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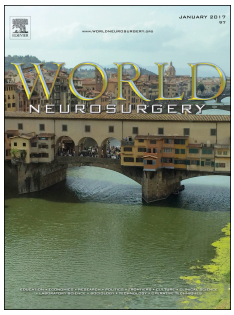

Visual mapping for tumor resection: A proof of concept of a new intraoperative task and a systematic review of the literature.

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• Title: **Visual mapping during tumor resection: literature review and proof of concept for a new intraoperative task.**

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Title: Visual mapping for tumor resection: A proof of concept of a new intraoperative task and a systematic review of the literature.

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Simple Summary: Hemianopia due to optic radiation damage can be a disabling condition, especially in young patients, and preservation of the horizontal field is important for daily activities such as driving. Nevertheless, the use of intraoperative tasks to evaluate the visual field during brain tumor resection in awake surgery is not routinely done and is far from being standardized. The aim of this study is to describe, as a proof of concept, a new intraoperative task for visual mapping in a small case series. Besides, we review the existing literature, their results, and the feasibility of the different methods for visual assessment during surgery. With this article, we hope to clarify the importance of intraoperative mapping of the optic radiations, the available methods to preserve them, and the lack of knowledge in the field for future studies.

Abstract: Homonymous hemianopia has been reported after brain tumor resection with a significant impact on quality of life. Nevertheless, no standardized methods exist for intraoperative optical radiations mapping. The purpose of this article is to describe a new intraoperative task for visual mapping and to review the existing literature.

A "Central and peripheral image task" was used to map optic radiations during brain tumor resection in three patients. A systematic review was performed following PRISMA 2020 guidelines with 25 out of 449 articles included.

Optic radiations were identified in all patients and preserved in all but one case where the extent of resection prevailed. The literature review exposed two methods to assess visual function. Visual evoked potentials (VEP) and direct electrical stimulation (DES), with 13 and 12 articles and 341 and 63 patients respectively. Hemianopia was developed in 13,49% of VEP cases versus 1,59% of DES cases.

The use of DES might be associated with a better outcome (level IV evidence). However, standardization of intraoperative tasks during DES could be improved. In this context, the "Central and peripheral image task" might be an adequate tool for the resection of tumors affecting the optic radiations.

Keywords: Hemianopia (H); visual mapping; visual evoked potentials (VEP); direct electrical stimulation (DES); awake surgery; brain tumor; optic radiation (OR).

1. Introduction

In neurosurgical oncology, the extent of resection (EoR) has proved to be a significant factor associated with outcome, as gross total resection (GTR) results in better survival rates (1–6). That being so, several brain mapping techniques have been developed as useful tools to achieve maximal tumor removal with lower morbidity rates (7–9). Furthermore, they are widely used for sensory, motor, and language functions, but not for others such as the visual perception and processing.

Visual deterioration consisting of homonymous quadrantanopia or hemianopia is frequently reported after tumor resection within the temporal, inferior parietal, or occipital areas (10–12). The arrangement of the posterior visual pathway (PVP) from the lateral geniculate nucleus of the thalamus to the primary visual area within the cortex of the calcarine sulcus is represented by the optic radiation (OR) and its damage during surgery can lead to a permanent visual field lost. This leads to a deterioration in the quality of life and neurological rehabilitation capability caused by this visual loss (13,14). Not to mention that homonymous hemianopia is a disabling deficit that prohibits driving under European laws (15).

Despite the multiple intraoperative techniques reported in the literature to assess and preserve the PVP during tumor removal, there is a lack of standardization on the technical aspects and indications among different authors (16–21). Besides, it remains unclear which technique yields better outcomes, and, to the best of our knowledge, no clinical trials have addressed this matter. Furthermore, the available literature reviews on the topic focus on just one of the visual mapping methods, without considering the others and, no systematic reviews exist comparing all the techniques to assess or map the PVP and their functional and oncological outcomes (22–24).

Due to the above mentioned, our aim is to describe, as a proof of concept, a new intraoperative task for visual mapping in a small series of patients harboring tumors located in the proximity of the PVP. Besides, we perform a systematic review of the existing literature, focusing on the outcome and the feasibility of the different methods for visual assessment during surgery. With this article, we hope to clarify the importance of intraoperative mapping of the OR and to describe the available methods to preserve them.

2. Materials and Methods

2.1. Subjects and intraoperative mapping:

Three consecutive patients harboring temporal parietal or occipital tumors and whose visual field was intraoperatively tested by using the Central and Peripheral Image (CaPI) task under awake tumor resection surgery were selected. The following variables were collected: demographic characteristics, tumor location, tumor histopathological features, preoperative and postoperative visual function, and extent of resection.

