Intraoperative Flash Visual Evoked Potential Recording and Relationship to Visual Outcome

David A. Houlden, Chantal A. Turgeon, Nathaniel S. Amyot, Idara Edem, John Sinclair, Charles Agbi, Thomas Polis, Fahad Alkherayf

ABSTRACT: *Objective:* To determine the relationship between intraoperative flash visual evoked potential (FVEP) monitoring and visual function. *Methods:* Intraoperative FVEPs were recorded from electrodes placed in the scalp overlying the visual cortex (Oz) after flashing red light stimulation delivered by Cadwell LED stimulating goggles in 89 patients. Restrictive filtering (typically 10–100 Hz), optimal reject window settings, mastoid reference site, total intravenous anesthetic (TIVA), and stable retinal stimulation (ensured by concomitant electroretinogram [ERG] recording) were used to enhance FVEP reproducibility. *Results:* The relationship between FVEP amplitude change and visual outcome was determined from 179 eyes. One eye had a permanent intraoperative FVEP loss despite stable ERG, and this eye had new, severe postoperative visual dysfunction. Seven eyes had transient significant FVEP change (>50% amplitude decrease that recovered by the end of surgery), but only one of those had a decrease in postoperative visual acuity. FVEP changes in all eight eyes (one permanent FVEP loss plus seven transient FVEP changes) were related to surgical manipulation. In each case the surgeon was promptly informed of the FVEP deterioration and took remedial action. The other eyes did not have FVEP changes, and none of those eyes had new postoperative visual deficits. *Conclusions:* Our FVEP findings relate to visual outcome with a sensitivity and specificity of 1.0. New methods for rapidly acquiring reproducible FVEP waveforms allowed for timely reporting of significant FVEP change resulting in prompt surgical action. This may have accounted for the low postoperative visual deficit rate (1%) in this series.

RÉSUMÉ: L'enregistrement du potentiel évoqué visuel par flash dans un contexte peropératoire et sa relation avec des résultats en matière d'acuité visuelle. *Objectif :* Déterminer la relation entre le suivi du potentiel évoqué visuel par flash (PEVF) dans un contexte peropératoire et la fonction visuelle. *Méthodes :* Le PEVF a été enregistré, dans un contexte peropératoire, au moyen d'électrodes placées dans le cuir chevelu recouvrant le cortex visuel, et ce, après qu'une lumière rouge clignotante, devant entraîner une stimulation, a été produite par des lunettes Cadwell à diodes électro-luminescentes données à 89 patients. Pour améliorer la reproductibilité du PEVF, nous avons utilisé les méthodes ou techniques suivantes : choisir un filtre restrictif (le plus souvent de 10–100 Hz) ; déterminer des réglages optimaux permettant de déterminer un intervalle de rejet des résultats (optimal reject window settings) ; opter pour un emplacement de référence sur les mastoïdes ; consigner la durée totale d'anesthésie intraveineuse ; et finalement s'assurer d'une stimulation rétinienne stable (assurée par des enregistrements concomitants par électrorétinogramme ou ERG). *Résultats :* La relation entre l'amplitude des variations de PEVF et nos résultats en matière d'acuité visuelle a été déterminée à l'aide de 179 yeux. Dans le cas d'un seul œil, on a noté, dans un contexte peropératoire, une perte permanente de PEVF en dépit de résultats stables à un ERG. Il faut aussi savoir que cet œil était atteint d'une grave dysfonction visuelle postopératoire. Si sept yeux ont montré des variations notables, bien que transitoires, en ce qui regarde leur PEVF (> 50 % de diminution de l'amplitude, cette dernière ayant été récupérée avant la fin de la chirurgie), seulement un œil a donné à voir une diminution post-opératoire de l'acuité visuelle. Au total, les variations de PEVF dans le cas de ces huit yeux ont été liées aux manipulations réalisées lors d'interventions chirurgicales. Pour chacun de ces cas, le chirurgien a été informé sans délai de la détérioration du PEVF et a pris des mesures correctives. Enfin, les autres yeux n'ont pas donné à voir des variations de PEVF ; plus encore, aucun d'entre eux n'a montré des signes de déficit visuel postopératoire. *Conclusions :* Nos résultats en matière de PEVF peuvent être reliés à des mesures d'acuité visuelle dont la sensibilité et la spécificité sont de 1,0. De nouvelles méthodes permettant d'enregistrer rapidement les ondes reproductibles du PEVF ont permis de détecter plus exactement les variations notables de ce potentiel, ce qui en retour a entraîné des interventions chirurgicales plus rapides. C'est peut-être pour cette raison que le taux de déficit visuel postopératoire était bas dans cette série de cas (1 %).

INTRODUCTION

Intraoperative flash visual evoked potential (FVEP) recording has become possible due to recent refinements in technical and anesthetic methods that have improved FVEP reproducibility. Specifically, the use of restrictive bandpass filtering, optimal reject window settings, mastoid reference site, total intravenous anesthetic (TIVA), and stable retinal stimulation (ensured by concomitant electroretinogram [ERG] recording) have greatly enhanced FVEP reproducibility.[1–5] The FVEP was previously considered difficult to obtain during surgery and, when obtained, a poor predictor of postoperative visual function.[6–10] Now that it is possible to obtain more reproducible intraoperative FVEPs, there is renewed interest in determining its relationship to iatrogenic visual pathway injury.

