

Prognostic Performance of Intraoperative Visual Evoked Potentials for Postoperative Visual Outcomes: Evidence from a Neurosurgical Cohort

Robert Lucaciu

`robert.lucaciu@sana.de`

Sana Kliniken Duisburg

Mamoun Ahmed

Sana Kliniken Duisburg

Abdelsalam Salem

Sana Kliniken Duisburg

Roman Arend

Sana Kliniken Duisburg

Niels Nordin

Sana Kliniken Duisburg

Nikola Dürr

Sana Kliniken Duisburg

Su-Zin Jung

Sana Kliniken Duisburg

Martin Scholz

Sana Kliniken Duisburg

Research Article

Keywords: Intraoperative monitoring, visual evoked potentials, neurosurgery, optic pathway, prognostic value, anesthesia.

Posted Date: May 20th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-9638725/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations:

No competing interests reported.

Tables 1 to 4 are available in the Supplementary Files section.

Prognostic Performance of Intraoperative Visual Evoked Potentials for Postoperative Visual Outcomes: Evidence from a Neurosurgical Cohort

Authors: R. Lucaciu*, A. Salem*, M. Ahmed, A. Roman, N. Nordin, N. Dürr, S. Jung*, M. Scholz*

*These authors contributed equally to this manuscript.

Corresponding Author: R. Lucaciu (Robert.lucaciu@sana.de)

Word-Count:

Disclosures: None (details of funding bodies with grant numbers)

Acknowledgements: None

Other statements / disclosures: None

Abstract

Objectives: To evaluate the clinical utility and limits of intraoperative flash visual evoked potentials (VEPs) during cranial neurosurgery for predicting early postoperative visual function.

Methods: We performed a retrospective single-center cohort analysis of 120 consecutive patients (July 2017 to June 2019) who underwent intracranial tumor/skull-base surgery with pre- and postoperative neuro-ophthalmologic assessment. Monitoring followed a predefined protocol based on total intravenous anesthesia (propofol/remifentanyl) with BIS guidance and active temperature/blood-pressure management. Flash VEPs were elicited using LED pads over closed eyelids (flash duration 40 ms, band-pass 20–500 Hz). The a-priori alarm criterion was a $\geq 50\%$ amplitude decrease or reproducible VEP loss sustained for ~ 3.5 –4 min, triggering standardized checks and corrective steps.

Results: VEPs were analyzable in 109 of 120 patients which corresponds to 90.8%. Eleven of 120 patients which corresponds to 9.2% had non interpretable signals due to poor documentation in four cases or predominant artifacts in seven cases. The most frequent pathologies were meningioma in 39 patients which corresponds to 32.5%, astrocytoma in 30 patients which corresponds to 25.0%, and metastasis in 18 patients which corresponds to 15.0%. Intraoperative VEP deterioration tracked postoperative visual dysfunction. False negative deterioration occurred in 5 of 120 patients which corresponds to 4.16% while no false positive change was observed.

Conclusion: Under standardized TIVA and modern LED stimulation, intraoperative flash VEP monitoring is feasible in most neurosurgical cases and can provide actionable warnings of optic-pathway compromise, though susceptibility to anesthetic depth and stimulus-delivery issues remains a key limitation. Larger prospective studies are warranted to refine diagnostic accuracy and validate alarm thresholds for clinical decision-making.

Keywords (3-6): Intraoperative monitoring; visual evoked potentials; neurosurgery; optic pathway; prognostic value; anesthesia.

Introduction

The derivation of evoked potentials (EP) is based on the fact that stimulation of sensory organs elicits an electrical response in the corresponding cortical area (Odom et al., 2004; Wiedemayer et al., 2004). Neurosurgical interventions in the area of the visual pathway are not only carried out to remove tumors, but also to improve function or at least to protect structures at risk. Nevertheless, unexpected visual deteriorations may occur postoperatively. Appropriate intraoperative monitoring of visual evoked potentials (VEP) aims to avoid postoperative visual deterioration (Chung et al., 2012; Jashek-Ahmed et al., 2021; Kikuchi et al., 2005).