All patients underwent preoperative brain magnetic resonance imaging (MRI; Achieva 3.0T; Philips Healthcare, Best, The Netherlands). Then, all patients underwent tumor resection under the sleep-awake-sleep technique for motor, sensory, and language mapping, extensively described by our group and others (25–28). In brief, intraoperative electrical stimulation (IES), cortical and subcortical, was performed by using a bipolar electrode (Nimbus; Hemodia, Labège, France) on standard 1.25 ms biphasic square waves current at a frequency of 60 Hz with 4 seconds tissue contact. Initial threshold intensity stimulation was range from 2mA to 5mA until speech arrest occurs if the ventral premotor area (VPM) is exposed or sensory or motor activity if no VPM is exposed. All surgeries were performed by one of the senior authors (J.M.). Visual field was tested pre- and post-operatively in all patients with Goldman or Humphrey automated perimetry test.

In addition to the language tasks routinely performed, the CaPI task was used to intraoperatively assess the PVP. A laptop screen was placed approximately 1 meter from the patient's head, and it was oriented according to its angulation, in the same plane as the horizontal visual field of the patient. Then, a series of slides with fixed duration was shown to the patient. Each slide was composed of two figures, like those used in the DO 80 picture-naming task (29), one of them was located in the center and the second one in the periphery of the slide (Figure 1). The central image has a double function, it simultaneously allows language mapping whereas avoiding gaze deviation from the center of the screen. The peripheral smaller images appear on the superior and inferior quadrant of the slide at a random frequency. This second peripheral image allows to map the visual function; the stimulation of the PVP creates a negative or positive effect on the contralateral visual field that enables the patient to see and name

the peripheral image while preserving the nomination of the central one. A dedicated neuropsychologist (E.G.) evaluated all patient responses.

Stimulation was considered positive for OR if the patient named just the central image without naming the peripheral one at least three times at the same spot. The reproducible patient subjective sensation of light or dark within the visual field during stimulation was also considered positive for visual function.

EoR was assessed according to the following criteria: total tumor resection was considered if complete removal of hyperintense or enhancing areas on postoperative FLAIR-weighted or T1 with gadolinium MRI sequences were achieved for low- and high-grade gliomas, respectively. Subtotal if less than 10% of the tumor remains and partial if resection does not reach 90%. MRI was done preoperatively and within three days after surgery to identify the extent of resection in all cases.

2.2. Literature systematic review:

The objectives of the systematic review were to determine the different techniques available to assess the PVP during tumor surgery and compare their outcome regarding the postoperative visual field function.

The systematic review was performed through the PubMed database by following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) 2020 guidelines. The search string "((Visual cortex) OR (visual pathway)) AND ((awake surgery) OR (intraoperative mapping))" retrieved 183 articles to date 20/08/21. Additionally, a parallel PubMed search for "(visual evoked potential) AND (intraoperative)" was done with 264 results to date 22/08/21. Additionally, two more studies, not included under the search, were identified from other sources, as the list of references.

Eligible studies were selected according to the following inclusion criteria under the PICOS (participants, interventions, comparisons, out- comes, and study design) framework (Table 1). All types of English or Spanish language articles reporting cases of intraoperative technic used to preserve or identify the PVP during cranial surgery in humans were included. Articles excluded were those monitoring only the anterior visual pathway (AVP), those referring to intraoperative DTI, and reviews of the topic without newly reported cases.

After removing non English or Spanish language and duplicated articles a total of 395 abstract were screened by one research. A total of 36 papers that met the inclusion and exclusion criteria were full text reviewed, of those, 11 articles were excluded. Nine due to lack of preoperative or postoperative information, one due to duplicated patients already mentioned in a previous report, one because it described a new technique only reported in a single case report, and one paper that the full text could not be found. A total of 25 articles, summarized in Table 2, were included in the systematic review. PRISMA flow diagram is showed in Figure 2.

The review's objectives were to determine all the types of intraoperative visual mapping or monitoring procedures available. The primary and secondary outcomes were the visual function outcomes from each method, and the ability for each one to identify the visual pathway, respectively. EoR was not assessed due to the lack of information.

No automatic tools or peer-reviewed was done. The data collected included: type of publication, visual mapping method and intraoperative task used, number of patients included, preoperative visual field and type of test used, location of the lesion, type of lesion, number of patients where the used method fail, intraoperative findings during the mapping, follow up, postoperative visual field function and extent of resection.

The preoperative and postoperative visual fields were classified as follows: normal (NL), partial quadrantanopia (PQ), complete quadrantanopia (Q), partial hemianopia (PH), or complete hemianopia (H). Intraoperative findings during DES were included as subjective sensations, whereas those during VEP were included as true or false positive responses, and true or false negative responses.

No other methods, as funnel plot or formal tests, were used to assess the risk of bias across studies due to the small number of records included.

3. Results

3.1. CaPI task for intraoperative visual mapping:

The CaPI task was done in 3 patients. Table 3 summarizes their sociodemographic and clinical features, and the intraoperative findings. Subtotal resection was achieved in patients 1 and 2 harboring a grade III glioma, with no postoperative visual deficit in either of them, quadrantanopia was resolved postoperatively in patient 2. Total resection was achieved in patient 3 suffering from a grade IV glioblastoma, with postoperative expected hemianopia.

