



The Predictive Role of Intraoperative Visual Evoked Potentials in Visual Improvement After Endoscopic Pituitary Tumor Resection in Large and Complex Tumors: Description and Validation of a Method

Rui Feng¹, Jeffrey Schwartz¹, Joshua Loewenstern¹, Karan Kohli¹, Svetlana Lenina¹, Sedat Ultakan¹, Alfred-Marc Illoreta², Satish Govindaraj², Joshua Bederson¹, Rudrani Banik³, Raj Shrivastava^{1,2}

■ **BACKGROUND:** With the advent of extensive endoscopic approaches for pituitary tumors, there has also been an increase in surgery for larger and more complex tumors. Intraoperative manipulation during endoscopic resection of sellar tumors poses potential risk in postoperative visual function in this tumor population. This study proposes a method of accurate intraoperative monitoring of visual evoked potentials (VEPs) and its role in predicting visual function outcomes.

■ **METHODS:** Intraoperative VEPs were monitored for 42 resections from a single surgical team, with average tumor size of 2.84 cm. Changes in VEP amplitude and latency in excess of 50% were considered significant. Preoperative and postoperative visual information was obtained from ophthalmology and hospital records, along with patient demographics, comorbidities, and tumor characteristics.

■ **RESULTS:** Patients were stratified as experiencing deteriorations in VEPs that did not restore to baseline ($n = 4$), deteriorations in VEPs that did restore to baseline ($n = 6$), no change in VEPs ($n = 31$), and improvement in VEPs ($n = 1$). Correlation between VEP changes and postoperative visual fields was measured through univariate ordered logistic regression. Improved intraoperative VEP measurements were associated with odds ratio (OR) of visual field improvement of 3.15 (95% confidence interval, 1.15–8.59). Specifically, changes in VEP amplitude were positively associated with visual field improvement with OR of 4.35 (OR, 1.29–14.7). No association was observed between VEPs and other patient or tumor characteristics.

■ **CONCLUSION:** Changes in VEP amplitude during endoscopic sellar tumor resection correlate with postoperative visual function. Intraoperative VEP monitoring can serve an important role in preventing postoperative visual field loss.

INTRODUCTION

With the recent advances in endoscopic transsphenoidal surgery, there has been a move toward removing larger sellar and suprasellar tumors.^{1,2} These tumors can compress either the optic nerve itself anteriorly or the chiasm or optic tract posteriorly. The goal of any surgery to the optic pathways is the preservation if not improvement of visual function. The difficulty in completely removing these larger tumors often lies in the concern for postoperative visual loss related to manipulations that occur during surgery. The incidence of visual loss in the postoperative transsphenoidal pituitary patient is low for routine microadenomas.²⁻⁴ However, this rate begins to increase with larger tumors and in patients presenting with unstable visual examinations.⁵ The factors related to postoperative visual loss are usually based on tumor size, consistency, invasiveness, patient age, and even presence of preexisting nonlesional visual loss (i.e., diabetic retinopathy).

The development and application of a detailed visual evoked potential (VEP) system designed for endoscopic transsphenoidal surgery would be beneficial in these complex procedures. However, VEP has never caught on in clinical use and applicability.⁶ Many consider VEPs to be unreliable, cumbersome, and user dependent. In the present study, we investigated the role of intraoperative monitoring of VEPs in predicting visual function

Key words

- Endoscopic resection
- Intraoperative monitoring
- Pituitary tumor
- Visual evoked potential (VEP)

Abbreviations and Acronyms

- LED:** Light-emitting diode
TIVA: Total intravenous anesthesia
VEP: Visual evoked potential

From the Departments of ¹Neurosurgery, ²Otolaryngology, and ³Ophthalmology, Icahn School of Medicine at Mount Sinai, New York, New York, USA

To whom correspondence should be addressed: Rui Feng, M.D.
 [E-mail: rui.feng@icahn.mssm.edu]

Citation: *World Neurosurg.* (2019) 126:e136-e143.
<https://doi.org/10.1016/j.wneu.2019.01.278>

Journal homepage: www.journals.elsevier.com/world-neurosurgery

Available online: www.sciencedirect.com

1878-8750/\$ - see front matter © 2019 Elsevier Inc. All rights reserved.

outcomes in endoscopic transsphenoidal surgery. We hypothesized that VEPs can be recorded consistently and reliably throughout the surgical procedure and that variations in the tracing are correlated with postoperative visual outcomes.

METHODS

Patient Enrollment and Outcome Measurement

Between November 2011 and February 2015, VEPs were prospectively monitored and recorded in 59 sellar lesion resections conducted by a single neurosurgical team at a large tertiary medical center. Any patient older than 18 years with a sellar lesion ≥ 1.0 cm who provided consent was enrolled.

