

Exploring the utility of neuro-monitoring in neurosurgery: The users' perspective in a single center

ABSTRACT

Background: The purpose of intraoperative neuro-monitoring (IONM) is to minimize injury to eloquent neural structures and optimize tumor resection.

Method: We explored the utility of IONM using a qualitative approach in a single center. Eight experienced users of its use in spinal and cranial surgery in adults and children were the informants. Using a constant comparative method, the findings were collated by thematic analysis.

Results: The user perspective is that of caution to minimize adverse effects whilst empowering the need for formal training to enhance its efficacy. The process of IONM needs standardization as practices vary amongst users. Most users expressed limited trust on its current capabilities but hoped for its advancement to achieve higher sensitivity and specificity. None were however prepared to abandon its use.

Conclusion: IONM needs optimization. Its utility depends on user vigilance, multi-disciplinary validation, and individual expertise. This study draws out key issues from the user perspective that need to be addressed in order to enhance the utility of IONM.


Key words: Intraoperative, neuro-modulation, neuro-monitoring, neurosurgery, risk-benefit, utility

Background

Contemporary intraoperative neuro-monitoring (IONM) uses surface and implanted electrodes to observe spontaneous electrical activity of the brain (e.g., electroencephalogram) or response evoked by a stimulus (motor, visual or auditory). This helps neurosurgeons “map” normal neural tissue and distinguish these from abnormal areas, therefore minimizing injury to critical structures.^[1,2] IONM often used multi-modal to enhance its sensitivity and specificity.^[3] It is expected to

improve neurosurgical outcomes, reduce post-operative morbidity and enhance recovery.^[3]

The efficacy of IONM has never been tested in a clinical trial, but most consider that it has passed the point at which a with or without IONM trial would not be ethical.^[4,5] Therefore, justification of the rationale for neuro-monitoring is needed, with quantifying evidence for how, when and

Access this article online	
Website: www.saudija.org	Quick Response Code 
DOI: 10.4103/sja.SJA_862_20	

This is an open access journal, and articles are distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 License, which allows others to remix, tweak, and build upon the work non-commercially, as long as appropriate credit is given and the new creations are licensed under the identical terms.

For reprints contact: reprints@medknow.com

How to cite this article: Goonasekera C, Jones H, Lawrence R, Hanrahan J, Iyer P, Nijhawan A. Exploring the utility of neuro-monitoring in neurosurgery: The users' perspective in a single center. Saudi J Anaesth 2021;15:7-13.

CHULANANDA GOONASEKERA, HOLLY JONES, REBEKAH LAWRENCE¹, JOHN HANRAHAN¹, PRIYANKA IYER¹, ADITI NIJHAWAN¹

Department of Anesthetics, King's College Hospital NHS Trust, Denmark Hill, London SE59RS, ¹King's College London Faculty of Life Sciences and Medicine, School of Medicine, London, UK

Address for correspondence: Dr. Chulananda Goonasekera, Consultant Anesthetist, Department of Anesthetics, King's College Hospital NHS Trust, Denmark Hill, London SE5 9RS. E-mail: cgoonase@gmail.com

Submitted: 12-Aug-2020, **Revised:** 01-Sep-2020, **Accepted:** 13-Sep-2020, **Published:** 05-Jan-2021

where it could be best utilized. Whilst IONM has become an essential adjunct for spinal intramedullary tumor removal^[6] and deep brain stimulation,^[7] formal training of staff for its use is becoming the norm in some countries.^[8-10] This study aimed to gain a deeper understanding of these aspects based on the experience of its users in spinal and cranial surgery both in adults and children.

Methods

This qualitative study based on the Grounded Theory involved the construction of theories through methodical gathering and analysis of data.^[11] The data were drawn from experienced neurosurgeons, neuro-anesthetists, and neurophysiologists from a single regional center following institutional ethical approval. Consenting informants faced an audience of doctors, nurses, and medical students. Following an opening presentation on the study objectives, methodology, and duties of the audience, the informants faced a semi-structured, open-ended, question and answer session based on a pre-designed “interview guide”. Each interview lasted 1–1.5 hours. Audio recordings were made with informants’ and participants’ permission. Additional questions were asked to probe emerging findings.

The interviewer was a medical student. This enabled the use of simple expressions and language with free direction. The interview was terminated at “saturation” point i.e., when researchers and the participant felt that no new or relevant information could be gained. After each interview, the recordings were replayed to assist synchronous analysis and coding.

The sample size was determined by investigators when it became clear that further enquiry was unlikely to provide any new findings. All data collected was confidentially stored, anonymized, and analyzed.

Data analysis

Using a constant comparative method, the data were coded, compared, and grounded.^[11] Codes were conceptualized into categories following open, axial, and selective coding. The core categories which emerged were listed and quotations from the interviews (submitted in supplementary data file) were saved to strengthen understanding. The credibility of the findings was established by open dialogue, critical thinking, and consensus between researchers.

Findings

The informants were 2 neurosurgeons, 4 neuro-anesthetists, and 2 neurophysiologists. Several themes emerged [Table 1].