Illustrative cases are presented in Figure 3 and 4. In brief, during the resection, reproducible task errors were encountered in patient 3 during subcortical stimulation. The patient named the central image but not the peripherical one located at the contralateral side of the tumor location. The first error was located in the inferior portion of the surgical cavity and corresponded to the left superior quadrant visual field; the second error was found superiorly to the first one and caused inferior quadrantanopia. Both errors were identified intraoperatively as seen in Figure 3. Despite the adequate identification of the OR area, tumor resection needed to be continued due to the high remaining tumoral mass. On the contrary, OR were preserved in patient 2 and the visual field improved after tumor resection, as seen in Figure 4.

3.2. Systematic literature review:

3.2.1. Intraoperative methods available to assess the PVP.

Two different methods were encounter: Visual evoked potentials (VEP) and Direct Electrical Stimulation (DES). Articles mixing patients with visual assessment with those evaluating other functions were carefully review and only patients with visual assessment were included for the review. The main features of the review are summarized in Table 2.

3.2.1.1. Visual evoked potentials (VEP) (16,17,19,30–39):

We found a total of 13 articles where VEP was used to monitor the visual function in different manners. Standard flash VEP (FVEP) with light emitted diodes (LED) embedded in goggles or directly attached to eyelids and the subcutaneous electrode or subdural grid recording were used in all cases. In 3 reports, additional direct electrical stimulation to the optic nerve (ON) or OR was used in addition to FVEP. Most of the studies reference the international EEG system 10-20 for scalp electrode placement (40). Total intravenous anesthesia was used in 7 articles (16,17,19,31,36,38,39), inhalational anesthetic in 2 reports (33,35), and both techniques in 1 paper (37). The remaining 3 papers did not report the type of anesthesia used (30,32,34).

The VEP parameters were not standardized. Red-light stimuli were used in 5 papers (16,33,36,38,39) and white-light only in one article as an innovative stimulus (19). The other 7 articles did not mention the type of light used, although red-light could be assumed. Different light parameters and bandpass filters were used, from 1Hz frequency over 20ms stimuli duration and low- (20Hz) and high- (500Hz) filters to 4,1Hz over 10ms and 3-1500Hz bandpass.

Alarm criteria were homogeneous through articles considering a 50% decrease of baseline amplitude recording between first negative (N) and first positive (P) waveforms as the principal alarm criteria. Only one article used a stricter cut point consisting of a 20% amplitude decrease (19). Additionally, latency increase was also considered in some reports.

Sensitivity (Sen), specificity (Spe), positive predictive value (PPV), and negative predictive value (NPV) was calculated on those articles with >10 patients included. For the analysis, VEP intraoperative changes (temporal or permanent) with postoperative visual deterioration were considered as true positive (TP), while those without deterioration were catalog as false positive (FP). On

the other hand, patients without VEP changes and no postoperative visual deterioration were considered true negative (TN), while those with visual deterioration were false negative (FN). Furthermore, VEP success rate was also registered as the number of patients where VEP could be correctly recorded over the total attempted patients. The results are given in Table 4 and Figure 5.

The results exposed a VEP success rate range from 82,35% to 93,50%, with erratic Sen and PPV parameters between studies, but a relatively stable Spe and NPV that kept above 90% and 80%, respectively, except for an old article date in 1987 (33).

3.2.1.2. Direct electrical stimulation (DES) (10–12,18,41–48):

Twelve articles where DES was used were included. Bipolar electrode stimulation was used in 10 reports, with the following parameters: pulse frequency of 60 Hz, 0,2 - 1 msec stimulation pulse with 3-4 second tissue contact in all but 1 article. Intensity ranged between 1,5 to 10 mA initially with later 2-5 mA during cortical and subcortical resection. One article used bipolar and monopolar mapping suction Probe, bipolar parameters were near as the abovementioned, and monopolar intensity was started at 4mA with a further 4mA increase up to 20mA maximum. The remaining article used monopolar stimulation with 3,5mA intensity and just cortical mapped is reported, without subcortical DES (41). Despite the homogeneity in the technique and stimulation parameters, five different intraoperative tasks were described:

