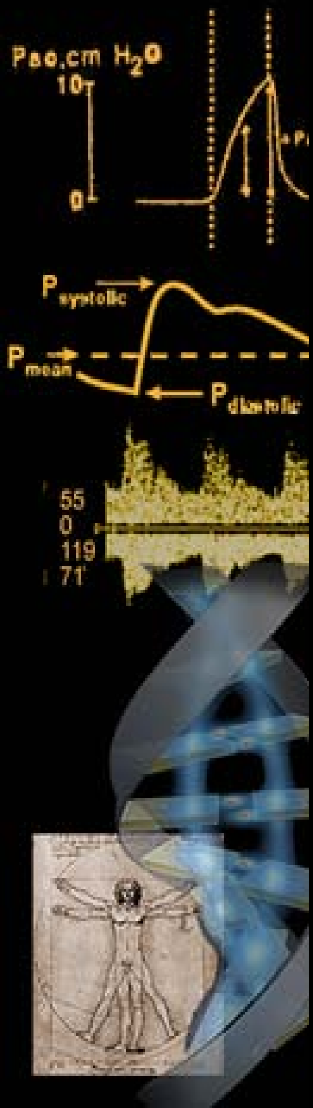
Università di Torino
Ospedale Molinette
Laboratorio di Biomeccanica
Anestesia e Rianimazione III



CHIRURGIA DEL BASICRANIO

QUALI MONITORAGGI?

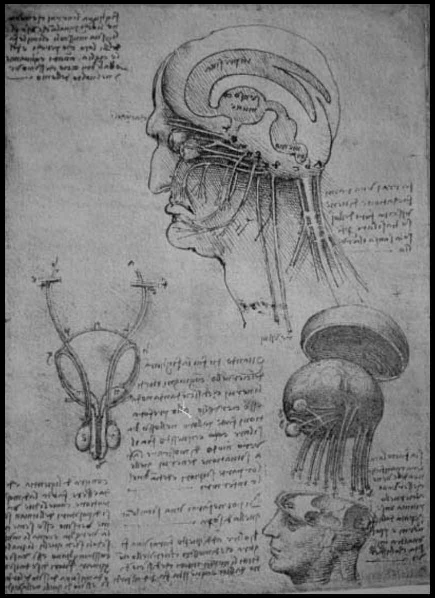
Anna Teresa Mazzeo

8° NeuroMeeting

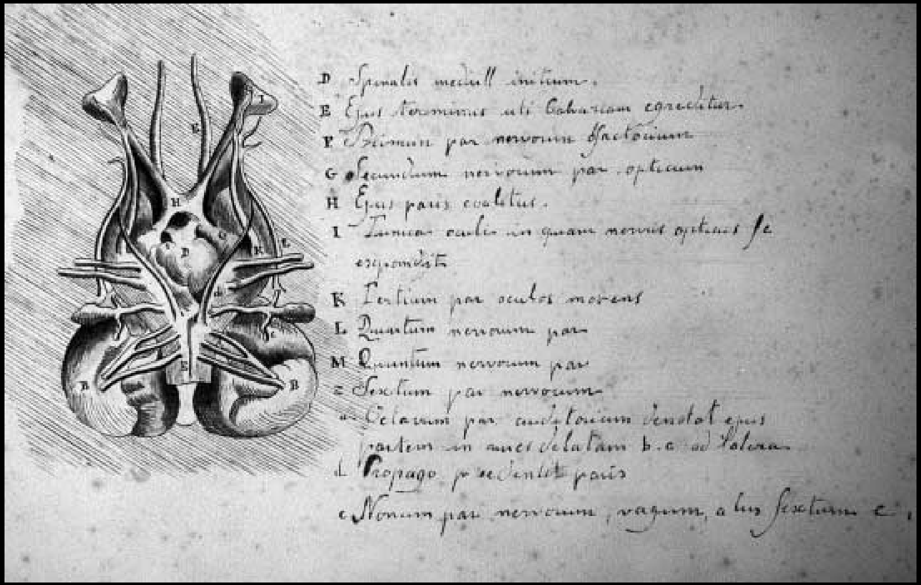
Napoli 12 maggio 2016

Outline

- **The role of monitoring for Skull base surgery (SBS)**
- **Intraoperative neurophysiological monitoring for SBS**
  (Physiologic rationale, Pharmacologic and physiologic influences, Outcome effect)
- **Other monitoring issues:**
  Depth of anesthesia monitoring and Trigemino-cardiac reflex
  Monitoring for the sitting position



Leonardo da Vinci (1452-1519)



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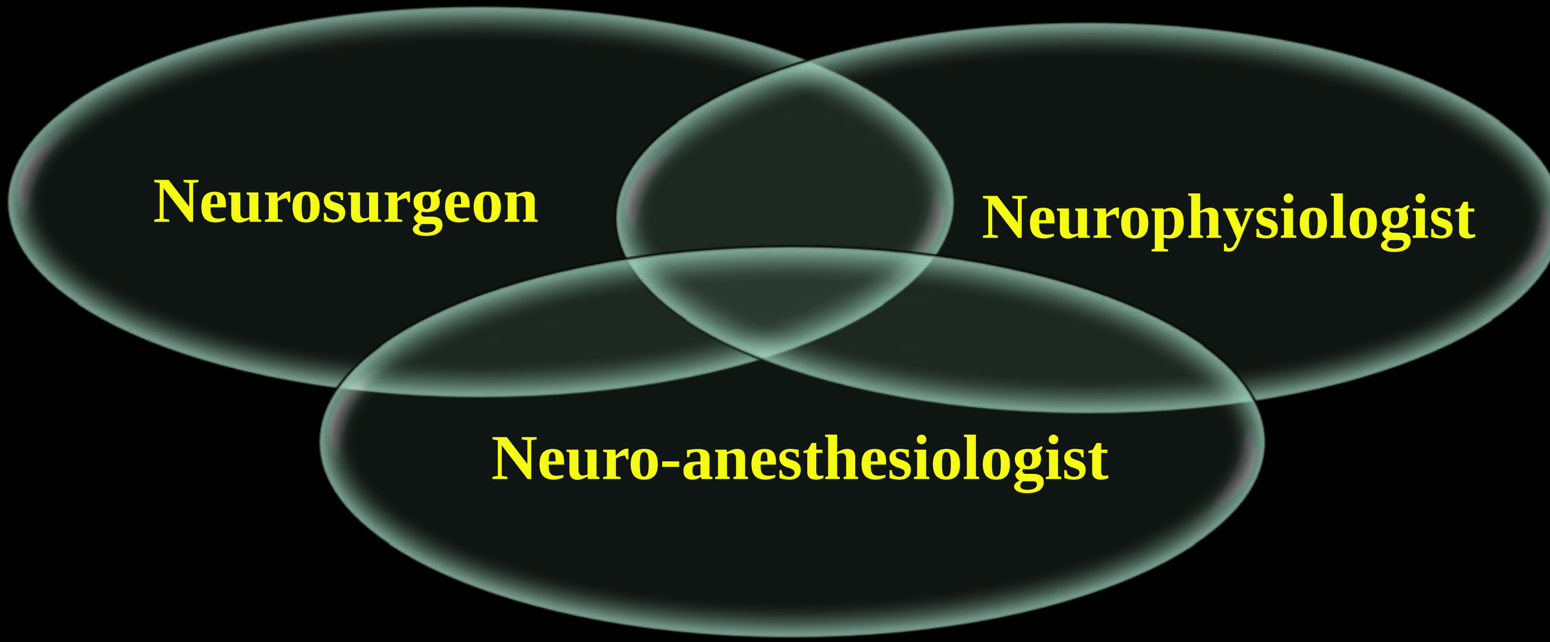
THE CONCEPT OF SKULL BASE TEAM



It is important for the anesthesiologist to know the primary type of tumor, its location within the skull base, the proximity of vital structures, and which skull base approach is to be used

OUTCOME IMPROVEMENT

Infratentorial Neurosurgery Is an Independent Risk Factor for Respiratory Failure and Death in Patients Undergoing Intracranial Tumor Resection

Alana M. Flexman, MD, FRCPC, Bradley Merriman, MD,* Donald E. Griesdale, MD, FRCPC,* Kelly Mayson, MD, FRCPC,* Peter T. Choi, MD, FRCPC,* and Christopher J. Ryerson, MD, FRCPC†*

1699 patients (79% supratentorial and 21% infratentorial)

The primary outcome (reintubation, failure to wean and death at 30days) in 3.8% of supratentorial procedures and 6.6% of infratentorial procedures (P=0.02)

TABLE 2. Final Multivariate Model of Postoperative Respiratory Failure and Death

Variables	Unadjusted OR	Adjusted OR	95% CI	*P*
Age*	1.38	1.30	1.07-1.57	0.007
Dyspnea				
None		Reference		
With moderate exertion	2.59	2.24	1.09-4.60	0.03
At rest	7.42	4.74	1.03-21.80	0.05
Cardiac disease	3.03	2.20	1.09-4.45	0.03
Impaired sensorium	3.14	2.28	1.19-4.37	0.01
Neurological disease	2.90	2.44	1.45-4.11	0.001
Infratentorial surgical site	1.77	1.75	1.03-2.99	0.04
Emergency surgery	3.11	3.07	1.07-7.14	0.009
Anesthetic duration†	1.13	1.18	1.07-1.30	0.001

FLEXMAN, J Neurosurg Anesthesiol 2014

Perioperative management of complex skull base surgery: the anesthesiologist's point of view

W. Scott Jellish, M.D., Ph.D., John Murdoch, M.D., and John P. Leonetti, M.D.

AIRWAY

PATIENT POSITIONING

BLOOD LOSS

HEMODYNAMIC CHANGES

PERIOPERATIVE NEUROPROTECTION

INTRAOPERATIVE MONITORING

POSTOPERATIVE CARE

Goal of skull base surgery

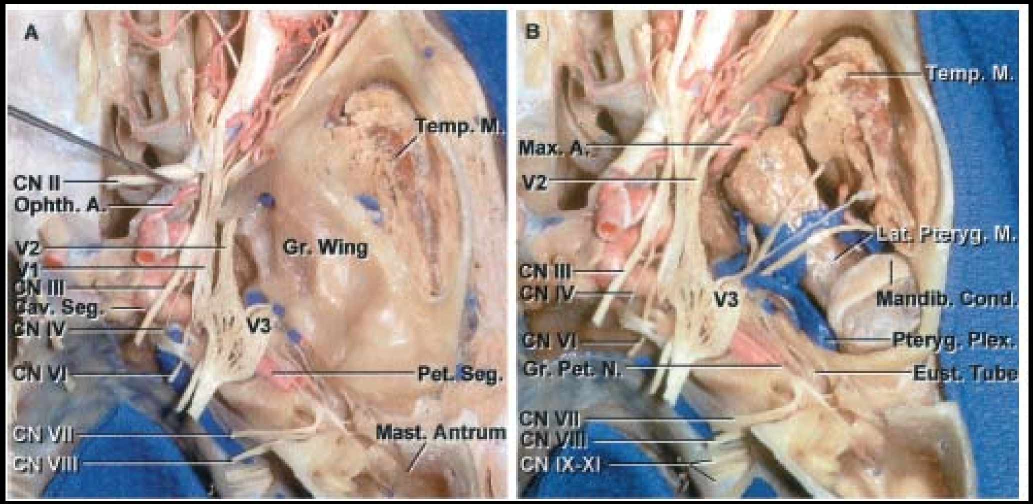
Tumor removal with preservation of neurological function

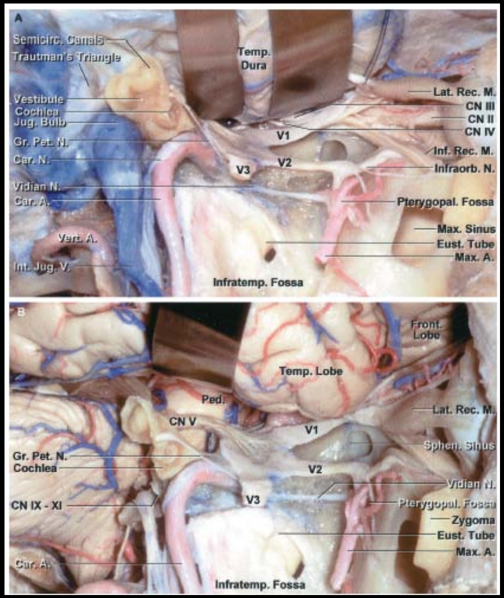
Perform neurovascular procedures avoiding cerebral ischemia

