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## Introduction

One of the important goals of surgical procedures involving the visual pathways (retina, optic nerve (ON), optic chiasm, optic tracts, lateral geniculate nucleus in the thalamus, optic radiation, and occipital visual cortex) is the preservation of visual function and in cases of visual impairment, where possible, its improvement [1–4]. With these goals in mind, efforts to evaluate and enhance the usefulness of intraoperative monitoring (IOM) of the visual pathways that began in the early 1970s have continued. Wright et al. [5] are generally credited with the first report of a method for continuous monitoring of the visual pathways in 1973; utilizing brief flashes of light to evoke electroretinographic (F-ERGs) and visual-evoked potentials (F-VEPs) during orbital surgery. This triggered a number of other researchers to test their usefulness [2, 3, 6–21]. While some have reported favorable results and outcomes [5, 22–31], others have dismissed their use, citing technical difficulties associated with the delivery of visual delivery in an operating room (OR) setting, large inter- and intra-

individual variability, instability and unreliability of the visual responses [32–36], their susceptibility to anesthetics, particularly inhalational agents [32–37], and lastly and most damning, the poor correlation of IOM results to postoperative functional outcomes. All of these findings have led to a general disenchantment with their intraoperative use [7, 12, 18, 32–35, 37–45].

Still, on a *case-by-case basis*, monitoring of visual-evoked potentials (F-VEPs) has helped guide surgeries of the orbit [46–48], and anterior visual pathways during tumor or lesion removal where its use has helped identify encroachment of tumors on the optic chiasm, and has aided in the differentiation of normal ON tissue from tumor tissue; especially when the tumor encompasses the ON [2, 12–15, 19, 20]. Direct ON stimulation has helped navigate during surgical removal of tumors involving the anterior visual pathway and skull base tumors [13–15, 49, 50] with good outcomes. Though improved microsurgical techniques during procedures involving the sellar and parasellar regions [19] have significantly reduced the incidence of visual complications related to ON or chiasmal manipulation and/or devascularization, the potential remains for real-time, inadvertent, and potentially harmful maneuvers that may cause prolonged or intense indirect traction or compression of the ON to go unnoticed. Concern for preventing devastating outcomes to

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the visual pathway has encouraged a small but dedicated group of researchers to pursue refinement of the techniques for IOM of the visual pathways [2, 3, 13, 15, 19–25].

Other reports of beneficial use of IOM visual pathway monitoring have been contained in the literature. F-ERGs [51, 52] and F-VEPs [36, 37, 53, 54] have been reported to be helpful in assessing the depth of anesthesia. F-ERGs have been utilized in monitoring retinal function during eye surgery [46, 47, 54–56] and endovascular procedures involving orbital or periorbital vascular lesions [21] with good outcomes. They also have been used to monitor retinal perfusion during procedures employing extracorporeal circulation and hypothermic circulatory arrest [11, 57]. F-VEPs have reportedly been helpful for anatomic navigation of the optic radiations during surgical treatment of an occipital arteriovenous malformation [17], and by use of diffusion tensor imaging-based tractography for functional monitoring of the visual pathway [58]. Finally, visual-evoked responses obtained from direct stimulation of the optic tract have been used as a method for globus pallidus internus (GPI) targeting during pallidotomy [59, 60] and deep brain stimulation (DBS) interventions for treatment of Parkinson's disease where such procedures are performed under general anesthesia or for patients who otherwise are unable to cooperate during the procedure [16]. Although many of the above reports involved case report(s) or series, their findings suggest that further examinations of these monitoring methodologies and applications are needed. A better understanding of visual stimuli, the portions of the visual pathways that are stimulated, the methods for recording neurophysiologic responses, the effects of surgical manipulation, anesthetic management, and other perioperative factors on responses, will hopefully lead to improved IOM results. This in turn may spark renewed interest in research to further enhance techniques and outcomes for IOM of the visual pathways.

## Anatomy and Physiology of the Visual System

The optic structures of the eye project images onto the light-sensitive receptors of the retina, where a surprisingly high degree of neural processing is accomplished through the retina's complex pattern of interconnections between excitatory and inhibitory neurons. Some nerve fibers have small excitatory fields surrounded by inhibitory areas, and others have inhibitory center areas surrounded by excitatory ones. As a result, a good stimulus for exciting the visual pathway would be one that undergoes changes in contrast gradients (i.e., pattern-reversal). Because, in general, patient cooperation is not possible for the majority of surgical procedures, it is not feasible to utilize stimulation using high-contrast pattern reversing checkerboard stimuli that are used in diagnostic testing. Hence, the frequently employed stimulus for eliciting VEP responses for monitoring purposes has been flash stimuli [24, 61–63]. While the spatial distribution of the light over the visual field of each eye is transmitted to the brain through the optic nerves, very little information regarding the temporal variations in illumination is conveyed. Therefore it is key to note that when flash stimuli are employed for IOM monitoring purposes, what is actually being monitored is the visual pathways for light perception and not for visual acuity [64].

The neural information of flash stimuli travels from the optic chiasm onward, via the optic tracts to the lateral geniculate body in the thalamus, which then projects via connections to the visual cortex (Fig. 4.1) [64]. Though coding of the visual system has been intensively studied yielding a wealth of information about the retina's complex neural network responses [65], information about the gross response from the ON and lateral geniculate body to flash stimuli remains relatively sparse, and in general, early cortical activation following flash visual stimulation is not well understood in humans [65]. It is important to note



**Fig. 4.1** Schematic drawing of the visual pathway. *OC* optic chiasm, *SC* superior colliculus, *LV* lateral ventricle (from Moller et al. [64]; with permission)

that the optic pathways cross at the chiasm such that monocular or binocular flash stimuli used in monitoring will produce bilateral pathway activation behind the chiasm unless a means of hemi-field visual stimulation can be utilized (as can be done in awake subjects).

### Eliciting and Recording Flash Visual-Evoked Potentials

Depending on the portion(s) of the visual pathways at risk during surgical procedures, a number of strategies for stimulation of those pathways have been explored.