VEPs have been used since the 1960s to verify correct function of the visual pathway, originally to examine visual function in demyelinating diseases such as multiple sclerosis and optic atrophies. Intraoperative VEP examinations have been performed since around 1970 to monitor the integrity of the visual pathway during surgery. However, intraoperative VEP monitoring is not yet widespread and its usefulness remains controversial. While some studies report a benefit of intraoperative VEP monitoring, others show no correlation between intraoperative VEP findings and postoperative visual function. The main controversies concern technical aspects and the reproducibility and accuracy of intraoperative findings (Chung et al., 2012; Jashek-Ahmed et al., 2021; Wiedemayer et al., 2003; Wiedemayer et al., 2004).

Because all volatile anesthetics and several intravenous agents suppress VEP amplitudes and increase variability, total intravenous anesthesia (TIVA) became widely used for surgeries requiring intraoperative monitoring at the turn of the millennium (Chi and Field, 1986; Kameyama, 1994). In addition to TIVA, the development of high-luminance light-emitting diodes (LEDs) has enabled more reliable intraoperative VEP recordings with improved reproducibility, provided correct positioning and shielding are ensured (Sasaki et al., 2010).

Physiological conditions further influence VEP reliability. Body temperature and blood pressure are crucial determinants of signal quality. Because the visual pathway is polysynaptic and synaptic transmission is highly sensitive to hypothermia, a 1 °C drop in temperature can reduce central transmission by ~15 % (Russ et al., 1987; Zeitlhofer et al., 1990). Maintaining stable hemodynamics and temperature is therefore essential for valid interpretation (Russ et al., 1987; Zeitlhofer et al., 1990).

Beyond these technical and physiological limitations, little is known about how intraoperative changes trigger modifications in surgical strategy and how such changes translate into functional outcome. Whether VEP monitoring can improve extent of resection while preserving visual function also remains uncertain (Chung et al., 2012; Jashek-Ahmed et al., 2021; Kikuchi et al., 2005). Therefore, we conducted the present study to investigate whether intraoperative VEP monitoring is a reliable method that correlates with postoperative visual status under a standardized protocol.

Methods

Study design and setting

We conducted a single-center, retrospective cohort study at the Department of Neurosurgery, Sana Hospital Duisburg, including all consecutive neurosurgical procedures in which intraoperative visual evoked potentials (iVEPs) were used between July 2017 and June 2019. iVEP monitoring was applied whenever patients presented with preoperative visual impairment or when the pathology/approach conferred elevated risk to the optic apparatus or post-chiasmal visual pathways. A total of 120 patients met these criteria and were analyzed. Eligible cases comprised supratentorial and skull-base operations with potential risk to the optic nerves, chiasm, tracts, or radiations, irrespective of histology. Monitoring was bilateral in all cases. Exclusion criteria were predefined and included conversion to inhalational maintenance anesthesia and technical monitoring failure (for example, persistent non-derivable VEPs at baseline despite troubleshooting). Analyses were performed primarily per patient, with side-specific notes where applicable.

Pre- and postoperative assessments

Pre- and postoperative visual assessments followed institutional standards. At minimum, bedside documentation by a neurosurgeon comprised visual acuity (fingers-counting based) and gross perimetry using finger perimetry. Formal ophthalmologic examinations were available in a subset of patients and were performed preoperatively in 39/120 (32.5%) and postoperatively in 30/120 (25%). Baseline examinations were obtained during the routine preoperative work-up, and early postoperative assessments were performed on the ward or ICU within the initial postoperative window.

97 **Anesthesia and physiological management**

98 Anesthesia and physiology were standardized. Monitoring included 5-lead ECG, pulse
99 oximetry, capnography, and invasive arterial blood pressure. Peripheral and central
100 venous access were placed as indicated. Depth of anesthesia was guided by bispectral
101 index (BIS). Temperature management relied on a forced-air warming blanket, a na-
102 sopharyngeal probe provided continuous core temperature measurement. Following
103 endotracheal intubation, anesthesia was maintained as total intravenous anesthesia
104 (TIVA) with propofol 8–12 mg·kg⁻¹·h⁻¹ and remifentanyl 0.3 µg·kg⁻¹·min⁻¹. Hypnotic
105 dosing was titrated to BIS targets; mean core temperature after induction was 35.7 ±
106 0.4 °C. Volatile agents were avoided after induction, and long-acting neuromuscular
107 blockers were not administered during monitoring epochs. Vasoactive agents were
108 used as needed to maintain stable hemodynamics. To minimize artifacts, the team
109 performed standardized checks before critical steps and whenever signal changes oc-
110 curred (brief electrocautery pauses, inspection for drape/LED displacement, and cable
111 strain relief).