Table 1: Conceptual modelling outcomes

Themes	Subthemes
Prevailing practice	Initiation Indications and use Contraindications When Why Limitations Reliability
Check lists	Request form Responsibility
Team dynamic	Necessary team members IONM booking process Team communication Interpretation ethic of lost signals Team efficacy
Optimizing benefit	Baseline recordings Advantages Disadvantages
Users	Training and experience Opinion on training Case load
Anesthetic technique	Access Depth of Anesthesia Anesthetic agent
Adverse events	Incidence Witnessed Other risks When to abandon Treatment Safety practices
Draw backs	Costs Medico-legal issues
Patient communication	Consent (verbal/written) Information provision (depth/risks)
Follow-up	Short-term Long-term
Future	Check lists Guidelines

Prevailing practice

Surgeons seem convinced that IONM facilitated almost complete removal of tumors, improved operative safety and reduced the risk of unexpected neurological damage and subsequent deficit. It enabled early recognition of neurological damage and rectification within the “golden hour”.

One drawback was the inability of the reversible and irreversible changes noted from the pre-induction baseline of the same modality of monitoring to predict the post-operative clinical outcome with absolute confidence. Another weakness was the interpretation of potentially reversible areas of neural dysfunction following surgery (due to decompression for example) as non-recoverable deficit at the baseline assessment.

Since IONM was often externally (private company) resourced it was not routinely available in neurosurgical theatres. Selection criteria were unclear. IONM was considered unsuitable but was not an absolute contraindication in the

presence of a pacemaker, ICD, or implanted DBS device in our center [Table 2]. It was used with caution in patients with epilepsy. It was avoided in early pregnancy because of the perceived risk that it may trigger labor. It was not used during Category-1 emergency operations. Patients undergoing surgery involving speech area needed a wake-up test in addition to IONM. Its use was limited to a fewer modalities in very young children due to poor myelination.

Check lists

IONM use had no formal check list but was mentioned as part of the WHO checklist. This is a standard in some countries.^[12] The need for formal preparation and lack of it as well as the resulting frustration was highlighted by Anesthetists. One neurophysiologist argued against check lists.

Team dynamic

All accepted that IONM is a team procedure and its optimal interpretation needed several concurrent modalities. The working environment should facilitate good communication. The nursing staff should understand its basics and safety needs. However, anesthetists got to know about the need for IONM on the day of surgery and this delayed preparation.

Optimizing benefit

The utility of IONM depends on the aim of the surgery and the neurosurgeon. Anesthesia modifications are essential for its optimal application. Baseline recordings were the foundation for comparatively detecting neurological deficits during the procedure. However, the optimal time to perform a baseline measurement was variable. A reduction of the signal or its latency was considered significant based on variable criteria

between the modalities. In general, a lost signal was bad news, but its trigger threshold was not consistent. All involved needed to understand and exclude confounding factors. Changes in anesthetic agent, or cerebral/spinal perfusion issues could interfere with the recordings. The influence of body temperature and hemoglobin on its own was minor but could be potentiated by concurrent other physiological abnormalities. Its reliability improved with experienced, collaborative, and interactive teams but not fool proof. External artefacts need to be considered. There were false positives and negatives. Increased surgical duration, higher doses of inhalational agents added to latency of signals but not remifentanyl.

IONM electrodes were generally applied and tested after induction of anesthesia but before positioning of the patient especially in critical spinal cases. The measurement was usually taken when the anesthetic induction agents have worn off and pre and post positioning for surgery.

User training and experience

Anesthesia for IONM was not included in the specialist anesthesia training curriculum until 2010. Most anesthetists learnt the needs for IONM on the job with senior advice. Some voluntarily attended short courses. All anesthetists interviewed had 4 or more years of experience on the job and agreed that exposure to IONM is increasing.

Surgeons too learnt IONM on the job, both as trainees as well as consultants taught by their seniors or colleagues. Some attended dedicated teaching sessions or short courses provided by local societies and companies that manufactured IONM equipment. The latter could have been subject to bias.

Clinical neurophysiologists had self-directed training courses, organized by IONM equipment manufacturing companies following a Masters in Neuroscience. They received initial mentoring followed by a minimum of 4 years' practice experience, 1:4 pediatric vs adult.

All agreed that IONM should be a formal training component during specialist training for anesthetists, surgeons and neurophysiologists as in other countries.^[8-10] This is because self-training is ad hoc and can be limited due to financial constraints. Neurophysiologists also recommended apprenticeship-type work until confident to work alone. They also noted a variable degree of user skill on it amongst practicing surgeons and anesthetists reflecting lack of a benchmark for practice.

Anesthetic technique

TIVA is commonly used with MEPs and BIS guidance as an adjunct. Addition of a 0.5 MAC of an inhalation agent is

Table 2: List of abbreviations

Acronym	Full text
BAEP	Brain Stem Auditory Evoked Potentials
BIS	Bispectral Index Monitor
DBS	Deep Brain stimulation
DCS	Direct Cortical Stimulation
DMS	Direct Muscle Stimulation
DNS	Direct Nerve Stimulation
ECG	Electrocardiography
ECOG	Electrocorticography
ICD	Implantable Cardioverter Defibrillator
IONM	Intra operative Neuro-monitoring
MAC	Minimal Alveolar Concentration
MEP	Motor Evoked Potential
SpO ₂	Peripheral pulse oximetry
SSEP	Somatosensory Evoked Potential
TCS	Transcranial Stimulation
TNS	Transcutaneous Nerve Stimulation
TIVA	Total Intravenous Anesthesia
VF	Ventricular fibrillation

possible. Challenges exist in pediatrics. All agreed that stable conditions were necessary.

All anesthetists agreed that depth of anesthesia monitoring was essential, but they were reluctant to share neurophysiologists EEG estimates. They were aware of the drawbacks of BIS. Neuro stimulation produced artefacts too on parameters such as SpO₂ and the ECG tracing [Figure 1].