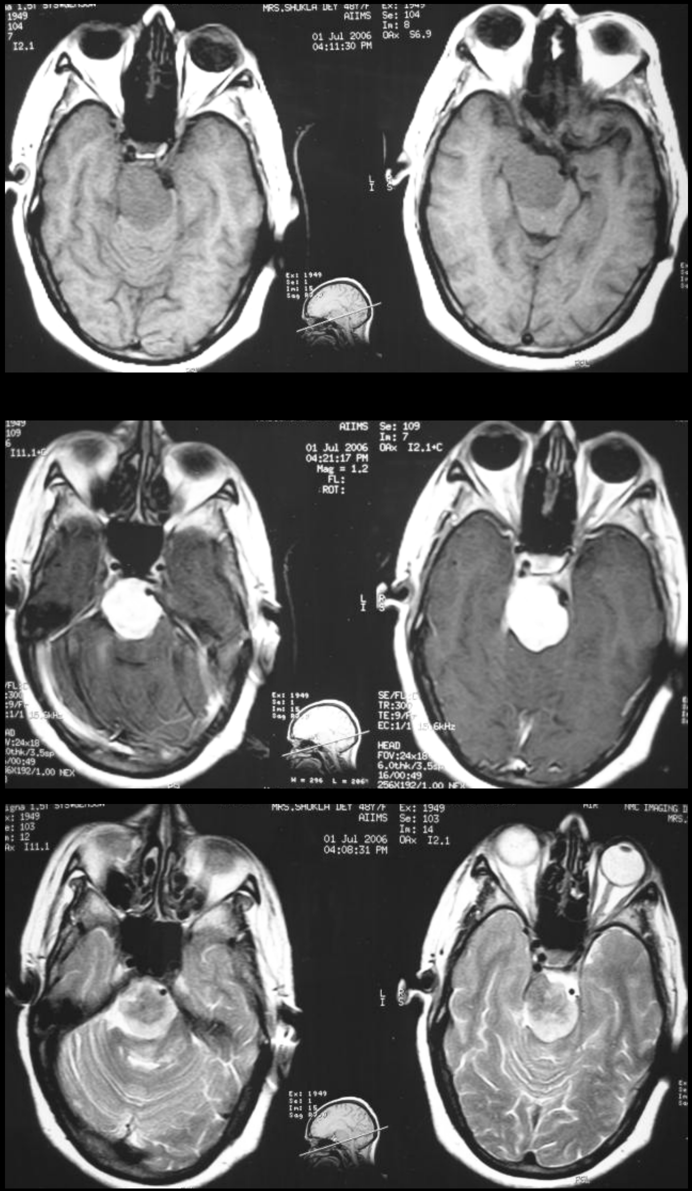
The purpose of IONM is to make the surgical team aware of the ongoing changes in neural function, permitting modifications in surgical strategies that can avoid neural damage

To detect intraoperative cerebral ischemia early enough to allow corrective intervention

Location of lesion and operative approach determine which structures need to be monitored







Brain stem infiltration+

ESTABLISHED TOOLS FOR MONITORING IN SKULL BASE SURGERY

CARDIAC

RESPIRATORY

ANESTHESIA DEPTH

COAGULATION

TEMPERATURE

IONM

INTRAOPERATIVE NEUROPHYSIOLOGICAL MONITORING

EVOKED potentials (EPs) are the electrophysiologic responses of the nervous system to sensory or motor stimulation.

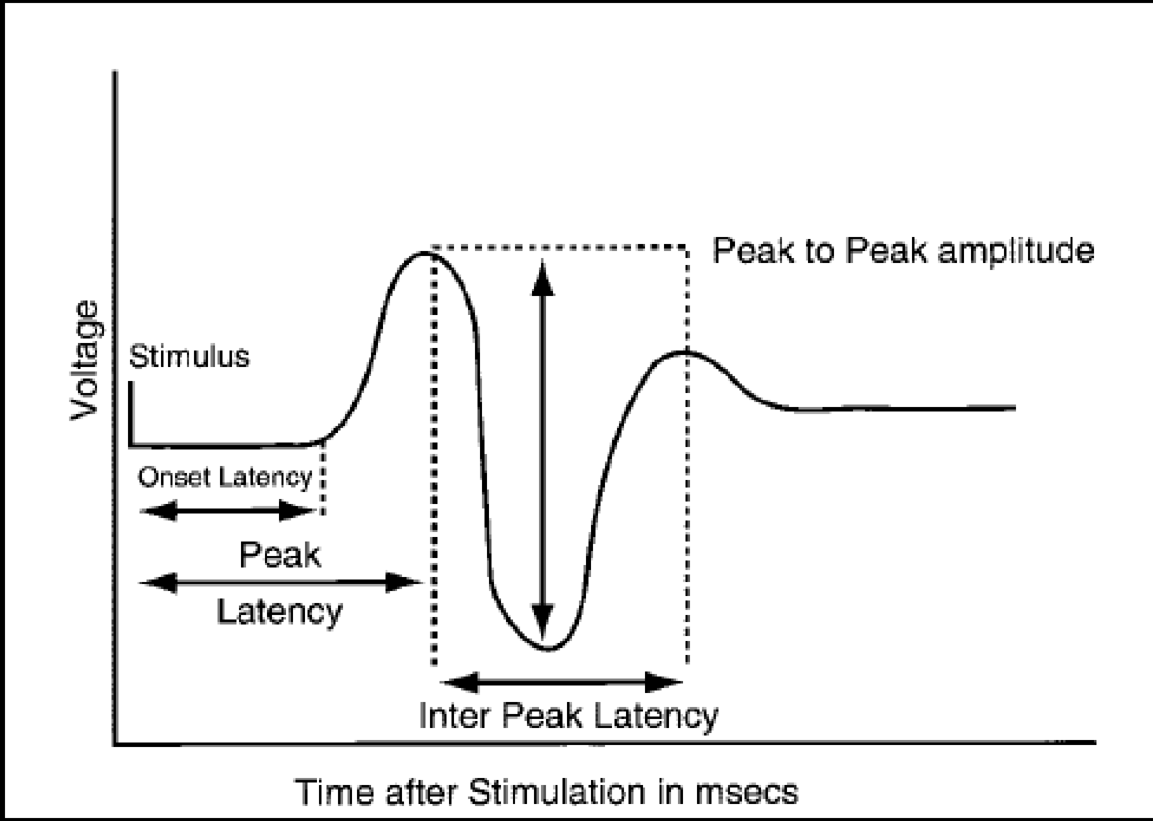
Stimulating the nervous system initiates the transmission of neural signals that may be recorded as EPs from various points along the stimulated pathway.

Somatosensory evoked potentials (SSEPs)

Brainstem auditory evoked potentials (BAEPs)

Motor evoked potentials (MEP)

EVOKED POTENTIAL



Amplitude is measured as the waves'peak-to-peak voltage difference.
Latency is the time from stimulus to the peak of the response.
Interpeak latency is the interval between the peaks of interest

Banoub, Anesthesiology 2003;99:716-37

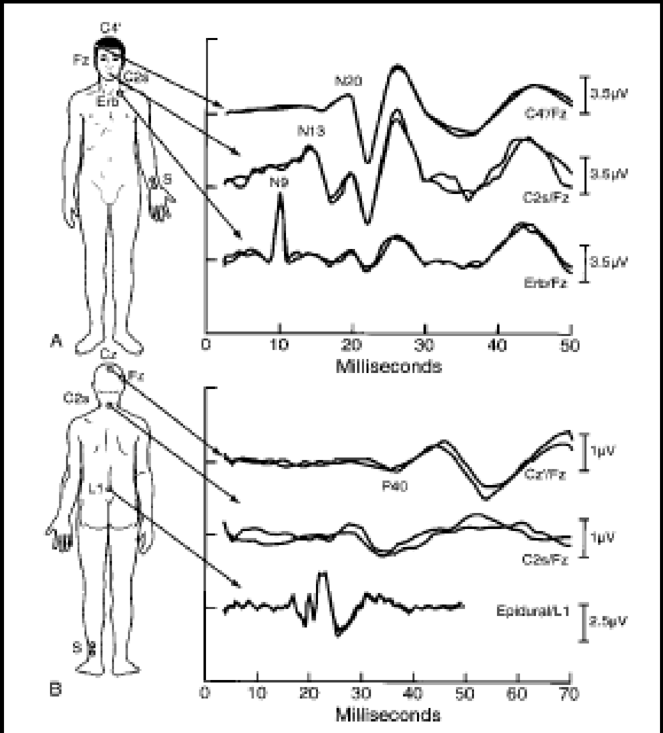
Perioperative applications of SSEP

SSEPs can assess the sensory system from the peripheral nerves through the spinal cord and brainstem to the cerebral cortex.

Median nerve or posterior tibial nerves stimulation

Cortical SSEPs are recorded from scalp overlying the contralateral primary sensory cortex

The central conduction time (CCT): time needed for the signal to travel from the cervicomedullary junction to the contralateral cerebral cortex (N20 to N14 latency diff)



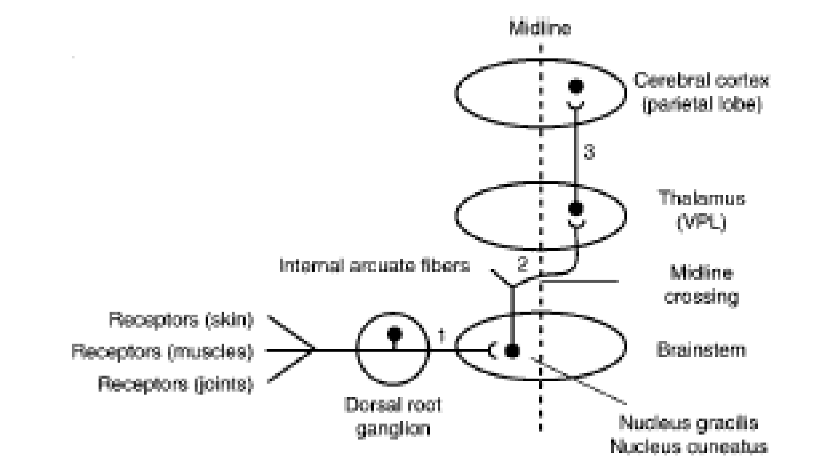
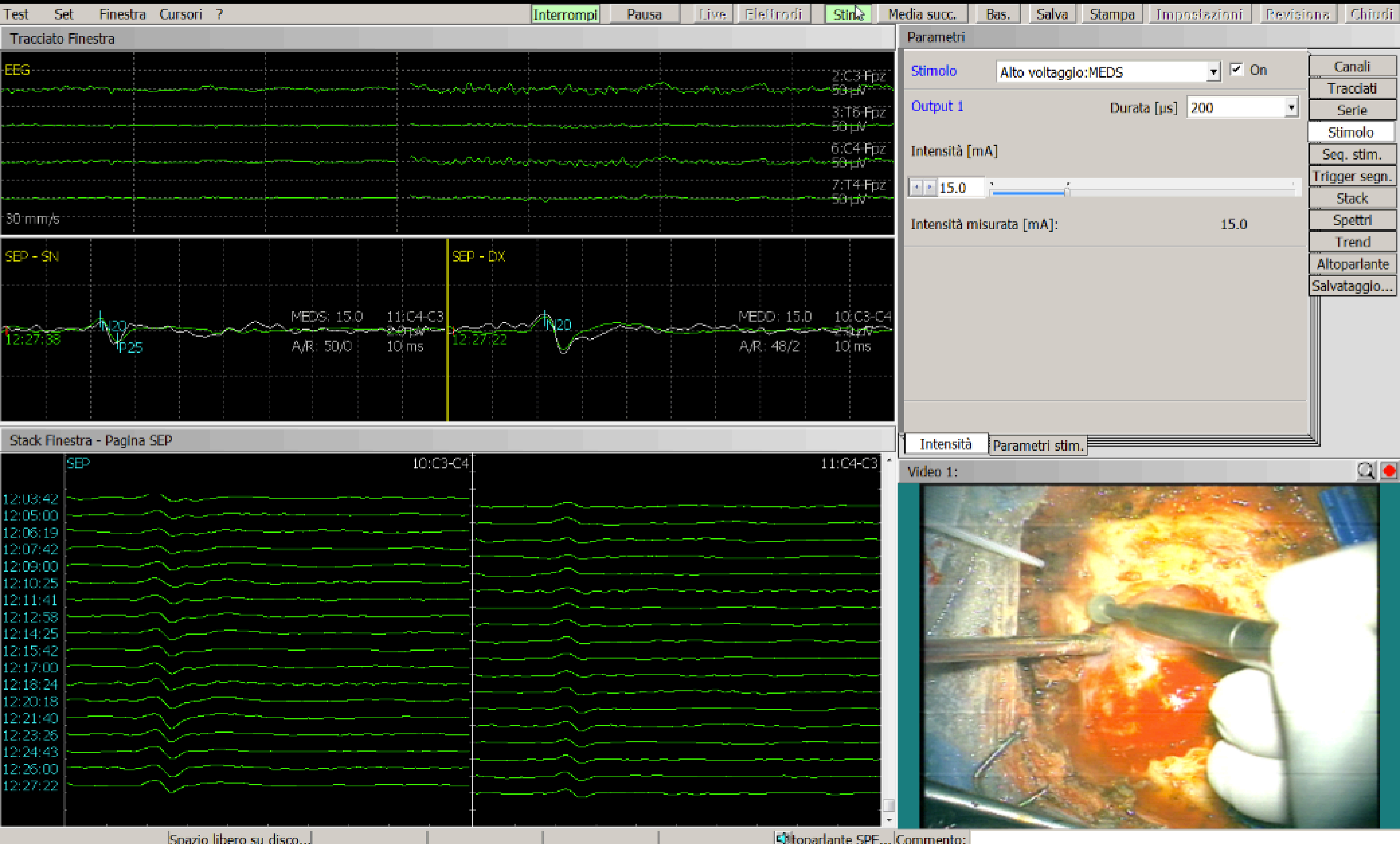