Inclusion Criteria

All enrolled patients received a magnetic resonance imaging stereotactic high-resolution volumetric study with Brainlab (Brainlab, Munich, Germany) navigational system before surgery. Only transsphenoidal endoscopic resections of primary neoplasms were included. Specifically, 11 nonendoscopic skull-based resections were excluded, 3 resections were excluded because of technical limitations (1 from unreliable VEP measures as a result of the anesthesia regimen and 2 from technical malfunctions of optic goggles), and 1 was excluded because of the nonneoplastic nature of the lesion (lymphocytic hypophysitis).

A comprehensive data set was compiled for the remaining 42 sellar neoplasms from patient medical records containing patient age, gender, tumor characteristics, length of stay, complications, 30-day readmission, and medical comorbidities including diabetes mellitus, hypertension, hyperlipidemia, obesity (defined as body mass index >30 , calculated as weight in kilograms divided by the square of height in meters), preexisting sinus disease, cardiac disease, and cerebrovascular accident.

Outcomes Measurement

Our primary outcomes of interest were changes in patient visual acuity and Goldmann perimetry patient visual fields before and after surgery. Patient visual acuity was reported and stratified. Cases with ambiguity were rounded into the worst category. Patient visual fields were reported as normal or containing a quadrant, hemi, or full defect. Preoperatively, all patients underwent formal ophthalmology assessment, and visual field information was obtained through ophthalmology records. Postoperatively, all patients received formal visual acuity and visual field assessment. In addition, most patients (55%) had repeat ophthalmology assessment, typically within 1–4 weeks after resection. For the patients without repeat formal postoperative ophthalmologist testing, visual function on confrontational testing performed immediately before discharge was obtained only. Any eyes that were deemed congenitally blind (visual acuity $<20/400$ or full visual field defect) from causes predating tumor development were excluded from analysis.

All patients provided their informed consent and this study was approved by the hospital's institutional review board. Associations between changes in VEPs and changes in visual outcomes as well as patient demographic information were observed through univariate ordered logistic regression. Each eye was analyzed separately when

examining visual acuity data. All statistical analysis was conducted through Stata 13 (StataCorp LLC, College Station, Texas, USA).

Intraoperative Methodology and Postoperative Interpretation

VEPs were measured using the Flash VEP technique, in which patients receive light stimuli directly to their eyes through ultra-bright light-emitting diode (LED) goggles worn throughout the tumor resection. These stimuli, each lasting 5 milliseconds with a frequency of 0.4–4 Hz, activated retina luminance as well as color detection in the eye. VEPs originating from several different cortical areas were measured directly from 6 pairs of corkscrew electrode sensors placed on the patient's scalp, and every set of 100 readings was summed as a single action potential and time stamped accordingly. All patients received a standardized regimen of total intravenous anesthesia (TIVA) including a fentanyl opioid and propofol, a sedative hypnotic agent. This anesthesia regimen ensured our ability to stimulate the optic nerve in the absence of processing by the retina, thereby allowing more synchronous axonal activation and the elicitation of responses with enhanced magnitude and sensitivity than in previous VEP studies.⁷

In seeking to quantify and understand our recorded action potentials, several different parameters were evaluated. The primary time frame of interest in which VEPs were evaluated occurred in the approximately 135 milliseconds after the light stimulus was administered. Amplitude was defined as the difference in amplitude between the apex of the largest positive and negative peaks at 75 and 100 milliseconds, respectively. In accordance with previous literature,⁸ a change in amplitude was defined as a magnitude shift $>50\%$, where an increase in amplitude was considered to be improvement and a decrease considered to be deterioration. Latency was defined as the time differential between the onset of the stimulus and the large negative peak at 100 milliseconds. An increase in latency was defined as a rightward shift of this peak and, reciprocally, a decrease in latency was considered to be a leftward shift. Reductions in latency were considered to be improvements and increases in latency were considered to be a form of deterioration.

In evaluating our VEP recordings for potential changes across these characteristics, we used several different and independent layers of screening to ensure consistency and accuracy in our proposed interpretation of our findings. First our research technicians, trained in measuring and interpreting potentials, denoted any potential change that they observed under the supervision of the operating neurosurgeon. Any recording in which intraoperative interpretation suggested the possibility of a change in amplitude, latency, or morphology underwent subsequent review by a separate member of the team. The accuracy of these interpretations was then evaluated by the principal investigator of the study.

RESULTS

Patient Characteristics

Of the 42 patients enrolled in this study, 24 were female. The average age was 51.6 years (range, 24–77 years). Thirty-two tumors were nonsecretory adenomas, 5 secreted growth hormone, 3 were prolactinomas, 1 was a low-grade meningioma, and 1 was a sellar

optic glioma. Average tumor size was 2.84 cm. Information concerning patient medical comorbidities can be found in [Table 1](#).