112 **Stimulation and recording**

113 After induction and before skin incision, VEP electrodes were applied and the stimula-
114 tion pads positioned. Commercial high-luminance LED flash pads (disc-shaped) were
115 placed bilaterally over closed eyelids and secured with protective tape to ensure stable
116 coupling throughout the procedure, stimulation was routinely delivered to both eyes,
117 with side-specific testing if clinically required. Flash duration was 40 ms. Signals were
118 recorded from occipital scalp positions according to the international 10–20 system (Oz
119 and O1/O2) referenced to a midline site, with impedances kept low and balanced. Re-
120 cordings were amplified and band-pass filtered at 20–500 Hz. Acquisition began before
121 dura opening and continued until dural closure, as post-closure changes were not ex-
122 pected to be procedure-related. Stable baselines were obtained prior to the first critical
123 surgical step (e.g., devascularization or dissection), with scheduled rechecks at prede-
124 fined milestones and ad hoc after surgical manipulations or physiological changes,
125 suspicious changes prompted immediate repetition of runs for confirmation.

126 **Alarm criteria and response protocol**

127 Alarm criteria and responses were predefined. The primary alarm was a ≥ 50% reduc-
128 tion in VEP amplitude relative to baseline and/or reproducible signal loss sustained for
129 approximately 3.5–4 minutes. Confirmation steps required repeat averaging, verifica-
130 tion of LED position/occlusion and cable integrity (and, where available, corroborative

checks such as ERG presence), as well as correction of potential physiological confounders (blood pressure, oxygenation/ventilation, anesthetic depth, and temperature). Surgical responses followed a stepwise algorithm and could include temporary pause, irrigation, meticulous hemostasis, gentle decompression, and modification of retraction, trajectory, or extent of dissection. Reversibility within the same operative episode was documented as reversible, partially reversible, or non-reversible.

Outcomes

Outcomes were defined a priori. The primary outcome was postoperative visual deterioration, any decline in visual acuity and/or new or worsened visual field deficit compared with preoperative baseline, assessed in the early postoperative period. Secondary outcomes included visual stability or improvement, intraoperative reversals of VEP deterioration after corrective actions, categorical signal quality (e.g., well-derivable, side difference, poorly derivable), and monitoring-related adverse events. Unilateral and bilateral findings were handled according to prespecified operational definitions used in the institutional database.

Statistical analysis

Statistical analysis proceeded in several steps. Descriptive statistics summarized demographics, pathology and approach, baseline vision, and monitoring feasibility. Group comparisons used χ^2 or Fisher's exact test for categorical variables and independent-samples t-test or Mann–Whitney U test for continuous variables, as appropriate. Diagnostic performance of iVEP for predicting postoperative deterioration was quantified as sensitivity, specificity, positive and negative predictive values, and overall accuracy, each with 95% confidence intervals. Concordance between intraoperative amplitude drops and postoperative outcome was further examined with logistic regression, adjusted for clinically relevant covariates (baseline vision, lesion proximity to visual pathways, operative time, and surgeon experience). Missing data were handled transparently using complete-case analyses with sensitivity analyses where feasible. Exploratory receiver-operating-characteristic analyses assessed amplitude-drop thresholds in relation to outcome. Analyses were conducted primarily per patient, where side-specific data were available, supportive per-eye analyses were performed.

Ethics

The study was conducted in accordance with the Declaration of Helsinki and approved by the local institutional review board. Given the retrospective design, consent requirements followed local regulations.