Neurosurgery performed in areas involving the visual pathway, including orbital, transsphenoidal, and transcranial approaches over the parietal, temporal, and occipital cortices are associated with varying levels of postoperative visual dysfunction.[4] For instance, surgical resection of suprasellar meningiomas has been shown to worsen visual function in 14–28% of patients,[11–14] and surgical resection of craniopharyngiomas worsen visual function in 3–11.5% of patients.[15,16] Rare cases of visual loss following surgery for aneurysms (particularly paraophthalmic and superior hypophyseal artery aneurysms) have been reported.[17–19] Manipulation of the optic nerve and interference with the microvasculature during microsurgical dissection is thought to be responsible for the visual loss.

Ultimately, the goal of intraoperative FVEP monitoring is to prevent iatrogenic visual pathway injury through prompt identification of FVEP deterioration at a time when corrective measures may be applied. With the recent improvements in FVEP monitoring, FVEPs could increasingly serve as a reliable tool for reducing the incidence of intraoperative injury to the visual pathway. In this paper we describe the relationship between our intraoperative FVEP results and visual outcome. We also describe surgical maneuvers associated with intraoperative FVEP deterioration and recovery.

METHODS

Patient population: FVEPs were attempted in 89 patients (35 males; mean age 52.2 years during 105 surgeries; 12 patients had 2 surgeries and 2 patients had 3 surgeries). FVEPs were recorded in 77 pre-chiasmal (62 via endonasal approach), 25 post-chiasmal (20 by craniotomy and 5 by endovascular approach), and 3 spinal surgeries. Further classification of pathology is shown in Table 1. Patients were selected based on the surgeon's determination that (a) the visual system was at risk of iatrogenic injury; (b) the intraoperative FVEP monitoring could rapidly detect this injury; and (c) corrective measures could be taken during surgery to reverse it. Three spinal surgeries were monitored because there are reports of blindness after lengthy spinal surgeries in the prone position.[20]

FVEP methods: Methods for reproducible intraoperative FVEP recording have been previously described and the technical and physiologic factors outlined.[1] In brief, left then right eyes were stimulated with flashing red light stimulation at a rate of 1.41 Hz using a Cadwell goggle stimulator (Cadwell Laboratories, Kennewick, WA, USA). Stimulation was delivered via three LEDs on each side, 640 nm peak wavelength, 10 ms pulse width, 3000 mCd of luminous intensity reflected back on an angle to give uniform illumination across the whole red plastic lens. FVEP recordings were obtained from subdermal corkscrew electrodes placed at Oz-linked mastoid and Oz–Fz (international 10–20 system) using a 32-channel Cadwell Elite machine (Cadwell instruments, Kennewick WA). The ground electrode was placed on the upper leg. Electroretinogram (ERG) was concomitantly recorded from a subdermal needle electrode placed just above the bridge of the nose and referenced to Fz. The electrode positioned above the bridge of the nose (between the eyes) allowed us to record ERG from each eye separately after left then right eye stimulation. Simultaneous monitoring of ERG and FVEP allowed for detection of post-retinal visual pathway compromise (FVEP change without ERG change) that was easily distinguished from retinal compromise or inadequate retinal stimulation (simultaneous FVEP and ERG change). When simultaneous loss of FVEP and ERG occurred during reflection of the frontal skin flap over the stimulating goggles, a downwardly displaced goggle from skin flap pressure was usually the culprit (as determined by visual inspection of the goggle position under the drape). The sweep duration was 300 ms and 50–150 repetitions were included in each average. The amplifier gain was 50,000 and the recording bandpass was 10–100 Hz for all channels. The reject window setting was 20 µV (peak-to-peak) for Oz-linked mastoid montage and 30 µV for Oz–Fz montage. If the FVEP was not reproducible, then the low cut filter was increased to 30 Hz. Applying tight reject window settings during signal acquisition blocked transient high-amplitude artifacts. This led to improvement in signal quality and decreased the number of stimulus repetitions necessary for a reproducible FVEP. The FVEP amplitude was measured from the first negative peak after 60 ms (N1) to the following positive peak (P1). A >50% decrease in the intraoperative FVEP N1–P1 amplitude recorded from Oz- linked mastoid (without a change in ERG amplitude) was considered a significant FVEP change and reported to the surgeon. We did not consider transient FVEP N1–P1 amplitude change without new postoperative visual deficit to be a false-positive result, rather an indication that there was reversible electrophysiological dysfunction within visual pathways contributing to the FVEP.

Anesthetic methods: Total intravenous anesthesia (TIVA) was used through the whole period of monitoring in all patients except two. Stable level of anesthesia was maintained by the continuous infusion of propofol (100–150 µg/kg/min), remifentanil (0.2–0.5 µg/kg/min), and ultra-low dose of ketamine (0.1–0.2 mg/kg/h).[21,22] Low-dose vasopressor infusion (phenylephrine or norepinephrine) was added if required to maintain mean arterial pressure in the range of 70–100 mm Hg. In two patients, inhalation agents (desflurane or sevoflurane), remifentanil, and occasional boluses of propofol were used. All changes in anesthetic medications were recorded in the neuromonitoring log.

