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Technique Application

Intra-operative mapping of the subcortical visual pathways using direct electrical stimulations

H. Duffau[1], **S. Velut**[4], **M.-C. Mitchell**[2], **P. Gatignol**[3], and **L. Capelle**[1]

[1] Department of Neurosurgery, Hôpital de la Salpêtrière, Paris, France
[2] Department of Anesthesiology, Hôpital de la Salpêtrière, Paris, France
[3] Department of Neurology, Hôpital de la Salpêtrière, Paris, France
[4] Department of Neurosurgery, Hôpital Bretonneau, Tours, France

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Summary

Despite the risk of postoperative visual field defect following surgery within the temporo-parieto-occipital region, visual mapping has rarely been described, in particular at the subcortical level.

In this report, we successfully performed a subcortical mapping of the visual pathways using intra-operative electrical stimulations (IES), during surgery under local anesthesia for a low-grade glioma invading the whole temporal lobe and the temporo-occipital junction. The optic radiations then constituted the posterior and deep functional boundary of the resection, avoiding the occurrence of a post-operative hemianopsia, in spite of an asymptomatic quadrantanopsia.

This preliminary experience illustrates the possibility to use intra-operative direct electrical stimulation during surgery of lesions involving the posterior afferent visual system, in order to identify and then preserve the visual pathways, as previously reported for sensorimotor and language subcortical fibers.

Keywords: Visual pathways; optic radiations; intra-operative brain mapping; direct electrical stimulations; subcortical functional mapping.

Introduction

During the last decade, functional mapping methods were regularly used in surgery within eloquent brain areas, allowing for improvement of neurological outcome [5, 6, 8, 9, 11]. However, although the identification of sensorimotor and language structures was extensively published (for a review, see [6]), pre- and/or or intra-operative visual cortex mapping was more rarely described in lesions involving the posterior afferent visual system [2, 8, 10, 11, 14, 15, 17–19]. Moreover, to our knowledge, direct intra-operative detection of the optic radiations was never reported, despite the frequent occurrence of visual field defects following surgery within the posterior part of the temporal lobe [7, 12, 13, 16, 20] and overall after surgery within the temporo-parieto-occipital junction (TPOJ) – which exposes a high risk of permanent homonymous hemianopsia (HH).

In the present case, we successfully performed an awake subcortical mapping of visual pathways using intra-operative electrical stimulation (IES), during surgery of a low-grade glioma invading the whole temporal lobe and the temporo-occipital junction. Thus, optic radiations constituted the posterior and deep functional boundary of the resection, avoiding production of a post-operative symptomatic HH. On the basis of this preliminary experience, the interest of a more systematic visual pathways tracking during surgery involving the TPOJ is discussed.

Case report

Patient presentation

A 26-year-old female had experienced partial seizures for 9 months. The neurological examination showed no neurological deficit, in particular no visual field defect using Goldmann perimetric evaluation. Nevertheless, on neuropsychological examination, cognitive dysfunctions were noted, in particular concerning verbal working memory. On the MRI, a voluminous tumor invading the right temporal lobe and the temporo-occipital junction was visible, with images in favor of a low-grade glioma (Fig. 1). Because of the mass effect due to this lesion, the risk of tumor growth and/or anaplastic transformation, and the difficulty

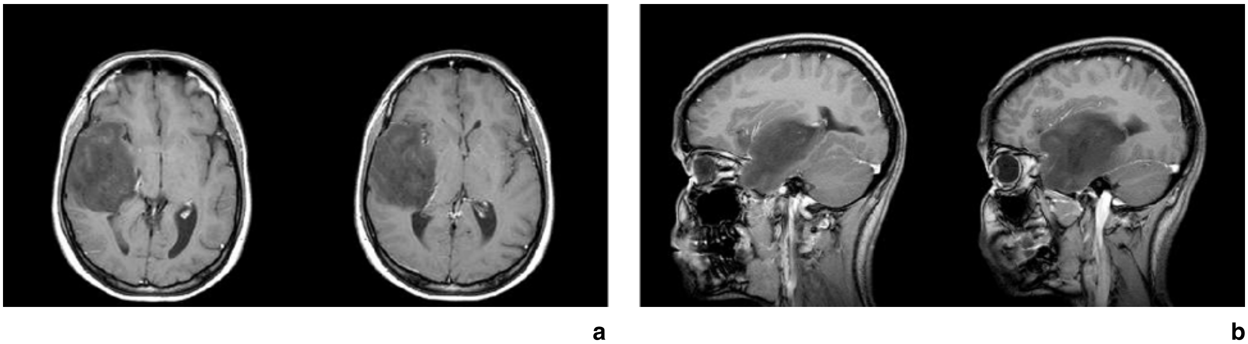

Fig. 1. Preoperative axial (a) and sagittal (b) T1-weighted enhanced MRI, showing a right temporal low-grade glioma, invading the temporo-occipital junction, in a patient without any visual defect

in control of the seizures despite administration of two antiepileptic drugs, surgery was decided upon.