Results

Cohort overview

A total of 120 patients (240 eyes) underwent intracranial surgery with intraoperative visual evoked potential (VEP) monitoring. Conclusive intraoperative data were available in 90.8%. 9.2% were excluded due to artifacts or incomplete documentation (Table 1). Pathologies per patient were as follows: meningioma 39/120 (32.5%), astrocytoma 30/120 (25.0%), metastasis 18/120 (15.0%), pituitary adenoma 7/120 (5.83%), vascular lesions 9/120 (7.5%), orbital lesions 8/120 (6.66%), chordoma 3/120 (2.5%), neurinoma 2/120 (1.6%), Rathke's cleft cyst/craniopharyngioma 2/120 (1.6%), and lymphoma 2/120 (1.6%) (Table 1). Among meningiomas (n=39), the most frequent sites were sphenoid wing, olfactory groove, and planum sphenoidale (full distribution in Table 1). Among astrocytomas (n=30), locations were temporal (n=11), parietal (n=8), frontal (n=3), occipital (n=6), suprasellar (n=1), and chiasmatic (n=1) (Table 1). Age distribution was: 20-30 y 1/120 (0.8%), 31-40 y 9/120 (7.5%), 41-50 y 17/120 (14.2%), 51-60 y 25/120 (20.8%), 61-70 y 35/120 (29.2%), 71-80 y 29/120 (24.2%), >80 y 4/120 (3.3%); mean age ~61 years.

Preoperative ophthalmologic documentation was available in 39/120 (32.5%) and early postoperative documentation in 30/120 (25.0%). Outcome analyses below are reported per patient using the available clinical ophthalmology records. All cases were managed with total intravenous anesthesia (propofol/remifentanyl), four cases required volatile anesthesia for clinical reasons and yielded poorly derivable VEPs. Mean intraoperative core temperature after induction was 35.7 ± 0.4 °C. VEP baselines were acquired pre-incision and recording continued until dural closure according to the protocol.

Signal acquisition and quality

Reliable, stable VEPs were obtained in 63/120 (52.5%) patients. Artifact-dominant recordings occurred in 7/120 (5.8%), and documentation was inadequate in 4/120

(3.3%). Intraoperative signal-change categories comprised badly derivable 5/120 (4.2%), side difference 26/120 (21.7%), and intraoperative deterioration 15/120 (12.5%) (Table 2).

Intraoperative changes and corrective actions

Direct contact of the lesion with the optic apparatus (optic nerve/chiasm) was documented in 20/26 cases with side-difference changes and in 15/15 cases with intraoperative deterioration (Table 3). VEP changes were most frequently time-stamped around dural opening or early tumor resection, frequent concurrent factors included bipolar coagulation/ultrasonic aspiration and hemodynamic/temperature shifts (Table 3). Corrective maneuvers comprised temporary pause and irrigation, blood-pressure optimization, and nimodipine (topical or IV). In the side-difference subgroup, nimodipine was used in 11/26 cases with signal improvement in 5/11. In the deterioration subgroup, nimodipine was used in 10/15 with signal improvement in 6/10 (Table 3).

Postoperative visual outcomes

Early postoperative ophthalmological assessment demonstrated a generally stable course of visual function across the cohort (Table 2). Among patients with stable intraoperative VEPs ($n = 63$), postoperative visual function improved in 20 cases (31.7%), remained unchanged in 41 cases (65.1%), and deteriorated in 2 cases (3.2%). In the subgroup with badly derivable VEPs ($n = 5$), vision improved in one patient, was unchanged in three, and worsened in one. Patients classified as having side differences between hemispheric recordings ($n = 26$) showed visual improvement in five (19.2%) and stable vision in twenty-one (80.8%), with no postoperative deterioration in this subgroup. In contrast, patients with intraoperative VEP deterioration ($n = 15$) demonstrated improvement in two (13.3%), unchanged vision in eight (53.3%), and visual decline in five (33.3%) cases. Taken together, postoperative visual deterioration occurred in eight patients (6.7%) across the entire cohort, while 28 patients (23.3%) showed measurable postoperative improvement and 84 patients (70.0%) remained unchanged.

