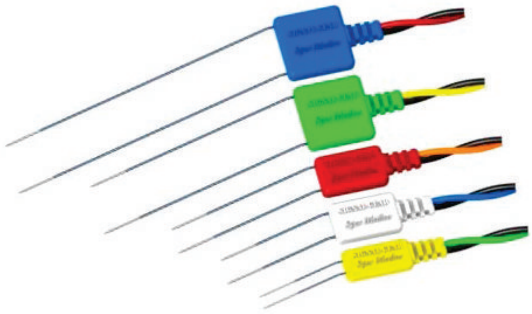
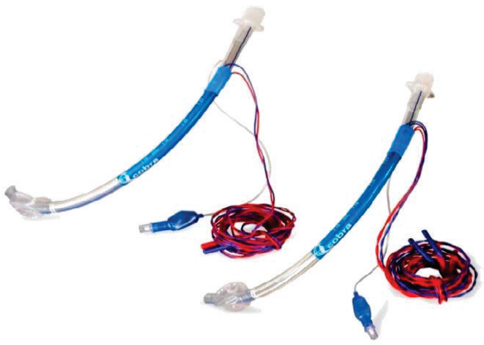




## Soon — Integrated laryngeal electrodes



## Soon — Dry Touch - Suction stimulator probes

## Soon — Disposable stimulation probes - New models

**More information contact us:**
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