Visual testing: Pre- and postoperative visual testing results were obtained retrospectively. To include as many FVEP-monitored patients as possible, we analyzed only the most commonly performed tests of visual function (administered by the neurosurgeon and/or ophthalmologist blinded to the intraoperative FVEP findings). These included pre- and postoperative color vision, visual acuity, and confrontational visual field testing. The confrontational visual field test, also referred to as Donder's test, was conducted by having the patient place a hand over one eye and maintaining a fixed gaze while simultaneously reporting awareness of the examiner's hand moving to various

Table 1: Number of cases with FVEP monitoring by pathology

Approach	Pre/post-chiasmal	Location	Pathology	# of cases
CR	PrC	ACOM	Aneurysm	1
CR	PrC	Ophthalmic/paraophthalmic	Aneurysm	4
CR	PrC	PCOM	Aneurysm	1
CR	PrC	Frontal	Cavernoma	1
CR	PrC	Suprasellar	Craniopharyngioma	1
CR	PrC	Sphenoid	Meningioma	6
CR	PrC	Temporal	Meningioma	1
CR	PoC	Parietal	Abscesses	1
CR	PoC	Occipital	AVM	1
CR	PoC	Temporal	AVM	1
CR	PoC	Temporal	Cavernoma	1
CR	PoC	Temporal	Epidermoid Cyst	1
CR	PoC	Occipital	Glioma	1
CR	PoC	Temporal	Glioma	2
CR	PoC	Occipital	Meningioma	2
CR	PoC	Parietal	Meningioma	2
CR	PoC	Temporal	Meningioma	1
CR	PoC	Parietal	Metastasis	1
CR	PoC	Frontal	Metastasis	1
CR	PoC	Occipital	Metastasis	3
CR	PoC	Temporal	Metastasis	1
CR	PoC	Intraventricular	Subependymoma	1
E	PrC	Pituitary	Adenoma	19
E	PrC	Nasopharynx	Angiofibroma	2
E	PrC	Ethmoid	Adenocarcinoma	2
E	PrC	Sphenoid	Metastasis	1
E	PrC	Nasopharynx	Nasopharyngeal carcinoma	1
E	PrC	Sphenoid	Chordoma	1
E	PrC	Suprasellar	Craniopharyngioma	8
E	PrC	Pituitary	Rathke's cleft cyst	2
E	PrC	Ethmoid	Encephalocele	1
E	PrC	Suprasellar	Glomangiopericytoma	2
E	PrC	Ethmoid	Meningioma	5
E	PrC	Pituitary	Meningioma	1
E	PrC	Sphenoid	Meningioma	10
E	PrC	Suprasellar	Meningioma	1
E	PrC	Ethmoid	Meningocele	1
E	PrC	Suprasellar	Sarcoma	4
E	PrC	Suprasellar	Teratoma	1
SP	SP	Spinal	Cervical myelopathy, thoracic myelopathy, foraminal stenosis	3
V	PoC	PCA	Aneurysm	1
V	PoC	Occipital	AVM	4

CR = craniotomy; E = endonasal ; SP = spine ; V = endovascular ; PrC = pre-chiasmal ; PoC = post-chiasmal; ACOM = anterior communicating artery; PCOM = posterior communicating artery; PCA = posterior cerebral artery; AVM = arteriovenous malformation.

Table 2: Data from five patients with transient intraoperative FVEP amplitude decrease (>50% decrease in N1–P1 amplitude compared with baseline)

Pathology	Location	Pre-op visual function	Event causing FVEP decrease (surgeon changed approach after event)	FVEP amplitude (% baseline) at time of event	FVEP amplitude (% baseline) at end of surgery	Postoperative visual function
Suprasellar meningioma (midline)	Pre-chiasmal and chiasmal	Lt: only finger counting; Rt: visual acuity 20/30	Retraction of dura and manual bony resection away from chiasm with Kerrison instrument	Lt 16%; Rt 36%	Lt ≥100%; Rt ≥100%	No change bilaterally
Lt adenoid cystic carcinoma	Pre-chiasmal and chiasmal	Normal bilaterally	Dissection around cyst	Lt 42%	Lt ≥100%	No change bilaterally
Pituitary adenoma (midline)	Chiasmal	Normal bilaterally	Retraction of tumor attached to optic chiasm	Lt 40%	Lt ≥100%	No change bilaterally
Rt planum, sellar meningioma	Pre-chiasmal	Lt: normal; Rt: no vision except left upper quadrant; no color vision	Dissection/retraction around left then right side of tumor	Lt 10%; Rt 0%	Lt ≥100%; Rt 53%	No change bilaterally
Lt paraophthalmic aneurysm	Pre-chiasmal	Normal bilaterally	Dissection around aneurysm	Lt 35%	Lt 100%	Lt: visual acuity 20/30; Rt: no change

Lt = left; Rt = right.

positions in the patient's visual field. In addition, the patient reported on the number of fingers presented in quick succession, in all four visual quadrants, to assess finger counting ability in each visual field quadrant. Postoperative visual testing was typically performed 1 month after surgery.

Research adhered to the tenets of the Declaration of Helsinki (Code of Ethics of the World Medical Association).