Pre-operative neuropsychological examination, functional MRI and Wada test gave strong arguments in favor of the participation of the right hemisphere in language. Consequently, an awake procedure with functional mapping was chosen.

Surgery

Intra-operative motor and language (counting and naming) cortico-subcortical mapping was performed under local anesthesia using the technique of direct IES previously described, in order to track and preserve functional structures [5, 6]. Briefly, a 5-mm spaced tips bipolar electrode delivering a biphasic current (pulse frequency of 60 Hz, single pulse phase duration of 1 ms, amplitude of 5 mA) (Ojemann Cortical Stimulator 1, Radionics*, Inc, Burlington, MA) was applied to the brain all along the tumor removal.

Cortical stimulation before any resection showed two eloquent sites within the Rolandic operculum, both eliciting motor facial responses associated with transient disturbances of speech, as assessed by a speech therapist present in the operating theatre (Fig. 2a). There was no language disorder elicited by stimulation on the cortical surface of the temporal lobe and temporo-occipital junction. Thus, resection was begun following identification of the tumor boundaries by ultrasonography.

During the removal of the lesion, IES of the posterior part of the superior temporal cortex buried within the Sylvian fissure (e.g. the planum temporale), induced language disturbances (semantic paraphasias). Thus, this area represented the limit of the resection at this level. Deeply, above the opened temporal horn of the ventricule, the internal capsule was identified by subcortical stimulations, eliciting motor responses of the upper (anteriorly) and the lower limbs (more posteriorly).

At this time of the surgery, the patient complained of an impression of a ⟪shadow⟫ in the left and superior visual field. Consequently, IES were performed in the more postero-superior and deep corner of the cavity, e.g. above the temporo-occipital junction of the ventricle horn, and behind the pyramidal pathways. The patient then described a transient increase of the visual disorders, with a ⟪shadow⟫ of the whole left hemifield, associated to a ⟪distortion⟫ of the pictures. Due to the limitation of time, no more precise visual task was performed. However, it is important to note that these subjective visual symptoms were reproducibly induced, since *systematically* elicited by each stimulation. Stimulations were performed 6 times, and the patient was not informed when the probe was applied on the brain. Surgical resection was then

