



Feasibility of Intraoperative Visual Evoked Potential Monitoring by Cortical Strip Electrodes in Patients During Brain Surgery: A Preliminary Study

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OBJECTIVE: The role of visual evoked potentials (VEPs) monitoring during neurosurgical procedure in patient remains unclear. The purpose of our study was to determine the feasibility of intraoperative VEP recording using a strip cortical electrode during surgical resection of intracranial lesions.

METHODS: In this prospective, monocentric, observational study, we enrolled consecutive patients undergoing neurosurgical procedure for intracranial lesions. After dural opening, a cortical strip was positioned on the lateral occipital surface. Flash VEPs were continuously recorded using both subdermal corkscrew electrodes and strip electrodes. An electroretinogram was also recorded to guarantee delivery of adequate flash stimuli to the retina.

RESULTS: We included 10 patients affected by different intracranial lesions. Flash VEPs were recorded using subdermal corkscrew electrodes in all patients except 1 in whom they were never identified during the recording. Flash VEPs were recorded using strip electrodes in all patients and showed a polyphasic morphology with a significantly larger amplitude compared with that of flash VEPs measured using subdermal corkscrew electrodes. No patient reported worsened postoperative vision and a >50% decrease in the VEPs amplitude was never registered.

CONCLUSIONS: We have reported for the first time in the literature that VEP monitoring during a neurosurgical

procedure is feasible via a cortical strip located on the occipital surface. The technique demonstrated greater stability and a larger amplitude compared with recordings with scalp electrodes, facilitating identification of any changes. Studies with more patients are needed to assess the clinical reliability of the technique.

INTRODUCTION

Surgery performed in brain areas involving the visual pathway are associated with varying levels of post-operative visual dysfunction.¹ Visual evoked potentials (VEPs) are usually used to assess the visual conduction pathways through the optic nerves, visual pathways, and visual cortex.² In contrast to somatosensory and motor evoked responses,^{3,4} the use of intraoperative VEPs monitoring^{5,6} is not so widespread because of its high intraindividual variability and instability.⁷⁻⁹ So, the reliability of intraoperative VEPs monitoring remains unclear. Furthermore, when pathologies involve the occipital lobe, it is difficult to place the VEPs recording electrodes in the points recommended by international guidelines² because of the craniotomy location. In these cases, it might be useful to record VEPs with cortical strip electrodes. The aim of this study was to determine the feasibility of recording VEPs using a strip electrode during surgical removal of intracranial lesions located in the temporo-parietal-occipital area.

Key words

- Intraoperative neuromonitoring
- Neurosurgery
- Occipital lesions
- Strip electrodes
- VEP
- Visual evoked potential

Abbreviations and Acronyms

FVEP: Flash visual evoked potential

SD-FVEP: Subdermal corkscrew electrodes flash visual evoked potentials

SI: Streep insertion

VEPs: Visual evoked potentials

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MATERIALS AND METHODS

Subjects

In this prospective, monocentric, observational study, we enrolled consecutive patients undergoing neurosurgical procedure for intracranial lesions. The inclusion criteria were 1) a lesion located into the temporo-parietal-occipital area in which visual pathway (cortical and subcortical) was at risk of surgical injury; 2) no previous neurologic or medical pathologies; and 3) a Glasgow Coma Scale of 15 at admission.

Intraoperative Neurophysiologic Monitoring

Flash visually evoked potentials (FVEPs) were recorded continuously throughout neurosurgery by a portable digital instrument (Nicolet Endeavor, Viasis Healthcare, Madison, Wisconsin, USA)

Stimulation. Binocular flash stimulation was delivered by flashing red light-emitting diode Light Google Stimulator (Nicolet Endeavor) at a rate of 1.41 Hz. For each trial, 30 stimuli were averaged, so it took us about 30 seconds to record each trial.

Recording. Intraoperative FVEPs were recorded using both subdermal corkscrew electrodes (SD-FVEP) and strip electrodes (stripFVEP). Whenever possible, corkscrew electrodes were placed on the scalp as close as possible to position O1, OZ, and O2 according to the 10–20 international system.² After opening the dura mater, a subdural strip was placed on the lateral surface of the occipital lobe under