RESULTS

Out of a possible 210 eyes, 31 (14%) were not monitored and considered non-contributive cases. The reasons were as follows: 16 eyes had absent or irreproducible baseline FVEPs (all had preoperative visual deficits); 7 eyes lost their FVEP (and ERG) due to intraoperative goggle movement; 1 patient (2 eyes) had FVEP amplitude decrease related to unanticipated anesthetic changes; FVEPs were not attempted in 4 eyes due to anticipated goggle movement related to reflection of the frontal skin flap; 1 patient (2 eyes) had intraoperative removal of goggles by neuromonitoring staff after the advent of an oculocardiac reflex. Every eye with an absent or irreproducible baseline FVEP had some form of preoperative visual deficit (typically profound deficits in visual acuity or dense visual field loss), but no degree of visual loss guaranteed an absent baseline FVEP. The relationship between FVEP N1–P1 amplitude change and visual outcome was determined from the remaining 179 eyes. Our success rate for obtaining reproducible intraoperative FVEPs was 86%. This would have been slightly higher if inadvertent intraoperative goggle movement did not occur (confirmed by loss of ERG and FVEP and by visual inspection, described in Methods section). Reproducible FVEPs were typically obtained in <1.5 minutes from each eye.

One eye (0.5%) with normal preoperative vision had a permanent FVEP loss (absent N1–P1 and subsequent FVEP waveforms, without change in ERG) during resection of a suprasellar tumor (Figure 1a and b). That eye had only light

perception after surgery (a true positive). Seven eyes (4%) had transient FVEP N1–P1 amplitude decrease (without change in ERG) that was related to either manipulation of tumor, aneurysm, or nerve (see Table 2). All of those eyes did not have new postoperative visual deficits except one that had mild changes in visual acuity (and optic neuropathy) after clipping of a paraophthalmic aneurysm. In that case, the FVEP amplitude transiently decreased by 65% (to 35% of baseline) for a period of just under 10 minutes (while dissecting around the aneurysm) and returned fully to baseline amplitude following the event. There was no change in the ERG, indicating stable retinal stimulation (Figure 2). All of the other eyes had no significant change in FVEP N1–P1 amplitude and no new postoperative visual deficits (no false-negatives; Table 3). There were no false-positives. If we exclude the transient changers from our analysis, then the sensitivity is 1.0 (95% CI = 2.5, 100) and specificity is 1.0 (95% CI = 97.9, 100). If we include them, then the sensitivity is 0.5 (95% CI = 1.3, 98.8) and specificity is 1.0 (95% CI = 97.9, 100), respectively.

Illustrative study showing transient FVEP deterioration (Table 2, case 4): A 39-year-old female, 38 weeks gestation, presented with progressive right visual field loss leading to a car accident. There were no symptoms of pituitary hormone deficiencies or excess, and she had no headaches, nausea, or vomiting. There were no other cranial nerve palsies on examination. On imaging she was found to have a suprasellar mass (Figure 3a). Due to loss of vision in the right eye, an urgent cesarean section was performed and 5 days later she had an expanded endoscopic endonasal approach for tumor resection (pathology revealed a transitional type meningioma; WHO grade 1). Despite right visual field loss preoperatively (no vision except left upper quadrant; no color vision), we were able to obtain reproducible FVEP bilaterally. There were significant transient changes in FVEP bilaterally associated with retraction near left, then right optic nerves
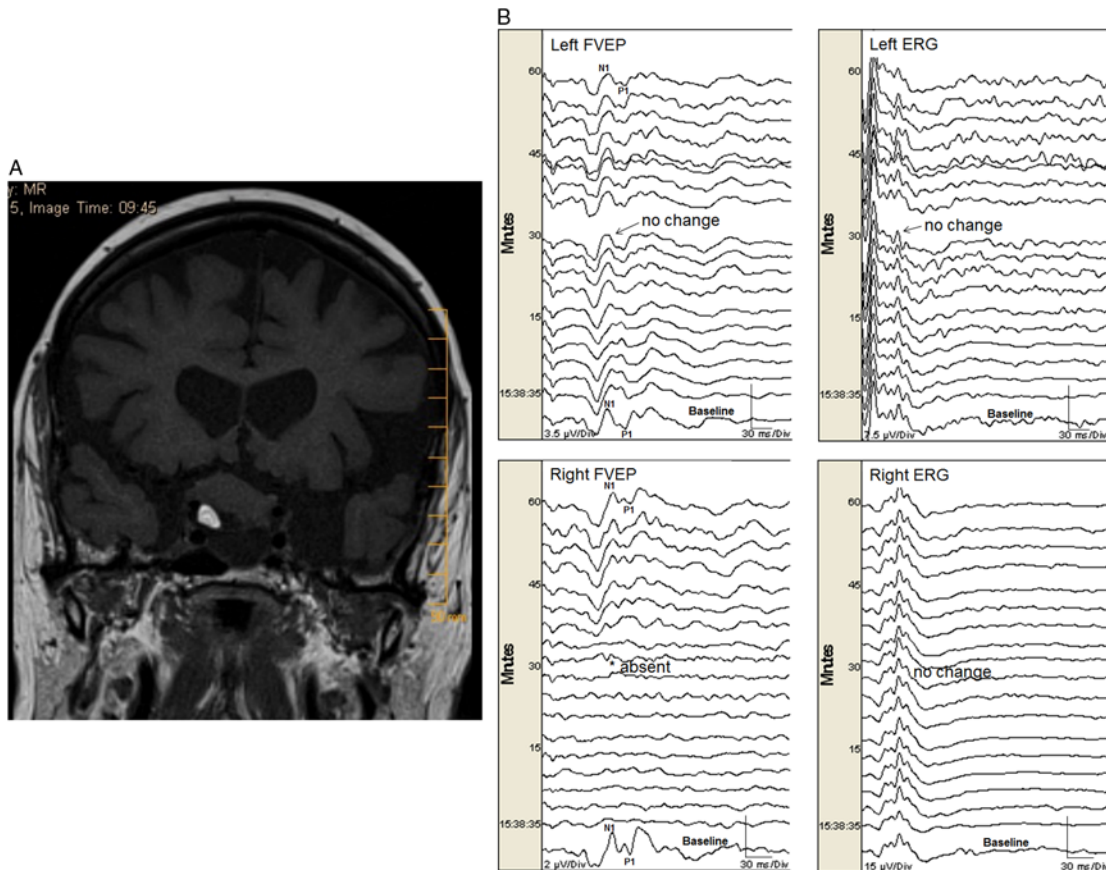
298