A. Subjective sensations (10,18,41): Mentioned in three articles, this technique is based purely on the patient's phenomena on its visual field, such as flashes, shadows, darkened, or image distortion. In one case, a laser was given to the patient to mark the area of the visual field sensations on a perimetry chart (41).
B. Color dots on a screen (43): this method was used in one article and is based on the ability of the patient to see red or green dots on a 30x40in white screen with a central fixation spot. A combination of static and kinetic perimetry was tested, static green dots were used as control in the hemifield not at risk, while static red dots were used to test the patient. Additionally red laser spot was moved from the periphery to the center of the screen periodically to assess kinetic perimetry.
C. Modified picture naming task (11,12,45,46,48): consisting of a series of slides where DO80 picture naming task images are disposed in opposed visual field quadrants. A red cross at the center of the screen is used for patient to focus on it during the tasks. This technique was used in 5 articles and allows a doble functional task, nomination and visual assement.
D. Dog in chard (44): on this method, a white screen with a black line drawing a dog picture (size 60 x 40 cm) and a central cross is placed in front of the patient at a distance of 50 cm. The patient was asked to stare at the central cross while naming the different dog body parts pointed out with a red laser. Each body part, head, tail, front leg, and back leg is located inside one of the quadrants of the patient's visual field. Only one article used this task.
E. Virtual reality headset (VRH) (47): during the resection patient wears an Oculus virtual reality headset where a modified Esterman test grid is display. Patients focus on a yellow circular central yellow dot. At the same time, an orthoptist sent peripheral 4mm white circular luminous stimuli to appear on the grey background for the patient to identify them, with 4 points to stimulate on each quadrant of the visual field. This method was only mentioned in one article.

3.2.2. Visual function outcome and intraoperative visual pathway identification.

The combined results for primary and secondary outcomes obtained after the data extraction are summarized in Table 5. All but one article were included for the analysis, the excluded paper did not mention intraoperative changes (17).

A total of 341 and 63 patients for VEP and DES, respectively, were found. Monitoring of the visual pathway was feasible in all DES patients while 14,77% of VEP patients could not be monitored. The reasons were technical problems or the lack of a reproducible baseline VEP recording before tumor removal.

Postoperative visual deterioration was observed in 26,19% of VEP patients compared to 53,97% of DES patients. The most frequent deterioration observed was quadrantanopia, a well-tolerated deficit. Nevertheless, disabling hemianopia occurs in 13,49% of the VEP patients, while just 1,59% of the DES patients developed hemianopia.

Only 19,06% of VEP patients experience intraoperative findings, compared to 69,84% of DES patients. Assuming all intraoperative findings are caused by visual pathway manipulation or stimulation, the DES method had a higher rate of intraoperative visual pathway identification. Moreover, 88% of VEP patients with intraoperative findings during the surgery developed postoperative hemianopia, in contrast to only 3% of the DES patients with intraoperative findings.

For the analysis of visual deterioration and postoperative hemianopia another article was excluded in which postoperative visual function was not specify (39).

Meta-analyses could not be undertaken due to the heterogeneity of interventions, settings, study designs and outcome measures.

4. Discussion

The OR has been depicted in various anatomical and tractography studies as running through the temporal, inferior parietal, and occipital lobes, adjacent to the temporal horn and atrium of the lateral ventricle (49–52). Furthermore, this tract can be functionally divided into three or two layers according to Párraga et al and others (49,52):

- The anterior bundle: carrying the superior of the hemi-visual field going in an anterior direction above the temporal horn before looping posterior to reach the visual cortex, forming Meyer's loop.
- The central bundle: carrying the horizontal part of the hemi-visual field going posteriorly in a relatively straight direction above the temporal horn and on the lateral side of the atrium.
- The posterior bundle: carrying the inferior hemi-visual field traveling also posteriorly but in a superior loop direction lateral to the temporal horn and atrium through the inferior parietal lobe.

Thus, damage to any of these areas adjacent to the temporal horn, atrium or the calcarine cortex can lead to permanent quadrantanopia or hemianopia.

Commonly, hemianopia has been regarded as a non-important deficit, still, it can be very disabling, especially for young patients, who see their quality of life significantly diminished. Moreover, these patients are usually banned from driving as, under European laws, the requirements for a standard driven license are a horizontal binocular visual field equal or greater than 120º (15), making it impossible for these patients to achieve a driven license.

Considering the abovementioned, the identification and functional preservation of the PVP during tumor resection is becoming one of the principal aims in neurosurgical oncology, as it has previously occurred in the last decades regarding motor and language functions. Among the currently available methods to intraoperatively identify the PVP, the DES technique allowed to precisely localize the visual

pathway during surgery, while VEP method just allowed monitoring of the visual pathway without further identification. Moreover, intraoperative findings such as blurred vision, phosphenes, shadows, black or white spots, and transient visual deficit on the tested hemi-visual field are approximately three times more reported than transient or permanent VEP intraoperative changes.

On the other hand, and regarding the visual outcome in both techniques, the percentage of postoperative hemianopia remains lower with the DES method when excluding the patients harboring pathology affecting the AVP from the VEP group. DES is also associated with a high rate of postoperative quadrantanopia in patients with intraoperative DES-elicited visual disturbances (10,12,42,44–46), suggesting that partial damage to the OR is produced prior to the PVP identification. Presumably, higher stimulation parameters during subcortical DES could be needed to avoid such deficits. However, as quadrantanopia might be a more tolerable deficit, the extent of resection should prioritize. Therefore, and according to these results, we might favor the use of DES as the first option for intraoperative visual mapping for tumor resection, which could lead at least to lower hemianopia postoperative rates.