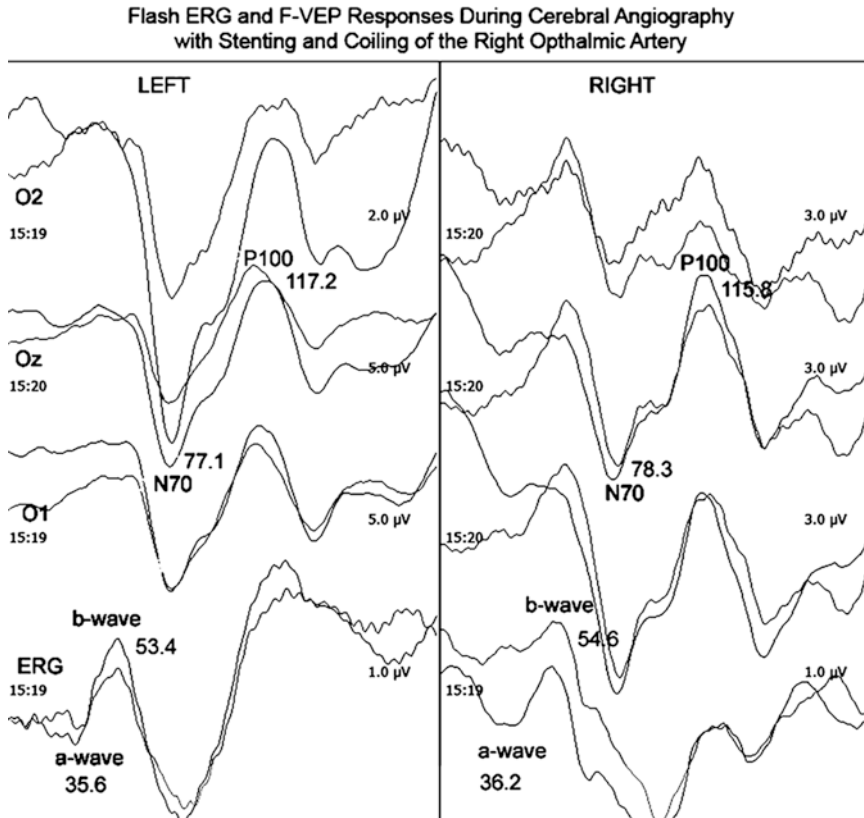
### Flash Electrographic Response

Responses generated by stimulation of the retina (F-ERG) have played a fundamental role in the diagnostic evaluation of retinal health [66]. For IOM purposes, they have been primarily used to

ensure retinal and visual pathway stimulation. They also have been used to monitor surgeries of the orbit and as a measure of anesthetic depth [46, 47, 51, 52]. The main components of the F-ERG are a negative-going a-wave with latencies occurring between  $24.2 \pm 1.1$  and  $27.2 \pm 3.7$  ms and a positive-going b-wave with latencies of  $45.0 \pm 1.5$ – $55.1 \pm 7.4$  ms. The a-wave, in response to a bright flash, largely reflects photoreceptor function but there may be a contribution from postreceptoral structures [67]. The b-wave, which is of higher amplitude than the a-wave in normal subjects, reflects postphototransduction activity. The origin of the ERGs' a- and b-waves is reportedly a combination of activities that include photoreceptor potentials, potassium-mediated current flow, and DC potentials within Müller cells [67]. The F-ERG to a flash stimulus is a mass response; thus F-ERG responses can appear normal when dysfunction is confined to small retinal areas (e.g., macular dysfunction). It has been reported that despite the macula's high photoreceptor density, an eye with purely macular disease has a normal bright single flash ERG response [67]. Typical ERG-VEP responses to flash stimuli delivered by light-emitting diode (LED) goggles are included in Fig. 4.2.

### Flash VEP Response

The F-VEP is generated by postretinal areas of the central nervous system in response to visual light stimulation and is a reflection of activity in segments of the primary visual pathway that project through the lateral geniculate body to the cortical visual fields. The response is composed of a triphasic waveform with an initial small positive deflection (40–50 ms), followed by a second negative deflection at 70–89 ms (often referred to as N70 or N1), followed by a positive wave at about 100 ms (P100 or P1) [68]. Though not unequivocally documented, the generator sites for the three waves of the F-VEP to LED stimulation are believed to originate from the lateral geniculate, striatum, and areas 17, 18, and 19 of the visual cortex [27, 68, 69].



**Fig. 4.2** An example of intraoperative flash electroretinograms (F-ERGs) recorded from surface electrodes placed in the orbital notches bilaterally and referenced 3 cm laterally and flash visual-evoked responses (F-VEPs) recorded from electrodes placed at left occipital (O1), mid-occipital (Oz), and right occipital (O2) scalp locations is shown. The responses were obtained at baseline for a patient undergoing endovascular cerebral

angiography with stenting and coiling for treatment of a right ophthalmic artery aneurysm. The rate of flash stimulation was 1.1/s. An average of 100 responses was obtained. Anesthetic management included induction with thiopental, sufentanil and dexmedetomidine (1 µg/kg), and maintenance with sufentanil infusion, 0.5 MAC of isoflurane and continuous infusion of dexmedetomidine (0.7 µg/kg/h)

### Techniques for Eliciting F-ERG and F-VEP

The lack of suitable equipment for visual stimulation has been a severe handicap to the use of ERG-VEP for IOM. Pattern-reversal stimuli or multifocal electroretinographic stimuli (which are routinely utilized in diagnostic settings to evaluate retinal function related to acuity) cannot be utilized on unconscious patients in the OR setting given the requirement for their cooperation and visual fixation on the stimuli. Moreover, the shift in dark vs. light pattern/contrast of these stimuli, which is key to stimulating the retinal

structures related to visual acuity, would certainly be diminished if not lost if one were to try to deliver these stimuli through closed eyelids. Because flash stimuli do not require patient fixation and cooperation and can be delivered through closed eyelids, they have been the most frequently used stimulus in the OR setting. Unfortunately, early research demonstrated that even when flash stimuli were employed for clinical diagnostic use (e.g., for assessment of ON pathology in multiple sclerosis patients), VEP responses to bright flashes were found to be normal while their responses to pattern-reversal stimulation were abnormal [68]. Moreover, the

amplitude and latency of VEPs elicited by the above flash stimulation methods unfortunately demonstrate considerable patient inter- and intra-variability of amplitude both in diagnostic and intraoperative settings [70]; especially in neonates, where maturation of the cerebral cortex appears to play a factor [71]. So although flash stimulation has largely been the stimulus of choice for IOM, it is not the best stimulus for assessing the preservation of fine visual acuity and function. Rather it has been used to assess in a rudimentary fashion whether response to stimulation can be conveyed along various points of the visual pathways [71]. Even so, it is important to note that when there is preexisting visual dysfunction that may disrupt the ability to convey such stimulation, recording responses may be compromised, although that has not been entirely confirmed. Multiple studies [2, 3, 20, 23–25] reported that preexisting severe visual dysfunction (even for patients with preexisting visual acuities of  $<0.4$  (20/50)) negatively impacted their ability to record F-VEPs while others indicate that F-VEPs for IOM can be obtained successfully from some patients with severe visual deficits [3, 19], when onset of the dysfunction was acute.

### Devices for Flash Stimulation

Researchers have worked to develop improvements in devices for the delivery of flash stimuli for IOM use, since the problems of delivering stimuli may be key to developing more effective activation of the pathways that correlate with functional vision. Initially a traditional strobe light was used to elicit responses but was found to be cumbersome in the OR and delivery of the flash could be ineffective since it might be partially obscured by the scalp flap and drapes if a bicoronal scalp incision is used, thus requiring a modification of the surgical approach.

Fiberoptic haptic lens [72] and scleral contact lens [26] connected to photostimulators were developed to provide flash stimuli in the 1970 and 1980s. Although some claim the resulting responses were more robust than those later obtained with LED stimulation (especially through dilated eyes) [72], use of contact lens for IOM has lost favor due to the invasive nature of

the technique (e.g., lid sutures to keep the corneal lens recording/stimulating device in place) and the potential risk of corneal abrasions and ulcerations with their use. The American Electroencephalographic Society (AEEGS) Guidelines for IOM recommend that such hard lens stimulators be kept on the eyes for a maximum of 45 min (limiting their practical use for a majority of surgical procedures) and that users need to carefully examine the safety data from the stimulator's developer before employing such lenses in the OR [73].