There can be a conflict of interest between the neurophysiologist and the neuro-anesthetist as the latter's priority is patient safety and not the production of optimal IONM recordings. These issues fade away with the formalization of anesthesia and neurophysiologist protocols.^[13]

Adverse events

Some users were concerned for not being fully acquainted with the risks involved, especially because of reporting bias and dismal opportunities for publication of such case reports. Bite injuries, electric shock, muscle contraction injuries, seizures, compartment syndrome of calves, cardiovascular events, and blindness are some recognized adversities. Most were aware of the risk of seizures, but management strategies were confounded, and secondary consequences of seizures were a concern. Teeth grinding and crumbling, tongue and lip damage have also been reported. Inadvertent burns were another risk. In the event of a serious complication abandoning the procedure was an option.

Repetitive overstimulation increases plasma lactate and potassium and may induce rhabdomyolysis leading to compartment syndrome and renal impairment. Excessive and repetitive lower limb stimulation can lead to calf necrosis needing a fasciotomy. One anesthetist used a plasma lactate

of 4.0 mmol/l as a decisive point where IONM, surgery, or both should stop.

Drawbacks

The placement of electrodes under anesthesia and its removal added significant anesthetic time that may exceed one hour especially when cranial nerve testing is planned with endotracheal tube, soft palate, tongue, pharyngeal, audio, visual, and ophthalmic muscle electrodes. IONM is also very expensive in the short-term due to additional manpower, equipment, and additional need for theater time. Some argued that the high cost of the neuromonitoring is easily offset by reducing huge claims against the hospital for damage, especially following neurosurgery.^[14,15] Neurophysiologists had their own indemnity, but claims were perceived to be uncommon as patients believed it was a safe technique. Assessing cost-effectiveness necessitates accurate outcome measures and its adversities.

Patient communication

The neurophysiologists accepted responsibility for preparing and using the equipment appropriately including the placement and removal of electrodes, but not for patient information.

Patients were usually informed verbally but comprehension and retention of this information was often poor. Information pamphlets may be useful. Surgeons mentioned IONM in surgical consent forms, but this was not consistent.

Follow-up

There were no follow up arrangements specifically for IONM after the surgery.

Future

The use of IONM is not novel, but the ethical challenges faced in clinical trials was a drawback. There is a need to formally improve training of staff.

Discussion

General user impressions

Most informants believed that IONM gives a better chance for scrupulous excision of the tumors or corrective spinal surgery minimizing risks to crucial neurological structures while promoting adherence to stable physiological conditions that are linked to best outcomes. One downside of IONM was that it had no mechanism to predict post-surgical recoverable function, thus overestimating true deficit. It was also not practical in all situations.

The existing NICE guidance for IONM was based on anecdotal findings and was not mandatory.^[16] The selection process of

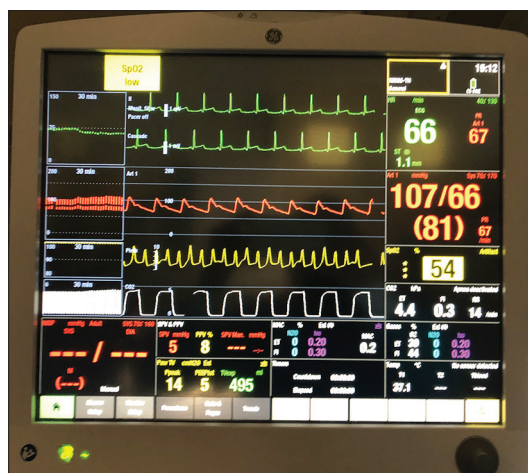


Figure 1: MEP induced artifact in SpO₂ waveform

patients too was not clear. Senior surgeons had reservations on its utility. A positive dimension on its utility was influenced by the team rapport. It was also stronger in younger surgeons and externally resourced neurophysiologists who may have been biased. The dimension of negativity mainly came from anesthetists. This was because of lack of muscle relaxation, lighter planes of anesthesia, prolonged recovery times, and risk of awareness. Increased theatre time to set up and dismantle the IONM equipment was a negative factor. However, informants across all three specialties agreed the need for medico-legal security was one good reason for the use of IONM.

Informants reported cases of unexpected injury such as teeth damage, tongue lacerations, bleeding from puncture sites and even risk of compartment syndrome and blindness. An awareness on the fact that surface stimulation can create unwanted muscle spasms, patient movement, and spurious artefacts on pulse oximetry and ECG readings was important. Patient movement, especially when pinned to a frame for surgery, could be detrimental.

One main concern was not having neither a sign out check list at the end of surgery nor a formal follow up for IONM. Since the neurophysiologist was working directly under the purview of the surgeon, they appeared less accountable for the complications that followed.

Limits of application

The informants understood that to extract an EP signal from the underlying EEG noise, multiple stimulations with summation, and frequency filtering were needed. Although EPs were claimed to be highly sensitive to fluctuations in physiological parameters such as peripheral and core body temperature, arterial blood pressure, hematocrit, etc., the perfusion of the neural tissue mattered most.

The informants agreed that in children or patients with cardiac issues, inhalational anesthetics <0.5 MAC may be applied without compromising the quality of monitoring. A balanced general anesthetic was possible with low doses of inhalational agents combined with low-dose infusions of remifentanyl, Propofol, or dexmedetomidine during EP monitoring. Higher doses of remifentanyl caused a decline in peak amplitude of SSEP.