Diagnostic performance

A $\geq 50\%$ sustained amplitude decrease or reproducible loss of VEP signal for ≥ 3.5 –4 min defined intraoperative deterioration (Table 4). On cross-tabulation with early postoperative outcomes, 5 patients with intraoperative deterioration had postoperative visual worsening, whereas 7 patients without intraoperative deterioration worsened. False positives were present ($n=8$), as reflected in Table 4 (TP=5, FP=8, FN=7, TN=92). From the 2×2 counts (TP = 5, FP = 8, FN = 7, TN = 92), the operating characteristics were: sensitivity 41.7% (95% CI 19.3–68.0), specificity 92.0% (85.0–95.9), positive predictive value 38.5% (17.7–64.5), and negative predictive value 92.9% (86.1–96.5) (Table 4).

Discussion

Visual preservation remains a critical challenge in cranial and skull base surgery. In the present cohort, intraoperative VEPs were analyzable in 90.8 % of cases under standardized TIVA. A sustained amplitude reduction of at least 50 % or reproducible signal loss over approximately four minutes was associated with early postoperative visual decline. The diagnostic profile demonstrated high specificity and NPV but modest sensitivity and PPV, indicating that while stable VEPs reliably predict visual integrity, not every alarm signaled irreversible damage. These findings provide a basis to discuss feasibility, prognostic value, and practical integration of VEP monitoring in the context of current literature.

Interpretation of key findings

Our analyzability rate is consistent with previous studies reporting stable intraoperative VEPs in 80–95 % of procedures when physiological parameters and anesthetic depth are tightly controlled (Jashek-Ahmed et al., 2021; Kamio et al., 2014; Sasaki et al., 2010). The association between sustained VEP deterioration and early visual decline supports prior evidence that amplitude loss reflects acute compromise of the anterior visual pathway (Luo et al., 2015; Soumpasis et al., 2023). In contrast to earlier work that questioned reproducibility under inhalational anesthesia, our results confirm that modern LED stimulation combined with TIVA achieves robust cortical responses (Wiedemayer et al., 2003).

The observed eight false-positive alarms highlight the known variability of VEPs even under optimized conditions. Similar findings have been reported in series using comparable thresholds, where unsustained amplitude loss did not result in visual decline (Chung et al., 2012; Jashek-Ahmed et al., 2021). Physiological factors such as brief hypotension, temperature shifts, and surgical traction on the scalp or dura can transiently alter waveform morphology (Russ et al., 1987; Zeithofer et al., 1990). Continuous control of these variables therefore remains essential to maintain interpretability.

Anesthetic and physiological determinants

The anesthetic regimen represents a decisive factor for VEP reliability. Volatile agents suppress cortical potentials and prolong latencies, whereas TIVA with propofol and remifentanyl preserves amplitude stability and reduces intertrial variability (Demirel et al., 2021; Kim et al., 2025; Ma et al., 2024). This evidence supports the exclusive use of TIVA in the present series. Maintenance of normothermia and stable blood pressure further improved reproducibility, in agreement with established electrophysiological principles (Wiedemayer et al., 2004).

Clinical implications and intraoperative responses

VEP monitoring enables time-critical feedback that can prompt immediate corrective actions. In our protocol, amplitude deterioration triggered predefined steps including signal verification, repetition of runs, optimization of blood pressure and anesthetic depth, gentle irrigation, and temporary cessation of manipulation. Comparable strategies are described in the literature and have been linked to recovery of cortical responses and improved postoperative vision (Hardian et al., 2021; Hayashi and Kawaguchi, 2017; Kamada et al., 2005). The pragmatic $\geq 50\%$ amplitude criterion remains the most widely accepted alarm threshold, balancing sensitivity and specificity (Kamio et al., 2014; Soumpasis et al., 2023).

Integration into multimodal monitoring

Recent advances integrate VEPs within multimodal IONM frameworks combining SEP, MEP, and ERG confirmation to safeguard multiple functional systems. Such approaches enhance intraoperative decision-making and reduce false-positive events (Choi et al., 2020; Fehlings et al., 2024). The concurrent use of tractography has further refined risk mapping around the optic radiation, allowing a more targeted surgical strategy (Baek, 2023; Winston et al., 2011). These developments support the incorporation of VEPs as a complementary modality rather than a stand-alone parameter.