VEP Results

Of the 42 patients enrolled in this study, 11 experienced a change in amplitude, latency, or morphology of their VEPs. Ten of these patients experienced deterioration in 1 dimension of their VEPs. Of these 10, 6 experienced a complete restoration of baseline VEPs, whereas 4 had VEPs fail to recover in either amplitude or latency either unilaterally or bilaterally. For 1 patient in this study, no VEPs could be obtained from the beginning portion of the surgery until the tumor was resected, at which point potentials began and were observed for the remainder of the procedure. Greater detail concerning the nature of these changes is provided in [Table 2](#).

Preoperative and Postoperative Visual Outcomes

All patients in this study received careful vision screenings both before and after their surgical procedures. [Table 3](#) provides an overview of associations observed between changes in VEP and patient visual outcomes. Of the 42 patients, 16 had improvements in visual acuity in at least 1 eye, and 16 had improvements in

visual field (23 patients with overall vision improvement). Of the 31 patients who had stable VEPs, 4 had decrease in visual acuity in at least 1 eye, and 1 had decrease in visual field on postoperative visual testing. Of the 7 patients who had temporary deterioration in either VEP amplitude or latency with subsequent restoration to baseline, 3 had postoperative deterioration in visual acuity in at least 1 eye, and 1 in visual field. For the 4 patients who had deterioration in VEP amplitude or latency without restoration to baseline, 1 had deterioration in visual acuity in at least 1 eye, and 2 in visual field. For the 1 patient who had improvement of VEP in both amplitude and latency, there were no change between preoperative and postoperative visual acuity and visual field. A direct correlation between intraoperative VEP changes and postoperative changes in visual fields was found, with an odds ratio of 3.15 (95% confidence interval, 1.15–8.59). Specifically, changes in VEP amplitude were most strongly correlated with visual field outcomes, with an odds ratio of 4.35 (odds ratio, 1.29–14.7) whereas changes in VEP latency were not significantly associated with visual field outcomes. Calculated sensitivity and specificity of VEP amplitude in detecting changes in visual field outcomes are 75% and 79%, respectively. No association was observed between VEPs and other patient or tumor characteristics.

Patient Characteristics	
Age (years)	
Male (n = 18)	55.0 ± 13.1
Female (n = 4)	48.7 ± 13.8
Overall (n = 42)	51.6 ± 13.7
Tumor type (n)	
Nonsecretory	32
Secretory	8
Growth hormone	5
Prolactin	3
Other	2
Tumor size (cm)	
Nonsecretory (n = 32)	2.81 ± 1.10
Secretory (n = 8)	3.29 ± 1.80
Other (n = 2)	1.55 ± 0.64
Overall (n = 42):	2.84 ± 1.23
Comorbidities (n)	
Diabetes mellitus	7/42
Hypertension	15/42
Hyperlipidemia	8/42
Obesity (body mass index >30)	6/42
Cardiac disease	6/42
Preexisting sinus disease	13/42
Postoperative steroids	41/42

DISCUSSION

The increased popularity and prevalence of expansive endoscopic surgery for pituitary tumors has significantly pushed the indications into more larger and anatomically complex tumors.^{1,2,4} Because endoscopic approaches are being used for these increasingly larger lesions, techniques that can reliably monitor the integrity of the optic pathway and preserve postoperative visual outcomes may have an important role in patient outcome. In addition, patients with pituitary tumors can often be asymptomatic despite having visual field defects, and the pattern of defects can be unpredictable.^{9,10} Highly sensitive monitoring can alert the surgeon to subtle defects and patients at risk for further visual impairment. In this study, we attempted to develop and devise a protocol to investigate VEP in patients with large sellar lesions undergoing endoscopic transsphenoidal resection. We further opted for continuous real-time monitoring. Our results showed that VEP signals can be recorded consistently and reliably in a population with complex tumor. In addition, the monitoring system, hardware, and software are the same as used for motor and sensory monitoring, which is found in most neurosurgical centers. The only additional costs include the reusable LED lights and goggles, which cost <\$50 combined. Therefore, cost is unlikely to be an issue for any center with the basic neuromonitoring system.

VEP had long been investigated as a method of intraoperative monitoring for neurosurgical procedures along the optic pathway ([Figure 1](#)).⁶ Unlike the somatosensory and auditory evoked responses, efficacy of VEP recordings had been controversial because of the inaccuracies in early monitoring data. Studies have shown VEP recordings to be too unstable and volatile, have high intraindividual variability and instability, and lack definite correlation between intraoperative monitoring results and postoperative visual outcomes.^{11–15} However, our study used a few techniques to address these issues. First, all patients in the present study underwent TIVA during the entirety of the procedure. VEP is especially susceptible to the influence of halogenated agents.^{11,16}

Table 2. Summary of Visual Evoked Potential Results

	Improvement	Stable	Deterioration with Baseline Restoration	Deterioration without Baseline Restoration
Amplitude	1	32	7	2
Latency	1	37	1	3
Total*	1	31	7	4

*Total is greater than number of patients because some patients had deterioration with baseline restoration in amplitude and without baseline restoration in latency.