Fig. 2. Three neuron (*1*, *2*, and *3*) organization of dorsal column-medial lemniscal system. VPL = ventral posterolateral. (Redrawn with permission from Bhatnagar SC, Andy OJ: Neuroscience for the Study of Communicative Disorders. Edited by Butler JP. Baltimore, Lippincott Williams & Wilkins, 1995.)

Banoub, Anesthesiology 2003;99:716-37

SSEP MONITORING



What constitutes an important SSEP Change?

↓ **decrease in amplitude of $\geq$ 50%**

↑ **increase in latency of $\geq$ 10%**

Loss of integrity of a neural pathway

Banoub, Anesthesiology 2003

CORRELATION BETWEEN CBF AND SEP

CBF ml/100g/min	SSEP
16-20	reversible decrease in the amplitude
12-15	disappear resulting in electric failure
10-12	ion pump failure or infarction occurs

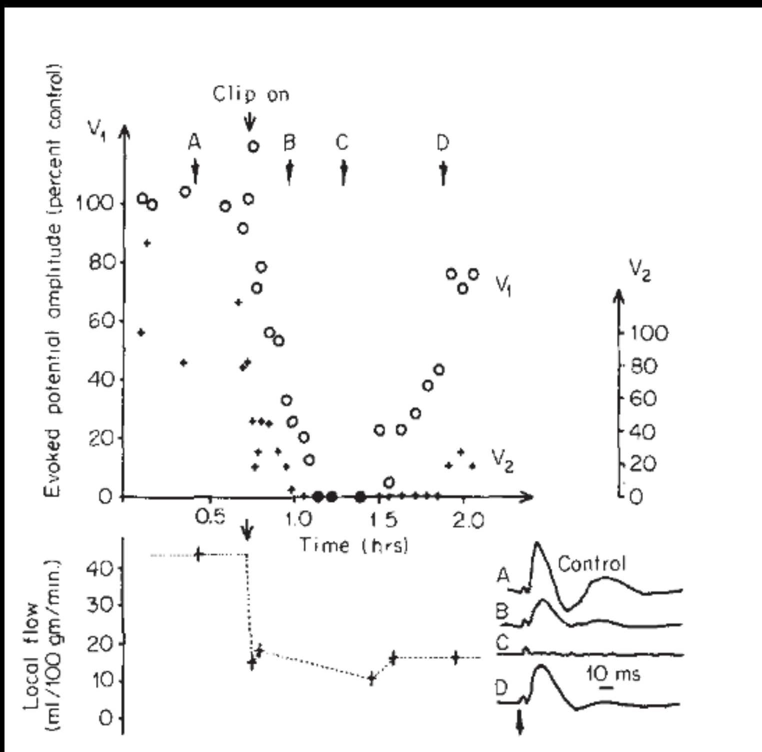
Neurophysiological responses is a precursor of ion pump failure

There is a time window after electric failure before ion pump failure sets in

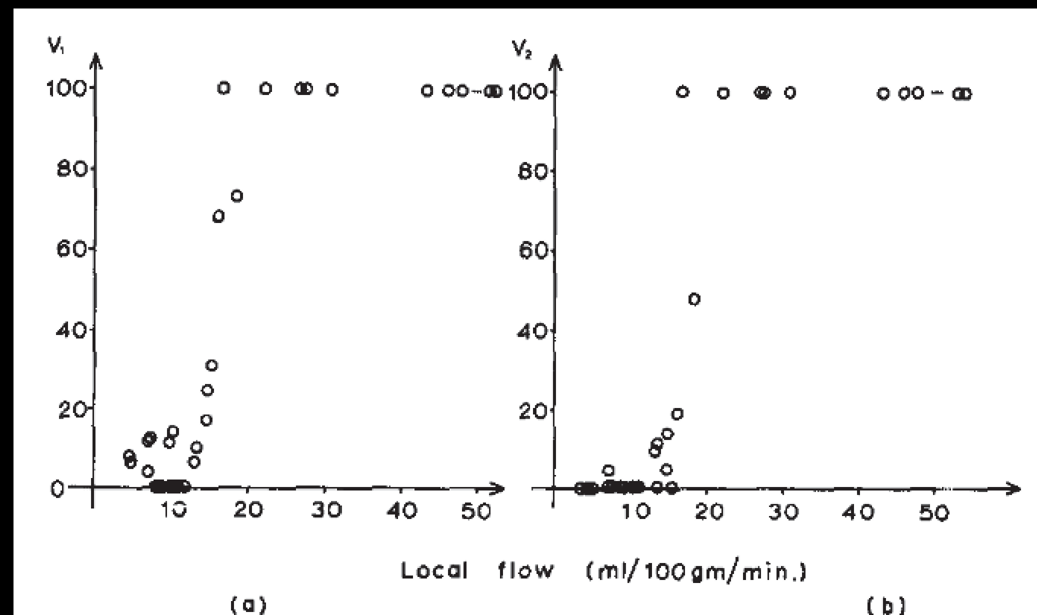
Relationship between the Cortical Evoked Potential and Local Cortical Blood Flow Following Acute Middle Cerebral Artery Occlusion in the Baboon

N. M. Branston, L. Symon, H. A. Crockard, and E. Pasztor [1]

Department of Neurosurgical Studies, Institute of Neurology, The National Hospital, Queen Square, London WC1N 3BG, England



The rate of depression of EP amplitude was highly correlated with the residual flow



EP is fully sustained only when CBF >16 ml/100g/min
EP critically dependent on flow in the range 12-16 ml/100g/min
If CBF < 12ml/100g/min, the EP is abolished

BRANSTON, Experimental Neurology 1974

David C. Warltier, M.D., Ph.D., Editor

Anesthesiology 2003; 99:716–37

Pharmacologic and Physiologic Influences Affecting Sensory Evoked Potentials

Implications for Perioperative Monitoring

Mark Banoub, M.D.,* John E. Tetzlaff, M.D.,† Armin Schubert, M.D., M.B.A.‡

- General anesthesia has an inhibitory effect on neurotransmission and EP
- The effect of anesthetics is greater on synaptic transmission than on axonal conduction
- Effect on SSEP and MEP depends on anesthetics.
  BAEPs (representing brainstem and subcortical activities) are the least sensitive to drug effects. Visual evoked potentials (VEPs)(which represent cortical activity) are very sensitive to the effects of anesthetics while

All volatile anesthetics produce a dose-dependent increase in SSEP latency, an increase in central conduction time and a decrease in amplitude

Table 1. Effect of Inhaled Anesthetics on Somatosensory Evoked Potentials

Anesthetic Drug/Concentration	Early Cortical Waveform‖ Latency	Early Cortical Waveform‖ Amplitude	Subcortical Waveform
Halothane[24,26,34]			
0.5 MAC + 60% N_2O	< 10% ↑	≈60% ↓	Negligible
1.0 MAC + 60% N_2O	< 10% ↑	≈70% ↓	Negligible
1.5 MAC + 60% N_2O	10–15% ↑	≈80% ↓	Negligible
1.5 MAC (alone)	10–15% ↑	≈70% ↓	Negligible
Isoflurane[23–28,31,35,36]			
0.5 MAC + 60% N_2O	< 10% ↑‡	50–70% ↓	Negligible
0.5 MAC (alone)	< 15% ↑	< 30% ↑	Negligible
1.0 MAC + 60% N_2O	10–15% ↑	50–75% ↓	Negligible
1.0 MAC (alone)	15% ↑	≈50% ↓	Negligible
1.5 MAC + 60% N_2O*	> 15% ↑	> 75% ↓	5% ↑ in latency
1.6 MAC (alone)*	15–20% ↑	60–70% ↓	5% ↑ in latency 20% ↓ in amplitude
Enflurane[24–26]			
0.5 MAC + 60% N_2O	< 10% ↑	≈50% ↓	Negligible
0.2–0.6 MAC (alone)	< 10% ↑	< 20% ↓	NA
1.0 MAC + 60% N_2O*	20% ↑	≈85% ↓	Negligible
1.5 MAC + 60% N_2O	Not recordable	Not recordable	Negligible
1.5 MAC (alone)*	> 25% ↑	≈85% ↓	Negligible
Sevoflurane[32,33]			
0.5 MAC + 66% N_2O	< 5% ↑	38% ↓	Negligible
1.0 MAC + 66% N_2O	< 10% ↑	≈45% ↓	Negligible
1.5 MAC + 66% N_2O	< 10% ↑	≈50% ↓	Negligible
1.7–2.5 MAC	10–15% ↑	≈100% ↑§	NA
Desflurane[38,39]			
0.5 MAC	<5% ↑	<20% ↓	Negligible
1.0 MAC	3–8% ↑	30–40% ↓	Negligible
1.5 MAC	≤ 10% ↑	< 50% ↓	Negligible
Any with 65% N_2O†	≥ 15% ↑	> 60% ↓	Negligible
Nitrous oxide[39,41,47]			
60–65 %	No effect	50–55% ↓	Negligible

Banoub, Anesthesiology 2003;99:716-37

Intravenous anesthetics generally affect SSEPs less than inhaled anesthetics

Table 3. Effect of Intravenous Anesthetics on Somatosensory Evoked Potentials

Drug/Dose	Early Cortical Waveform§ Latency	Early Cortical Waveform§ Amplitude	Subcortical Waveform
Thiopental[43,50,51,53]			
2.5–5.0 mg/kg	<10% ↑	5–30% ↓	Negligible
75 mg/kg	15% ↑	60% ↓	Negligible
Pentobarbital[54,55]			
Up to 20 mg/kg	≈10% ↑	45% ↓	None (latency) 20% ↓ (amplitude)
Ketamine[44,63,236,237]			
0.5 mg/kg	No effect	No effect	No effect
2–3 mg/kg + 2 $mg \cdot kg^{-1} \cdot h^{-1}$	No effect	0–30% ↑	Negligible
Etomidate[43,50,56]			
0.3–0.4 mg/kg + 2 $mg \cdot kg^{-1} \cdot h^{-1}$	<10% ↑	40–180% ↑	None (latency) 50% ↓ (amplitude)
1 mg/kg	10% ↑	150% ↑	Negligible
Propofol[62]			
2.5 mg/kg	< 10% ↑	No change	Negligible
Propofol			
2.5 mg/kg, then 10 $mg \cdot kg^{-1} \cdot h^{-1}$ + sufentanil[48] 0.5 μg/kg, then 0.25 $\mu g \cdot kg^{-1} \cdot h^{-1}$	10–15% ↑	50%	NA
Midazolam[43,63,65,238]			
0.1–0.3 mg/kg*	< 5% ↑	25–40% ↓	Negligible
Diazepam[66,69]			
0.1–0.25 mg/kg	Minimal	↓	NA
Morphine[72]			
0.25 mg/kg	< 10% ↑	≈20% ↓	NA
Lidocaine[74, 239, 240]			
1.5 mg/kg, then 3 $mg \cdot kg^{-1} \cdot h^{-1}$	5% ↑	25–30% ↓†	Negligible
Fentanyl[28,50,71,72]			
2.5 μg/kg + N_2O	5–10% ↑	Variable‡	No change
25–100 μg/kg	<10% ↑	10–30% ↓	Negligible
Sufentanil[68,73,74]			
Sufentanil + N_2O + 0.5%isoflurane/1 μg/kg + infusion	5–10% ↑	≈50% ↓	No change
5 μg/kg Sufentanil (alone)	≈5% ↑	≈40% ↓	No change (latency) Amplitude: 40% ↓
1 μg/kg + Sufentanil propofol	5–10% ↑	No change	NA
Remifentanil[76] (with 0.4 MAC isoflurane)			
1 μg/kg + 0.2 $\mu g \cdot kg^{-1} \cdot min^{-1}$	NA	15–30% ↓	NA
2.5 μg/kg + 0.5 $\mu g \cdot kg^{-1} \cdot min^{-1}$		30–40% ↓	
5.0 μg/kg + 1.0 $\mu g \cdot kg^{-1} \cdot min^{-1}$		≈40% ↓	
Clonidine[84–86]			
2–10 μg/kg	No effect	No effect	10% Amplitude ↓ No effect (latency)
Alfentanil[75,241]			
10 μg/kg alone	NA	50% ↓	NA
100 μg/kg + 2 with N_2O	No effect	40% ↓	NA
Dexmedetomidine[87]			
Low sedative dose	NA	≈10% ↓	≈20% Amplitude ↓
High sedative dose	NA	≈30% ↓	≈10% Amplitude ↓