Despite the mentioned benefits, DES method entails some technical difficulties. For instance, during DES for visual mapping, an unintentional gaze deviation during the tasks might occur and this fact can overlook visual deficits and risk the efficacy of the mapping. Previous visual tasks encountered in the literature used a central cross or central dot for the patient to focus on it (21,44,47,53), but as surgery goes on, in our experience, patients get tired and deviate from the central target. That is why we propose the use of the CaPI task as a potential tool during the intraoperative assessment of the PVP, as it helps the patient to maintain the gaze on the center of the screen, as the central image will always be there. Our technique allowed us to correctly identify OR during the resection, even in patient 3, who developed hemianopia after the surgery. In this case, OR were encountered and deliberately resected to achieve total resection and increase the life expectancy of a high-grade glioma patient. Maximal resection was prioritized over visual deficit following the patient's will.

Another limitation during DES mapping is the available time of optimal patient collaboration. For this reason, multifunctional tasks have been reported to increase DES efficacy (54). Our task allows for simultaneous mapping of naming and visual function, similarly, as the modified picture naming task reported in this review (53), with the advantage of gaze deviation avoidance. This multifunctional task had proved to be relevant in tumors located in the temporal lobe or near the sagittal striatum of the dominant hemisphere, a highly interconnected area with OR intertwined with the arcuate fascicle and the middle longitudinal fasciculus (42,53). On the contrary, several of the other tasks used during DES and reviewed here do not allow to perform a simultaneous language mapping.

While it is true, some of these methods, such as the color dots on a screen (21) or the VRH (47), allows a more precise intraoperative assessment of the overall visual field, and not just a quadrant. Despite this advantage, as partial or complete quadrantanopia might be well-tolerated deficits, it does not seem to add improvements to the other methods in hemianopia avoidance. Besides, some of these methods are technically demanding and expensive, such as the VRH.

What about the VEP, are they useless? Since being firstly reported in 1976 (55) VEP has made progressive improvements to obtain better recordings during surgery. Total intravenous anesthesia favors VEP stability compared with inhaling anesthetic agents (56–58). Besides, better light stimulation devices, such as light embedded googles or white light diode instead of red ones, can improve the technique (19). Furthermore, simultaneous electroretinogram (ERG) allows differentiating pre-retinal from post-retinal VEP changes and should be included nowadays in every VEP recording. Simultaneous ERG and VEP changes occur during pre-retinal causes such as light axis deviation. On the contrary, VEP decrease with stable ERG only occurs in post-retinal causes, such us OR damage (57). Low-amplitude EEG rather than high-amplitude EEG also favors the VEP recording (39). Despite the mentioned advances, VEP monitoring still has significant limitations, such as the high variability of recordings among patients and centers that make it difficult to standardize the technique (16,59).

Our results confirm the heterogeneity of VEP parameters between groups without any clear standardization except the electrode placement and the alarm criteria. Furthermore, the differences in Sen and PPV between studies highlight the low reliability of this technique to correctly identify patients at risk or with established visual pathway damages during the surgery. On the contrary, the high Spe and NPV favor the idea that patients without VEP decrease during the surgery should not develop visual deterioration. Some authors also agree that intraoperative FVEP changes are associated with changes in visual

acuity rather than visual field due to amplification phenomenon and the inability to selectively stimulate different parts of the retina with the actual light devices (60). From our point of view, VEP monitoring is inferior to the DES technique to preserve de PVP. Despite this, it is still a viable option to monitor the AVP or patients where DES cannot be done.

For instance, despite the apparent good results from Sasaki et al. during VEP monitoring with 87,50% of Sen and 98,24% Spe, when analyzing the subgroups of 27 patients with pathology near the PVP, we found that six out of the total eight hemianopia occurs in these group, leaving a 22% of postoperative hemianopia in PVP monitoring (57). These results can be explained as the ability of VEP to predict the integrity or destruction of the PVP when VEP remains stable or decrease respectively. With the inability to alert the surgeon before the damage is already established to the tract. Interestingly, most VEP changes were reversible to surgeons' actions, such as aneurysm clipping surgery and tumor removal near the AVP. The VEP decrease in these cases was caused by the interruption of blood flow to the visual pathway due to vascular clip misplacement or compression to the ON, chiasma, or OR due to tumor manipulation (39,57). All the situations mentioned above are reversible causes where the PVP maintains its integrity if no prolonged ischemia or excessive retraction occurs, contrary to the irreversible destruction of the fibers when removing tumors around the PVP.

Finally, we must emphasize that most VEP studies included anterior and PVP patients. As the PVP is characterized by the amplification phenomenon that occurs at the lateral geniculate nucleus of the thalamus (61), we could hypothesize that this could limit the use of the VEP technique to map the AVP and PVP indistinctly. In other words, a lesion compromising the ON can generate a significant VEP amplitude decrease during surgery with minimum ON damage due to the amplification phenomena. In comparison, lesions at the level of the OR cannot generate such significant decreases until extensive damage is done to the tract. In our review, only one article referring to VEP evaluated the PVP alone (62). The remaining articles included anterior and posterior pathways indistinctively.