The anesthetic conditions optimized for MEP were also suitable for SSEP. All refrained from using any muscle relaxants after tracheal intubation. Midazolam and other benzodiazepines were avoided as they suppressed the intraoperative EP. Bolus dosing was avoided during IONM to minimize negative impacts on EP signals indistinguishable

from changes triggered by surgical trauma. During lengthy neurosurgical procedures, gradual attenuation of the EP signals occurred. Above observations matched with prerequisites considered best for IONM.^[4] D-wave was popular as it was not dependent on ganglion transmission but was applicable only in selected cases.

Since BIS interprets motor stimulation and related muscle movement as light anesthesia it may not be accurate with MEPs and covertly guide an anesthetist deepen anesthesia unnecessarily. In diabetes, MEP and SSEPs may have poor responses due to peripheral neuropathy.

IONM monitoring during positioning is important especially in patients with cervical myelopathy. Implanted devices such as pacemakers and cochlear implants were relative contraindications for use of IONM. Its value in pediatric surgery was less robust but still useful in complex spinal deformity correction.^[17]

The neurophysiologists were uncomfortable with the use of muscle relaxants at induction as they had no true baseline soon after. However, IONM signals were fully established before the surgeon entered the brain or spinal canal, as the initial anesthetic agents have worn off by that time.

Lost signal is a pre-warning of imminent neural damage, but certain anesthetic drugs and varying depths of anesthesia was a major confounder. Loss of MEPs appears to link best with adverse prognostic information. Preserved but persistently diminished MEPs usually predict a neurological injury that will significantly improve and recover.

Team dynamic

This was a theme that arose across the data collection and analysis. The interpretation of IONM required a profound knowledge of neurophysiology, comprehension of the surgical procedure, and an understanding of the effects that general anesthesia and physiological changes may have on signal quality and integrity.

Surgeons preferred familiar anesthetist and neurophysiologist colleagues for IONM. This facilitated understanding and communication across the operating theatre. They used informal agreed methods to justify the readings before any actions were executed. Some anesthetists were keen to demonstrate that there were no additional neurological deficits following intubation.

An MDT decision on the type of neuromonitoring to be used will enable the team to prepare well in advance,

inform patient adequately, and reduce delays on the day of surgery.

Patient communication

The inadequacy of patient's awareness of the full implications of IONM was a concern as most patients believed it was for their benefit with no inherent risks. This reflected inadequate preoperative communication and this needs to improve. Patients need to be informed about the type of needles used, particularly in sensitive areas such as eyeball, tongue, sexual organs, anus, and the "pin cushion" appearance to be expected post operatively. They must be made aware of all risks, including needle access, the need for bite block to prevent tongue injury, risk of seizures, awareness during surgery, and pressure/muscle contraction effects. Frequent MEPs may also increase serum K⁺ levels and lactate. Surgeons were often unaware of this risk.

All agreed that IONM is expected to improve outcomes with increasing experience and expertise in its use.^[3] The current claim for it to have gone beyond the stage of ethical testing is not surprising considering the literature being mostly pro-IONM despite minimal RCT evidence to support its effectiveness and lack of reporting of its adverse events. The informants had a clear request to enhance its scrutiny.

Limitations of this study

This qualitative study was limited to one center, and hence the results are more relevant locally. However, it raises the areas of concern that need exploration in depth in the wider healthcare system. In the absence of any incentives, the participation of informants may have been biased.

Conclusion

This study showed two main themes, firstly the need for all team members involved in IONM to have formal training and secondly the need to reiterate the importance of team dynamic in the theatre. All users were keen to learn and improve the technique, but the number of neurophysiologists committed to work within the theatre for long hours was limited.

Therefore, guidance on crew resource management seems most appropriate for the IONM team, which includes reporting existing deficits, expressing challenges to the neurophysiologist especially for high-risk areas, discussing surgical steps and the IONM equipment to be used. There is a need for high-powered RCT evidence to assess its clinical utility and cost-effectiveness.

Acknowledgements

We are indebted to all informants and the members of the audience who generously shared their experience. We appreciate the assistance provided by Bassel Zebian, Asme Sheikh, Carlos Fiandeiro, Natalie Simon, Alastair Asher, Ali Ansaripour and Hazel Sanghvi during thematic analysis.

Financial support and sponsorship

All work was voluntary and there was no special funding.

Conflicts of interest

There are no conflicts of interest.