Because most shy away from the use of contact lens stimulators, LEDs mounted in eye patches [23–25] or goggles [9, 27] have been used, but the latter are bulky, require a headband, and can interfere with surgery. Their use also carries some risks. Care needs to be taken to ensure that the goggles are well-supported by the bony ridge of the patient's orbit and that they remain in place during the surgery. Should they inadvertently slip down and put direct pressure on the globe of the eye, they can cause central retinal artery thrombosis [9].

### Type of Light Stimulation

The AEEGS issued a recommendation that flash VEPs induced by white stroboscopic light (F-VEPs) be differentiated from those induced by red LEDs (LED-VEPs) [73] by utilizing the appropriate abbreviations. However, in general, in the IOM literature, the terms F-ERG and F-VEPs have been used to represent both. However, abbreviations aside, the two methods of stimulation may actually activate different retinal and cortical pathways [12]. Newer LED stimulating goggles and patches provide significantly increased luminosity [23–25]. Although safety data regarding their use is scant, authors reporting on their IOM use have not reported any postoperative sequelae, including cases involving lengthy neurosurgical procedures [2, 3, 20, 23–25].

### Monocular vs. Binocular Stimulation

Although binocular stimulation has been used for some studies, when the goal is to evaluate individual retinal and anterior pathways, the visual stimulus should be delivered and



recorded monocularly with responses from the contralateral eye, if clinically unaffected, used as a control [73].

### Pupillary Size and Retinal Luminance

When employing flash stimuli to elicit F-ERGs and F-VEPs, efforts to maintain pupil size and retinal luminance throughout the surgical procedure are important because these parameters affect the response latency and amplitude. Kriss et al. [74] showed that F-VEP latency through closed eyes is increased when compared to those recorded through open eyes. Intraoperative use of narcotics often results in miotic pupils that reduce retinal luminance, and staged dosing of narcotics during the surgical procedure may induce changes in latency and amplitude that may be misinterpreted as a surgically related event. It has been recommended that maximal dilation of the pupils be done through use of conjunctival instillation of mydriatics at the start of the case [73], but that may be contraindicated when perioperative assessment of pupillary response is required or preferred. Of note, recent and notably successful reports of intraoperative recordings of F-ERG and F-VEPs did not employ pupil dilation as part of their total intravenous anesthetic and monitoring management: propofol [2], administration of opioids [23–25], or remifentanyl [2]. It is important to note that those with successful IOM recordings of F-VEPs employed newer and brighter 16 LED arrays embedded in soft round silicone disks [2, 20, 23–25] or in goggles [3, 18] with luminosity adjustable from 500 to 20,000 Lumens (Lx), which helped to ensure retinal illumination and stimulation.

### Recording F-ERGs and F-VEPs

The recommended standards for IOM of VEPs were issued in 1987 by the American EEG Society [73]. To obtain consistent results, the guidelines advised that the following parameters be documented and remain constant throughout the IOM period. Though no such standards for IOM recording of ERG have been published, the following would likely apply to them as well. Given the expected high degree of F-VEP response variability even in *awake*

subjects [73], each patient with a reproducible response should serve as his or her own control in the IOM setting. A simultaneous recording of F-ERG responses is useful for confirmation of retina stimulation.

Before the surgeon approaches the optic pathways, the monitoring team should have identified reproducible waves to be used as benchmarks for meaningful assessment during subsequent monitoring during critical stages of the surgery. Stacked plots of sequentially recorded averages are indispensable for assessing changes during surgery. Interpretation of intraoperative VEPs should be done in relation to pharmacologic, physiologic, and surgical factors. Change in response trends should be reported as soon as identified, and immediate steps should be taken to prevent the risk of lasting damage and to optimize normal function [73].

### Stimulus Color

The color of the flash or LED (white vs. red) should be indicated on the record and kept constant throughout the case.

### Stimulus Rate

For transient F-ERGs and F-VEPs, a stimulus rate of 1–2.5 Hz is suggested and for steady-state responses a rate of 8–30 Hz may be used. Steady-state stimulation has not gained wide use for monitoring purposes. In a study published in 2004, their use during surgery for monitoring purposes did not facilitate improved or more stable F-VEP recordings [42].

### Recording Electrodes and Their Placement

Corneal or scleral lenses for IOM recording of ERG responses were supplanted in the 1980s with less invasive devices and methods. Corneal recording devices using a Burian Allen electrode and other devices placed on or near the cornea yielded larger, robust responses but are rarely used due to the risks of corneal abrasion and ulceration with IOM use. F-ERGS can be recorded from skin with subcutaneous needles or skin disc electrodes placed at the center of the right lower lid proximal to the lid margin

(infraorbital notch), and referenced to an electrode 2 cm lateral to the lateral canthus where the largest amplitudes of ERG responses from skin can be obtained [75, 76]. Esakowitz et al. [77] compared the relative amplitudes of F-ERG b-wave responses when recording with corneal versus other electrode types placed on the skin. The largest response amplitudes were obtained with the Burian Allen electrode (125  $\mu\text{V}$ , 100%), with other corneal electrodes yielding responses of less amplitude in proportion to those made with the Burian Allen electrode: JET (93%), C-glide (78%), gold foil (60%), and DTL (60%). Recordings from skin electrodes yielded the smallest response amplitudes (14%). Obviously, one has to weigh the risks and benefits of the use of these devices for recording F-ERGs [77]. F-ERGs recorded with noncorneal versus corneal electrodes, except for amplitude differences, are nearly identical in both time (a- and b-wave latencies) and frequency domains (dominant power spectrum peaks), meaning noncorneal F-ERGs do not differ significantly from corneal ERGs aside from amplitude [78].

One intriguing way to record F-ERGs was recently reported by Houlden et al. [3]. In their small sample of study patients ( $N=12$ ), they were able to reliably record F-ERGs from EEG electrodes placed at Fz' (2 cm behind Fz) and referenced to FPz (10–20 International EEG placement) to confirm retinal stimulation in the patients ( $N=12$ ) evaluated in their study. Though a novel and appealing recording methodology for F-ERGs, further studies are needed in larger patient populations to confirm its feasibility and utility for IOM.

For F-VEPs, standard subdural needle or surface EEG electrodes may be used to record scalp responses [73]. Ota et al. [29] reported that F-VEPs acquired with subdural electrodes better reflect cortical activity since they have considerably greater spatial resolution and amplitude when compared to responses acquired from surface EEG electrodes placed on the scalp. Single-channel response recordings are acquired using the 10–20 International nomenclature for the placement of EEG electrodes with electrodes typically placed at the midline occipital (5 cm

above inion) to midline frontal (MQ-MF or Oz-Fz) positions. The AEEGS guidelines [73] recommend a second channel be recorded for signal confirmation (however, few studies employ them). When used, the secondary set of electrodes would be placed at midline occipital and referenced to linked earlobes (MQ-Ipsilateral Earlobe (AI)/Contralateral Earlobe (A2) or Oz-AI/A2) locations. Typically the ground electrode is placed at CZ. Additional channels may be used to study the scalp distribution of VEPs [73].