Banoub, Anesthesiology 2003;99:716-37

Neuroscience in Anesthesiology and Perioperative Medicine

Section Editor: Gregory J. Crosby

Dexmedetomidine Does Not Affect Evoked Potentials During Spine Surgery

Irene Rozet, MD,*† Julia Metzner, MD,* Marcia Brown, MD,* Miriam M. Treggiari, MD, PhD,* Jefferson C. Slimp, PhD,‡ Greg Kinney, PhD,‡ Deepak Sharma, MD,* Lorri A. Lee, MD,§ and Monica S. Vavilala, MD||

40 patients, spine surgery, total IV anesthesia with propofol and remifentanil randomly assigned To either dexmedetomidine or placebo in a double-blind, placebo-controlled trial

Table 3. Primary Outcomes

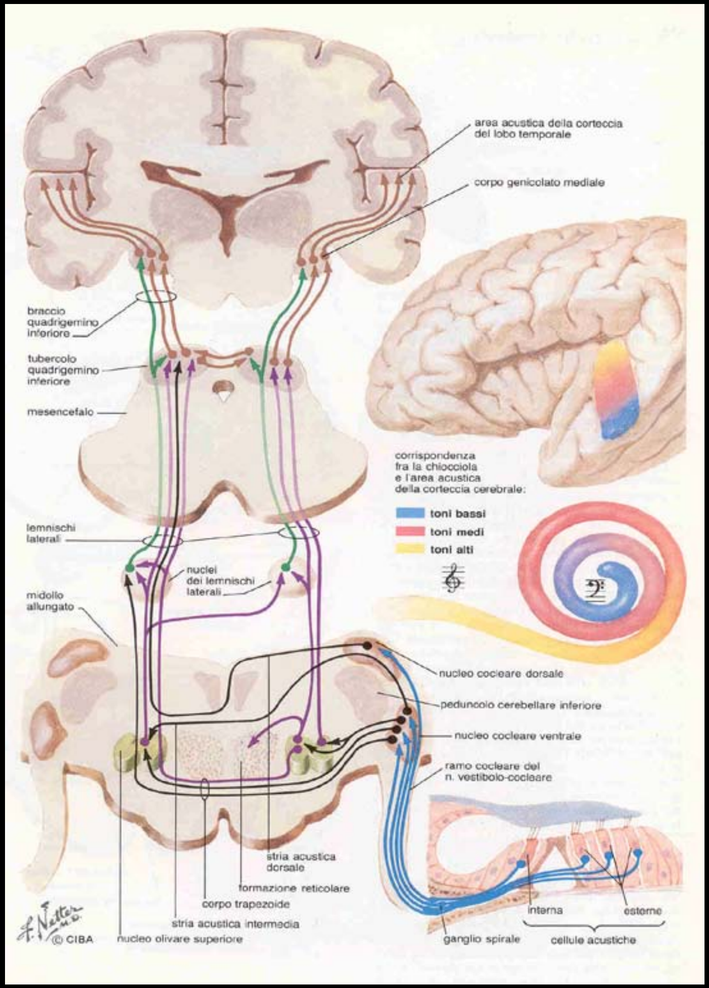
	Placebo	Dexmedetomidine	P value (95% CI)
SSEP	*n* = 20	*n* = 20	
Latency P37	0.01 ± 1.3 (−0.64, 0.65)	0.4 ± 1.2 (−0.2, 0.62)	0.43 (−1.24, 0.45)
Amplitude N33-P37	−0.01 ± 0.13 (−0.07, 0.05)	−0.03 ± 0.14 (−0.06, 0.02)	0.76 (−0.074, 0.1)
MEP	*n* = 16	*n* = 18	
Amplitude	109.2 ± 241.4 (−24, 243)	65.1 ± 194.8 (−35, 165)	0.57 (−113.5, 241.57)
VEP	*n* = 14	*n* = 11	
Latency N1			
Right eye	0.3. ± 6.0 (−3.3, 3.9)	2.3 ± 3.6 (−0.4, 5.1)	0.38 (−6.7, 2.6)
Left eye	0.6 ± 6.2 (−3.2, 4.4)	−0.17± 2.5 (−2.1, 1.7)	0.36 (−6.7, 26)
Latency P1			
Right eye	−1.4 ± 8.1 (−6.3, 3.5)	−1.6 ± 13.4 (−11.9, 8.7)	0.97 (−9.3, 9.7)
Left eye	0.7 ± 6.2 (−3.1, 4.4)	1.4 ± 5.4 (−2.7, 5.5)	0.78 (−6.0, 4.7)
Amplitude N1-P1			
Right eye	−0.34 ± 1.2 (−1.1, 0.4)	−0.6 ± 1.6 (−1.9, 0.69)	0.7 (−1.0, 1.5)
Left eye	0.04 ± 1.8 (−1.1, 1.15)	−0.23 ± 1.1 (−1.1, 0.6)	0.69 (−1.1, 1.67)

Primary outcome is a change from baseline to T1. Latency was measured in milliseconds, and amplitude was measured in microvolts. Data are presented as mean ± SD and 95% CI.

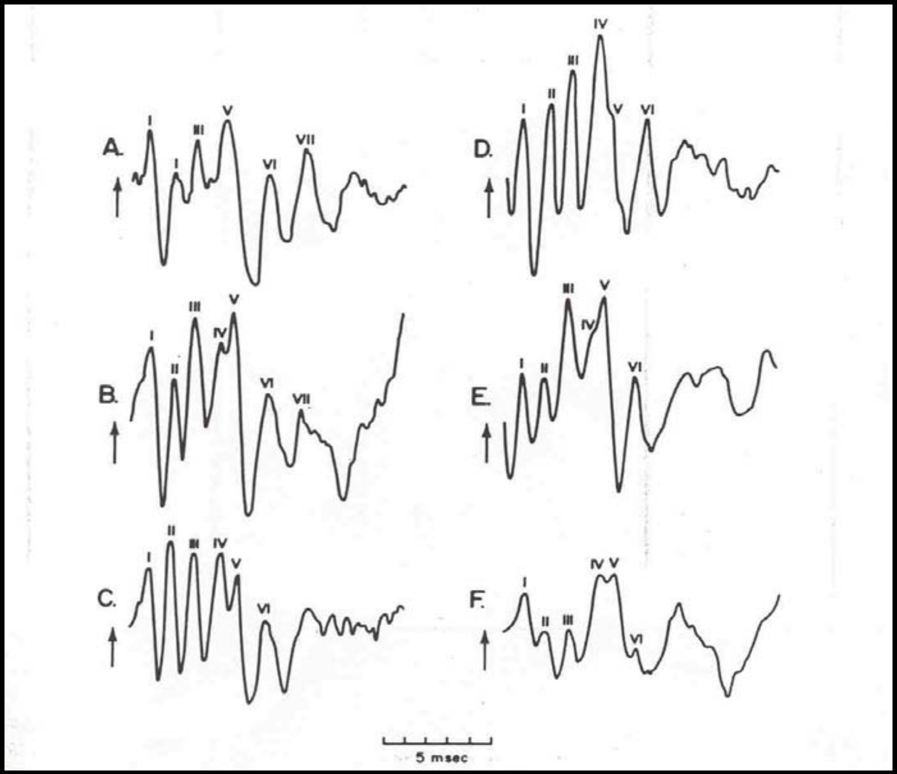
Dexmedetomidine at dose of 0.6 µg /kg/h as an adjunct to TIVA does not seem to impair SSEPs, MEPs, and VEP

Rozet, Anesthesia Analgesia 2015

Brainstem Auditory Evoked Potentials (BAEP)



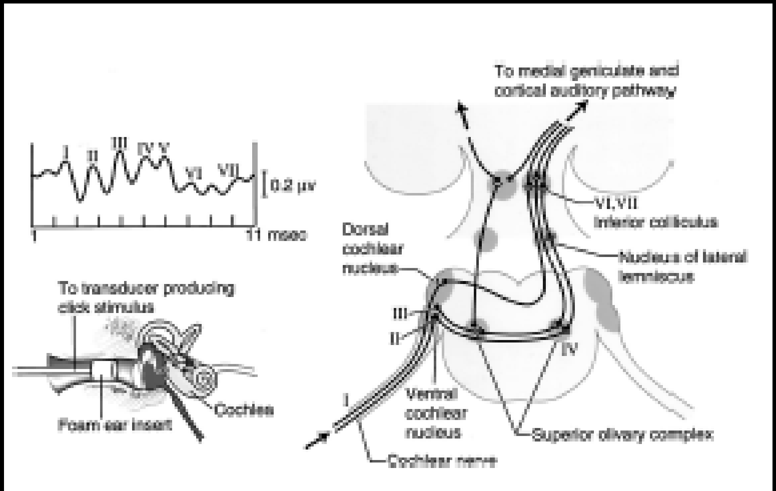
Risposte evocate tronco-encefaliche



Potenziali evocati acustici a breve latenza

Rappresentano l'attività elettrica lungo la via uditiva, dal nervo acustico nel suo tratto più distale al tronco encefalico, in risposta a stimoli acustici.

Brainstem Auditory Evoked Potentials (BAEP)



To assess the structural integrity of the brainstem during certain surgical procedures in the posterior cranial fossa, e.g. , resection of acoustic neuromas and other cerebellopontine tumors, as well as microvascular decompression of the trigeminal and facial nerves

Table 4. Anesthetic Effect on Brainstem Auditory Evoked Potentials

Anesthetic Drug	Dose/Concentration	Latency Wave V	Amplitude Wave V
Volatile agents[27,36,122–130]	Up to 1.5 MAC	<10% ↑	No effect
Nitrous oxide[132–134*]	50%	No effect	Inconsistent
Thiopental[53,131]	4–6 mg/kg	No effect	No effect
	75 mg/kg	≈10% ↑	< 20% ↓
Pentobarbital[54,55]	Up to 20 mg/kg	< 5% ↑	No effect
Propofol[135–137]	10–50 µg · kg^{-1} · min^{-1}	No effect	No effect
Etomidate[138]	10–15 mg	No effect	No effect
Midazolam[145]	0.2–0.3 mg/kg	No effect	NA
Diazepam[145]	0.3–0.4 mg/kg	No effect	NA
Fentanyl[141,142]	10–50 µg/kg	No effect	No effect
Morphine/scopolamine[144]†	10 mg Morphine	No effect	40% Amplitude ↓
Premedication[141]	0.4 mg scopolamine		
Sufentanil[143]	5 µg/kg	No effect	NA
Alfentanil[142]	100–500 µg/kg	No effect	No effect
Morphine[142]	1–3 mg/kg	No effect	No effect
Lidocaine[242,243]	60 µg · kg^{-1} · min^{-1}	< 5% ↑‡	No effect
Ketamine[140]	2 mg/kg	No effect	No effect
Clonidine[86]	10 µg/kg	No effect	No effect