Methodological strengths and limitations

Strengths of this work include a uniform anesthetic protocol, predefined alarm and response algorithms, and outcome assessment by ophthalmologic criteria. These features enhance internal validity and enable comparison with contemporary series. The limitations, however, must be acknowledged. The single-center retrospective design restricts generalizability and may introduce selection bias. Ophthalmologic follow-up was incomplete in a subset, which limits precise sensitivity estimates. Moreover, derivability remains reduced in patients with severe preoperative visual loss or in technically adverse situations such as excessive coagulation, cerebrospinal fluid loss, or unstable hemodynamics (Sasaki et al., 2010; Wiedemayer et al., 2003). The variability of stimulation and recording parameters across studies continues to impede quantitative meta-analysis and contributes to divergent accuracy reports (Jashek-Ahmed et al., 2021).

Future perspectives

Future research should focus on prospective multicenter validation with harmonized stimulation parameters, standardized anesthetic protocols, and ERG-verified stimulus delivery. Per-eye reporting and uniform postoperative visual assessments will allow robust comparison of diagnostic metrics. Automated signal analysis and artifact detection algorithms, as proposed in recent concept papers, may further improve intraoperative interpretability and shorten reaction times (Soumpasis et al., 2023). Continued integration of VEPs within multimodal IONM and imaging-guided workflows represents a promising direction for maximizing surgical safety near the optic pathway.

Conclusion

Under standardized TIVA and strict physiological control, intraoperative VEP monitoring is feasible and provides reliable information about optic-pathway function. The presence of false-positive alarms underscores the necessity of multimodal confirmation and disciplined corrective measures, whereas the high specificity and predictive value of stable recordings support their use as an early safety signal. Further prospective validation and methodological harmonization are required to establish definitive thresholds and optimize their role in contemporary neurophysiological monitoring.

322 **Table Legend**

323 **Table 1. Distribution of pathologies in the study cohort (N = 120):** Overview of
324 surgical pathologies monitored with intraoperative VEPs. The most frequent lesions
325 were meningiomas (32.5%), astrocytomas (25.0%), and metastases (15.0%). Aneu-
326 rysmal or arteriovenous malformation–related vascular lesions accounted for 7.5%.
327 The remaining entities included orbital, pituitary, skull base, and optic nerve–associ-
328 ated tumors. In total, 90.8% of patients yielded analyzable intraoperative data, while
329 9.2% were excluded due to artifacts or incomplete documentation.

330 **Table 2. Intraoperative VEP signal quality and postoperative visual outcomes:**
331 Categorization of intraoperative signal quality and its association with early postoper-
332 ative vision. Stable VEPs represented 52.5% of the cohort and were generally linked
333 to unchanged or improved visual outcomes. Significant deterioration (12.5%) corre-
334 lated with postoperative visual decline in one third of cases. Percentages are calcu-
335 lated relative to the total cohort (N = 120). Abbreviation: VEP, visual evoked potential.

336 **Table 3. Intraoperative VEP alterations and corrective interventions:** Intraopera-
337 tive subgroups with signal changes and applied corrective measures. VEP deteriora-
338 tion or side differences were most often observed during manipulation near the optic
339 nerve or chiasm, or during early resection phases involving bipolar coagulation or
340 CUSA. Interventions included irrigation, hemodynamic optimization, and topical ni-
341 modipine in selected cases, resulting in partial signal recovery in several instances.
342 Abbreviation: VEP, visual evoked potential.

343 **Table 4. Association between intraoperative VEP changes and postoperative vis-**
344 **ual outcomes.:** Correlation between intraoperative VEP patterns and postoperative
345 visual status. The presence of intraoperative VEP deterioration predicted early post-
346 operative visual decline with a sensitivity of 41.7%, specificity of 92.0%, positive pre-
347 dictive value (PPV) of 38.5%, and negative predictive value (NPV) of 92.9%. False-
348 positive alarms occurred in eight cases and false negatives in seven. Diagnostic met-
349 rics were computed per patient for cases with analyzable monitoring and available
350 early ophthalmologic follow-up. Abbreviation: VEP, visual evoked potential.