### Analysis Periods for F-ERGs and F-VEPs

The AEEGS guidelines recommend the use of analysis periods of 100–200 ms for F-ERG [79] and 250–500 ms for F-VEP [73]. A total of 50–200 responses are commonly recorded per average [73], with the caveat that the number per average should remain constant throughout the monitoring period. At least two consecutive ERG and VEP averages should be acquired to confirm the reproducibility of the ERG and VEP waveforms after setup and prior to surgical incision to establish a baseline (control) recording [23, 73].

### Amplifier Settings for Recording F-ERG and F-VEP

For years the standard “clinical diagnostic settings” for system bandpass settings for F-VEPs have also been employed for IOM purposes, which are 1 to 200–300 Hz (–3 dB) with filter roll-off slopes not exceeding 12 dB/octave for low frequencies and 24 dB/octave for high frequencies. If irreducible artifacts occurred, filter settings could be adjusted to 5–100 Hz. Digital smoothing and filtering could also be employed to reduce artifact, and filter settings should remain constant throughout the monitoring session [73].

Houlden et al. [3] recently suggested that the difficulties in recording F-VEPs in IOM settings may be due to the high mean alpha EEG amplitudes ( $>50 \mu\text{V}$ ) in patients, contributing “noise” that impedes recording the F-VEP “signal.” For 9 of 12 patients with low mean alpha EEG amplitudes ( $<30 \mu\text{V}$ ), IOM F-VEPs were reproducible, including one whose vision was limited to finger counting. To improve the recording of responses in three patients with high mean alpha amplitudes

(>50  $\mu\text{V}$ ), Houlden et al. [3] elected to see if raising the low pass settings had any effect. In these patients, they simultaneously recorded EEG from Oz–Fz and Fz–Fpz' using 3-, 10-, and 30-Hz low cut filters (six independent recording channels) and two channels of F-VEP using low cut filters settings of 10 and 30 Hz. They found that F-VEP amplitude reductions were minimal for low pass filter settings of 3–10 Hz but at 30 Hz, the F-VEP's N1–P1 amplitude decreased by about 40% and its morphology was significantly altered. They also found that as the low pass filter setting increased, the "noise" contribution to the averaged F-VEP associated with electrocautery blocking time was also reduced. Based on those findings, Houlden et al. recommended using 15–20 Hz as a low pass filter setting for F-VEP responses. Houlden et al. points out that over 30 years ago, Nuwer and Dawson [80] recommended increasing the low cut filter settings from 1 to 30 Hz to improve intraoperative somatosensory-evoked potential (SSEP) reproducibility, but at the time, did not offer any reasons why the change improved the SSEP response. Houlden et al. [3] suggested that the improvement was due to reduction from the averaged response of the patient's alpha EEG and artifact due to electrocautery amplifier blocking. Though it seems a simple enough change to implement, only one recent study, by Kamio et al. [20], has employed a higher low bandpass setting (20 Hz) during recordings of F-VEP. Hopefully others will take the opportunity to test Houlden et al.'s hypotheses and determine whether indeed raising the low pass filter setting improves the reproducibility of F-VEP responses in IOM settings.

### Monitoring Criteria

Given the documented variability of flash VEPs, responses recorded from patients in operative settings cannot be universally characterized [73]. That and perhaps the technical difficulties associated with obtaining reproducible F-VEPs in operative settings have contributed a lack of clear guidelines for warning criteria to be used during surgery to preserve the visual pathway. For recent neurosurgical procedures involving removal of intraorbital, parasellar, and cortical lesions,

Kodama et al. [23] and Sasaki et al. [24, 25] have used a warning criterion whereby a F-VEP amplitude decrease >50% from baseline control levels prompted cessation of the surgical procedure until recovery of the F-VEP occurred and provided that other factors (e.g., anesthesia, use of bipolar cautery) could not be used to explain the amplitude changes. Martinez Piñeiro et al. [81] reported on monitoring patients undergoing endovascular treatment of their occipital arteriovenous malformations (AVM) with F-VEPs. He reported successful intraoperative recordings and postoperative outcomes employing the same stimulation methods and parameters that Kodama et al. [23] and Sasaki et al. [24, 25] used as well as their warning criteria. On the other hand, Kamio et al. [20], who examined the use of F-VEPs for patients undergoing transphenoidal surgery for tumor removal, employed a warning criterion of either an increased or decreased amplitude of greater than 50% compared to control levels. In a study utilizing a similar study population, Chacko et al. [40] used a complete loss of visual responses as the warning criteria to halt surgery until responses returned to baseline. Hussain et al. [44], reporting on the use of monitoring F-VEPs from five patients undergoing functional endoscopic sinus surgery, was the only study involving the anterior visual pathway to employ an increase in F-VEP P100 latency as an indicator of optic nerve compression. They noted that for this criterion to be useful for IOM, the patient's intraoperative diastolic blood pressure had to remain higher than 50 mmHg, oxygen saturations 98% or higher, and bleeding to be minimized. Given the notable disparity of F-VEP IOM warning criteria in the previously discussed studies, it is clear that more research is needed to better define IOM F-VEP warning criteria that better correlate with patient outcomes.

Regarding warning criteria for studies utilizing F-ERGs for monitoring, Padalino et al. [21] used them to monitor retinal perfusion during a single case involving endovascular treatment of a dural AVM supplied by the bilateral superficial temporal, ophthalmic, and the right middle meningeal arteries. The intraoperative monitoring warning criteria that they employed was a 10-ms increase



in the F-ERG latency and a 30% decrease in its amplitude compared with baseline and control responses from the other eye. As with the warning criteria for F-VEPs during IOM, further study is needed to define and confirm warning criteria for use of F-ERGs for IOM.

### **Other IOM Applications with F-ERG and F-VEP**

Keenan et al., Burrows et al., and Reilly et al. [11, 82, 83] have explored the F-VEP as an objective measure of the short-term effects of various cardiopulmonary procedures on neurophysiological function given the cortex's sensitivity to small changes in cerebral perfusion due to its proximity to the watershed area of the posterior and middle cerebral arteries. Reilly et al. [83] showed that F-VEPs are a more sensitive indicator of central nervous system (CNS) stress provoked by combined hypothermia and hypoxia than EEG. Burrows et al. [11] found F-VEPs to be an objective measure of neurophysiologic function in the visual pathway during profound hypothermic circulatory arrest (PHCA) in neonates and infants undergoing surgical correction of congenital heart defects. Although their findings seemed promising as an IOM tool for such cases, Markand et al. [84] found VEPs to be too inconsistent during the surgical course of hypothermia and recovery; and that their disappearance at temperatures below 25 °C made them less than ideal for monitoring brain function during hypothermia. Even Burrows and Bissonnette [85] appear to have abandoned the use of F-VEPs for this application, opting instead to use other measures of cerebral blood flow (transcranial Doppler sonography) for monitoring perfusion during CPB surgery in their subsequent study.