Neurophysiologic Changes in BAEPs

Related to systemic factors

- Hypotension
- Blood loss
- Hypothermia

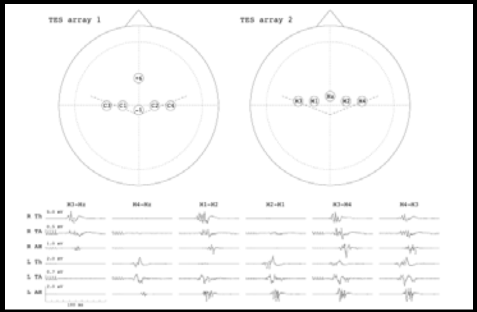
Related to injurious surgical maneuvers

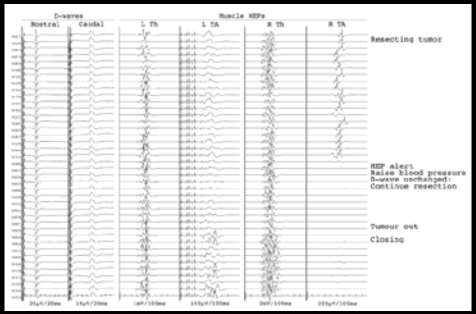
- Early drilling
- Cerebellar retraction
-Tumor dissection and removal
- Vasospasm
-Dura closure

Simon, J Clinical Neurophysiology 2011

Motor evoked potential (MEP)

For cortical and subcortical mapping and for monitoring during surgeries risking motor injury in the brain, brainstem, spinal cord or facial nerve





Amplitude ratio of Final to initial MEPs

> 50% = MEPs were considered to be stable

< 50% = deterioration
10-50% : mild deterioration
<10% : severe deterioration
0% : MEP loss

Muscle MEP monitoring is consistently successful under total intravenous anesthesia that is widely recommended as optimal

Muscle MEP thresholds are higher and success rates lower with inhalational anesthesia that is therefore suboptimal

Neuromuscular blockade omitted for muscle MEPs

Clinical Neurophysiology 2013

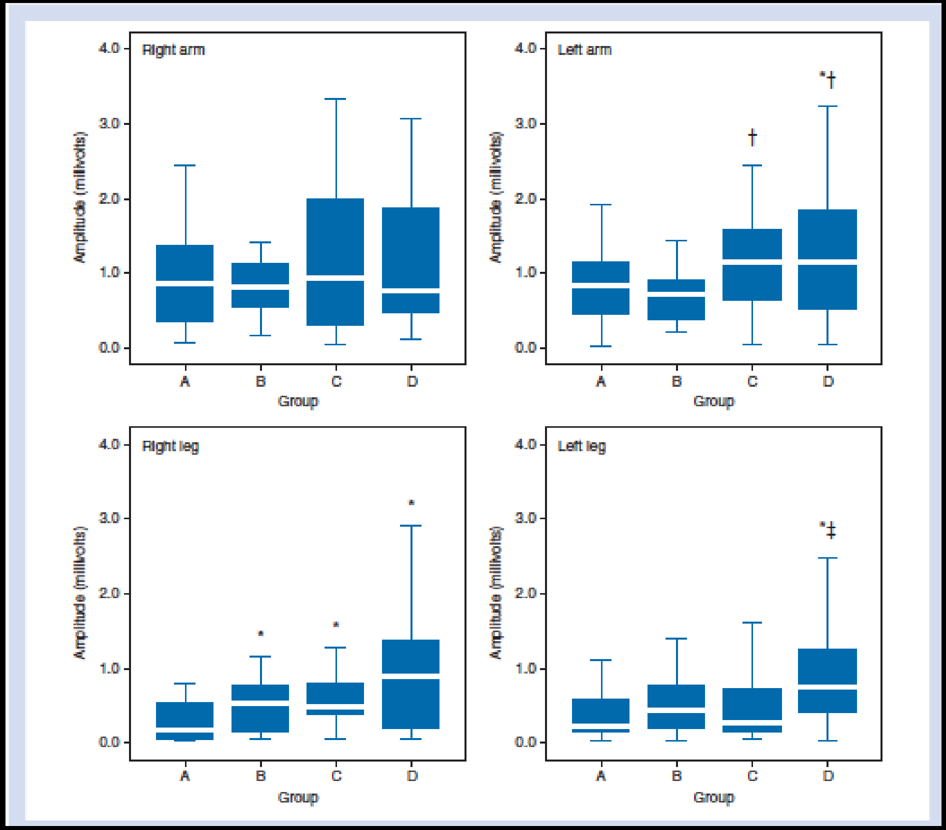
British Journal of Anaesthesia **110** (4): 567–76 (2013)
Advance Access publication 1 February 2013 · doi:10.1093/bja/aes395

BJA

NEUROSCIENCES AND NEUROANAESTHESIA

Comparison of motor-evoked potentials monitoring in response to transcranial electrical stimulation in subjects undergoing neurosurgery with partial *vs* no neuromuscular block†

W. H. Kim[1], J. J. Lee[1*], S. M. Lee[1], M. N. Park[1], S. K. Park[2], D. W. Seo[2] and I. S. Chung[1]



A : 2 count response of TOF

B : 0.5 twitch height of the first evoked response of TOF stimulation (T1) compared with the control twitch (Tc);

C: 0.5 twitch height of the second evoked response of TOF stimulation (T2) compared with Tc.

D: NO vecuronium infusion

Conclusions. If NMB is used during MEP monitoring, a target T_2/Tc of 0.5 is recommended. In terms of the MEP amplitude and variability, no NMB was more desirable than any level of partial NMB.

Confounding factors

Rostral or contralateral control MEPs can help identify some of these factors

GENERALIZED
Gradual MEP reductions: systemic factors such as anesthesia or fade.
Abrupt reduction: stimulus failure, drug boluses, abrupt hypotension, NMB or bilateral intracranial air during sitting position.
Cortical SEP and EEG traces can provide clues about systemic changes.

FOCAL
Focal MEP deterioration is the hallmark of surgical neurologic compromise
Confounding focal muscle MEP deterioration: shoulder malpositioning or limb pressure or ischemia. Peripheral SEPs can help to identify these problems.
Confounding lateralized deterioration: asymmetric intracranial air during sitting position; skull X-ray can demonstrate it.

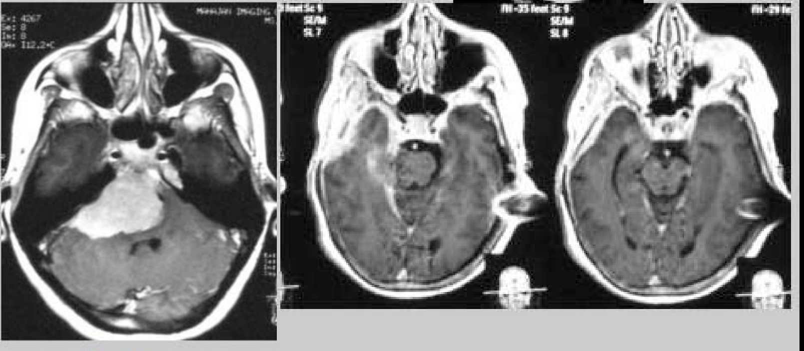
Clinical Neurophysiology 2013;124:2291-2316

Guidelines

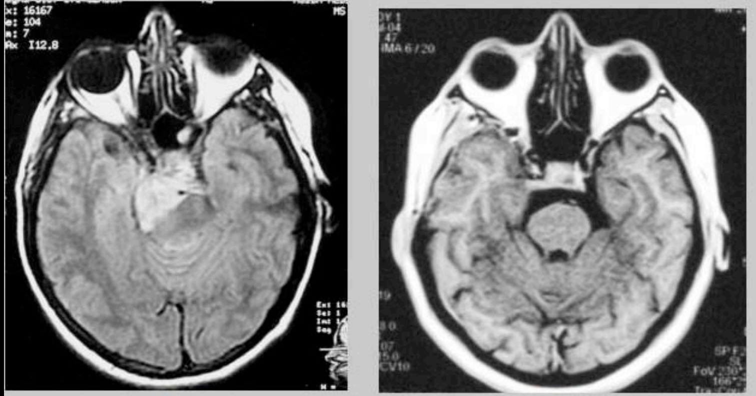
Intraoperative motor evoked potential monitoring – A position statement by the American Society of Neurophysiological Monitoring

D.B. MacDonald [a,*], S. Skinner [b], J. Shils [c], C. Yingling [d]

A. Appropriately qualified personnel should acquire and interpret intraoperative MEPs (Class III, Type C).
B. Intraoperative MEP techniques are sufficiently safe for clinical use in qualified hands using appropriate precautions (Class II and III, Type B).
C. Intraoperative MEPs are an established practice option for localizing motor cortex, judging subcortical proximity to corticospinal tract fibers and monitoring motor pathways during surgical procedures that risk motor system injury in the brain, brainstem, spinal cord or facial nerve (Class II and III, Type B).
D. Total intravenous anesthesia usually based on propofol and opioid infusion is optimal for muscle MEP monitoring. Benzodiazepines, ketamine and etomidate may be suitable intravenous alternatives. Inhalational anesthetic agents are suboptimal and discouraged unless medically necessary. This does not exclude the development of new anesthetic protocols. (Class II and III, Type B).
E. Interpretation should consider limitations and confounding factors (Class III, Type C):
   1. Commonly used anesthetic drugs, physiological parameters and other confounding factors affect MEPs. Monitoring should include tracking of anesthetic dosages and physiological parameters, and rostral or contralateral control MEPs when possible.
   2. Muscle MEPs exhibit substantial intrinsic variability and a tendency to gradual amplitude fade and threshold elevation.
   3. Intraoperative MEPs cannot predict motor deficits of inadequately monitored structures or arising postoperatively.
F. Warning criteria for D-waves are based on amplitude reduction having no apparent confounding factor explanation.
   1. Intramedullary spinal cord tumor surgery: >50% reduction (Class II and III, Type B).
   2. Brain surgery with DCS cervical D-waves: >30–40% reduction (Class III, Type C).
   3. Orthopedic spine and other surgeries: No established criterion (Class III, Type U).
G. Warning criteria for muscle MEPs may need to be tailored to monitoring situations and are based on deterioration clearly exceeding spontaneous variability with no apparent confounding factor explanation.
   1. Spinal cord: Disappearance is always a major criterion (Class II and III, Type B). Depending on the monitoring program's technique and experience:
      i. For IMSCT surgery, marked amplitude reduction, acute threshold elevation or morphology simplification could be additional minor criteria (Class II and III, Type C).
      ii. For orthopedic spine surgery, marked amplitude reduction or acute threshold elevation could be additional moderate criteria (Class II and III, Type C).
      iii. For descending aortic surgery, marked amplitude reduction could be an additional moderate criterion (Class II and III, Type C).
   2. Brain and brainstem: Major criteria include disappearance or consistent >50% amplitude reduction when warranted by sufficient response stability, or amplitude reduction clearly exceeding variability when responses are less stable (Class III, Type C). Acute threshold elevation might be relevant (Class III, Type U).



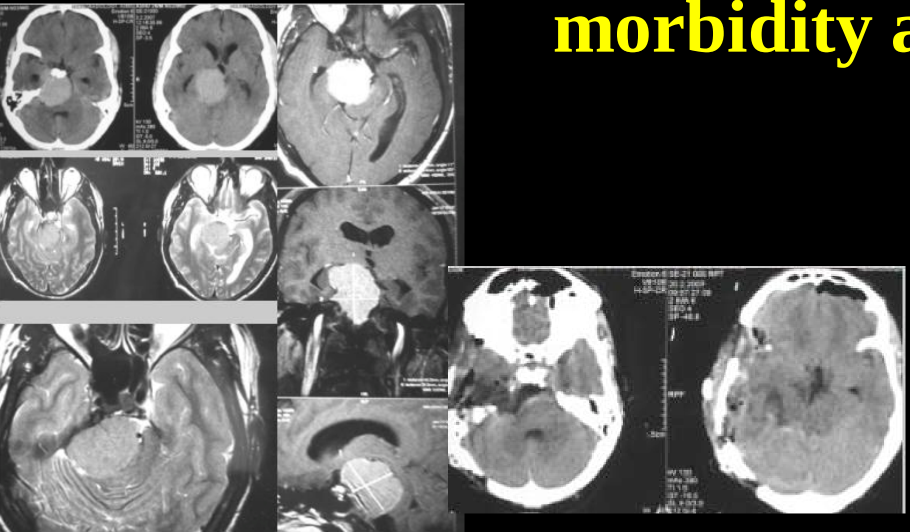
Pre op Post op

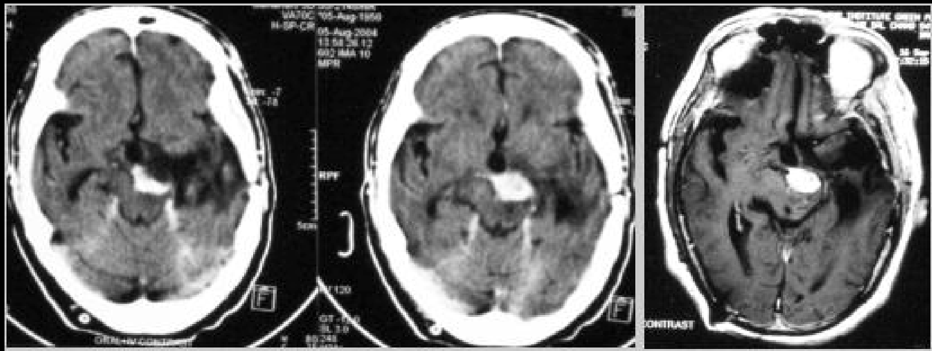


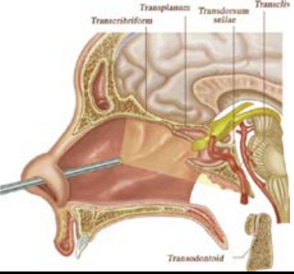
Pre op Post op

INTRAOPERATIVE NEUROPHYSIOLOGICAL MONITORING
DURING SKULL BASE SURGERY

Does it affect morbidity and mortality?