Other studies using TIVA generally showed improved stability and consistency in VEP tracings.^{17,18} Another modification in our study was the use of flexible silicone-patch LED goggles, which provide better adaptation to the eyelids (Figure 2). Several studies have already reported improved stimulus delivery and recoding consistency.^{7,8}

As a result, our recordings showed excellent consistency and reliability. Most patients (74%) had stable VEP measures throughout the procedure, whereas 6 (14%) had a temporary deterioration in VEP that restored to baseline and 4 (10%) deteriorated without restoration (see Table 2). These findings are consistent with past studies of intraoperative VEP monitoring involving pituitary surgery, which have found stable VEP measures for about 70%–90% of patients, transient deterioration for 10%–20% of patients, and nonrestoring deteriorations for 3%–10%.^{6,8,17–20} In addition, of the patients with stable VEP measures, 16% had a decrease in a postoperative visual measure. This finding was similar to past work noting decline in visual function after stable VEP measurements.^{6,8,19} However, Kuruzumi et al.²⁰ reported in a study of pituitary transsphenoidal endoscopic surgery that 0 of their 17 patients with stable intraoperative VEP measures had visual deteriorations, but lesion sizes were not reported. The average tumor size of the current

patient cohort is relatively large, at 2.84 ± 1.23 cm, which may have contributed to the variability in visual outcomes. Furthermore, none of our patients developed any direct complications from the recording procedures, which indicates that our protocol is safe.

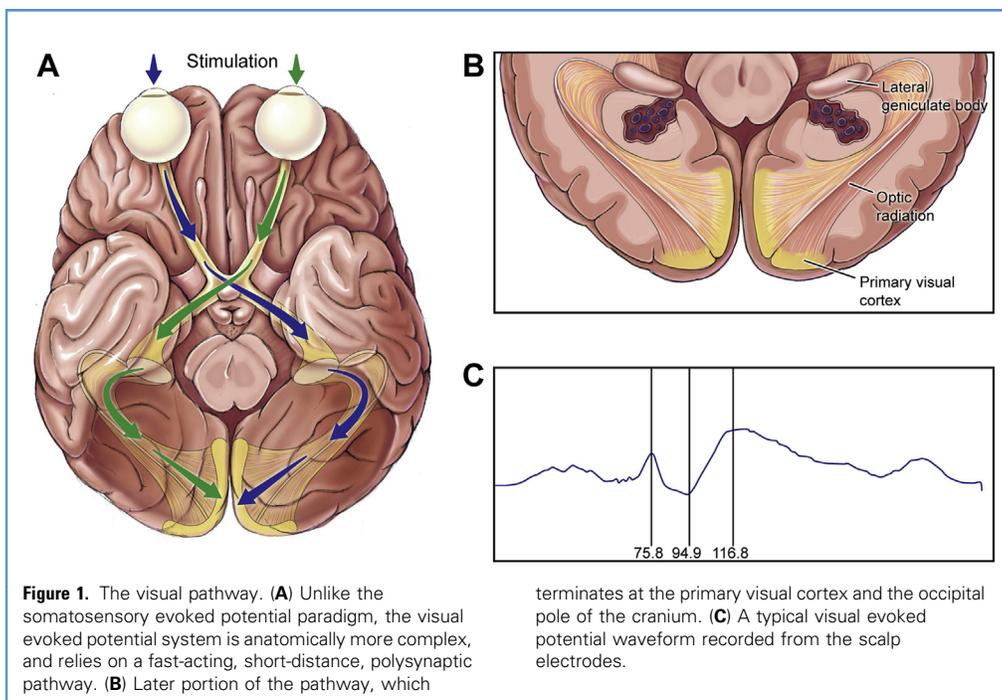
Postoperative visual function of those with transient and enduring VEP deteriorations was more concerning. Four of 6 patients (67%) with temporary deteriorations had either visual acuity or visual field loss on postoperative testing. Past studies^{17–19} have noted that about 50%–100% of patients with transient VEP deterioration remained stable or improved in visual outcomes but did not worsen. In these studies, lesion size was not recorded and may have been smaller than in the present analysis, which may involve more complex tumor-compressing visual structures. A study by Kamio et al.¹⁸ of 33 patients undergoing transsphenoidal surgery with TIVA showed reliable intraoperative VEP tracings. More importantly, it concluded that VEP monitoring aided preservation of visual function. During the operations, the surgeon was alerted to when the VEP changed beyond a preset threshold, and surgical manipulations were stopped until VEP recovered. Postoperatively, 4 patients who showed transient intraoperative VEP decrease had no postoperative visual deterioration.