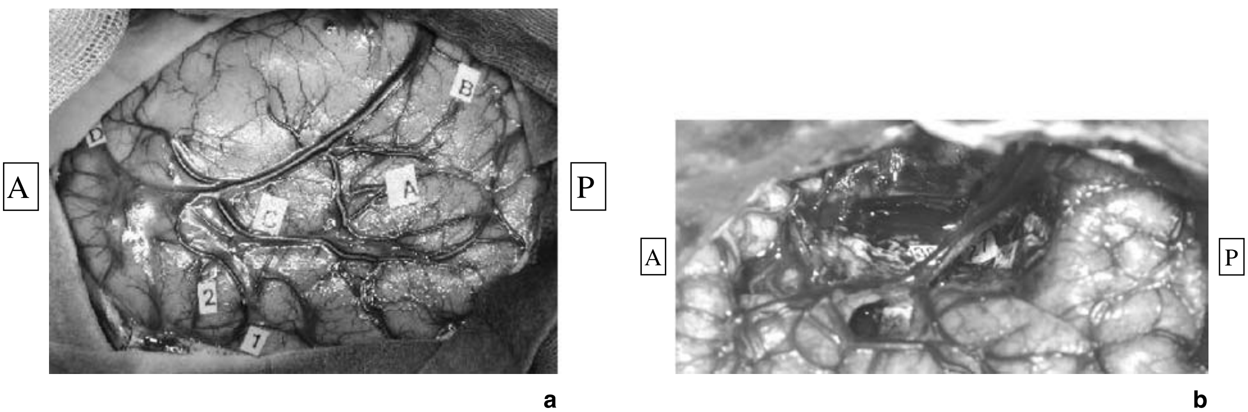

Fig. 2. (a) Intra-operative view before resection. The letter tags (*A*, *B*, *C*) marked the tumor boundaries identified using ultrasonography. The number tags (*1*, *2*) corresponded to two eloquent sites within the Rolandic operculum, both eliciting motor facial responses associated with transient speech disturbances during electrical stimulations. (b) Intra-operative view after resection, with enlargement at the level of the surgical cavity. The subcortical mapping allowed the detection of the pyramidal pathways of the left upper (30) and lower (27) limbs. More posteriorly and superiorly, stimulation elicited transient left hemianopsia and metamorphopsia: the tag 24 marked the subcortical visual pathways. *A* Anterior; *P* Posterior

stopped at the level of these structures, which were interpreted as corresponding to the optic radiations (Fig. 2b).

Post-operative course

The post-operative course was uneventful. There was neither motor, nor language deficit. Conversely, early post-operative neuropsychological examination showed an improvement of the cognitive functions, with normalization of the verbal working memory tasks. Moreover, the patient had no visual complaint. However, ophtalmological examination using Goldmann perimetric evaluation performed 6 days after surgery showed a left superior quadrantanopsia (Fig. 3). The visual acuity was normal.

On control MRI, the resection was subtotal, namely with a residual abnormal signal at the level of the postero-superior and deep edge of the cavity, near the temporo-occipital junction of the ventricle horn (Fig. 4).

The histological examination diagnosed a low-grade glioma (Grade II WHO).

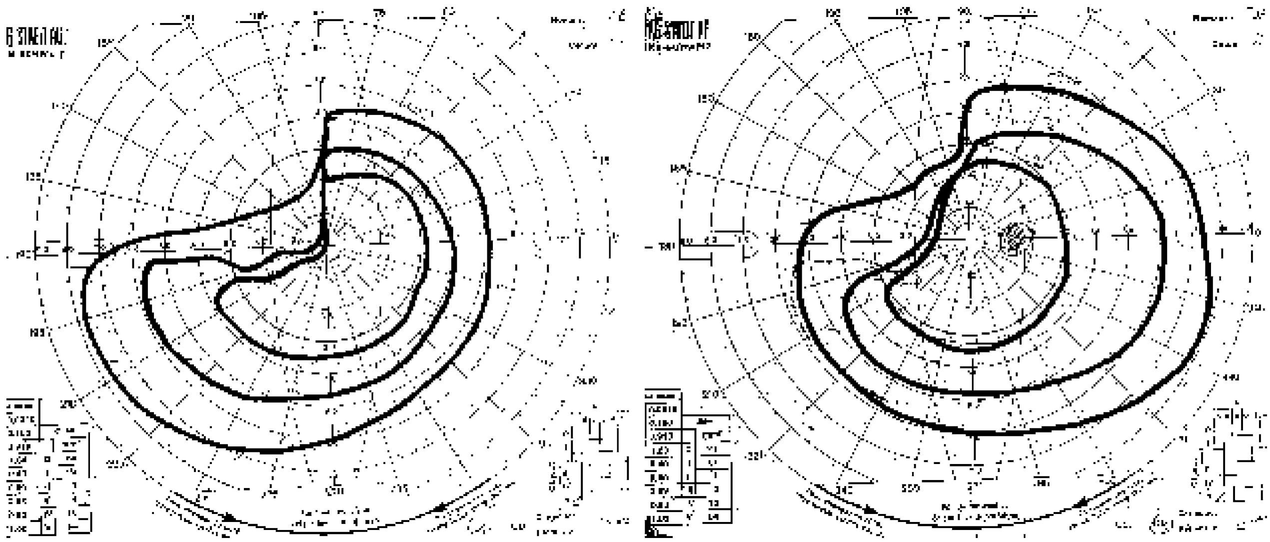

Fig. 3. Postoperative Goldmann perimetric evaluation performed 6 days after the surgery, showing a left superior quadrantanopsia