Somatosensory Evoked Potential Monitoring During Endoscopic Endonasal Approach to Skull Base Surgery: Analysis of Observed Changes

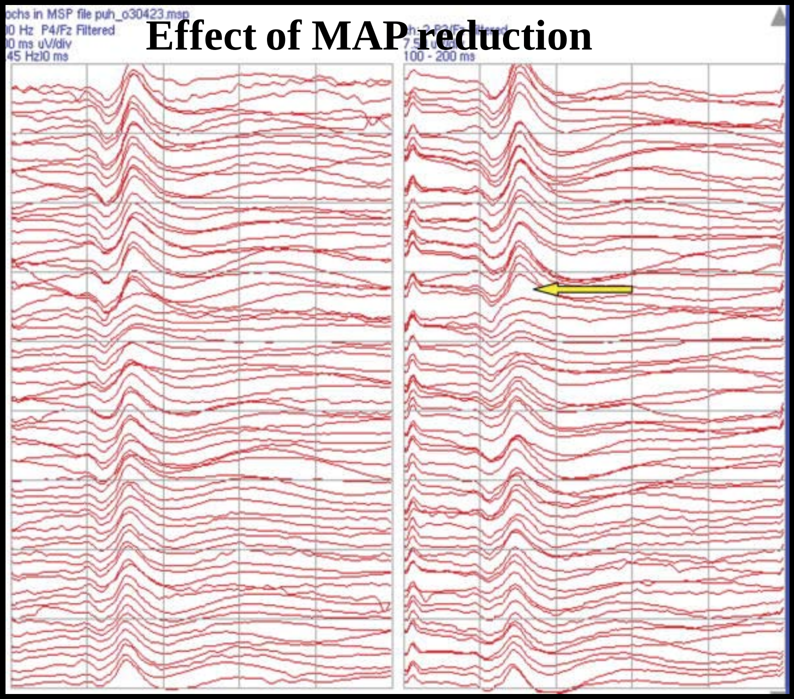
Retrospective on 976 pt - SSEP monitoring and documented postoperative neurol exam

Changes in SSEP 2%
Postop neurol deficits 0.5%
Positive predictive value: 80%, Negative predictive value: 99.79%
sensitivity : 88.89% specificity: 99.58%

TABLE 6. Intraoperative Somatosensory Evoked Potential Monitoring Results and Postoperative Neurologic Status in a 2 × 2 Table[a]

	Impending or Resultant Intraoperative Injury/ New Postoperative Neurological Deficit	
	Yes	No
Significant intraoperative SSEP signal change[b]		
Yes, n	17 (TP)	3 (FP)
No, n	2 (FN)	954 (TN)
Data in percentage of the entire cases,	Yes	No
Yes, %	1.74	0.31
No, %	0.20	97.75

[a]FN, false negative; FP, false positive; SSEP, somatosensory evoked potential; TN, true negative; TP, true positive.
[b]Defined as >50% decrease in amplitude and/or >10% increase in response in latency.



Thirumala, Neurosurgery 2011

Conjunct SEP and MEP monitoring in resection of infratentorial lesions: lessons learned in a cohort of 210 patients

Occurrence of changes in MEPs and SEPs and association with neurological outcome

210 cases: skull base (n = 104), cerebellum (n = 63), fourth ventricle (n = 28), brainstem (n = 12), foramen magnum (n = 3)

Alterations of SEPs and/or MEPs : 18.6%

High correlation between changes in IONM and outcome

Results. Of 210 surgeries, 171 (81.4%) were uneventful with respect to long-tract monitoring. Nine (23%) of the 39 SEP and/or MEP alterations were transient and were only followed by a slight permanent deficit in 1 case. Permanent deterioration only was seen in 19 (49%) of 39 cases; the deterioration was related to tumor dissection in 4 of these cases, and permanent deficit (moderate-severe) was seen in only 1 of these 4 cases. Eleven patients (28%) had losses of at least 1 modality, and in 9 of these 11 cases, the loss was related to surgical microdissection within the vicinity of the brainstem. Four of these 9 patients suffered a moderate-to-severe long-term deficit. For permanent changes, the positive predictive value for neuromonitoring of the long tracts was 0.467, the negative predictive value was 0.989, the sensitivity was 0.875, and the specificity 0.918. Twenty-eight (72%) of 39 SEP and MEP alterations occurred in 66 cases involving intrinsic brainstem tumors or tumors adjacent to the brainstem. Lesion location and alterations in intraoperative neuromonitoring significantly correlated with patients' outcome ($p < 0.001$, chi-square test).

Conclusions. In summary, long-tract monitoring with SEPs and MEPs in infratentorial surgeries has a high sensitivity and negative predictive value with respect to postoperative neurological status. It is recommended especially in those surgeries in which microdissection within and in the vicinity of the brainstem might lead to injury of the brainstem parenchyma or perforating vessels and a subsequent perfusion deficit within the brainstem.

KODAMA, J Neurosurg 2014;121:1453-1461

Feasibility of intraoperative motor-evoked potential monitoring for skull base tumors with a high risk of postoperative motor deterioration

76 procedures

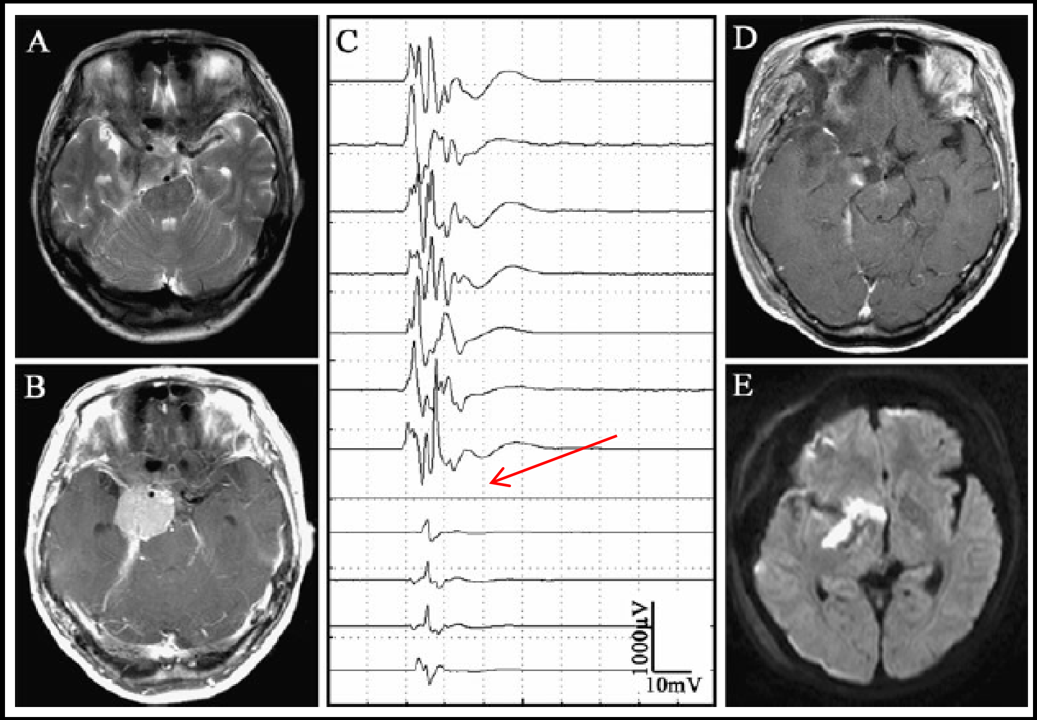
Table 3 Relationship between intraoperative MEP change and postoperative motor score

MEP change		Number of cases	Postoperative motor score					
			5/5	4/5	3/5	2/5	1/5	0/5
Stable (>50%)	W/o TW	56	53 cases	3 cases*1				
	With TW	7	6 cases		1 case*2			
Mild (10 to 50 %)	W/o TL	3	3 cases					
	With TL	2			1 case	1 case		
Severe (1 to 9%)	W/o TL	2				1 case	1 case	
	With TL	1					1 case	
MEP loss		5					3 cases	2 cases*3

Transient or permanent deterioration : 26.3%

Reversible 9.2%
Irreversible 17.1%

Irreversible loss (6.6%)
= severe hemiparesis



Hashiguchi, Acta Neurochir 2011; 153:1191-1200

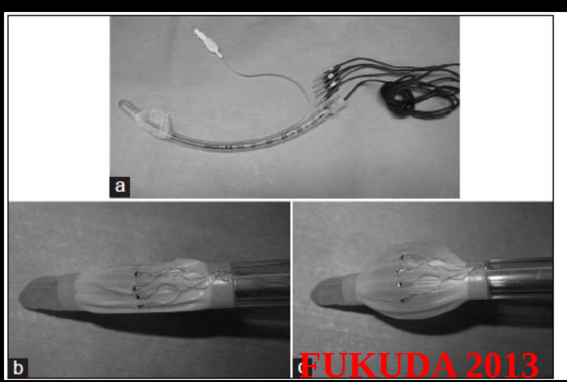
CRANIAL NERVE MONITORING

J Neurosurg 116:605–610, 2012

Pharyngeal motor evoked potentials elicited by transcranial electrical stimulation for intraoperative monitoring during skull base surgery

Skull base tumors involving the vagus and glossopharyngeal nerves

Swallowing function evaluated 1 week postop: 0=normal; 1= mild dysfunction; 2= severe



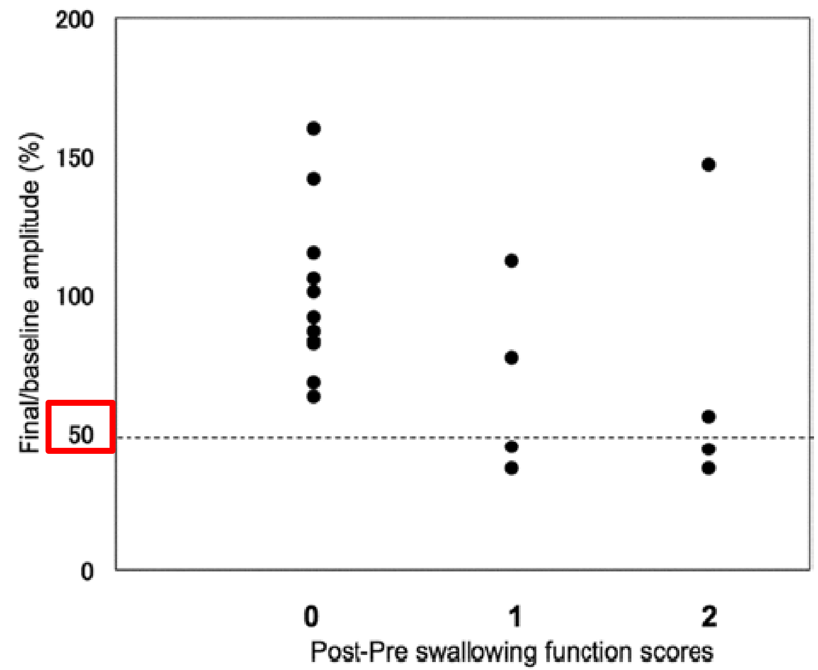


FIG. 3. Correlation between postoperative swallowing deterioration (postoperative – preoperative grade) and the final/baseline PhMEP ratio. Postoperative deterioration of swallowing function was significantly correlated with the final/baseline PhMEP ratio ($r = -0.47$, $p < 0.05$).