References

1. Jameson LC, Janik DJ, Sloan TB. Electrophysiologic monitoring in neurosurgery. *Anesthesiol Clin* 2007;25:605-30, x.
2. Coppola A, Tramontano V, Basaldella F, Arcaro C, Squintani G, Sala F. Intra-operative neurophysiological mapping and monitoring during brain tumour surgery in children: An update. *Childs Nerv Syst* 2016;32:1849-59.
3. Cabraja M, Stockhammer F, Mularski S, Suess O, Kombos T, Vajkoczy P. Neurophysiological intraoperative monitoring in neurosurgery: Aid or handicap? An international survey. *Neurosurg Focus* 2009;27:E2.
4. Soghomonyan S, Moran KR, Sandhu GS, Bergese SD. Anesthesia and evoked responses in neurosurgery. *Front Pharmacol* 2014;5:74.
5. Howick J, Cohen BA, McCulloch P, Thompson M, Skinner SA. Foundations for evidence-based intraoperative neurophysiological monitoring. *Clin Neurophysiol* 2016;127:81-90.
6. Kothbauer K, Deletis V, Epstein FJ. Intraoperative spinal cord monitoring for intramedullary surgery: An essential adjunct. *Pediatr Neurosurg* 1997;26:247-54.
7. Shah RS, Chang SY, Min HK, Cho ZH, Blaha CD, Lee KH. Deep brain stimulation: Technology at the cutting edge. *J Clin Neurol* 2010;6:167-82.
8. Dionigi G, Bacuzzi A, Barczynski M, Biondi A, Boni L, Chiang FY, *et al.* Implementation of systematic neuromonitoring training for thyroid surgery. *Updates Surg* 2011;63:201-7.
9. Mashour GA, Avitsian R, Lauer KK, Soriano SG, Sharma D, Koht A, *et al.* Neuroanesthesiology fellowship training: Curricular guidelines from the Society for Neuroscience in Anesthesiology and Critical Care. *J Neurosurg Anesthesiol* 2013;25:1-7.
10. Wilkinson M, Houlden D, Morris S, Holmes LM, Strantzas S. A strategic view for intraoperative neuromonitoring in Canada 2017. *Can J Neurol Sci* 2018;45:259-61.
11. Strauss AL, Corbin JM. *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*. 2nd ed. Sage Publications, Inc.; 1998.
12. Vitale MG, Skaggs DL, Pace GI, Wright ML, Matsumoto H, Anderson RC, *et al.* Best Practices in Intraoperative Neuromonitoring in Spine Deformity Surgery: Development of an Intraoperative Checklist to Optimize Response. *Spine Deform* 2014;2:333-9.
13. Tewari A, Francis L, Samy RN, Kurth DC, Castle J, Frye T, *et al.* Intraoperative neurophysiological monitoring team's communique with anesthesia professionals. *J Anaesthesiol Clin Pharmacol* 2018;34:84-93.
14. Cheney FW. The American Society of Anesthesiologists Closed Claims Project: What have we learned, how has it affected practice, and how will it affect practice in the future? *Anesthesiology* 1999;91:552-6.

15. Cheney FW. The American Society of Anesthesiologists closed claims project: The beginning. *Anesthesiology* 2010;113:957-60.
16. National Institute for Health and Care Excellence. Intraoperative nerve monitoring during thyroid surgery. (Clinical guideline [IPG255]). Available from: <https://www.nice.org.uk/guidance/ipg255/chapter/4-About-this-guidance>. [Last updated 2008 March; cited 2020 Sep].
17. Drake J, Zeller R, Kulkarni AV, Strantzas S, Holmes L. Intraoperative neurophysiological monitoring during complex spinal deformity cases in pediatric patients: Methodology, utility, prognostication, and outcome. *Childs Nervous System* 2010;26:523-44.

“Quick Response Code” link for full text articles

The journal issue has a unique new feature for reaching to the journal’s website without typing a single letter. Each article on its first page has a “Quick Response Code”. Using any mobile or other hand-held device with camera and GPRS/other internet source, one can reach to the full text of that particular article on the journal’s website. Start a QR-code reading software (see list of free applications from <http://tinyurl.com/yzlh2tc>) and point the camera to the QR-code printed in the journal. It will automatically take you to the HTML full text of that article. One can also use a desktop or laptop with web camera for similar functionality. See <http://tinyurl.com/2bw7fn3> or <http://tinyurl.com/3ysr3me> for the free applications.

Supplementary data file: Informant statements and thematic analysis.

Findings

Eight experienced professionals including 2 neurosurgeons, 4 neuro-anesthetists and 2 neurophysiologists were interviewed. Several themes emerged (Table 2) directly relevant to IONM application in clinical practice.

Table 2 Conceptual modelling outcomes

Prevailing practice

Surgeons were convinced that IONM facilitated almost complete removal of tumors, improving operative safety whilst reducing the risk of unexpected neurological damage and subsequent deficit. Another justification was that neurological damage had a 'golden hour', with early detection during surgery enabling rectification and reversal of insults.

One neurosurgeon commented;

"It's extra information that you get before and during an operation that increases safety. You don't need a randomized control trial" and an anesthetist agreed "It's most useful when the patient already has a deficit. It helps you to be proactive".

There was no protocol in place for the formal initiation of IONM. Since IONM was not a routinely available facility in neurosurgical theatres it had to be externally resourced. Selection criteria for patients were unclear to key stakeholders as evidenced from one of the neurophysiologists' comment:

"I'm from a 'private' company. The surgeons call me, and I ask them if it's a spinal, brainstem or brain, and bring relevant equipment for the set up. I discuss the case on the day with the surgeon."

An anesthetist commented;

"The patient selection criteria are a bit of a mystery, but the numbers have really increased".

One neurophysiologist justified their involvement and expressed their independence.

"Anything that puts the brain or spinal cord at risk should be monitored."

IONM is contraindicated in the presence of a pacemaker, ICD or implanted DBS devices, as nerve stimulation can dysregulate these signals. It is avoided in early pregnancy because it can trigger labor but is considered an acceptable risk during the 3rd trimester. It is used with caution in patients with epilepsy. One neurophysiologist commented:

"In the past maybe, nowadays we can work around epilepsy for seizures, it's not such a contraindication. The stimulation we use for awake testing, focused stimulation, is different to what is used under anesthesia for motor assessment".

Since definitive resection procedures are rarely undertaken as an emergency, IONM is not required during emergency operations. IONM in its current form cannot monitor the speech area and such patients need a wake-up test. Its use is also limited in very young children, especially under the age of one, due to poor myelination.