In the present study, 3 of the 4 patients (75%) without restoration of VEP deterioration were found to have worsened visual outcomes, which was consistent with past work reporting 100% decline in visual outcomes,^{6,17,18} although others have reported mostly stable visual function after resection.^{8,19} Although there was a significant correlation with visual field testing, we did not find an association of VEP measures with postoperative visual acuity. Recent data of 35 pituitary adenoma patients undergoing transsphenoidal endoscopic resection²¹ reported that intraoperative VEP amplitude increases >50% correlated with postresection visual acuity. However, there was no information on tumor size to compare with the present analysis. Overall, our findings suggest that intraoperative VEP tracings can be reliably and consistently recorded in endoscopic transsphenoidal approaches, and signals can correlate with postoperative function.

To characterize the exact mechanism that caused the VEP changes, we further investigated the 11 patients who experienced intraoperative VEP fluctuations (Table 4). For 6 of these patients, the VEP signal deteriorated in latency and/or amplitude and never recovered to baseline. One patient had improvement in VEP amplitude as well as latency, which persisted. For the other 4, the VEP signal showed transient deterioration or improvement and subsequent recovery to baseline. Because of the small sample size, we were not able to find any statistically significant correlations. However, we were able to postulate on a few trends.

Table 3. Correlation Between Visual Evoked Potentials and Visual Outcomes and Patient Characteristics

Characteristic	P Value	Odds Ratio
Visual outcomes		
Visual acuity right eye	0.44	1.49 (0.54–4.06)
Visual acuity overall survival	0.34	1.62 (0.60–4.32)
Visual field	0.024	3.15 (1.15–8.59)
Tumor characteristics		
Tumor size	0.96	1.02 (0.59–1.75)
Secretory (binary)	0.94	0.94 (0.17–4.91)
Patient characteristics		
Hypertension	0.78	0.82 (0.21–3.3)
Diabetes	0.60	1.68 (0.24–1.58)
Hyperlipidemia	0.41	0.52 (0.11–2.47)
Gender	0.28	2.16 (0.56–8.78)
Age	0.82	0.99 (0.94–1.04)
Obesity	0.46	0.51 (0.08–3.07)



First, patients with temporary VEP changes had relatively large tumors, largest of which was measured at 5.5 cm. The mean tumor size in these patients was 3.25 cm, compared with 2.83 cm for the rest of our patient cohort. Tumor volume and optic chiasm height have been correlated with severity of visual field defects.²²⁻²⁴ The larger tumor size suggests that the optic nerves were under more severe compression (**Figure 3**). Studies²⁵ have shown that size of the tumor and extent of erosion into the surrounding sella are likely correlated to intrasellar pressure. Second, 6 of these patients had evidence of intratumor hemorrhage on preoperative imaging. The residual hemosiderin contained within these tumors may affect the VEP signals.

Furthermore, in 9 of these patients, the diaphragm and/or arachnoid was opened intraoperatively. The opening of the diaphragm and/or arachnoid potentially caused changes in cerebrospinal fluid flow. These maneuvers may have affected the amount of pressure on the surrounding optic nerve, subsequently affecting the VEP signal variability.

Based on the findings of our study, we suggest a few points of consideration for future clinical investigation and use of VEP recordings. First, TIVA should be used for the entirety of the procedure to ensure reliability and consistency of the VEP recordings. Similarly, goggles or other devices that are safe for patients to wear intraoperatively should be used to ensure good and