Other methods described in the literature to preserve the OR during surgery, such as the intraoperative tract identification through neuronavigation (63,64), intraoperative optical imaging (IOI) (20) or intraoperative cortical evoked potentials after stimulation of ON (65) were not included in the review. Brain shift makes neuronavigation inaccurate to precisely localize OR, although intraoperative MRI can correct this limitation (64), its cost and time consumption, makes it unviable for every center. IOI is based on the changes in blood flow, volume, and oxygenation at a cortical level caused by repeated peripheral stimulation light emitted diode to the eyes. The described method identifies eloquent cortical areas during tumor resection. Despite it, IOI to assess the visual function during tumor resection was found just in one case report. This limitation does not provide enough evidence to assume conclusions about the technique (20). Lastly, cortical evoked potentials after stimulation of ON requires the surgical exposure of the nerve, usually not feasible during brain tumor resection (65).

4.1. Limitations

Despite the proposed CaPI task and its design to prevent gaze deviation, there is no objective method to identify intentional or unintentional patient gaze deviation. Future studies should focus on developing other strategies to objectively control the patient's gaze.

Nevertheless, and despite mentioned benefits of DES for visual mapping, some significant methodological limitations should be considered before being able to reach a definitive conclusion. First, DES patients included in the analysis were more homogeneous, with tumors involving the temporal, occipital, and inferior parietal areas with higher proximity to the PVP. On the contrary, VEP patients were more heterogeneous, with lesions involving both the AVP and PVP in most articles reviewed. This heterogeneity makes it difficult to compare both techniques.

Besides, it is important also to acknowledge the lack of preoperative visual field studies in some articles where VEP was done (33,39,57) and the assumption of those as normal for the analysis. This supposition can overrate the percentage of postoperative hemianopsias in the VEP group. Lastly, the VEP article with the best sensitivity and specificity results excluded 14% of the cases, as non-contributing without further information. Furthermore, most of the patients (76%) had pre-chiasmatic lesions and the analysis was done over the number of eyes instead of patients overrating their results (39).

5. Conclusions

Based on our review and experience we can conclude that DES is a feasible and useful technique to identify OR and prevent homonymous hemianopia during tumor resection at the temporal, inferior parietal, and occipital areas. It is a plausible and simple technique to do during awake surgeries. Besides, we propose further validation of the CaPI task to be included in the DES mapping protocol to improve higher rates of standardization and improve some of its limitations of DES for visual mapping. Finally, VEP should only be considered as an alternative monitoring method if DES is not possible, considering its limitations.

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Tables and figures legend:

Table 1. PICOS: participants, interventions, comparisons, outcomes, and study design.

Table 2. Articles included in systematic review. Visual evoked potentials (VEP), electroretinogram (ERG), direct electrical stimulation (DES), normal (NL), patial quadrantanopia (PQ), quadrantanopia (Q), partial homonimous hemianopia (PH), homonimous hemianopia (HH), low grade glioma (LGG), high grade gliomas (HGG), Anaplastic astrocytoma (AA), Oligodendroglioma (OD), ganglioglioma (GG), Glioblastoma (GBM), arteriovenous malformation (AVM) and dysembryoplastic neuroepithelial tumor (DNET).

Table 3. Patient characteristics. visual function (VF), posterior visual pathway (PVP), extent of resection (EoR), central and peripheral image task (CaPI), Male (M), Female (F), right (R), left (L), normal (NL), homonimous hemianopia (HH) and quadrantanopia (Q).

Table 4. Reviewed VEP article results analysis. Sensibility (Sen), Specificity (Spe), Positive predictive value (PPV), Negative predictive value (NPV).

Table 5. Compared analysis of VEP and DES. * For the analysis 85 patients from Houlden et al were not included due to not specify postoperative visual field. VEP: Visual Evoke Potentials (VEP), Direct Electrical Stimulation (DES), Operative findings (OP), Visual function (VF), Post-Operatie (PO) and Hemianopia (H).

Figure 1. Central and peripheral image task (CaPI) sample slide. Electrical stimulation is applied just immediately after slide changes (created with Biorender.com).

Figure 2. PRISMA Flow diagram.

Figure 3. Patient 3. A. Preoperative MRI T1 with gadolinium contrast axial plane, B. And sagittal planes. C. Postoperative MRI T1 with gadolinium contrast axial plane, D. And sagittal planes. E. Intraoperative Cortical exposure with tumor reconstruction according to neuronavigation. F. Intraoperative image of the visual disturbances place location during DES before complete resection was achieved. Spanish flag tag 1 for reading mistake. Orange tag 1 for transient superior quadrant visual disturbance. Orange tag 2 for transient inferior quadrant visual disturbance. G. Intraoperative neuronavigation for Orange tag 1. H. Intraoperative neuronavigation for Orange 2. I. And J. Preoperative visual field tested by Humphrey Field Analyzer 3 (ZEISS). White circles for visual field stimulus detected, black squares for visual field stimulus not detected. I. Left and right preoperative visual fields Humphrey test, without any significant disturbances. J. Left and right postoperative visual fields Humphrey test, with clear homonymous hemianopia.