But the situation is evolving as stated by a neurophysiologist;

"Trying SSEPs for spinal surgery is not much value. This is because even if you cut a sensory nerve, the SSEP will still work. It will only disappear if something major happens such as spinal artery supply occlusion. There is no age cut off. There are no standard voltages, it is usually raised incrementally from a minimum".

Check lists

There was no formal check list for IONM use. It was usually mentioned as part of the WHO checklist to ensure personnel and equipment availability. The need for formal preparation and lack of it as well as the resulting frustration was highlighted by an Anesthetist;

“All have to be made aware because everyone has to adapt their technique accordingly. It is normally mentioned on the operating list but not always. We need to ensure all the equipment is available, the neurophysiologist is present, and the anesthetic equipment is there to enable it”.

A neurophysiologist argued against check lists;

“I personally don’t like a check list as each patient is different. I have another hospital who sends me a check list requesting MEPs, SSEPs’ and I resist these because it doesn’t tell me anything. I need to know what the procedure is”

Team Dynamic

IONM is a team procedure and the neurophysiologist, anesthetist and all theatre staff need to be well informed. One neurosurgeon discouraged surgeon-led neuro-monitoring;

“I’d rather have a neurophysiologist. They can tell you when at risk of being paralyzed and if we’re doing too much or too little. Even if I could gain the skill, I couldn’t operate and do neurophysiology at the same time.”

Optimal interpretation needs several concurrent IONM modalities. A team judgement on this was recognized. A neurosurgeon said;

“I make the decision but if anyone has any ideas to monitor this or not, I’m happy to listen”.

A Neurophysiologist added;

“Although the surgeon requests the modalities of IONM, I suggest additional modes based on the type of lesion”.

The nursing staff should also understand IONM basics and its safety needs. For example, the diathermy plate should not cross IONM wires, as it can create burns at electrode entry sites. It is now normally specified on the operating list. One theatre sister said;

“The surgeons have slowly learnt that if they put it on the list the anesthetist and operating department practitioner can get the appropriate equipment in advance and this reduces delays.”

One anesthetist expressed dissatisfaction;

“What IONM modalities to run is usually a joint decision between the neurophysiologist and the surgeon. However, I occasionally get involved if the decision was inappropriate. For example, recently a neurophysiologist placed a tongue electrode in a patient who was due to have an intra operative wake-up test. I removed this for obvious reasons.”

Often anesthetists get to know about the need for IONM on the day of surgery and this delays preparation due to inadequate planning. Ad hoc anesthetist allocation in departments may also contribute to the uncertainty.

The working environment should facilitate good communication. A neurosurgeon commented;

“You have to provide an environment where everyone is comfortable and happy to talk. The neurophysiologists need to be loud and firm and speak up. Loud music in theatre is not helpful”.

All agreed that the team should be made aware of the need for IONM well in advance for good preparation.

Optimizing benefit

The utility of IONM depends on what is being looked for, the aim of the surgery and the neurosurgeon. The anesthesia modifications are needed to ensure its optimal application. The set-up costs approximately £4000 per session and adds an additional 30 minutes to an hour to the theatre time.

When asked at what stage of surgery neuro-monitoring is used, a neurophysiologist said;

“for the entire procedure, starting from baseline following anesthesia.”

Baseline recordings are the foundation for comparatively detecting neurological deficits during the procedure. An 80% reduction of the signal or 20% latency is considered significant loss of signal.

The optimal time to perform a baseline measurement is variable. A neurosurgeon commented;

“Sometimes even positioning and moving the patient may end up paralyzing the patient so sometimes you do a baseline at the beginning before you start any manipulation” .

An anesthetist agreed with the risk of manipulation;

“Poor positioning alone can do more damage than the surgeons cutting the wrong bit.”

IONM electrodes are generally applied and tested after induction of anesthesia but before positioning of the patient especially in critical spinal cases. The measurement is usually taken when the anesthetic induction agents have worn off and pre and post positioning for surgery. During intracranial surgery, baseline recording depends on the modality used. For example, ECoG can only be done on an open brain.

IONM reliability improves with experienced teams. Both neurosurgeons and neuro-anesthetists reiterate that good interaction with the neurophysiologist is required to ensure utmost reliability. In general, a lost signal is often bad news and communication is the key to trigger rescue actions, but the trigger threshold not consistent. This is particularly important due to the potential impact of independent actions by key team members:

“If something’s not working it’s probably my fault. Are all my wires connected? Is the system working? If all clear I think what else can do it? Anesthesia? I’ll check with the anesthetist; did you change anything? If not, then it’s probably the surgeon” ... Neurophysiologist

Another neurophysiologist stated;

“Consistency and experience help me interpret it reliably. I need to be able to distinguish artefact versus genuine loss of signal. If the loss of signal is not related to where the surgeon is operating - I disregard the information”.

The informant also acknowledged that IONM is not fool proof.

“I have seen at least one case who had a neurological deficit post operatively that was not recognized intraoperatively by the neurophysiologist”.

When signals are lost for whatever reason, direct stimulation of nerves are possible using D waves, especially during spinal surgery. All agreed that stable conditions were necessary. An anesthetist said;

“If you provide stable conditions, then it means all other things being equal, changes that occur are down to what’s going on in the operative field”.

A neurophysiologist acknowledged that we are still learning;

“It’s all about consistency, experience and following correct guidelines. IONM is still very new so we don’t have a standard”

...