Figure 1: (A). A heterogeneous mass lesion in the suprasellar region (slightly more right of midline) measuring approximately 20 × 25 × 19 mm (AP × transverse × craniocaudal) likely splaying the optic nerves and chiasm. There was a focus of fat noted within the lesion. There was also an inferior cystic component. No significant enhancement noted in the post gadolinium images. (B). Permanent FVEP loss in this patient undergoing endonasal resection of a midline suprasellar teratoma. Preoperatively the patient had decreased visual acuity bilaterally with left worse than right eye. When working near the right optic nerve, the right FVEP was suddenly lost (bottom left panel). There was no change in the left FVEP (top left panel) and ERG bilaterally (top right and bottom right panels, respectively). At that time, the surgeon could not delineate a margin between the tumor and the nerve. Surgery ceased but the right FVEP remained absent. Postoperatively, the patient had worsened visual function in the right eye (only light perception) and improved visual function in her left eye.

(Figure 3b). Postoperatively, she developed pan-hypopituitarism, but her right eye vision improved. Three months later, all visual fields were normal to confrontation testing and she was deemed safe to drive.

Illustrative study showing permanent FVEP loss: A 77-year-old female with a history of multiple myeloma presented with bilateral visual loss over a period of 5 years but more recent progressive worsening of visual acuity in her left eye. Imaging revealed a suprasellar mass with heterogeneous content and significant chiasmal and optic nerve compression (more on the right side) (Figure 1a). She had an expanded endoscopic endonasal approach for tumor resection of the lesion, with dissection of the lesion from cranial nerves II and III as well as from the frontal lobes (pathology revealed a mature teratoma). Intraoperatively, there was a plane between the optic tract and the lesion bilaterally. Nevertheless, the most anterior part of the lesion was adherent to the right optic nerve, and traction on the lesion was associated with sudden FVEP loss (Figure 1b), so the procedure was aborted. The FVEP did not recover by the end of surgery. Postoperatively, she had only light perception in the right eye, while visual acuity improved in her left eye.

Discussion

Our FVEP findings relate strongly to visual outcome. We had one eye with permanent FVEP loss associated with severe deterioration of visual function (0.5% of all eyes monitored) and one eye with transient FVEP change associated with mild postoperative deterioration of visual acuity (0.5% of all eyes monitored). In the former case, the right FVEP N1–P1 (and all subsequent FVEP waveforms) permanently disappeared (Figure 1b). At that time, the margin between optic nerve and tumor was ill-defined. The surgeon was promptly informed of the FVEP loss and he stopped resecting and retracting, but the FVEP did not return. In contrast, we had seven eyes (4%) with significant *transient* FVEP amplitude deterioration related to surgical manipulation. In all of those cases the surgeon was promptly informed of the FVEP deterioration and stopped resecting and/or retracting near the offended optic nerve or chiasm. The FVEP amplitude recovered within 10–15 minutes in all cases (Table 2). All but one of those eyes had unchanged postoperative visual function (one had a mild deterioration in visual acuity postoperatively despite full recovery of the FVEP). Accordingly, we believe prompt reporting of FVEP deterioration resulted in prompt surgical action that was important for FVEP

Table 3: Intraoperative flash visual evoked potential changes and relationship to patient outcome

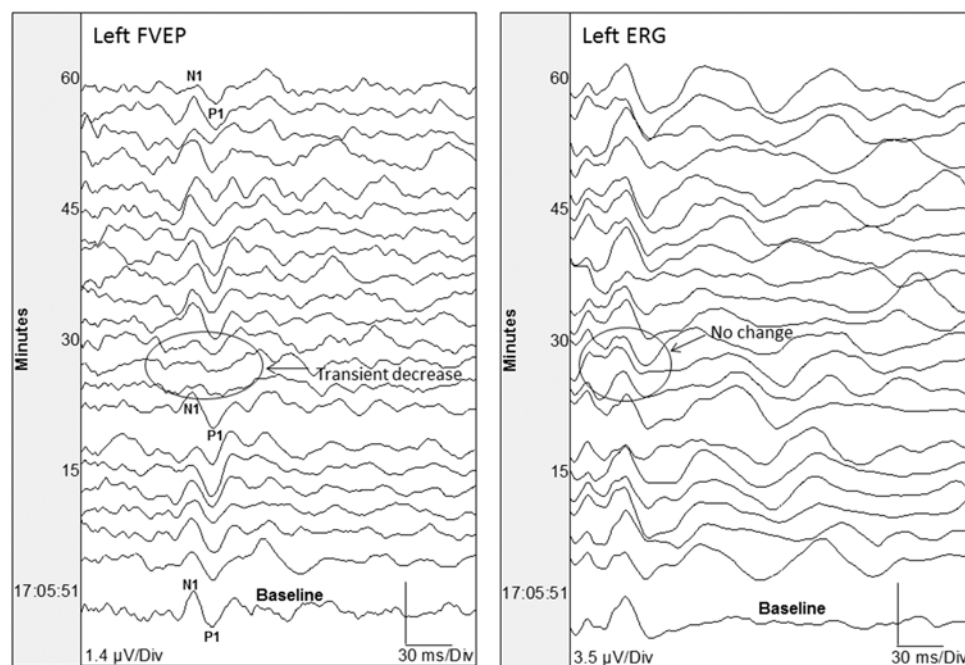|	N (eyes)	Visual deficit	No visual deficit
Significant FVEP change	1	1	0
Transient FVEP change	7	1	6
No significant FVEP change	171	0	171