neuronavigated microscope view (**Figure 1**). Positioning the strip on the lateral surface rather than on the medial surface of the occipital lobe was chosen for multiple reasons. First, the tumor was generally exposed with a craniotomy, which allowed the placement of the strip in that location. Second, the placement of the strip on the lateral aspect of the occipital pole was generally easier than placement on the medial aspect of the interhemispheric fissure, sometimes compressed by the presence of the lesion. Third, to monitor all visual pathways afferent to the occipital pole of 1 side, we used a binocular stimulation. In this condition, the opposite pole was stimulated. Placing the strip on the medial aspect of the occipital pole would have increased the probability of contamination of the recording for activation of the contralateral pole. Therefore to reduce this risk, we opted for lateral positioning. Intraoperative use of the neuronavigated microscope (**Figure 1**) allowed positioning the strip directly in contact with the brain parenchyma not exposed after the craniotomy, inserting the strip partially under the dura layer. In this way, the surgeon had a clear vision and idea of the length and direction of the strip and the neuro-navigated microscope, used as a neuronavigational pointer, allowed understanding if an electrode was located on the lateral surface of the occipital lobe and which one it was, through a cutaneous projection of it. For both electrode types, the reference electrode was placed at Fz. An electroretinogram was also recorded by needle electrodes placed subcutaneously at the lateral canthi to

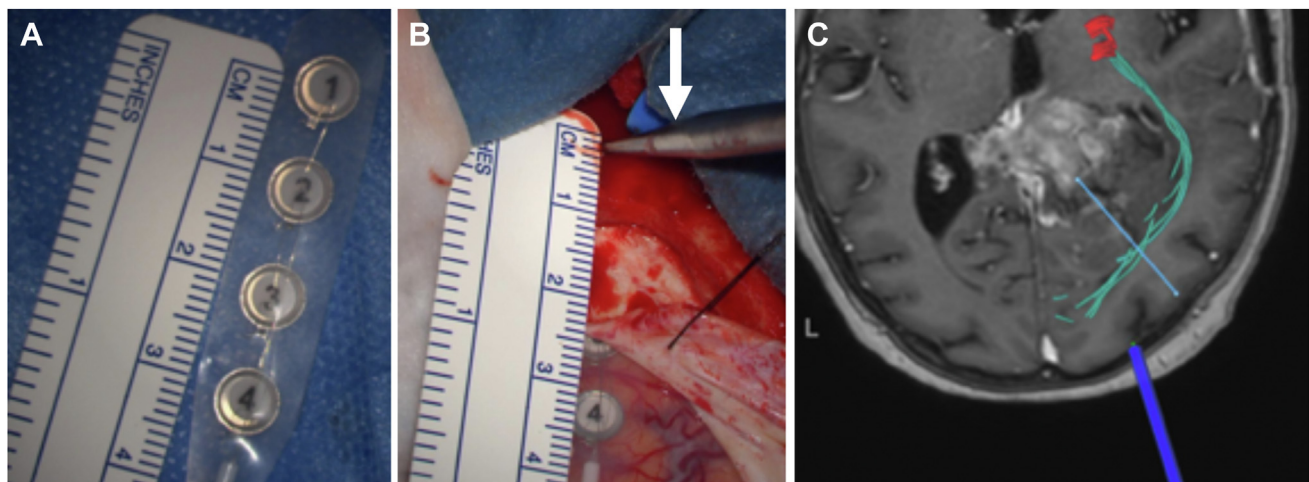


Figure 1. Clinical case illustrating the surgical protocol for asleep visual evoked potentials recorded by subdural electrodes presented in the study. **(A)** The image shows the size of the subdural electrode strip used and the interelectrode distance. On the left, the measurement is in inches; on the right, the measurement is in centimeters. These data are crucial for the surgeon to understand the positioning of the single electrodes on the cortex not exposed by the craniotomy. **(B)** Intraoperative microscopic picture showing the cortex exposed by craniotomy planned for tumor removal with the strip placed for intraoperative recording of visual evoked potentials. The well-known distance between electrode 4 and electrode 1 (3 cm) along a

right line enabled the neurosurgeon to realize where electrode 1 was approximately placed under the dura. The neuronavigation's pointer (*white arrow*) showed in the neuronavigation system where electrode 1 was placed with regard to the visual pathway. **(C)** Neuronavigation magnetic resonance image, corresponding to pointer placed as in B. Optic radiation (light blue) and the corticospinal tract (red) had been charged in the neuronavigation for tractography-targeted strip electrode placement. The estimated position of electrode n.1 was indicated by the probe (blue) in the 3-dimensional reconstruction just on the lateral occipital cortex, close to the optic radiation.

guarantee delivery of adequate flash stimuli to the retina.¹⁰ Restrictive filtering was 10–200 Hz, the sweep duration was 200 ms, and amplifier gain was 50,000. The optimal rejection window was set at 10–20 μ V (peak-to-peak). After inserting the strip electrode, the SD-FVEP, stripFEV, and electroretinogram were recorded simultaneously. A 50% decrease in the wave amplitude was the alarm criterion.