Intraoperative MEP can be useful for predicting swallowing deterioration

Fukuda 2012

Pharyngeal Motor Evoked Potential Monitoring During Skull Base Surgery Predicts Postoperative Recovery from Swallowing Dysfunction

Masafumi Fukuda, Tetsuro Takao, Tetsuya Hiraishi, Naoki Yajima, Akihiko Saito, Yukihiko Fujii

PhMEP monitoring to predict outcomes of swallowing function in the postop recovery period

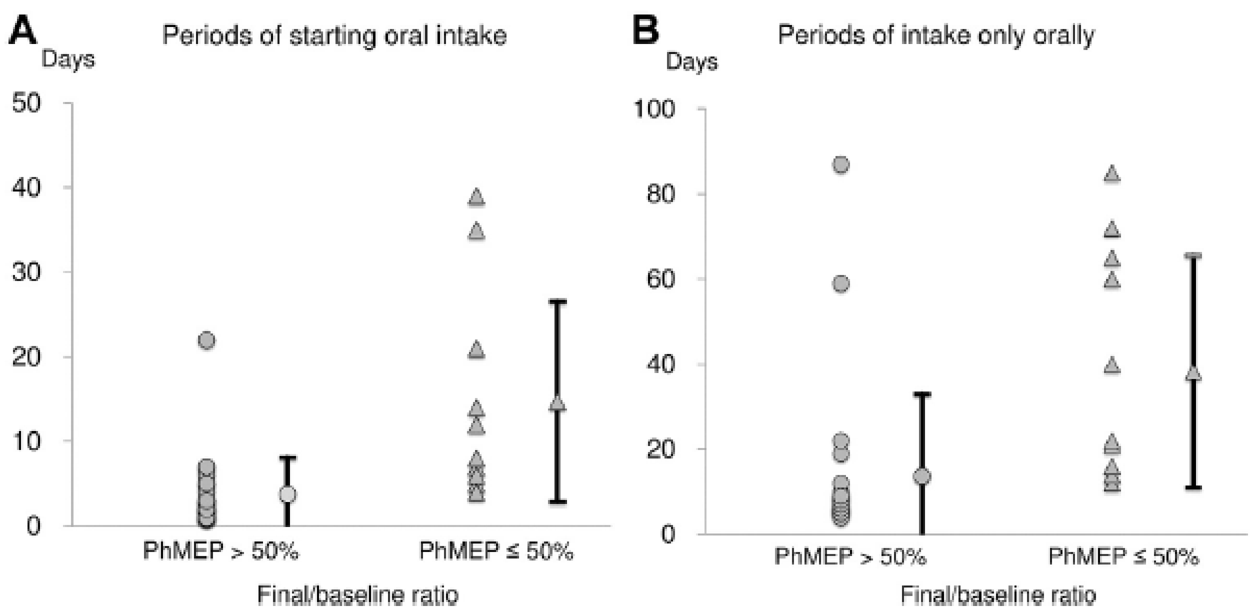
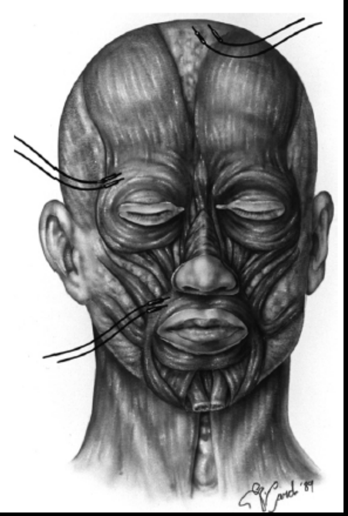


Figure 3. Scatter plots comparing periods to the start of oral intake (**A**) and oral intake only (**B**) in patients with final/baseline PhMEP ratios >50% and ≤50%. Patients with a PhMEP ratio >50% had shorter periods than those with a PhMEP ratio ≤50%. Error bars represent means ± SD ($P < 0.05$).

PhMEP ratios >50% = faster recovery outcomes not only immediately after surgery but also in the period of recovery from swallowing dysfunction

FUKUDA World Neurosurgery 2015



Intraoperative Facial Nerve Monitoring

Helps in localization of the nerve displaced by tumor distortion, detects nerve injury during dissection and provides a means for assessing nerve function after dissection is complete

Intraoperative neurophysiological monitoring during endoscopic endonasal surgery for pediatric skull base tumors

Cheran Elangovan, MBBS,[1] Supriya Palwinder Singh, MBBS,[1] Paul Gardner, MD,[1] Carl Snyderman, MD,[1,3] Elizabeth C. Tyler-Kabara, MD, PhD,[1] Miguel Habeych, MD, MPH,[1] Donald Crammond, PhD,[1] Jeffrey Balzer, PhD,[1,4] and Parthasarathy D. Thirumala, MD, MS[1,2]

159 PEDIATRIC procedures- EMG, BAEPs,SSEPs to predict and/or prevent postoperative deficits

For BAEPS: Persistent decrease in amplitude ≥50% of wave V
And/or persistent absolute latency increase of the peak of wave V ≥0.5 msec

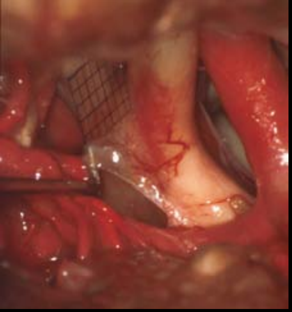
TABLE 1. Monitored CNs and muscle groups

CN	Monitored Muscle Group
Occulomotor nerve	Medial rectus muscle
Trochlear nerve	Superior oblique muscle
Abducent nerve	Lateral rectus muscle
Trigeminal nerve	Masseter
Facial nerve	Orbicularis oris, orbicularis oculi, & mentalis (ipsilateral)
Motor component of the glosso-pharyngeal nerve	Soft palate (after intubation)
Recurrent laryngeal component of the vagus nerve	Cricothyroid muscle
Spinal accessory nerve	Trapezius muscle
Hypoglossal nerve	Tongue muscles

TABLE 6. Prevalence, sensitivity, specificity, predictive value, and likelihood ratios of significant EMG activity to detect CN deficits

Significant Free-Run EMG Activity	All Procedures	≥2 Stages
No. of CNs	321	165
No. of deficits	9	7
Prevalence	2.8%	4.2%
Sensitivity (95% CI)	0.55 (0.22–0.84)	0.42 (0.11–0.79)
Specificity (95% CI)	0.83 (0.79–0.87)	0.86 (0.79–0.9)
Positive predictive value (95% CI)	0.08 (0.03–0.2)	0.12 (0.03–0.32)
Negative predictive value (95% CI)	0.98 (0.95–0.99)	0.97 (0.92–0.99)
Likelihood ratio (95% CI)	0.02 (0.00–0.04)	3.07 (1.2–7.8)

J Neurosurg Pediatr Volume 17 • February 2016



NEUROVASCULAR SURGERY

Intraoperative Monitoring for Intracranial Aneurysms: The Michigan Experience

Kinshuk Sahaya, Aditya S. Pandey,† Byron G. Thompson,† Brian R. Bush,‡ and Daniela N. Minecan‡*

Retrospective - 470 intracranial aneurysms (endovascular or microsurgical)
SSEP, BAEP, EEG

IONM changes 3.8%

Reversible in 44%, partly reversible in 22%, irreversible in 33%

Sensitivity 90%   Specificity 98.04%
Negative predictive value 99.78%
Positive predictive value 50%

Sahaya, Journal of Clinical Neurophysiology 2014

Adenosine-Induced Flow Arrest to Facilitate Intracranial Aneurysm Clip Ligation: Dose-Response Data and Safety Profile

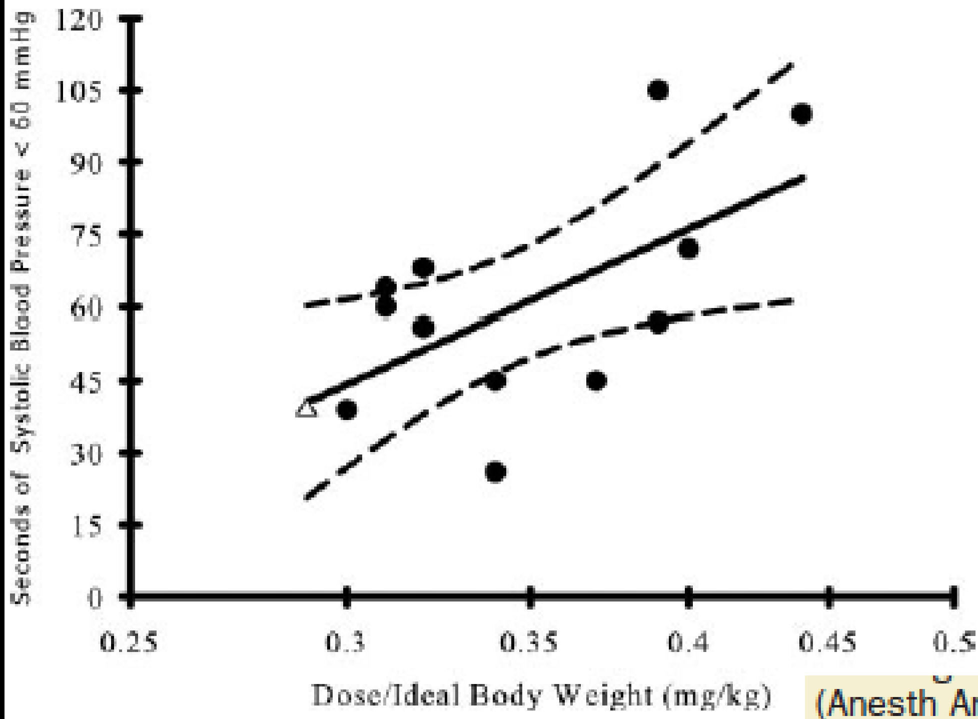
John F. Bebawy, MD, Dhanesh K. Gupta, MD, Bernard R. Bendok, MD, Laura B. Hemmer, MD, Carine Zeeni, MD, Michael J. Avram, PhD, H. Hunt Batjer, MD, and Antoun Koht, MD

Adenosine
0.3-0.4 mg/Kg IBW

Table 2. Summary of Dose-Response Data (Initial Doses for 13 Patients)[a]

Dose (mg/kg IBW)	Duration SBP <60 mm Hg (s)	Duration SBP <baseline (s)
0.34 (0.29–0.44)	57 (26–105)	116 (65–200)

IBW = ideal body weight; SBP = systolic blood pressure.
[a] All values reported as median (minimum, maximum).