Figure 4. Patient 2. A. Preoperative MRI T1 with gadolinium contrast axial plane, B. And sagittal planes. C. Postoperative MRI T1 with gadolinium contrast axial plane, D. And sagittal planes E. Tumor reconstruction according to neuronavigation. F. Intraoperative resection cavity. Spanish flag tag 1 for speech arrest. Spanish flat tag 2 for speech arrest and jaw movement. Spanish flag tag 3 for anomia I. and J. Preoperative visual field tested by Humphrey Field. Grey and black areas correspond to visual loss. I. Left and right preoperative visual fields Humphrey test, with superior quadrantanopia. J. Left and right postoperative visual fields Humphrey test, without significant disturbances.

Figure 5: Analysis of the reviewed VEP article. Sensibility in blue and specificity in orange of each article included in the analysis.

Table1

Visual mapping systematic review inclusion criteria	
PICOS criteria	**Inclusion criteria**
Participants	Patients diagnosed with brain tumor or epileptic foci near the PVP.
Interventions	Surgical resection done with intraoperative visual mapping procedures.
Comparisons	No comparison with other treatments was made.
Outcomes	1º Visual function outcomes from each procedure. 2º Ability to identify the visual pathway from each procedure.
Study design	Observational studies and systematic review.

Table 2

	Author / Year	Type of article	Visual mapping method	Patients	Lesion location	Tumor or lesion	PreOp Visual field	Intraoperative findings	PostOp Visual field
1	Cedzich C et al / 1987	Case series	Transcranial VEP	35	Orbit: 3 Perisellar: 25 Retroquiasmatic: 7 Intraventricular: 4 Occipital: 2 Pineal: 1	Hemangioma: 1 Glioma: 1 Pituitary adenoma: 15 Craniopharyngioma: 6 Meningioma: 8 Germinoma: 2 Angioma: 1 GBM: 1	Not specified	VEP feasibility: 19/35 VEP changes: 25/35	Q: 4 PH: 2 HH: 19
2	Curatolo JM et al / 2000	Case report	Subcortical VEP + ERG	2	Occipital: 2	Epileptic focus: 2	PQ: 1 PH: 1	VEP feasibility: 2/2 VEP changes: 0	Q: 1 HH: 1
3	Duffau H et al / 2004	Case report	DES Cortical and subcortical (subjective sensation)	1	Temporal lobe	LGG	NL	Visual disturbances: 1/1	Q: 1
4	Kamada K et al / 2005	Case series	Transcortical VEP Cortical VEP	2	Parietal Temporal	Epileptic focus GBM	NL	VEP feasibility: 2/2 VEP changes: 1/2	NL: 1 HH: 1
5	Sasaki T et al / 2010	Prospective case series	Transcranial VEP + ERG	100	Parasellar: 28 Temporal: 16 Parietal: 6 Occipital: 5 Frontal: 2 Orbital: 1 Vascular aneurism: 42	Tumor: 53 AVM: 5 Aneurism: 42	Not specified	VEP feasibility: 187/200 eyes VEP changes 39/200 eyes	Q: 3 HH: 8
6	Ota T et al / 2010	Case series	Cortical VEP	17	Temporal 5 Occipital 12	Epilepsy 4 GBM 4 Hemangioma 2	NL: 9 P Q: 1	VEP feasibility: 14/17	NL: 8 PQ: 1 Q: 5

						Metastasis 2 Meningioma 1 AVM 1 Radionecrosis 1 Ganglioglioma 1 Cryptococcal granuloma 1	Q: 6 HH: 1	VEP changes: 4/14	PH: 0 HH: 3
7	Nguyen HS et al / 2011	Case report	DES cortical and subcortical (Colour dots on screen)	1	Occipital lobe	AA (G III)	NL	Visual disturbances: 1/1	NL: 1
8	Gras-combe G et al / 2012	Clinical article	DES cortical and subcortical (Modified picture naming task).	14	Temporo-ocipito-parietal junction: 10 Temporal lobe: 2 Occipital lobe: 2	ODs (GII): 11 ODs (GIII): 2 Angiocentric glioma GI: 1	NL: 14 PQ: 0 Q: 0 PH: 0 H: 0	Visual disturbances: 11 / 14	NL: 1 PQ: 2 Q: 10 PH: 0 HH: 1
9	Steno A et al / 2012	Case report	DES Cortical and subcortical (Dog on screen task)	1	Temporal lobe	LGG (GII)	NL	Visual disturbances: 1/1	PQ: 1
10	Torres C et al / 2012	Case report	Cortical VEP	1	Occipital	Metastasis	Q	VEP change 1/1	Q: 1
11	Fernández-Coello A et al / 2013	Case report	DES Cortical and subcortical (Modified naming task)	1	Temporo-occipital junction	LGG (GII)	NL	Visual disturbances: 1/1	Q: 1
12	Chan-Seng E et al / 2014	Case series	DES cortical and	8	Temporo-occipito-	LGG (GII): 8	Normal : 8	Visual disturbances: 5/8	NL: 3 PQ: 0 Q: 5