Figure 2: *Transient significant FVEP N1–P1 amplitude change in a patient undergoing surgery for clipping of a left paraophthalmic aneurysm. Preoperatively the patient had normal vision. When dissecting around the aneurysm, the left FVEP N1–P1 amplitude decreased by 65% (to 35% of baseline; left panel). The surgeon stopped resecting and the amplitude recovered 10 minutes later. There was no concomitant change in left ERG (right panel), indicating adequate retinal stimulation. The right FVEP and ERG did not change (not shown). Postoperatively, the patient experienced mild optic neuropathy in the form of decreased left-sided visual acuity (20/30). This was thought to be the result of segmental interruption of the blood supply to the posterior optic nerve.*

amplitude recovery, which, in turn, may have accounted for the low postoperative visual deficit rate (1%) in this series. We believe that transient change should be excluded from the analysis of sensitivity and specificity because it reflects functional compromise of the visual pathway that is undergoing some degree of recovery and, as such, is not categorically a positive or negative finding. Consequently, our sensitivity and specificity were 1.0 (excluding the transient changers).

Careful exclusion of eyes that produced low amplitude, irreproducible baseline FVEP (despite good ERG) from our analysis (non-contributive cases; 14% of all eyes tested) likely helped to eliminate false-positive and false-negative results. Lack of false-negatives in our study (excluding transient changers from false-negative calculations for the same reasons described above) may also be explained by our relatively few post-chiasmal operations (24% of surgeries). Other investigators have associated false-negative FVEPs to new partial field defects after post-chiasmal surgery.[5,23] Intraoperative deterioration of visual function in a partial field may be difficult to detect with FVEP monitoring because the FVEP is generated from all quadrants of the retina.

As such, the FVEP likely relates more to a measure of gross visual function. Some investigators have described no relationship between FVEP and visual acuity.[6,24] Others have shown that intraoperative FVEP changes are associated with changes in visual acuity more than changes in visual field testing,[3] and our results support this (both patients with FVEP change and new visual deficits had changes in visual acuity). A recent study showed that if the criterion for significant FVEP change is decreased to $\geq$20% amplitude reduction (instead of $\geq$50%) while using multiple recording sites (O1, O2, and Oz) and white light stimulation, then there may be improved detection of iatrogenic injury resulting in quadrantanopia.[25]