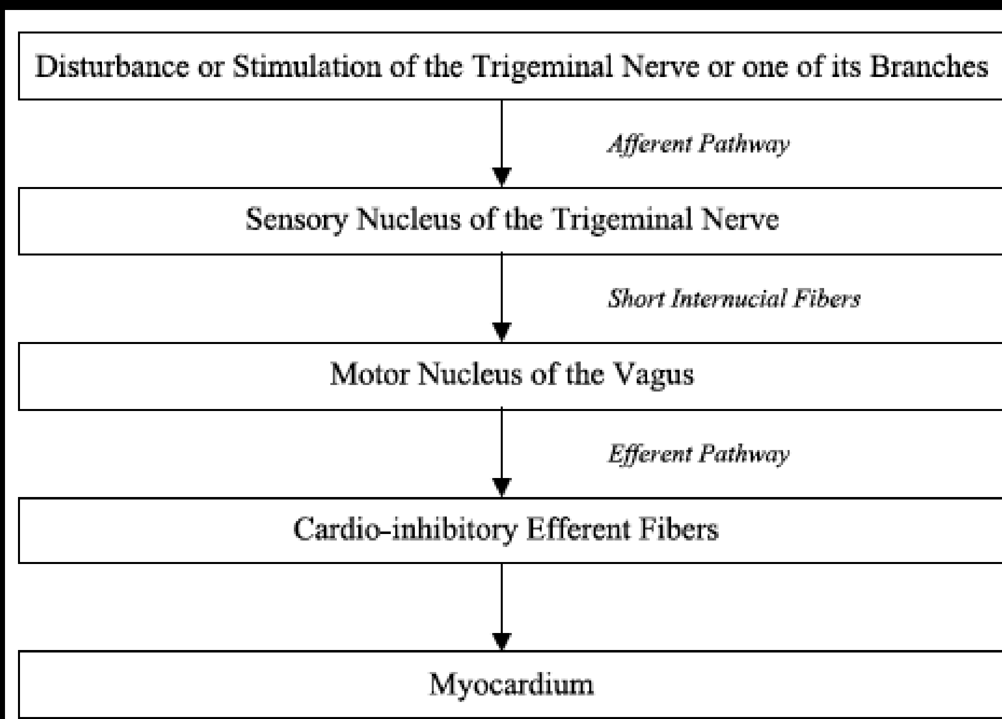


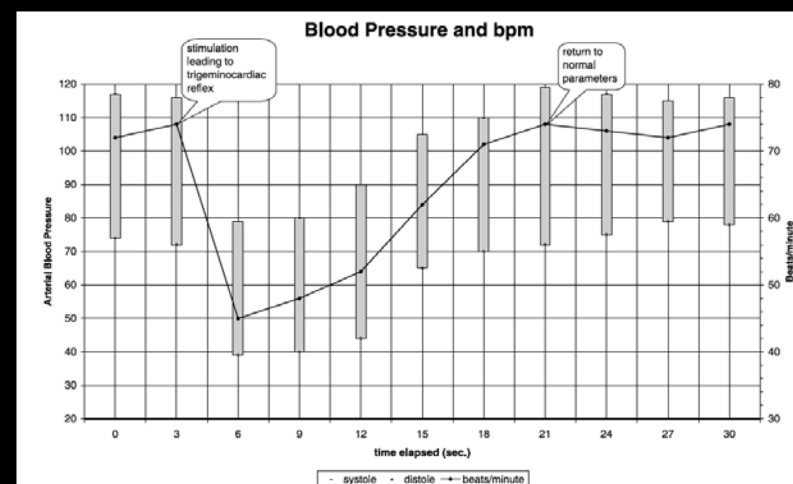
(Anesth Analg 2010;110:1406–11)

Clinical Article

Trigeminocardiac reflex during skull base surgery: mechanism and management

The onset of bradycardia lower than 60 beats/minute along with hypotension with a drop in MABP of 20% or more due to intra-operative manipulation or traction of the trigeminal nerve





KOERBEL – Acta Neurochir 2005

Surg Neurol Int. 2013 Sep 18;4:116. doi: 10.4103/2152-7806.118340. eCollection 2013.

Trigeminocardiac reflex in neurosurgical practice: An observational prospective study.

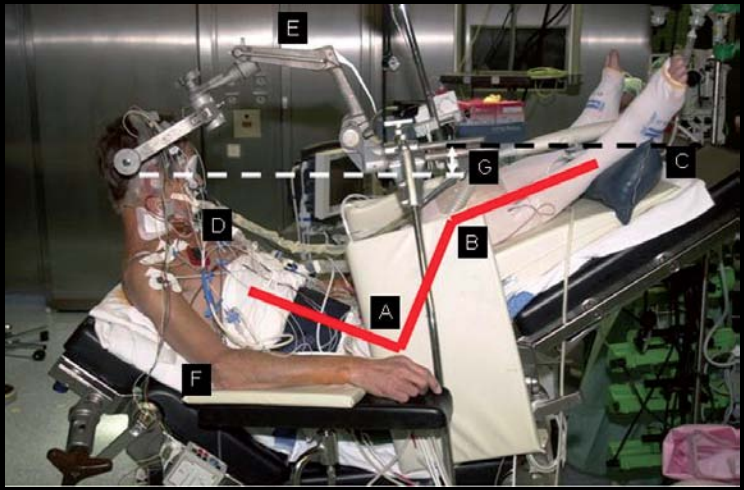
Etezadi F[1], Orandi AA, Orandi AH, Najafi A, Amirjamshidi A, Pourfakhr P, Khajavi MR, Abbassioun K.

190 cranial and skull base procedures, Propofol and alfentanil anesthesia
Cerebral state index (CSI) monitor (target values 40-60)
TCR during surgery 2.1 %

Variables	Case no. 1	Case no. 2	Case no. 3	Case no. 4
Age (years)	56	14	45	26
Weight (kg)	70	45	93	67
Sex	Female	Female	Male	Male
Type of pathology	Supra-tentorial meningioma	Adenoma of pituitary	Supra-tentorial meningioma	Skull base meningioma
Site of operation	Fronto-temporal	Trans-nasal	Fronto-temporo-parietal	Occipital
Fluid intake (ml)	4000	3300	5300	4560
Urine output (ml)	1900	2100	2700	2500
Mannitol (g)	70	60	80	60
Operation time (min)	170	164	232	211
Anesthesia time (min)	205	214	275	246
Transfusion during surgery				
Packed cell (unit)	0	0	0	0
FFP (unit)	0	0	0	0
Platelet (unit)	0	0	0	0
Hemodynamic variables just before TCR episode				
SBP (mmHg)	102	89	92	87
DBP (mmHg)	64	55	54	64
MAP (mmHg)	83	72	66	85
HR (Beat/min)	68	85	74	68
Lowest BP and heart rate at TCR episode				
SBP (mmHg)	61	64	73	53
DBP (mmHg)	35	36	33	28
MAP (mmHg)	43	48	51	37
HR (beat/min)	41	34	32	18
CSI value at TCR episode	74	77	70	51
Manipulated tissue at the time of event				
Skin	+	+	+	-
Brain	-	-	-	+
Bone	-	-	-	-
Dura	-	-	-	-
Medical history	Mild hypertension	-	-	Nephrectomy due to renal cell carcinoma
Drug history	Captopril	-	-	-

FFP: Fresh frozen plasma, BP: Blood pressure, SBP: Systolic blood pressure, DBP: Diastolic blood pressure, MAP: Mean arterial pressure, HR: Heart rate, CSI: Cerebral state index

SITTING POSITIONING ISSUES



Advantages of sitting position:

Good surgical exposure, improved ventilation, better access to airways, greater confort for the surgeon, possible reduced blood loss

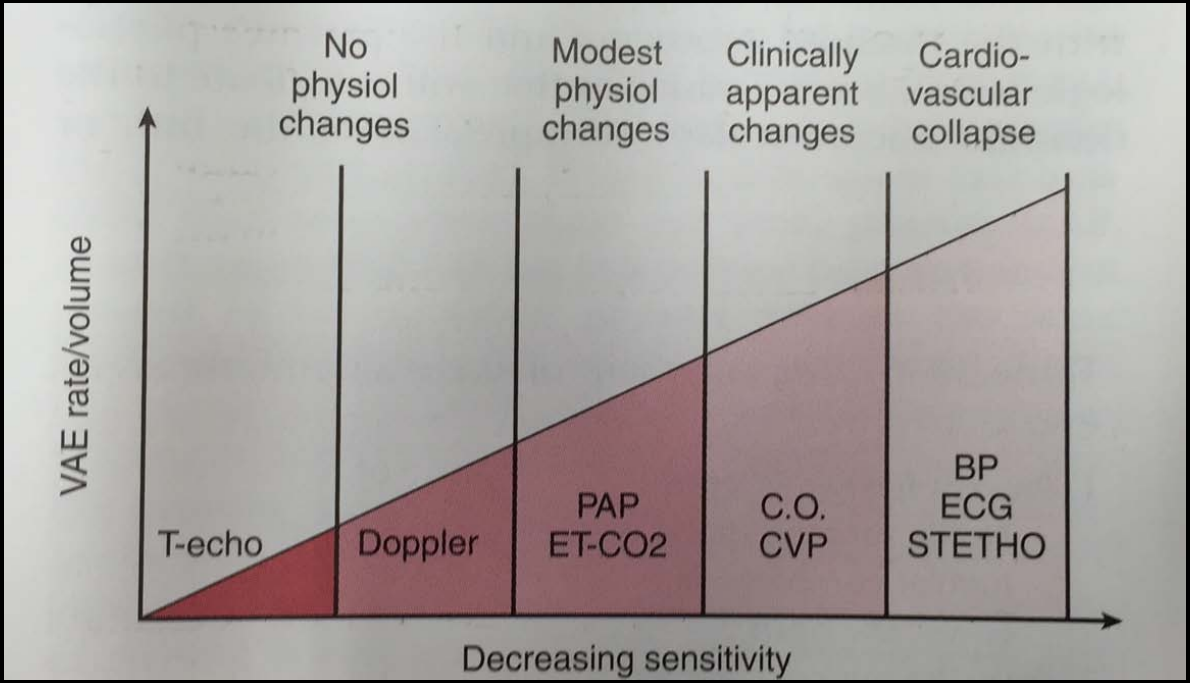
Disadvantages of sitting position:

The risk of venous air embolism and pneumocephalus and the potential for hemodinamic instability

The main contraindication to sitting position:

Documented rigth to left intracardiac or pulmonary shunt which would facilitate systemic embolization of air

SENSITIVITY OF MONITORING TECHNIQUES TO THE OCCURRENCE OF VENOUS AIR EMBOLISM



Method of Detection	Sensitivity (ml/kg)	Availability	Invasiveness	Limitations
TEE	High (0.02)	Low	High	Expertise required, expensive, invasive
Precordial Doppler	High (0.05)	Moderate	None	Obese patients
PA catheter	High (0.25)	Moderate	High	Fixed distance, small orifice
TCD	High	Moderate	None	Expertise required
ETN_2	Moderate (0.5)	Low	None	N_2O, hypotension
$ETCO_2$	Moderate (0.5)	Moderate	None	Pulmonary disease
Oxygen saturation	Low	High	None	Late changes
Direct visualization	Low	High	None	No physiologic data
Esophageal stethoscope	Low (1.5)	High	Low	Late changes
Electrocardiogram	Low (1.25)	High	Low	Late changes

MIRSKI, Anesthesiology 2007

Ideal monitor for Venous Air Embolism (VAE)

High level of sensitivity
Good specificity
Rapid response
Quantitative measurement of VAE event
Indication of the course of recovery of VAE event

- Combination of precordial doppler and $etCO_2$ meets these criteria
- TEE is more sensitive to VAE than precordial doppler and offers the advantage of identifying rigth to left shunting of air

High probability of venous air embolism

> 5 mm drop in $etCO_2$
> 15% increase in heart rate
> 20% drop in systolic pressure
If the 3 signs are sustained for > 5 min

The Hemodynamic Management of 5177 Neurosurgical and Orthopedic Patients Who Underwent Surgery in the Sitting or "Beach Chair" Position Without Incidence of Adverse Neurologic Events

Pathomporn Pin-on, MD, Darrell Schroeder, MS, and James Munis, MD, PhD

Table 2. Intraoperative Blood Pressure Changes from Preoperative Baselines[a]

	Orthopedic patients		Neurological patients	
	NIBP (n = 3545)	A-line heart level (n = 682)	A-line heart level (n = 422)	A-line head level (n = 528)
Systolic blood pressure (mm Hg)				
Preoperative (mean ± SD)	130 ± 17	131 ± 18	133 ± 18	130 ± 16
Intraoperative (mean ± SD)	103 ± 11	110 ± 9	115 ± 10	112 ± 9
Difference (%)	−19.3 ± 12.6	−14.4 ± 12.7	−12.1 ± 13.5	−12.1 ± 12.4
	<0.001	**<0.001**	**<0.001**	**<0.001**
Mean arterial blood pressure (mm Hg)				
Preoperative (mean ± SD)	94 ± 11	93 ± 11	95 ± 11	94 ± 11
Intraoperative (mean ± SD)	75 ± 8	74 ± 7	78 ± 7	75 ± 7
Difference (%)	−19.5 ± 11.9	−19.5 ± 11.4	−17.6 ± 11.5	−19.7 ± 10.7
	<0.001	**<0.001**	**<0.001**	**<0.001**

(Anesth Analg 2013;116:1317–24)

TAKE HOME MESSAGES

- **Intraoperative EP as biomarkers for postoperative neurological status**
- **Complicated skull base surgeries under advanced monitoring should be performed in specialized centers**
- **The nerve monitoring system is an adjunct, not a replacement, for surgical skill and judgment in the assessment and preservation of neural structures.**
- **Poor nerve monitoring is worse than no monitoring (false sense of security akin to walking in a minefield with a dysfunctional minesweeper)**
- **False-positive and false-negative errors can occur with monitoring**
  (a knowledgeable surgeon and monitoring team - essential to troubleshoot system errors)