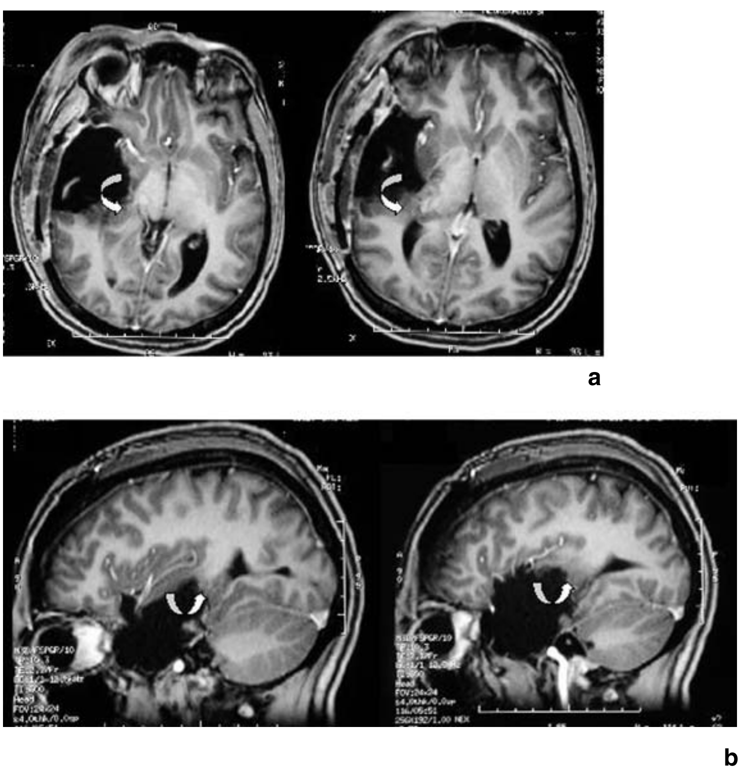

Fig. 4. Postoperative axial (a) and sagittal (b) T1-weighted enhanced MRI performed 6 hours following the surgery, showing a residue located in the postero-superior and deep edge of the cavity, e.g. at the level of the superior optic radiations, which were identified then preserved using stimulation (arrow) intra-operatively

Discussion

Post-operative visual field defects due to injury of the optic radiation were often reported after resection involving the temporal lobe, particularly in epilepsy surgery – from 52% to 100% [7, 12, 13, 16, 20]. Even if these visual deficits were usually minor, they could have repercussions on the quality of life, notably on driving [16]. Moreover, although the superior quadrant was preferentially affected, large temporal resections might also be associated with involvement of the inferior quadrant [13]. Then, in more posterior lesions involving the TPOJ, the risk of a more severe deficit such as a HH (and not only an ⟨⟨asymptomatic⟩⟩ homonymus quadrantanopsia) is increased.

However, despite the frequent use of functional mapping in surgery within eloquent regions (for a review, see [6]), the identification of visual structures was rarely reported, either pre-operatively – using fMRI [11, 18, 19], PET [8], MEG [17], TMS [9], subdural grid electrodes [14, 15] – or intra-operatively – using visual evoked potential (VEP) [10, 19] or direct electrical stimulation [2]. Moreover, in these studies, the visual mapping was exclusively performed at the cortical level, without attempting to track the visual pathways – nevertheless with frequent visual defects by deafferentation after surgery in the TPOJ.

Here, we described the use of IES, in order to identify and then preserve the afferent visual fibers, as previously reported for sensorimotor and language subcortical bundles [5, 6]. Indeed, while the patient already described a ⟨⟨shadow⟩⟩ in the left superior visual field when the visual mapping was begun, most probably corresponding to a previous surgical damage of the right inferior optic radiations, she noted at each IES a transient increase of the left visual field defect (associated with distortion of the pictures). This transitory left HH could be explained by the inhibition of the right superior optic radiation's functioning. Our results are in accordance with TMS studies, which showed that stimulation over the occipital cortex induced controlateral visual suppression [9]. It was hypothesized that the site of action was the primary visual cortex, and that the process disrupted was the thalamo-cortical volley of visual information from the lateral geniculate nucleus [1]. It is possible that IES applied at the level of the optic radiation generated such a disruption of afferent volleys, while stimulation of the visual cortex induced phosphenes [14].

Despite this difference between cortical and subcortical stimulations eliciting respectively visual perception and visual suppression, both are able to generate metamorphopsia. Visual illusions were already noted during stimulations of the basal temporo-occipital cortex, indicating that visual distortions can be caused by stimulation of specific visual cortical areas [14]. Our patient described such ⟨⟨a distortion of pictures⟩⟩ when stimulated, simultaneously with transient HH. This metamorphopsia might be due to the stimulation of fibers afferent to the temporo-occipital cortex, since this cortical region was not involved in the surgical resection. The 5 mm probe applied on the visual pathways has probably stimulated both fibers joining the calcarine fissure (visual suppression: HH) and fibers joining the association visual cortex for higher-order visual processing (visual illusion: metamorphopsia), all these pathways gathering together around the temporo-parieto-occipital horn of the ventricle.