Anesthesia

All patients received a standardized regimen of total intravenous anesthesia (TIVA) by propofol 2.0% using a Schnider model,¹¹ target-controlled infusion system.¹¹ During intubation only, patients received fentanyl (1.0–2.0 μ g/kg) and rocuronium (0.7 mg/kg).

Analysis

We considered the recordings at strip insertion (SI), 15 seconds after SI (15' after SI) and immediately before strip elimination (SE), for both SD-FVEP and stripFVEP. At each recording time, we considered 10 consecutive trials over a period of 7 minutes (30 stimuli at 1.4 Hz). We considered VEPs obtained by binocular stimulation so as to obtain the activation of all the visual fibers present at the level of the hemisphere affected by the lesion. For SD-FVEP, we monitored the peak-to-peak amplitude of the N2-P2 wave¹² at OZ. For stripFVEP we monitored the 2 main negative-positive components present in the FVEP considering the electrode of the strip in which it had the greatest amplitude. If no clear components were identified, they were indicated as not evaluated. We then measured the amplitude and latency of the identified components of both SD-FVEP and stripFVEP.

RESULTS

We included 10 subjects (6 female, 4 males; mean $\pm$ standard deviation age: 45.5 $\pm$ 21.5 years). Surgical indications were lesions of diverse origins localized in the supratentorial temporo-parietal-occipital area of the brain as summarized in **Table 1**. At the preoperative evaluation, 6 patients presented a deficit in visual function and 4 did not. The anesthesia protocol was

applied in all subjects without complications. There was no decrease >50% for any surgical procedure. The visual function in the postoperative period was unchanged in 8 patients and improved in 2 patients.

Flash Visual Evoked Potentials

SD-FVEPs were recorded in all patients except 1, in which they were never identified during the recording. StripFVEPs were recorded in all patients, including in the patient without SD-FVEPs. They showed a polyphasic morphology composed of 4–6 negative or positive components. The recorded amplitudes and latencies are presented in **Table 2**.

In each period of 7-minute monitoring period, the stripFVEP morphology was relatively stable, as indicated in **Figure 2**, with respect to SD-FVEP morphology. Moreover, the stripFVEP amplitudes were significantly larger than the SD-FVEPs amplitude (**Table 2**, $P < 0.05$). Anesthesia, induced by propofol-targeted effect-site concentrations of 3.5–8.0, was maintained by the continuous infusion of propofol and remifentanyl (0.01–0.30 μ g/kg/min). There were no differences in latency, although the standard deviation of the SD-FVEP latency was always greater than the stripFVEP latency, indicating less variability in the latter.

DISCUSSION

We have shown that VEP could be easily recorded by strip electrodes positioned on the lateral occipital surface. Moreover, at all recording times the stripFVEP amplitudes were significantly larger and more stable than the SD-FVEPs amplitude (**Table 1**).

Neurosurgical procedures for the treatment of lesion along the visual pathways carry a risk of visual impairment.¹ A reliable method for monitoring visual function in real time would aid in intraoperative decision making regarding the radicality of excision and sparing of the visual pathways. Intraoperative VEP monitoring by scalp electrode^{5,6} has not become more common mainly because of its high intraindividual variability and instability, both of which have limited its clinical usefulness.¹³ Due to conflicting reports on the usefulness of intraoperative VEP monitoring, a consensus has yet to be reached and it remains unclear whether intraoperative VEP monitoring can be used in real-time visual function monitoring with satisfactory

Table 1. Patients' Data

Patients	Age	Sex	Pathology	Location	Side	Preoperative Visual Symptoms	Postoperative Visual Symptoms
#1	77	F	HGG	P-O	Right	None	None
#2	58	F	Meningioma	O	Left	None	None
#3	30	F	HGG	O	Left	Left HLH	Improved
#4	24	F	Cavernoma	T-O	Left	Defect of visual acuity	None
#5	55	F	HGG	O	Right	Left HLH	Unchanged
#6	56	F	HGG	P-O	Right	Left HLH	Unchanged
#7	15	M	LGG	T-O	Left	None	None
#8	52	F	HGG	T-P	Left	Right HLH RT	Unchanged
#9	20	F	AVM	O	Right	None	None
#10	68	M	HGG	T-O	Right	Left HLH	Unchanged

F, female; M, male; HGG, high-grade glioma; LGG, low-grade glioma; AVM, arterio-venous malformation; P, parietal; O, occipital; T, temporal; HLH, homonymous lateral hemianopia.