However, the use of F-ERGs to monitor *cardiac surgery and extracorporeal circulation* may serve as a new area to consider for IOM purposes. Indeed, monitoring the retina as an extension of the brain for such cases has been encouraged by Nenekidis et al. [86]. They believed that better quantification of the hemodynamic state of retina–optic nerve head (ONH) during on-pump CPB, is needed, stating that, “The retina provides a ‘window’ for the study of cerebral microcirculation; it lies in the territory of the internal carotid artery

and has a blood barrier analogous to the blood–brain barrier. It would seem reasonable to assume that the changes observed in the retinal microcirculation also occur in brain. The central nervous system can suffer from the same pathophysiological entities that affect the retina and the ONH during hypothermic CPB procedures.” During CPB procedures, retinal ischemia and infarction due to emboli, anterior ischemic optic neuropathy (AION), posterior ischemic optic neuropathy (PION), damage of nerve fibers, chorioretinal hypoperfusion and hypoxia secondary to hemodynamic and hematologic changes have resulted in profound visual deficits and other neuro-ophthalmological complications [86]. Because F-ERG responses are sensitive to (1) alteration of blood flow as a consequence of the reduction of perfusion pressure and (2) to body hypothermia, associated with hemodilution, which helps to depress neural function and neural tissue oxygen requirements, but may also bring on tissue hypoxia, it stands to reason that focus be given to the use of F-ERGs as a tool to monitor patients undergoing cardiosurgical procedures with CPB. A recent, intriguing recent paper by Brandli and Stone [87], while not directly related to intraoperative monitoring and performed in rats, suggests that F-ERGs are indeed sensitive to ischemia, even when the induced ischemia is remote to the retina. A pilot study done by Nebbioso et al. [57] examined the use of F-ERGs for monitoring patients during extracorporeal circulation (ECC), both hypothermic and normothermic with some promising results. Under hypothermic ECC, they reported that the amplitude of the F-ERG response decreased by 50% while those under normothermic ECC only decreased 10%. Recovery of response amplitudes to baseline levels occurred upon the end of ECC and with the rewarming of the patient, with the exception of one individual whose F-ERG response recovery was very prolonged. That patient required postoperative ventilatory support and a long stay in the intensive care unit [57]. Time and further studies will tell whether use of F-ERGs will become a useful tool for monitoring and maintaining adequate retinal as well as cerebral microcirculation and perfusion during surgical procedures.

## Retinal Stimulation and Intracranial Recording of Responses

Recording directly from cortical structures for lesions of the visual pathways, though feasible (albeit in studies with relatively small sample sizes), has limited utility but has yielded responses with greater amplitudes and better signal-to-noise ratio [45]. Møller et al. [88] recorded compound action potentials directly from optic nerve (ONEP) elicited by short light flashes via LEDs during tumor resection in two patients and was able to record responses that had an initial small positive deflection, with a latency of about 45 ms, followed by a negative wave with a latency of 60–70 ms, although considerable individual variation in the shape and size of those responses was observed [88].

In another application of this type of recording, Curatolo et al. [89] found that monitoring the responses recorded from the visual cortex during photic stimulation proved to be a reliable technique for preserving central vision during occipital lobe surgery [89]. Ota et al. also evaluated the usefulness of cortically recorded VEPs as an IOM tool of the posterior visual pathway in 17 patients who underwent posterior craniotomy for lesions or epileptic foci in the parietal, posterior temporal, and/or occipital lobes; reporting detection of VEPs in over 90% of cases with preserved vision that was independent of the type of anesthesia employed for those procedures [29].

In still another application of this type of recording, photic stimulation while recording averaged visual responses in the optic tract during pallidotomy and deep brain stereotaxic surgery has been reported to be useful in guiding those surgeries [16, 59]. Such recordings have also been useful in determining the generators for scalp-derived VEP responses. Tobimatsu et al. [90] was able to record VEPs using pattern-reversal stimuli in eight awake patients with Parkinson's disease undergoing stereotactic pallidotomy using a depth recording electrode located at or below the stereotactic target in the ventral part of the GPi and dorsal to the optic tract. They simultaneously recorded VEPs from the scalp to provide information for differentiation of the generators of the scalp VEP components. In such

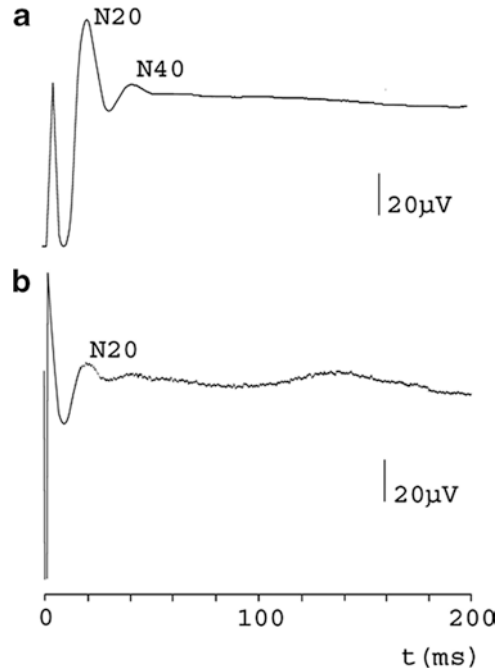
cases where little or no anesthesia is used during surgery, the option to use pattern reversal and other visual stimuli that provide more information in visual pathway function (e.g., visual acuity), may open up a new era for using VEPs for monitoring purposes. Indeed, their use during other “awake” procedures (e.g., endovascular stenting and coiling procedures) when visual function is at risk, has yet to be fully explored.

## Direct Electrical Stimulation of Optic Nerve

Bošnjak and Benedičič [14, 15, 50] evaluated the feasibility and utility of recording scalp VEP responses to direct electrical stimulation (eVEP) of the ON during tumor removal surgery involving the anterior visual optic pathways [14], skull base [15], and during orbital enucleation due to malignant melanoma of the choroid or the ciliary body [91]. To acquire cortical potentials elicited by electrical epidural stimulation of the optic nerve (ON), insulated platinum needle-stimulating electrodes with a noninsulated ball tip were attached epidurally to both sides of the ON. Bošnjak et al. [50] used the following procedure for placement of these electrodes, noting that “When the exit of the optic nerve (ON) from the periorbit is fully visualized through a small fenestration of the orbital apex, needle electrodes are placed in contact on each side of the ON into the cleft between the nerve itself and the basal remnants of the lateral walls of the optic canal. The needles are manipulated during positioning with bipolar forceps through grip connectors. After placing the epidural stimulating electrodes, their position is secured with wet cotton patties laid over the orbital apex and leads.” Monopolar optic nerve potentials after retinal flash or electrical epidural stimulation of the ON were then recorded with insulated platinum ball-tipped wire electrodes placed on the surface of the ON using an extracephalic reference electrode. The distance between the stimulating and recording electrodes was approximately 25 mm. The same recording electrodes were used for monopolar recordings from structures outside of the visual pathway to collect control data. The electrical stimulus con-