1 References

- Baek S-H. Usefulness of intraoperative neurophysiological monitoring for supratentorial brain tumor surgery. *J Intraoper Neurophysiol* 2023;5(2):31–6. <https://doi.org/10.33523/join.2023.5.2.31>.
- Chi O, Field C. Effects of Isoflurane on Visual Evoked Potentials in Humans. *Anesthesiology* 1986;65(3):328–30. <https://doi.org/10.1097/00000542-198609000-00018>.
- Choi SY, Park SR, Kim JH, Seo D-W, Jo H. Good reproducibility of visual evoked potential monitoring during the surgery of prechiasmatic, chiasmatic, and retrochiasmatic lesions: case report. *J Intraoper Neurophysiol* 2020;2(2):92–7. <https://doi.org/10.33523/join.2020.2.2.92>.
- Chung S-B, Park C-W, Seo D-W, Kong D-S, Park S-K. Intraoperative visual evoked potential has no association with postoperative visual outcomes in transsphenoidal surgery. *Acta neurochirurgica* 2012;154(8):1505–10. <https://doi.org/10.1007/s00701-012-1426-x>.
- Demirel I, Yildiz Altun A, Bolat E, Kilinc M, Deniz A, Aksu A, et al. Effect of Patient State Index Monitoring on the Recovery Characteristics in Morbidly Obese Patients: Comparison of Inhalation Anesthesia and Total Intravenous Anesthesia. *Journal of perianesthesia nursing official journal of the American Society of Peri-Anesthesia Nurses* 2021;36(1):69–74. <https://doi.org/10.1016/j.jopan.2020.07.005>.
- Fehlings MG, Alvi MA, Evaniew N, Tetreault LA, Martin AR, McKenna SL, et al. A Clinical Practice Guideline for Prevention, Diagnosis and Management of Intraoperative Spinal Cord Injury: Recommendations for Use of Intraoperative Neuromonitoring and for the Use of Preoperative and Intraoperative Protocols for Patients Undergoing Spine Surgery. *Global spine journal* 2024;14(3_suppl):212S–222S. <https://doi.org/10.1177/21925682231202343>.
- Hardian RF, Ogiwara T, Sato A, Fujii Y, Suzuki Y, Hanaoka Y, et al. Comparison Between Conventional Flash and Off-Response Intraoperative Visual Evoked Potential Monitoring for Endoscopic Endonasal Surgery. *Operative neurosurgery (Hagerstown, Md.)* 2021;21(6):516–22. <https://doi.org/10.1093/ons/opab329>.
- Hayashi H, Kawaguchi M. Intraoperative monitoring of flash visual evoked potential under general anesthesia. *Korean journal of anesthesiology* 2017;70(2):127–35. <https://doi.org/10.4097/kjae.2017.70.2.127>.

384 Jashek-Ahmed F, Cabrilo I, Bal J, Sanders B, Grieve J, Dorward NL, et al. Intraoper-
385 ative monitoring of visual evoked potentials in patients undergoing transsphe-
386 noidal surgery for pituitary adenoma: a systematic review. *BMC neurology*
387 2021;21(1):287. <https://doi.org/10.1186/s12883-021-02315-4>.

388 Kamada K, Todo T, Morita A, Masutani Y, Aoki S, Ino K, et al. Functional monitoring
389 for visual pathway using real-time visual evoked potentials and optic-radiation
390 tractography. *Neurosurgery* 2005;57(1 Suppl):121-7; discussion 121-7.
391 <https://doi.org/10.1227/01.neu.0000163526.60240.b6>.

392 Kameyama Y. Effect of isoflurane and sevoflurane on evoked potentials and EEG.
393 Masui. *The Japanese journal of anesthesiology* 1994;43(5):657–64.

394 Kamio Y, Sakai N, Sameshima T, Takahashi G, Koizumi S, Sugiyama K, et al. Use-
395 fulness of intraoperative monitoring of visual evoked potentials in transsphenoidal
396 surgery. *Neurologia medico-chirurgica* 2014;54(8):606–11.
397 <https://doi.org/10.2176/nmc.oa.2014-0023>.