Table 2. Mean Value of Amplitude and Latency

	Ampl. (μ V)	SD	P	Lat. (ms)	SD	P
DO (strep insertion)						
Subdermal	4.3	3.5	0.001	105.5	39.5	NS
Strip	70.5	62.2		115.4	22.9	
15' after DO						
Subdermal	3.8	3.4	0.015	105.1	41.9	NS
Strip	61.1	43.5		115.4	21.9	
DC (strep removal)						
Subdermal	4.3	3.9	0.003	104.7	41.5	NS
Strip	50.1	39.1		114.5	18.8	

Ampl, amplitude; SD, standard deviation; Lat, latency; DO, dura opening; DC, dura closing.

accuracy for preservation of visual function. Moreover, there have been difficulties and technical limitations of VEPs recorded by electrical stimulation of the optic nerve from the occipital area¹⁴⁻¹⁶ or directly from the optic nerve, such as how to use post-processing of the data after surgery to remove the stimulus artefact from the recorded traces.¹⁷ Obviously, this last technique does not contribute to intraoperative functional evaluation. Subdural strip electrodes allow for the recording of cortical activity directly from the cortex by eliminating the impedance of the skull; therefore the recorded VEPs have a larger amplitude than those recorded by scalp electrodes. This makes it much easier to identify reductions in amplitude due to any lesions of the visual pathways. From a technical point of view, the registration of VEPs by strip electrodes does not require any other precautions or equipment than those used in the registration of somatosensory potentials, a technique that is now commonly used in intraoperative monitoring (phase-reversal). As a result, this technique can be performed reliably by personnel who are already experienced in using strip electrodes and recording VEPs.

This procedure has some main limitations. First, the recorded response has a polyphasic morphology (mean 4–5), which makes it more difficult to identify the components of the VEP to be monitored (see [Figure 1](#)). Although in our cases there was a fair amount of interpatient variability, we were always been able to identify at least 1 or 2 prevalent components that could be monitored. Second, stripFVEP modifications may occur due to movements of the electrodes or as a consequence of surgical maneuvers or brain relaxation. This problem can be at least partially reduced by fixing the strip with cotton or gauze. Furthermore, in most cases, repositioning of the strip, as well as its high stability, allowed us to reidentify the components to be monitored. Obviously, this last technique does not contribute to the intraoperative functional intraoperative evaluation. Regarding brain relaxation, the strip electrodes can also be repositioned to obtain a good VEP again, something that cannot be done with the corkscrew electrodes. A third limitation is due to the lack of well-defined alarm criteria for significant changes in potentials. In current clinical practice, it is useful to refer to the common criteria proposed for VEPs recorded with scalp

electrodes (reduction of at least 50%).¹² Definition of reliable alarm criteria would require recording stripFVEPs in more patients, an aim outside the scope of this study. Fourth, the use of this registration technique is limited to those pathologies that require a temporal-parieto-occipital craniotomy. However, considering the importance of the preserving visual function, we believe that even if limited to this type of intervention, the recording of the VEPs by strip electrodes could be an important intraoperative monitoring tool.

In conclusion, FVEPs can be recorded with subdural electrodes applied on the occipital cortex, demonstrating greater stability and larger amplitudes compared with recordings performed with scalp electrodes, facilitating the identification of any changes. Of course, our data are preliminary and must be confirmed in a larger number of patients. Larger studies are needed to assess the clinical reliability of the technique.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Carrai R: contributed to the conception, design of the study, acquisition, analysis and interpretation of data, drafting the article and revising it critically for important intellectual content; **Martinelli C:** contributed to the conception, design of the study, acquisition and interpretation of data, drafting the article; **Baldanzi F:** contributed to the acquisition of data; **Gabbanini S:** contributed to the acquisition of data; Troiano S. contributed to the acquisition of data; **Bonaudo C:** contributed to the acquisition and interpretation of data, drafting the article; **Esposito A:** contributed to the acquisition of data; **Muscas G:** contributed to the acquisition of data; Tola S. contributed to the revision process according to the last reviewer indications; **Caramelli R:** contributed to the acquisition of data; **Spalletti M:** contributed to the acquisition of data; **Lolli F:** contributed to the analysis of data; **Grippio A:** contributed to the acquisition of data and to final approval of the version to be submitted; **Bucciardini L:** contributed to final approval of the version to be submitted; **Amadori A:** contributed to the acquisition of data and to final approval of the version to be submitted; **Della Puppa A:** contributed to the acquisition of data and to final approval of the version to be submitted.