Lost responses are the key, but all involved need to understand and exclude confounding factors. Changes in anesthetic agent, or cerebral/ spinal perfusion issues can interfere with the recordings. The influence of body temperature and hemoglobin in practice is minor.

Increased surgical duration adds latency to IONM. There are also false positives and negatives. Muscle movement with MEP may be interpreted as an awake patient with a high BIS score.

External artefacts need to be considered. For example, BAEP is an acoustic signal-response which may confuse with drilling noises of the bone leading to gross misinterpretation.

User training and experience

Anesthesia for IONM was not included in the specialist anesthesia training curriculum until 2010. Most anesthetists learnt the needs for IONM on the job with senior advice. Some voluntarily attended short courses. All anesthetists interviewed had 4 or more years of experience on the job and agreed that exposure to IONM is increasing.

Surgeons too learnt IONM on the job, both as trainees as well as consultants taught by their seniors or colleagues. Some attended dedicated teaching sessions or short courses provided by local societies and companies that manufactured IONM equipment. The latter was subject to bias, particularly on adverse events and complications.

Clinical neurophysiologists had self-directed training courses, organized by IONM equipment manufacturing companies following a Masters in Neuroscience. They received initial mentoring followed by a minimum of 4 years’ practice experience, 1:4 pediatric vs adult.

All agreed that IONM should be a formal training component during specialist training for anesthetists, surgeons and neurophysiologists as self-training is ad hoc and can be limited due to financial constraints. Neurophysiologists also recommended apprenticeship-type work until confident to work alone. They also noted a variable degree of user skill on IONM amongst practicing surgeons and anesthetists. When asked on staff competence, the lack of a benchmark for practice was evident.

Anesthetic technique

The ideal anesthetic technique is still evolving. TIVA is commonly used with BIS guidance and a 0.5 MAC of an inhalation agent is possible without affecting MEPs. The need for reliable IV access is a must for TIVA. Challenges, especially in pediatrics were highlighted by anesthetists;

“Not all patients like TIVA, depending on their hearts and various other things. The babies certainly don’t tolerate it very well. Cumulative doses of propofol during TIVA was a concern. If you use too much Propofol then it accumulates, and it takes a while for the patient to wake up.”

“I never give midazolam to any cases and avoid clonidine if possible but do give it in spinal cases only if the BP is difficult to control. I give Optiflow in awake cases, and always use BIS even in awake.”.

“Intubation may need Opti flow and fiber optic awakes in very unstable cervical spines”

All agreed that depth of anesthesia monitoring with TIVA is essential. However, there was unwillingness to share neurophysiologists estimates of depth of anesthesia.

*“I want to be able to look at what I believe the depth of anesthesia is and respond accordingly and immediately” ...
Anesthetist*

This is despite BIS monitoring being unreliable, as it can misinterpret muscle stimulation as an awake patient. This may lead to inadvertent over sedation of the patient. IONM stimulation also produces artefacts on parameters such as SpO2 and the ECG tracing (Figure 1).

Figure 1 MEP induced artefacts in SpO2 waveform

Intraoperatively, there can sometimes be a conflict of interest between the neurophysiologist and the neuro-anesthetist as the latter’s priority is patient safety and not the production of optimal IONM recordings.

Adverse events

Some users expressed concern that we were not yet fully acquainted with the risks involved, especially because of lack of reporting of adverse effects of IONM and opportunities for publication of such case reports scarce. Bite injuries, electric shock, muscle contraction injuries, seizures, compartment syndrome, cardiovascular events and blindness are some recognized adversities.

Most anesthetists were aware of the risk of seizures, but management strategies were confounded by IONM interests.

“I would not want thiopentone – that would be the end of IONM’ Neurophysiologist

The secondary consequences of seizures were also a concern.

“I have had seizures on the table on a patient pinned and prone, and this can lead to tearing of the skin and scalp vessels and potentially cervical spine damage.” “Seizures may occur especially with awake craniotomy, perhaps with a 1-3% incidence”.

Cardiac events were also likely due to IONM with inadvertent consequences.

“I had a patient go into asystole and VF after stimulation, luckily both resolved spontaneously, but the risk here is overtreatment and delivery of adrenaline in an open brain situation where on return of spontaneous output the BP is raised, and bleeding occurs that may be catastrophic. Some cardiovascular events such as bradycardia, hypo or hypertension may spontaneously recover” ...Anesthetist

“Seizures are likely if IONM stimulation is near temporal lobe and can produce asystole/ VF cardiac arrest ” ... Anesthetist

In the event of complications one management strategy was to abandon the procedure with full team judgement.

“If signal is lost for some other reason, especially with complications it is perhaps a good reason to stop further surgery, wake patient up and come back on another day once a full assessment has been made” Anesthetist

“I have abandoned when we had that asystole. Most of these problems will happen when they’re just trying to get the last bit of the tumor out. It will always be a team decision” ... Anesthetist

One neurosurgeon was skeptical about the current utility of neuromonitoring as it interprets reversible areas of neural dysfunction following surgery also as non-recoverable deficit at the baseline assessment. This is one area of false security.

“Occasionally you do have situations where the neuro-monitoring is not working very well from the beginning but then as soon as you open and do a debulking of the tumor it improves, and that’s very reassuring” ... Neurosurgeon

Teeth grinding and crumbling, tongue and lip damage have also been reported. Although burns due to IONM are rare, the risk of tissue damage through this mechanism exists. Unintended earthing is a recognized reason for burns during IONM. However, some modern machines can detect it before the damage is done.