The high success rate in this study was mostly related to the use of restrictive filtering, optimal reject window settings, mastoid reference, concomitant ERG recordings, and TIVA anesthesia.[4] In a previous paper, we showed that FVEPs are more reproducible in the presence of low-amplitude EEG than high-amplitude EEG.[1] EEG amplitude can be strategically decreased using a mastoid reference (instead of Fz) and setting the low-cut filter to a minimum of 10 or 15 Hz.[23] We acknowledge that the use of 10 Hz
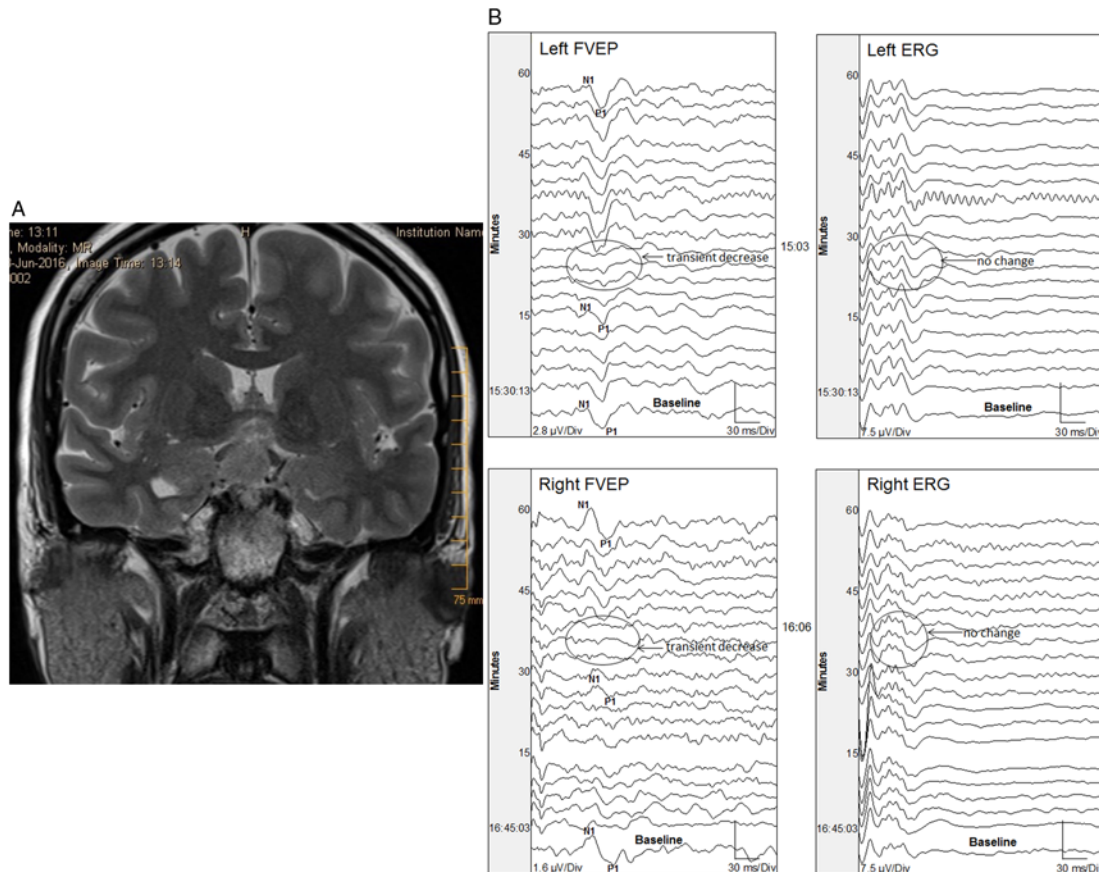
Figure 3: *(A). A sellar/suprasellar mass, separate from the pituitary gland, measuring approximately 17 × 16 × 21 mm (AP × transverse × craniocaudal) abutting the optic chiasm (not separate from it) displacing the optic chiasm postero-superiorly. The cisternal component of the optic nerves was stretched. The infundibulum was not identified. The A1 segments of the anterior cerebral artery were displaced superiorly. The lesion had homogenous enhancement. (B). Transient significant FVEP N1–P1 amplitude change in this patient undergoing endonasal resection of a right planum, sellar meningioma. Preoperatively the patient had normal vision in the left eye but no vision in the right eye except from the left upper quadrant. When working near the left optic nerve, the left FVEP N1–P1 amplitude decreased to 10% of baseline (top left panel; time 15:03). When the surgeon decreased retraction and slowed resection, the amplitude recovered over the next 10–15 minutes. Later, there was a loss of the right FVEP while working near the right optic nerve (bottom left panel; time 16:06). The right FVEP N1–P1 amplitude recovered to 53% of baseline after decreased retraction and slowed resection. There was no significant change in ERG bilaterally (top right and bottom right panels, respectively). Postoperatively, there were no new visual deficits bilaterally.*

low-cut filter will reduce low-frequency contributions to the FVEP, but this compromise is necessary for recording reproducible intraoperative FVEPs.[1] Accordingly, in the current study we mainly used a 10 Hz low-cut filter and a 20 µV (peak-to-peak) reject window for the Oz-linked mastoid recording montage. The reject window was optimal for excluding artifacts, so they could not contaminate the FVEP response. Previous investigators have used a wide variety of techniques to varying degrees of success (see Table 1 in Rajan et al.).[4] Our recording method (described above) incorporates the parameters used by those who had most success in obtaining reproducible intraoperative FVEP monitoring and combines them with the use of a reject window to further improve FVEP reproducibility and detection of FVEP change. Although our FVEPs were not obtained in real time (due to imperative signal averaging), in some cases we were able to generate a reproducible FVEP after averaging 10 stimuli (in less than 7 seconds), while the longest acquisition time was 71 seconds. In the majority of cases the acquisition time was <35 seconds.

This facilitated prompt communication of FVEP deterioration to the surgeon so timely corrective measures could be initiated.

Surgical resection of lesions adjacent to or adherent to the optic apparatus has always created much trepidation for neurosurgeons due to the inability to obtain immediate physiological feedback during removal. Surgery involving the sensorimotor pathways can be monitored with somatosensory and motor evoked potentials, and surgery involving speech pathways may be mapped during awake surgery. Unfortunately, the definitive assessment regarding the morbidity of visual pathway surgery has relied on postoperative assessment, so surgery is often more conservative in nature for fear of yielding a permanent visual deficit. In this study, we have shown that reproducible intraoperative FVEP recording is possible and, when deteriorations occur, corrective surgical measures can be undertaken to improve FVEPs resulting in improved or stable visual function postoperatively. Accordingly, reproducible intraoperative FVEP monitoring may keenly affect surgical decision-making and contribute to the

prevention of postoperative visual dysfunction while allowing more total resection of tumors when monitoring is stable.