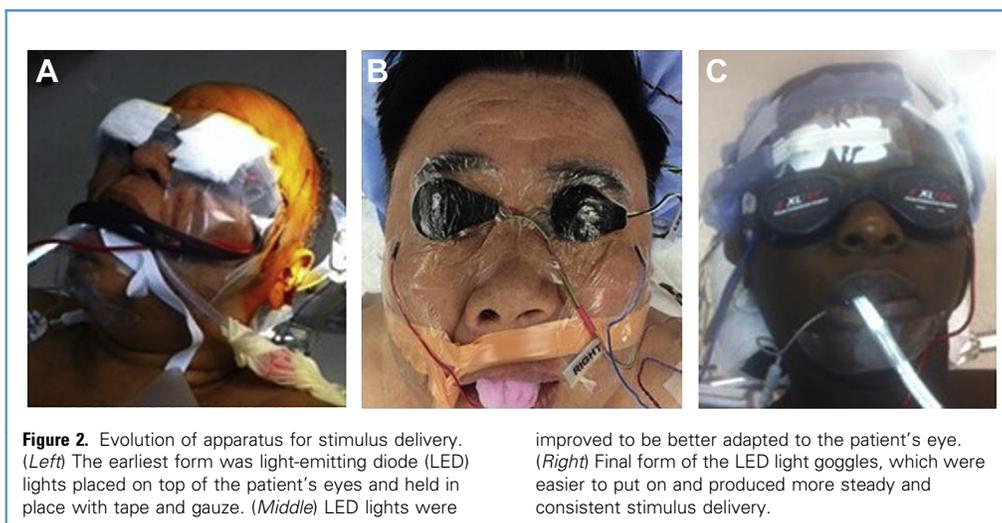
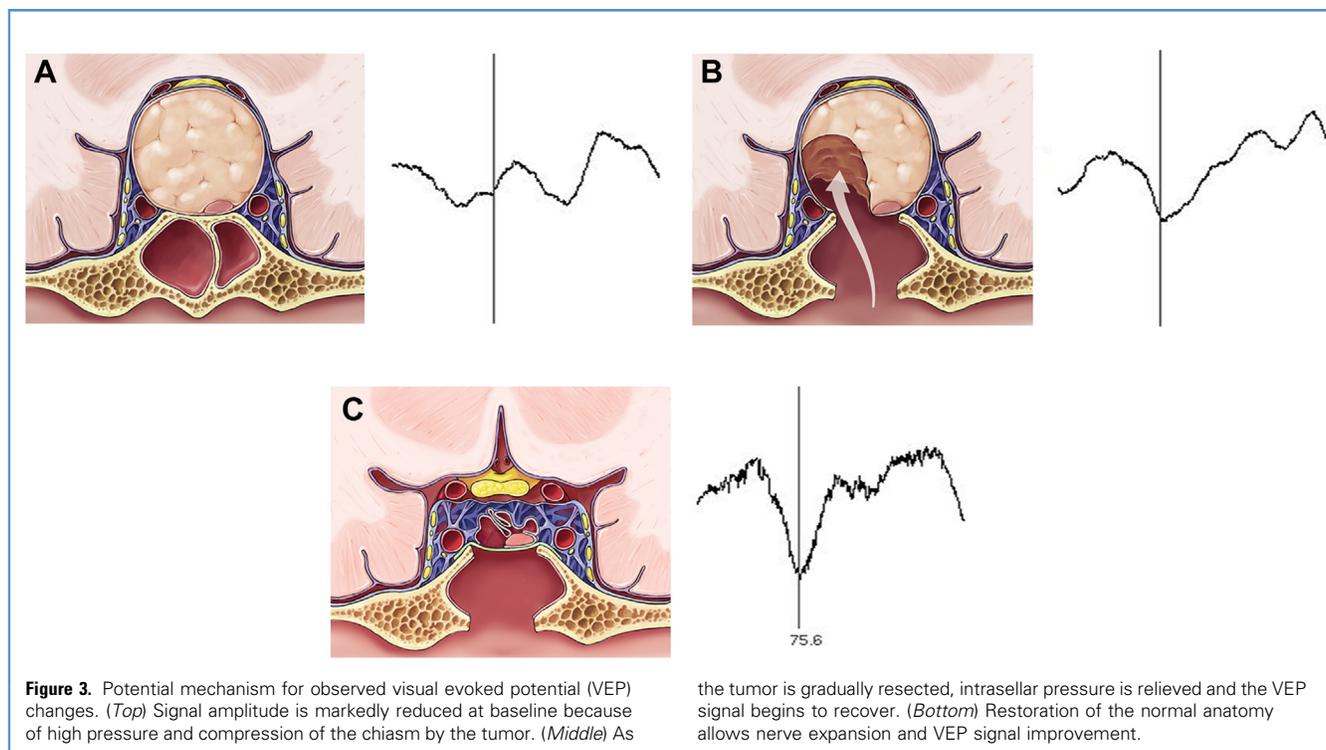


Table 4. A Total of 11 Patients had Intraoperative Visual Evoked Potential (VEP) Changes. Of the 6 Patients Who had Temporary Deterioration in Either VEP Amplitude or Latency with Subsequent Restoration to Baseline, 3 had Postoperative Deterioration in Visual Acuity in at Least 1 Eye, and 1 in Visual Field. For the 4 Patients Who had Deterioration in VEP Amplitude or Latency Without Restoration to Baseline, 1 had Deterioration in Visual Acuity in at Least 1 Eye, and 2 in Visual Field. For the 1 Patient Who had Improvement of VEP in Both Amplitude and Latency, There Were No Change Between Preoperative and Postoperative Visual Acuity and Visual Field