sisted of a rectangular current pulse of varying intensity (0.2–5.0 mA) and duration (0.1–0.3 ms) using a stimulation rate of 2 Hz [14, 15]. The bandpass filter settings utilized in previous studies were 1–1000 Hz when recording these cortical potentials after electrical epidural stimulation of the ON. The analysis time used was between 10 and 300 ms. Each trace was generated from the average of 100 responses. Of note, considerable stimulus-related artifact from direct ON stimulation does present a technical hurdle to recording these potentials [14, 15]. Using this stimulation and recording technique, Benedičič and Bošnjak [14, 15] concluded that it was beneficial in preventing ON damage and improving outcomes. They did not report any warning criteria used in the studies and their sample sizes were small [4]. The typical eVEP they recorded consisted of N20 and N40 waves (Fig. 4.3) [50]. Considerable variability in the amplitude of the responses was observed (e.g., N40 wave amplitudes prior to tumor removal varied as much as 25%). Not surprisingly, artifact was observed with use of bipolar coagulation, ultrasonic aspirator, laser, and craniotome-hampered IOM [15]. In one patient with an ON sheath meningioma and vision limited to light sensation, only the N20 wave was observed (*see* Fig. 4.3) [50]. In their subsequent report of IOM monitoring for a very small sample ( $N=3$ ) of patients undergoing orbital enucleation due to malignant melanoma of the choroid or the ciliary body, both F-VEPS and cortical potentials from direct stimulation of the optic nerve were inconsistent or absent in patients with a history (>3 months) of severe visual deterioration, but obtainable from a single patient with a short history of mild visual impairment [91]. Clearly, more studies are needed to confirm the utility of direct electrical stimulation of the optic nerve for visual pathway IOM use and for the development of effective preoperative criteria for patients in whom these techniques may be useful, as well as warning criteria that correlates with and improves patient outcomes.

Duffau et al. [13] described the use of intraoperative electrical stimulations (IES) during surgery to help identify and preserve afferent visual fibers during removal of a low-grade glioma invading the whole temporal lobe and temporo-occipital



**Fig. 4.3** (a) An example of a typical electrically elicited visual-evoked potential (eVEP) response is depicted. The response consists of a larger N20 wave and a smaller N40 wave. The stimulus duration was 0.5 ms, and its frequency 2 Hz. An average of 100 responses was obtained. (b) The eVEP responses recorded from a patient with an optic nerve sheath meningioma and visual perception of light only is shown for which a decreased N20 wave and absent N40 wave are observed (from Bošnjak and Benedičič [50]; with permission)

junction. They used a 5-mm spaced bipolar electrode to deliver biphasic current stimuli (pulse frequency of 60 Hz, single-pulse duration of 1 ms, and amplitude of 5 mA) to cortex involving the optic tracts, in a nonsedated patient, to guide tumor removal. By mapping the optic radiations using this electrical stimulation and obtaining the patient's report of visual effects related to that stimulation, they were able to detect the posterior and deep functional boundary of the tumor resection, and to avoid production of a postoperative symptomatic homonymous hemianopsia. Given the incidence of visual field defects following surgeries involving the posterior temporal lobe and temporo-parieto-occipital junction (TPOJ) with considerable risk for the occurrence of permanent homonymous hemianopsia, it may be of great interest for surgeons and IOM practitioners to consider conducting further research in the

application of this direct electrical stimulation technique to help preserve visual function and improve patient outcomes for those undergoing such procedures [13].

## Effects of Temperature

In conscious humans, F-VEP latency is 10–20 % longer at 33 °C than at 37 °C. With increasing hypothermia, progressive increases in F-VEP latency and decreases in F-VEP amplitude occur with complete loss of the components of the responses at 25–27 °C. When cooling occurred more swiftly, F-VEP responses disappeared at higher temperatures than when a slower cooling process was utilized [92].

## Effects of Anesthesia on F-ERGs

Although for IOM purposes, F-ERG responses are most frequently being employed for confirmation of stimulation of the retina, gaining an understanding of the reported effects of anesthetic and sedative agents on retinal responses, and conducting additional studies to further elucidate the effects of these agents on retina physiology, is of interest.

Wongpichedchai et al. [93] evaluated the effects of halothane in a pediatric population, on dark-adapted (scotopic) and light-adapted (photopic) F-ERGs and found it had little effect on the a-wave and b-wave latency and amplitude of the scotopic F-ERG and amplitudes and latencies of the F-ERG photopic responses to red flashes and 30 Hz flickering white light. In another study, Tremblay et al. [66] retrospectively compared the effects of sedatives and inhalational agents on scotopic and photopic F-ERGs in a small sample of pediatric patients diagnosed free of retinal disease. In that study, F-ERGs were recorded in subjects who either were (1) conscious (no anesthetic or sedative medications) [ $n=9$ ]; (2) under sedation (chloral hydrate [75–125 mg/kg] and pentobarbital sodium sedation [5–6 mg/kg]) ( $n=9$ ); or (3) under general anesthesia (intravenous injection of propofol [2 mg/kg] with or without fentanyl 4 µg/kg, and maintained with isoflurane 2–3 % or halothane 1–2.4 % with 50 % O<sub>2</sub> and 50 % N<sub>2</sub>O [ $n=9$ ]). They found that sedation appeared to decrease a- and b-wave amplitudes of the scotopic bright-flash F-ERG responses, without affecting the responses' latencies. Though Tremblay et al. [66] reported that F-ERG responses recorded under photopic conditions showed minimal changes in latencies and amplitudes, if one examines the table provided in the paper [66] (Table 4.1), it appears that while

**Table 4.1** Summary of statistical analysis performed on ERG parameters obtained after 5 min in photopic conditions in the conscious (C), sedated (S), and anesthetized (A) patients

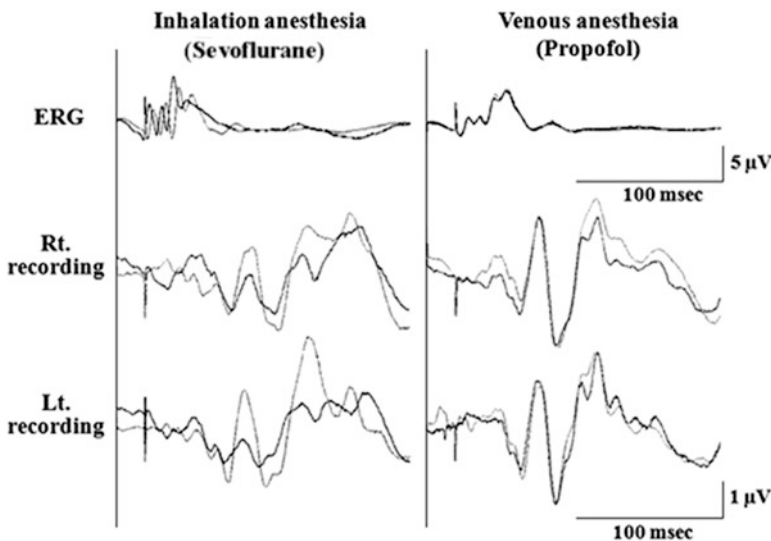
ERG parameter	Conscious	Sedated	Anesthetized	C-S	C-A	S-A
<i>Amplitude (µV ± 1 SD)</i>						
a-wave	76 ± 20	63 ± 9	54 ± 20	–	+	–
b-wave parameters	216 ± 49	186 ± 35	163 ± 47	–	–	–
OP2	19.1 ± 0.9	15.2 ± 4.0	17.1 ± 4.6	–	–	–
OP3	21.1 ± 2.7	17.3 ± 7.2	18.5 ± 11.7	–	–	–
OP4	35.5 ± 14.5	22.6 ± 11.6	9.6 ± 4.7	–	+	–
OP5 2	9.2 ± 10.7	20.1 ± 8.6	8.8 ± 2.0	–	+	–
<i>Implicit time (ms ± 1 SD)</i>						
a-wave	13.7 ± 0.4	14.1 ± 0.5	16.2 ± 1.0	–	+	+
b-wave	33.1 ± 0.8	34.4 ± 1.5	46.8 ± 4.9	–	+	+
OP2	16.4 ± 0.3	17.2 ± 0.4	20.0 ± 0.8	+	+	+
OP3	24.3 ± 1.1	25.4 ± 1.6	29.3 ± 1.6	–	+	+
OP4	32.0 ± 1.1	32.6 ± 1.5	44.3 ± 5.2	–	+	+
OP5	40.8 ± 1.5	41.1 ± 1.7	52.6 ± 4.8	–	+	+