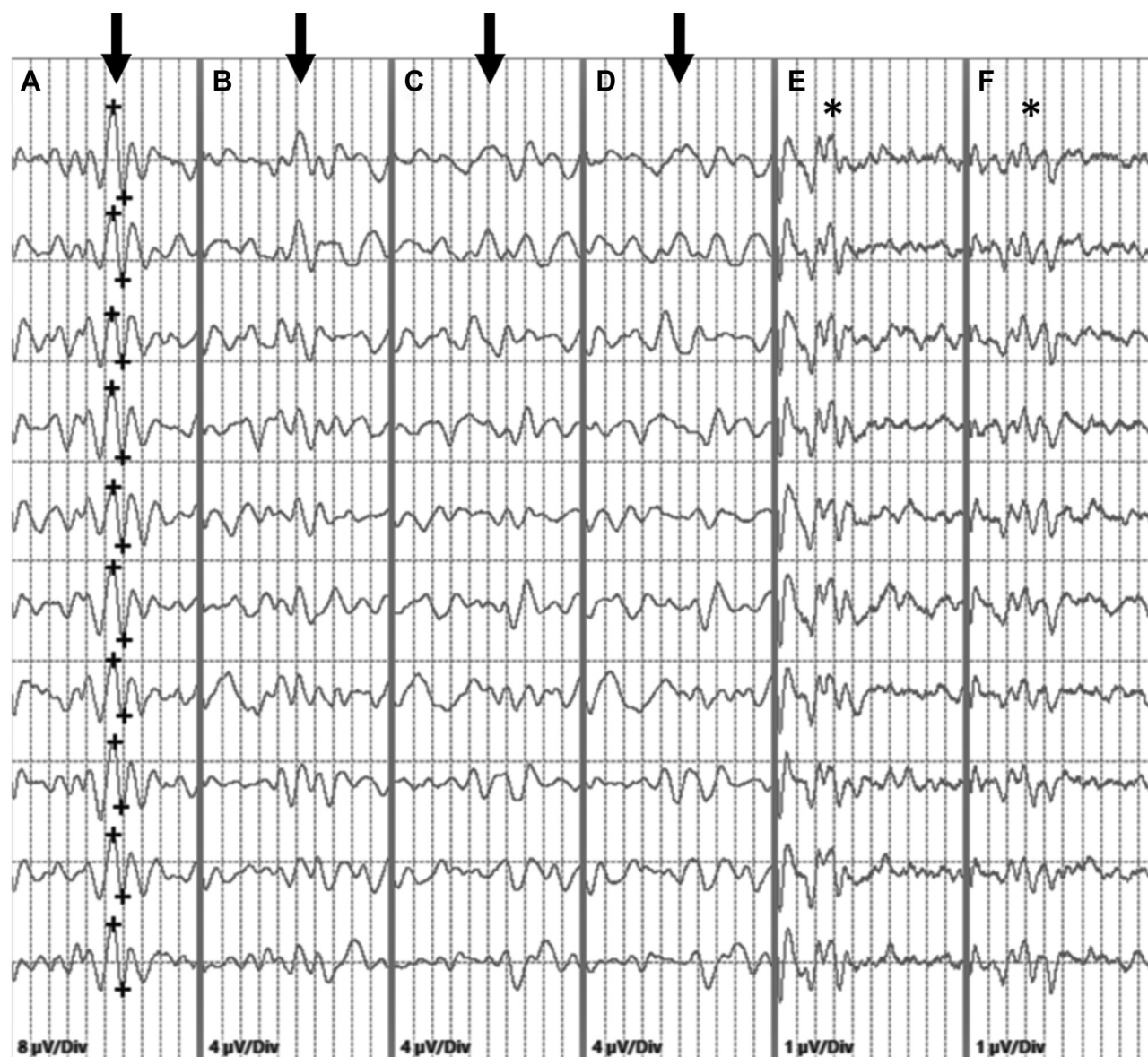


Figure 2. Visual evoked potentials (VEPs) recorded by strip electrodes (A) and scalp electrodes, respectively, O1(B), Oz (C), O2 (D), and electroretinogram left (E) and right (F) by binocular flash stimulation. Note the stability of VEP components recorded by strip electrodes with respect to VEP components recorded by scalp electrodes and the greater breadth

of the former than the latter (see sensibility). The arrow in A shows the main components of PEV recorded by subdural strip electrodes, while in E and F, respectively, those recorded by scalp electrodes. The asterisk indicates the electroretinogram potentials. Sweep time: 20 ms/Div; sensibility: A: 8.0 μ V/Div, B–D: 4.0 μ V/Div; E–F: 1.0 μ V/Div.

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