Patient	Age (Years)	Gender	Tumor Size (cm)	Intraoperative Visual Evoked Potential Amplitude Change	Intraoperative Visual Evoked Potential Latency Change	Visual Acuity Change	Visual Field Change	Notes
1	61	Female	2.5	Deterioration with recovery	Deterioration with recovery	Improved	Improved	Optic nerve and chiasmal compression, evidence of hemorrhage, diaphragm opened
2	54	Male	4.8	Deterioration with recovery	No change	No change	Improved	Evidence of hemorrhage, diaphragm opened
3	46	Male	5.5	Deterioration with recovery	No change	No change	No change	Initial complete compression of bilateral optic nerves, opening diaphragm
4	34	Male	2	Deterioration with recovery	No change	Deteriorated	No change	Significant bilateral optic nerve compression, diaphragm opened
5	64	Female	2.7	Deterioration with recovery	No change	Deteriorated	No change	Acromegalic, evidence of hemorrhage, diaphragm opened
6	33	Male	2	No change	Sustained deterioration	No change	No change	Evidence of hemorrhage in tumor
7	61	Male	3.2	Deterioration with recovery	Sustained deterioration	Improved	Deteriorated	Evidence of hemorrhage/blood product diaphragm opened
8	27	Female	2	Sustained improvement	Sustained improvement	No change	No change	Evidence of optic atrophy, compression of chiasm
9	55	Male	2	Deterioration with recovery	No change	Deteriorated	Deteriorated	Significant suprachiasmatic compression, evidence of hemorrhage, diaphragm opened
10	48	Female	1	Sustained deterioration	No change	Improved	Improved	Low-grade meningioma, significant optic compression, diaphragm opened
11	52	Female	2.5	Sustained deterioration	Sustained deterioration	Deteriorated	Deteriorated	Optic glioma, nerve resected, diaphragm opened



consistent stimulus delivery. The present study used scalp recordings, which is less than ideal because of the dampening of the signal through the long visual pathway and subsequently the skull and scalp. However, direct electrode recording of the optic pathway is impractical to achieve in nonopen procedures. Thus, better recording methods and/or signal amplifiers should be developed and investigated for VEPs. Furthermore, more detailed correlations of real-time VEP changes and intraoperative manipulations can be valuable in future studies. In the present study, once alerted of intraoperative VEP change, the surgical team would stop any surgical dissection and/or manipulation. Blood pressure is also increased temporarily as a standard in all monitoring protocols. In addition, other surgical techniques used that may affect VEP included arachnoid dissection, diaphragm fenestration, cerebrospinal fluid drainage, and tumor dissection and decompression. Further analyses regarding surgical augmentation of VEP may contribute to increased efficacy and safety of endoscopic procedures in these complex and large lesions.

Our study has several limitations. First, our patient sample size is small, and our study is limited by the associated biases. Second, although our results showed a statistically significant correlation between change in VEP amplitude and visual outcomes, 5 patients experienced postoperative visual function deterioration despite having unchanged intraoperative VEP recording. This situation may be caused by the limited sensitivity of our recording system and signal amplification (i.e., these patients may have had VEP

changes but were undetected). In addition, we did not map the timing of the VEP changes with intraoperative maneuvers, so it is unclear whether certain steps of the procedures affected VEP, such as opening the diaphragm or debulking the tumor. We did not have long-term follow-up data many of the patient cohort. Previous study²⁶ has shown that late phase of visual function recovery after decompression of the anterior visual pathway can take up to 3 years. It remains unclear whether VEP monitoring affected long-term patient visual outcome and tumor recurrence rates.

CONCLUSIONS

Recent advances in several areas have drastically improved the quality and efficacy of VEP for intraoperative monitoring. Results from our study suggest that changes in intraoperative VEP signals correlate with postoperative visual function, consistent with other recent studies. Further investigation of VEP technology has the potential value for intraoperative monitoring of the optic nerve and visual pathway integrity. Real-time changes in VEP can alert the surgeon to excessive disturbance of the optic nerve and allow immediate correction. Intraoperative VEP can also have predictive value for long-term visual outcomes, which can aid postoperative patient counseling. Postoperative visual function may be even more accurately predicted when combined with more complex neuroimaging analysis.^{23,27}