Due to the retrospective nature of the present study, our analysis was limited to the tests of visual function that were performed during the pre- and postoperative period in all patients (color vision, visual acuity, confrontational field testing). Unfortunately, most patients did not have Goldman perimetry testing; due to the retrospective nature of the study, the opportunity for obtaining it was lost. This is a limitation of our study because Goldman perimetry testing is better than confrontational testing in detecting visual field defects. Better detection of field defects may have decreased the sensitivity of our study because intraoperative FVEP monitoring does not always detect intraoperative visual deterioration in a single quadrant.[3,5,23] This may be related to the fact that the goggles themselves are unable to stimulate each quadrant of the visual field separately. In addition, the bulky goggle stimulators used in our study sometimes became displaced during craniotomy due to pressure of the frontal skin flap over the eyes. Lower profile eye patch stimulators (not yet approved for use in North America) are less prone to movement during skin flap retraction than goggle stimulators and should improve the success rate of FVEP monitoring in these cases.

Future studies should be designed to compare FVEP amplitude, latency, morphology, and reproducibility between eye patch stimulation and goggle stimulation, so intraoperative neurophysiology practitioners know what to expect from each stimulation technique. In addition, the effect of different flash intensity and color on intraoperative FVEP reproducibility and visual outcome should be studied.

DISCLOSURES

The authors have no conflicts of interest to declare.

REFERENCES

1. Houlden DA, Turgeon CA, Polis T, et al. Intraoperative flash VEPs are reproducible in the presence of low amplitude EEG. J Clin Monit Comput. 2014;28:275–85.
2. Kamio Y, Sakai N, Sameshima T, et al. Usefulness of intraoperative monitoring of visual evoked potentials in transsphenoidal surgery. Neurol Med Chir. 2014;54:606–11.
3. 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. 2010;152:643–8.
4. Rajan S, Simon MV, Nair DG. Intraoperative visual evoked potentials: there is more to it than meets the eye. J Neurol Neurosci. 2016;7:1–11.
5. Sasaki T, Itakura T, Suzuki K, et al. Intraoperative monitoring of visual evoked potential: introduction of a clinically useful method. J Neurosurg. 2010;112:273–84.
6. Cedzich C, Schramm J, Fahlbusch R. Are flash-evoked visual potentials useful for intraoperative monitoring of visual pathway function? Neurosurgery. 1987;21:709–15.
7. Cedzich C, Schramm J, Mengedoht CF, Fahlbusch R. Factors that limit the use of flash visual evoked potentials for surgical monitoring. Electroencephalogr Clin Neurophysiol. 1988;71:142–5.
8. Raudzens PA. Intraoperative monitoring of evoked potentials. Ann NY Acad Sci. 1982;388:308–25.
9. 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.
10. Wiedemayer H, Fauser B, Sandalcioglu IE, Armbruster W, Stolke D. Observations on intraoperative monitoring of visual pathways using steady-state visual evoked potentials. Eur J Anaesthesiol. 2004;21:429–33.
11. Andrews BT, Wilson CB. Suprasellar meningiomas: the effect of tumor location on postoperative visual outcome. J Neurosurg. 1988;69:523–8.
12. El-sayed M. Visual and hormonal outcome after surgical treatment of suprasellar meningiomas. AAMJ. 2010;8:142–55.
13. Gregorius FK, Hepler RS, Stern WE. Loss and recovery of vision with suprasellar meningiomas. J Neurosurg. 1975;42:69–75
14. Rosenstein J, Symon L. Surgical management of suprasellar meningioma: Part 2: prognosis for visual function following craniotomy. J Neurosurg. 1984;61:642–8.
15. Caldarelli M, Massimi L, Tamburrini G, Cappa M, Di Rocco C. Long-term results of the surgical treatment of craniopharyngioma: the experience at the Policlinico Gemelli, Catholic University, Rome. Childs Nerv Syst. 2005;21:747–57.
16. Chakrabarti I, Amar AP, Couldwell W, Weiss MH. Long-term neurological, visual, and endocrine outcomes following transnasal resection of craniopharyngioma. J Neurosurg. 2005;102:650–7.
17. Day AL. Aneurysms of the ophthalmic segment. A clinical and anatomical analysis. J Neurosurg. 1990;72:677–91.
18. Horiuchi T, Goto T, Tanaka Y, et al. Role of superior hypophyseal artery in visual function impairment after paraclinoid carotid artery aneurysm surgery. J Neurosurg. 2015;123:460–6.
19. Rizzo JF. Visual loss after neurosurgical repair of paraclinoid aneurysms. Ophthalmology. 1995;102:905–10.
20. Mohammed YTA, Houlden DA, AlKherayf F. Utilization of intraoperative visual evoked potential in long spine surgery: case report. J Neurol Neurophysiol. 2015;6:332.
21. Choi E, Lee H, Park HS, Lee GY, Kim YJ, Baik HJ. Effect of intraoperative infusion of ketamine on remifentanil-induced hyperalgesia. Korean J Anesthesiol. 2015;68:476–80.
22. Weinbroum AA. Postoperative hyperalgesia – a clinically applicable narrative review. Pharmacol Res. 2017;120:188–205.
23. Luo Y, Regli L, Bozinov O, Sarnthein J. Clinical utility and limitations of intraoperative monitoring of visual evoked potentials. PloS ONE. 2015;10:e0120525
24. Mauguiere F, Fischer C. Potentiels évoqués en neurologie: réponses normales. EMC Neurologie. 2007;4:1–38.
25. Gutzwiller EM, Cabrilo I, Radovanovic I., Schaller K, Boëx C. Intraoperative monitoring with visual evoked potentials for brain surgeries. J Neurosurg. 2018;1–7 doi: 10.3171/2017.8.JNS17 1168.