The absence of post-operative HH, despite the existence of a left superior quadrantanopsia, is another argument in favor of the genuine identification of the optic radiation by IES. Finally, the control MRI showed a residual tumor (left because of the complete left visual suppression during subcortical stimulations) at the level which anatomically corresponds to the classical trajectory of the optic radiation, also supporting the value of IES for visual fibers tracking.

However, several problems persist.

First, the reliability of the method, since informations given by the patient during IES were subjective, even if reproducible. Overall, electrical visual mapping was begun partly too late, since inferior optic radiations were already damaged, due to the fact that the patient did not immediately realize the occurrence of the quadrantanopia (⟨⟨left superior shadow⟩⟩). To be more objective and accurate, the technique of pattern reversal VEP and intra-operative cortical VEP (reverseing checkerboard pattern) should be combined with subcortical IES [10]. Indeed, the extent and spread of stimulation effects are unknown. A larger current can evoke local afterdischarges, which have sometimes been shown to become epileptic activity. So, patient's description as ⟨⟨shadow⟩⟩ on subcortical IES would be objectivised and less time consuming if combined with VEP. Moreover, in patients in whom language and/or somatosensory mappings are not necessary, it would be possible to operate under general anesthesia, thus without any limitation of time, by combining IES and the technique of flash VEP using light emitting diode goggles and cortical grid recordings [19], as previously described in the anesthetized state [10].

Another possibility to gain time might be to use subcortical IES only when the resection comes close to the optic radiations (but not too late), on the basis of the data provided by pre-operative diffusion tensor MRI (DTI) integrated in a neuronavigation system [3], as already described for visual fMRI information [18]. Indeed, DTI was reported to be able to identify optic radiations [4]. IES seems nevertheless still mandatory, due to the risk of brain shift especially in cases of voluminous tumors [6].

Conclusions

Intra-operative subcortical mapping using direct electrical stimulation may represent a valuable tool for the identification and preservation of the visual pathways during surgery of lesions involving the posterior afferent visual system. This method could be combined with the preoperative data, provided by the functional neuroimaging method allowing visual cortical mapping, plus the DTI allowing optic radiation tracking, both integrated in a neuronavigation system, and to the intraoperative VEP. Subcortical electrostimulations might allow the decrease of permanent post-operative (symptomatic) visual defects in all kinds of surgery within the TPOJ (epilepsy surgery and/or space-occupying lesion resection, also ventricular surgical approaches) and might improve the understanding of the functional organization of the visual system in humans.

However, more patients and studies are needed to validate this method, by correlating intra-operative electrophysiological data and post-operative clinico-radiological results.

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Comments

This is a case report of a patient harbouring an astrocytoma of the insula in which the authors used intra-operative electrical stimulation during resection to avoid damage to the visual pathway. The operation was done under local anaesthesia, i.e. the patient could respond to questions and could give subjective answers. This is also the shortcoming of the method, since there is no objective control. Some deficit went even unnoticed by the patient. This point is well discussed by the authors as well as the other point of the constraints for patient and surgeon under local anaesthesia.

Ch. Ostertag

They report a case with successful subcortical mapping of the visual pathways using intra-operative electrical stimulations during awake surgery under local anesthesia. This preliminary report needs to be confirmed in a larger number of patients. Furthermore we would like to suggest the electrical subcortical stimulation of the visual pathways should be combined with intra-operative cortical visual evoked potentials VEP (reverseing checkerboard pattern) in order to achieve objectiveness of the changes in the visual field of patients operated on under local anesthesia. The extent and spread of stimulation effects are certainly unknown. Larger currents can evoke local afterdischarges, which have sometimes been shown to become epileptic in activity. But patient's description as "shadow" on subcortical stimulation would be then objectivised and less time consuming when combined with the VEP.

Thus the method of electrical subcortical visual mapping in addition to pre-operative data provided by VEP, fMRI and DTI could lead to a more radical and safer tumor resection within the temporo-parieto-occipital junction when patients are being operated upon under local anesthesia.

M. Bjeljac and *Y. Yonekawa*

Correspondence: Hugues Duffau, M.D., Ph.D., Service de Neurochirurgie, Hôpital de la Salpêtrière, 47-83 Bd de l'hôpital, 75651 Paris, Cedex 13, France. e-mail: hugues.duffau@psl.ap-hop-paris.fr