Overstimulation increases plasma lactate and potassium, and induces rhabdomyolysis leading to compartment syndrome and renal impairment. Excessive lower limb stimulation can lead to calf necrosis needing a fasciotomy. One anesthetist used a plasma lactate of 4.0 mmol/l as a decisive point where IONM, surgery or both should stop.

“If they’re stimulating at a high voltage frequently, particularly in a muscular patient, complications are more likely compared with patients with no muscle mass. Other effects include swelling of the area, swelling of the throat with postoperative airway issues” Anesthetist

“Retained needle electrodes is a risk at the end of the operation, as these are placed and removed by a single operator without a formal counting process” ... Anesthetist

Treatment of complications

Most methods of management were learnt on the job and relatively unorthodox.

Anesthetists described the following instances;

“ The scalp often bleeds for a brief period then it just stops bleeding”.

“For a seizure it’s easy, the surgeon pours cold saline on the brain and the brain goes to sleep. The neurophysiologist should stop stimulating and the surgeon needs to take the instruments out of the brain and stand back. Then, nearly always the brain just settles on its own”

“I’ve never had an asystole or severe bradycardia that hasn’t resolved with just removal of all the stimulants”

Drawbacks

Costs

The placement of electrodes under anesthesia and its removal at the end of operation adds significant anesthetic time often exceeding one hour. IONM is very expensive in the short-term due to additional manpower, equipment and additional need for theatre time.

Some argue that the high cost of the neuromonitoring is easily offset by reducing huge claims against the hospital for damage, especially following neurosurgery. Assessing cost-effectiveness necessitates accurate outcome measures and accurate reporting of this information is often poor. There are no clinical trials to show its benefit, but users seem to be happy with their experiences and reported benefits.

“It costs a lot of money, but in reality, if we are able to prevent a deficit or a handicap – it’s worth it, but there are no clinical trials” ... Neurosurgeon

“You cannot really trial patients with and without neuro-monitoring. It’s like jumping off a plane with or without a parachute trial” ...Neurophysiologist

Medical-legal issues

Neurophysiologists do have their own indemnity, but claims are rare as patients believe it is a safe technique. Most users agree that the consenting process for IONM needs improvement.

Patient communication

The neurophysiologists accept responsibility for preparing and using the equipment appropriately including the placement and removal of electrodes, but not for patient information. A neurophysiologist said;

“I check for the case, what we need for the neuro-monitoring, which nerves, or structures are at risk and prepare the needles. Everything has to be set up before the operation.”

Patients are usually informed verbally but comprehension and retention of this information is often poor. Information pamphlets may be useful, but lack of a formal process has created an environment of poor accountability. Sometimes surgeons mention IONM in surgical consent forms, but this is not consistent.

“Patient information leaflets on IONM may be useful. Protocols are available only in some situations such as scoliosis surgery and its more likely to be procedure specific”. ... Neurophysiologist.

“I do not cover this in my anesthetic visit, although I do mention it to the recovery nurses that the patient has multiple puncture sites due to neuro monitoring” Anesthetist.

“You just have to tell them you’re going to use neuro-monitoring” ... Neurosurgeon

“I expect surgeons to talk about IONM to patients. I have no direct involvement pre-operatively or post operatively”... Neurophysiologist

“When I see them, I tell them that their nerves will be monitored and, I need to adapt the anesthetic and what that involves. Usually what I’ll tell them is they’ll get a special strip on their head, and they’ll get a bite block to stop their teeth, lips and tongue being chewed away” ... Anesthetist

“There’s so much to consent for, if you hear a surgeon consent, I think they do it very well these days, but there’s still only so much that you can say and that can be taken in” ... Anesthetist

One neurophysiologist expresses their desire to be involved with the pre-surgery patient communication side of IONM;

‘I do not get involved as the patient is usually asleep when I enter the theatre. It would be nice to have the opportunity to explain to them what’s going on’

Follow-up

There were no follow up arrangements specifically for IONM after the surgery.

“I wouldn’t do anything special. I just inspect the areas where you’ve put the needles” ... Neurosurgeon

“I make sure everything has been removed and no damage to any part of the body as a result” ... Anesthetist

Future

The use of IONM is not novel, but the ethical challenges faced in patient trials means that the practice is still evolving.

"I am interested in having anesthetist-delivered neuromonitoring instead of surgeons. It is definitely the way forward for preventing damage" ... Anesthetist

Some interviewees felt that a lot needed to be improved in the training of staff:

"I'd like probably some more training on it, and probably some practical on the job training...to observe the actual neuro-monitoring process to get an idea of what's going on" ... Anesthetist

"In general, in the UK, it is not standard yet, and there's not many people with the same standards. We need to bridge that standard. We need to train more people in this area." ... Neurophysiologist

"I think it's all about education and awareness. Knowing what we can choose and adapt to achieve good monitoring would be great" ... Neurophysiologist

Some were ambivalent:

"I'm quite happy with the way things are but just for it to become more established in some conditions" ... Neurosurgeon

"I think using it when it's not needed is a waste of resources and time and it just increases the time that the patient is asleep for. I'm more than happy to operate for 12 hours if I think I can make a difference. If you're going to add 2 or 3 hours to the operation not necessarily from surgical but either side, that can increase complications, so you have to just use it when you really need it" ... Neurosurgeon

Table 1 List of abbreviations

Table 2 Conceptual modelling outcomes