Stars in the three rightmost columns indicate statistical difference between paired-wise groups after post hoc Bonferonni/Dunn correction ( $P > 0.016$ ) (from Tremblay et al. [66]; with permission)

the amplitude of the responses are not affected, the latencies of the photopic responses recorded under anesthesia versus consciousness are significantly and statistically increased and that the same holds true for F-ERG responses recorded under sedation versus under anesthesia [66].

Early studies by Raitta et al. [94] evaluated F-ERG responses recorded in ten adults before and 15–20 min after induction of anesthesia with a combination of thiopentone sodium, halothane, and nitrous oxide ( $N_2O$ ) and found that the amplitudes of F-ERG a- and b-waves were significantly decreased when compared with preoperative levels, but that latencies were unchanged. The findings of a study by Yagi et al. [52] evaluated the effects of enflurane on F-ERG in a small sample of patients undergoing surgical procedures and found that use of enflurane significantly increased latencies of F-ERG a-waves and b-waves and decreased their amplitudes but did not have any significant effects on F-ERG b-wave responses, with increasing concentrations of enflurane (0, 0.8, and 1.7%) [52]. Interestingly, a study conducted by Ioholm et al. [95] in adult populations examined photopic F-ERGs before and after

surgery under general anesthesia induced with sevoflurane (8%) in 100% oxygen ( $O_2$ ) and maintained with sevoflurane (range, 0.05–0.31%, mean  $0.22 \pm 0.07\%$ ) and nitrous oxide (mixture of 33%  $O_2$  and 66%  $N_2O$ ). The F-ERG responses were recorded preoperatively from unpremedicated American Society of Anesthesiologist (ASA) classification I and II patients, and again immediately following discharge from the recovery room, and 24 h following sevoflurane/ $N_2O$  anesthesia. Ioholm et al. [95] found that the F-ERG b-wave latency in these subjects was increased at both postoperative time points compared with preoperative responses and that b-wave amplitudes were also decreased postoperatively compared with their preoperative levels. Similar findings were obtained in a subsequent study conducted by Ioholm [96]. Of interest, Sasaki et al. [24] reported that “after induction of inhalation anesthesia with sevoflurane, ERG data were not reproducible” [24]. An example of the comparison of the F-ERG responses obtained by Sasaki et al. [24] with anesthesia employing sevoflurane versus total intravenous infusion of propofol with fentanyl is shown in Fig. 4.4. Given the



**Fig. 4.4** Illustrates the reproducibility of ERG and VEP following induction of inhalation and venous anesthesia in the same patient, same eye (without visual dysfunction). F-ERG and VEPs were obtained twice to confirm the reproducibility of the data in the absence of surgical procedures. Following induction with inhalation anesthesia

(left), F-ERG responses were not reproducible and the VEP amplitude was also affected. Conversely, following induction of propofol-based infusion anesthesia, reproducibility of ERG and VEPs were both good (from Sasaki et al. [24] with spelling modifications: revised “Seboflurene” to “Sevoflurane”; with permission)



variance in the reports regarding the effects on F-ERG responses to different combinations of sedative and halogenated agents, one would have to agree with Tremblay's conclusion that normal retinal physiology is affected by sedation and anesthesia through different mechanisms that remain to be fully elucidated by future research [66].

Total intravenous anesthesia (TIVA) utilizing propofol and opioid medication is touted as F-ERG friendly. Indeed F-ERGs obtained from 20 normal children undergoing evaluations of their visual function under anesthesia with propofol and fentanyl versus topical anesthesia showed that F-ERG b-wave response latencies were only slightly increased and b-wave amplitudes decreased when propofol and fentanyl versus topical anesthesia were employed and were not statistically different [97]. This finding was further supported by an animal study conducted in pigs [98]. Although no specific reports have been

published on the effects of bolus administrations of fentanyl or other opioids on F-ERGs in humans during surgery, bolus administrations (additional injections of fentanyl every 60 min) were used in Sasaki's et al. study [24], with what can presumed to be little detriment to their use of F-ERG responses (chiefly to ensure retinal stimulation) for IOM purposes.

## Effects of Anesthesia on VEPs

A summary of the effects of anesthesia on F-VEPs prepared by Banoub et al. is shown in Table 4.2 [1]. F-VEPs are very sensitive to the effects of anesthetics and physiologic factors because they represent polysynaptic cortical activity. Because flash stimulation activates both temporal and nasal parts of the retina and the nasal fibers cross to the contralateral side at the

**Table 4.2** Summary of the effects of anesthetics on visual-evoked potentials responses

Anesthetic drug	Dose/concentration	Latency of P-100	Amplitude
Halothane [102]	1 MAC	≈10% ↑	Inconsistent
Isoflurane [41, 103]	0.5 MAC	10% ↑	40% ↓
	1.0 MAC	20% ↑	66% ↓
	1.5 MAC <sup>a</sup>	30% ↑	80% ↓
	1.0 MAC + 70% N <sub>2</sub> O	Abolished	Abolished
	1.5 MAC + 70% N <sub>2</sub> O	Abolished	Abolished
Sevoflurane [104]	0.5 MAC + 66% N <sub>2</sub> O	5–10% ↑	20% ↓
	1 MAC + 66% N <sub>2</sub> O	Abolished	Abolished
	1.5 MAC + 66% N <sub>2</sub> O	Abolished	Abolished
	1.4–1.7 MAC	Abolished	Abolished <sup>b</sup>
Nitrous oxide [105–107]	10–50%	No effect	25–80% ↓ <sup>c</sup>
Propofol [108]	2 mg/kg + 10 mg kg <sup>-1</sup> h <sup>-1</sup>	Negligible	≈20% ↓
Thiopental [109]	3 mg/kg	<10% ↑	No change
	6 mg/kg	Abolished	Abolished
Etomidate [109]	0.3 mg/kg	<10% ↑	No change
Fentanyl [99]	10–60 μg/kg	<10% ↑	30% ↓
Ketamine [108]	1 mg/kg + 2 mg kg <sup>-1</sup> h <sup>-1</sup>	Negligible	≈60% ↓
Morphine scopolamine (premedication) [99]	0.2 mg/kg morphine + 0.4 mg scopolamine	No change	≈20% ↓
Neuroleptanalgesia [110]		10% ↑	No change
Fentanyl, droperidol nitrous oxide			

From Banoub et al. [1]; with permission. All data are from humans

MAC minimum alveolar concentration, N<sub>2</sub>O nitrous oxide, ↑ increase, ↓ decrease

<sup>a</sup>In a substantial fraction of patients, waveforms were not recordable at this concentration

<sup>b</sup>During electroencephalogram suppression; visual-evoked potentials reappeared during electroencephalogram bursts [111]

<sup>c</sup>Some report a 40% increase in N-70–P-100 amplitude [108] (Fig. 4.10)

level of the optic chiasma, retrochiasmatic lesions cannot be monitored [33]. In addition, VEPs are highly dependent on appropriate stimulation of the retina and may be unduly affected by narcotic-induced pupillary constriction [99].