398 Kikuchi Y, Sasaki T, Matsumoto M, Oikawa T, Itakura T, Kodama N. Optic nerve
399 evoked potentials elicited by electrical stimulation. *Neurologia medico-chirurgica*
400 2005;45(7):349-55; discussion 354-5. <https://doi.org/10.2176/nmc.45.349>.

401 Kim MH, Park J, Park YG, Cho YE, Kim D, Lee DJ, et al. Comparison of intraopera-
402 tive neurophysiological monitoring between propofol and remimazolam during to-
403 tal intravenous anesthesia in the cervical spine surgery: a prospective, double-
404 blind, randomized controlled trial. *Korean journal of anesthesiology*
405 2025;78(1):16–29. <https://doi.org/10.4097/kja.24613>.

406 Luo Y, Regli L, Bozinov O, Sarnthein J. Clinical utility and limitations of intraoperative
407 monitoring of visual evoked potentials. *PloS one* 2015;10(3):e0120525.
408 <https://doi.org/10.1371/journal.pone.0120525>.

409 Ma J, Wang J, Li Y, Fu Y, Li Y, Qiao H, et al. Effect of desflurane anesthesia on flash
410 visual evoked potential monitoring in patients undergoing spine surgery: study
411 protocol for a randomized controlled trial. *Trials* 2024;25(1):362.
412 <https://doi.org/10.1186/s13063-024-08211-9>.

413 Odom JV, Bach M, Barber C, Brigell M, Marmor MF, Tormene AP, et al. Visual
414 evoked potentials standard (2004). *Documenta ophthalmologica. Advances in*
415 *ophthalmology* 2004;108(2):115–23.
416 <https://doi.org/10.1023/B:DOOP.0000036790.67234.22>.

- Russ W, Sticher J, Scheld H, Hempelmann G. Effects of hypothermia on somatosensory evoked responses in man. *British journal of anaesthesia* 1987;59(12):1484–91. <https://doi.org/10.1093/bja/59.12.1484>.
- Sasaki T, Itakura T, Suzuki K, Kasuya H, Munakata R, Muramatsu H, et al. Intraoperative monitoring of visual evoked potential: introduction of a clinically useful method. *Journal of neurosurgery* 2010;112(2):273–84. <https://doi.org/10.3171/2008.9.JNS08451>.
- Soumpasis C, Díaz-Baamonde A, Ghimire P, Baig Mirza A, Borri M, Jarosz J, et al. Intraoperative Neuromonitoring of the Visual Pathway in Asleep Neuro-Oncology Surgery. *Cancers* 2023;15(15). <https://doi.org/10.3390/cancers15153943>.
- Wiedemayer H, Fauser B, Armbruster W, Gasser T, Stolke D. Visual evoked potentials for intraoperative neurophysiologic monitoring using total intravenous anesthesia. *Journal of neurosurgical anesthesiology* 2003;15(1):19–24. <https://doi.org/10.1097/00008506-200301000-00004>.
- Wiedemayer H, Fauser B, Sandalcioglu IE, Armbruster W, Stolke D. Observations on intraoperative monitoring of visual pathways using steady-state visual evoked potentials. *European journal of anaesthesiology* 2004;21(6):429–33. <https://doi.org/10.1017/S0265021504006039>.
- Winston GP, Yogarajah M, Symms MR, McEvoy AW, Micallef C, Duncan JS. Diffusion tensor imaging tractography to visualize the relationship of the optic radiation to epileptogenic lesions prior to neurosurgery. *Epilepsia* 2011;52(8):1430–8. <https://doi.org/10.1111/j.1528-1167.2011.03088.x>.
- Zeitlhofer J, Steiner M, Bousek K, Fitzal S, Asenbaum S, Wolner E, et al. The influence of temperature on somatosensory-evoked potentials during cardiopulmonary bypass. *European neurology* 1990;30(5):284–90. <https://doi.org/10.1159/000117382>.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Tables.pdf](#)