REFERENCES

- Koutourousiou M, Gardner PA, Fernandez-Miranda JC, Paluzzi A, Wang EW, Snyderman CH. Endoscopic endonasal surgery for giant pituitary adenomas: advantages and limitations. *J Neurosurg.* 2013;118:621-631.
- Black PM, Zervas NT, Candia G. Management of large pituitary adenomas by transsphenoidal surgery. *Surg Neurol.* 1988;29:443-447.
- Berker M, Hazer DB, Yücel T, et al. Complications of endoscopic surgery of the pituitary adenomas: Analysis of 570 patients and review of the literature. *Pituitary.* 2012;15:288-300.
- Juraschka K, Khan OH, Godoy BL, et al. Endoscopic endonasal transsphenoidal approach to large and giant pituitary adenomas: institutional experience and predictors of extent of resection. *J Neurosurg.* 2014;121:75-83.
- Nishioka H. Recent Evolution of endoscopic endonasal surgery for treatment of pituitary adenomas. *Neurol Med Chir (Tokyo).* 2017;57:151-158.
- Metwali H, Kniese K, Fahlbusch R. Intraoperative monitoring of the integrity of the anterior visual pathways: a methodologic review and meta-analysis. *World Neurosurg.* 2018;110:217-225.
- Kodama K, Goto T, Sato A, Sakai K, Tanaka Y, Hongo K. Standard and limitation of intraoperative monitoring of the visual evoked potential. *Acta Neurochir (Wien).* 2010;152:643-648.
- Chung SB, Park CW, Seo DW, Kong DS, Park SK. Intraoperative visual evoked potential has no association with postoperative visual outcomes in transsphenoidal surgery. *Acta Neurochir (Wien).* 2012;154:1505-1510.
- Poon A, McNeill P, Harper A, O'Day J. Patterns of visual loss associated with pituitary macroadenomas. *Aust N Z J Ophthalmol.* 1995;23:107-115.
- Lee IH, Miller NR, Zan E, et al. Visual defects in patients with pituitary adenomas: the myth of bitemporal hemianopsia. *Am J Roentgenol.* 2015;205:W512-W518.
- Cedzich C, Schramm J, Fahlbusch R. Are flash-evoked visual potentials useful for intraoperative monitoring of visual pathway function? *Neurosurgery.* 1987;21:709-715.
- Cedzich C, Schramm J, Mengedoh CF, Fahlbusch R. Factors that limit the use of flash visual evoked potentials for surgical monitoring. *Electroencephalogr Clin Neurophysiol Evoked Potentials.* 1988;71:142-145.
- Wiedemayer H, Fauser B, Armbruster W, Gasser T, Stolke D. Visual evoked potentials for intraoperative neurophysiologic monitoring using total intravenous anesthesia. *J Neurosurg Anesthesiol.* 2003;15:19-24.
- Jones NS. Visual evoked potentials in endoscopic and anterior skull base surgery: a review. *J Laryngol Otol.* 1997;111:513-516.
- Cedzich C, Schramm J. Monitoring of flash visual evoked potentials during neurosurgical operations. *Int Anesthesiol Clin.* 1990;28:165-169.
- Nakagawa I, Hidaka S, Okada H, Kubo T, Okamura K, Kato T. Effects of sevoflurane and propofol on evoked potentials during neurosurgical anesthesia. *Japanese J Anesthesiol.* 2006;55:692-698.
- Sasaki T, Itakura T, Suzuki K, et al. Intraoperative monitoring of visual evoked potential: introduction of a clinically useful method. *J Neurosurg.* 2010;112:273-284.
- Kamio Y, Sakai N, Sameshima T, et al. Usefulness of Intraoperative Monitoring of Visual Evoked Potentials in Transsphenoidal Surgery. *Neurol Med Chir (Tokyo).* 2014;54:606-611.
- Luo Y, Regli L, Bozinov O, Sarnthein J. Clinical utility and limitations of intraoperative monitoring of visual evoked potentials. *PLoS One.* 2015;10:e0120525.
- Kurozumi K, Kameda M, Ishida J, Date I. Simultaneous combination of electromagnetic navigation with visual evoked potential in endoscopic transsphenoidal surgery: clinical experience and technical considerations. *Acta Neurochir (Wien).* 2017;159:1043-1048.
- Nagata Y. Or178 Correlation between postoperative visual outcome and intraoperative visual evoked potentials during endoscopic transsphenoidal surgery. *Clin Neurophysiol.* 2017;128:e236.
- Lee JP, Park IW, Chung YS. The volume of tumor mass and visual field defect in patients with pituitary macroadenoma. *Korean J Ophthalmol.* 2011;25:37.
- Carrim ZI, Reeks GA, Chohan AW, Dunn LT, Hadley DM. Predicting impairment of central vision from dimensions of the optic chiasm in patients with pituitary adenoma. *Acta Neurochir (Wien).* 2007;149:255-260.
- Ho R-W, Huang H-M, Ho J-T. The influence of pituitary adenoma size on vision and visual outcomes after trans-sphenoidal adenectomy: a report of 78 cases. *J Korean Neurosurg Soc.* 2015;57:23.
- Gondim JA, Tella OI Jr, Schops M. Intracranial pressure and tumor volume in pituitary tumor: relation study. *Arq Neuropsiquiatr.* 2006;64:971-975.
- Kerrison JB, Lynn MJ, Baer CA, Newman SA, Biousse V, Newman NJ. Stages of improvement in visual fields after pituitary tumor resection. *Am J Ophthalmol.* 2000;130:813-820.
- Tokumaru AM, Sakata I, Terada H, Kosuda S, Nawashiro H, Yoshii M. Optic nerve hyperintensity on T2-weighted images among patients with pituitary macroadenoma: correlation with visual impairment. *AJNR Am J Neuroradiol.* 2006;27:250-254.

Conflict of interest statement: The authors declare that the article content was composed in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Previous presentation: 13th Congress of the European Skull Base Society, April 19–21, 2018, Warsaw, Poland; oral presentation.

Received 25 November 2018; accepted 30 January 2019

Citation: World Neurosurg. (2019) 126:e136-e143.

<https://doi.org/10.1016/j.wneu.2019.01.278>

Journal homepage: www.journals.elsevier.com/world-neurosurgery

Available online: www.sciencedirect.com

1878-8750/\$ - see front matter © 2019 Elsevier Inc. All rights reserved.