The findings included in Table 4.1 suggest volatile anesthetics prolong VEP latency and decrease F-VEP amplitudes in a dose-dependent fashion. Nakagawa et al. [37] found that even at a 1% (0.5 minimum alveolar concentration [MAC]) concentration of sevoflurane, responses were significantly decreased. At 1.5 MAC, responses could not be interpreted [37]. However, as mentioned previously, conflicting information about the effect of low-dose sevoflurane on F-VEP responses have been reported, with one researcher finding amplitude decreases with its use [37] while another did not find any such decrease [29], although the latter recorded responses directly from cortex and those responses are reportedly not as susceptible to the effects of inhalational agents as those recorded from scalp [45, 88]. Nitrous oxide (N<sub>2</sub>O) alone considerably reduces VEP amplitude. Its use in addition to volatile anesthetics can make VEP responses unrecordable. Increased concentrations of nitrous oxide significantly increase VEP latencies.

In general, it appears that opioid and ketamine or propofol-based anesthetic techniques (TIVA), along with those employing low-dose volatile anesthetics without nitrous oxide, seem to facilitate intraoperative recording of VEPs but do not ensure it. In some cases, the use of these anesthetic protocols may involve a high incidence of false-positive and false-negative results [33].

Opioids (e.g., fentanyl, alfentanil, sufentanil, and remifentanil) reportedly have a very mild effect on other evoked responses [100], which presumably extend to VEP responses. However, it is important to keep in mind that bolus administration of opioids has been reported to significantly reduce the amplitude of scalp-recorded responses [101]. Chi et al. [99] studied the effects of incremental doses of fentanyl (10 µg/kg) given every 10 min for a total dose of 60–90 µg/kg for patients undergoing coronary artery bypass graft procedures and observed that while fentanyl administration did not affect latency, amplitude

was decreased. They posited that those decreases may be due to changes to retinal luminance related to pupillary-induced constriction associated with fentanyl bolus administration [99]. Accordingly, bolus administration of fentanyl, while not precluded during such surgeries, may indirectly affect F-VEP responses induced by retinal flash stimulation, and therefore should be taken into account if responses change post-administration. Loughnan et al. [100] showed that neither fentanyl, 200 µg, nor diazepam, 20 mg administered intravenously, significantly changed F-VEP latency or amplitude, suggesting that an anesthetic technique based on these two drugs might be suitable when intraoperative evoked potential monitoring is required to assess ischemia and preservation of visual-evoked responses [100].

With respect to anesthetic techniques that employ infusion of propofol, although most of the new studies for visual pathway IOM espouse the use of propofol, Neuloh [45] points out that TIVA alone cannot ensure success, as one recent study found that “a satisfactory rate of successful VEPs could not be achieved despite use of TIVA for anesthetic management” [41]. Moreover, a couple of studies have found that the amplitude of VEP is strongly affected by the concentration of propofol and that caution and perhaps further studies are needed in evaluating VEP in patients undergoing propofol anesthesia. Nakagawa et al. [37] found that at a propofol concentration of 3.0 µg/mL (80–100 µg/kg/min), VEP amplitudes were decreased significantly compared with the amplitude at 1.5 µg/mL concentration (40–50 µg/kg/min). It led him to conclude that a propofol-based TIVA technique appears to induce less change in evoked potentials, including VEP, than halogenated agents [37]. Hamaguchi et al. [36] further investigated the influence of propofol concentration on F-VEP components in three patients with cranial aneurysm and four with brain tumor. Anesthesia was maintained with intravenous propofol using target controlled infusion. Changes in F-VEP amplitude and latency were measured during three propofol concentrations (effect site concentrations of 1.5, 2.0, and 3.0 µg × mL<sup>-1</sup>, and correlated with bispectral index (BIS) readings at each concentration.

At  $3.0 \mu\text{g} \times \text{mL}^{-1}$  propofol concentration, F-VEP amplitude was decreased significantly compared with the amplitude at  $1.5 \mu\text{g} \times \text{mL}^{-1}$  concentration. No significant change was observed with the latency of F-VEP. The value of BIS at  $3.0 \mu\text{g} \times \text{mL}^{-1}$  propofol concentration also decreased significantly compared with  $2.0 \mu\text{g} \times \text{mL}^{-1}$  concentration.

Thankfully, neuromuscular blocking drugs do not directly influence F-VEP responses. In fact, their use may contribute to an improved signal-to-noise ratio by eliminating electromyographic artifact [12].

## Conclusion

A number of researchers [2, 3, 13–15, 19–21, 23, 25, 78, 79] have continued their efforts to overcome the poor reputation that IOM of the visual pathways has had for several decades. By employing new and brighter stimuli, direct cortical stimulation methods, and monitoring new types of cases, these researchers hope to spawn revitalization of research that will help evaluate, establish, and improve the usefulness of visual pathway intraoperative monitoring. Certainly, the success of Sasaki et al. [24, 25] (93.5%), Kodama et al. [23] (97%), and subsequent research [19, 20] for acquisition of stable scalp F-VEPs recordings during surgeries involving the anterior pathways, with good correlation of monitoring results and visual outcomes, have been encouraging. Their ability to achieve those goals has largely been attributed to the combined use of (1) a brighter reusable (sterilizable); (2) flexible LED stimulating devices that guarantee supramaximal retinal stimulation, even when VEPs cannot be recorded; and (3) use of TIVA with propofol to minimize the effects of anesthetics on the responses. However, monitoring of patients with preoperative visual deficits remains controversial. Indeed, Kodama et al. limited their monitoring to patients with preoperative acuities of less than 0.4 (20/50) [23]. Because impaired preoperative vision is a major predictor of postoperative deterioration [45], eliminating such patients from monitoring limits the broad usefulness of VEPs for IOM of these surgical procedures. Regarding enhancements in

anesthetic management, it is still not clear that the use of TIVA with propofol ensures F-VEP recording in all patients [41]. Still, there clearly is a need for continuous monitoring during cases involving the visual pathways, and indeed studies indicating that they were able to detect ischemic response changes in the F-VEP that would have been missed by imaging data [58] make a compelling argument to encourage those who would continue efforts to optimize the methodologies for use of VEPs for IOM purposes. Certainly, replication of their protocols and confirmation of their results will help solidify their methods. Only time will tell if others take up that cause [5, 45]. The development of visual stimulation methodologies that can better assess visual acuity during surgical procedures, coupled with improved anesthetic management techniques may serve to revitalize the efforts to confirm the usefulness of IOM of the visual pathways: a plea that was issued years ago and still remains true [73].

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