			subcortical (Modified picture naming task).		periatrial junction (SS): 8				PH: 0 HH: 0
13	Sarubbo S et al / 2015	Case series	DES Cortical and subcortical (Modified naming task)	3	Optic radiation	LGG 2 HGG 1	NL	Visual disturbances: 3/3	NL: 0 PQ: 1 Q: 2 HH: 0
14	Luo Y et al / 2015	Case series	Transcortical VEP + ERG	46	Parieto-Occipita junctionl: 2 Occipital lobe: 1 Temporo-occipital juncton: 5 Parietal lobe: 1	Linfoma: 1 Astrocytoma: 1 Hemangioma: 1 Metastasis: 2 GBM: 2 Glioma: 2	NL: 16 Q: 4 H: 14 Other: 12	VEP feasibility: 38/46 VEP changes 2/38	NL: 14 Q: 5 HH: 17 Other: 10
15	Mazerand E et al / 2017	Clinical trial	DES Cortical and subcortical (Modified Esterman test on virtual reality headset)	1	Inferior parietal lobe	GBM (GIV)	NL	Visual disturbances: 1/1	NL: 1
16	Shahar T et al / 2018	Case series	VEP transcranial, cortical, and subcortical	18	Parietal: 8 Parieto-temporal: 3 Temporal: 6 Temporo-occipital: 1	AA: 6 Metastasis: 2 GBM: 7 OD: 2 Anaplastic OD: 1	NL: 13 PQ: 0 Q: 1 PH: 3 H: 1	Cortical VEP feasibility: 14/18 Subcortical VEP feasibility: 10/13 VEP changes not mention	NL: 9 PQ: 0 Q: 2 PH: 2 HH: 5

17	Rolland A et al / 2018	Case series	DES cortical and subcortical (Modified picture naming task).	14	Inferior parietal lobe: 14	- LGG (GII): 11 - AA (GIII): 1 - GBM (GIV): 1	Normal : 14	Visual disturbances: 6/14	NL: 10 PQ: 0 Q: 1 PH: 0 HH: 0
18	Joswig H et al / 2018	Case report	DES cortical (subjective sensations marked with laser on perimetry chart)	1	Occipital lobe	Epileptic foci.	NL	Visual disturbances: 1/1	NL: 1
19	Gutzwiller EM et al / 2018	Prospective case series	Transcranial and subdural VEP + ERG	29	Temporal: 14 Parietal: 8 Frontobasal: 7	Gliomas: 14 DNET: 3 Metastasis: 3 AVM: 2 Meningioma: 7	Not specified	VEP feasibility: 26/29 VEP changes 6/26	No changes : 18 PQ: 3 Q: 1 HH: 5
20	Houlden DA et al / 2019	Case series	Transcortical VEP + ERG	89	Temporal: 8 Parietal: 4 Occipital: 11 Frontal: 2 Sellar / suprasellar: 39 Sphenoid: 10 Intraventricular: 1 Nasopharynx: 3 Ethmoid: 9 Arterial aneurisms: 7 Spinal: 3	Aneurysm: 7 AVM: 6 Cavernoma: 2 Craneopharyngioma : 9 Meningioma: 29 Abscess: 1 Epidermoid cyst: 1 Glioma: 3 Metastasis: 7 Subependymoma: 1 Adenoma: 19 Angiofibroma: 2 Adenocarcinoma: 2 Carcinoma: 1 Chordoma: 1 Rathke's cleft cyst: 1 Encephalocele: 1	Not specified	VEP feasibility: 77/89 VEP changes: 4/77	Not specified

						Glomangiopericytoma: 2 Sarcoma: 4 Teratoma: 1 Spine degenerative: 3			
21	Qerama E et al / 2019	Case report	Transcranial VEP + ERG	1	Ventricle	Meningioma	NL	VEP changes: 1/1	NL: 1
22	Talabaev M et al / 2020	Case report	DES cortical and subcortical (Subjective sensation).	1	Occipital lobe	DNET	Not specified	Visual disturbances: 1/1	NL: 1
23	Mammadkhanli O et al / 2020	Case series	VEP not secify	8	Occipital lobe: 8	Not specified	Normal: 8	VEP feasibility: 8/8 VEP critical changes: 0	NL: 7 PQ: 0 Q: 0 PH: 0 HH: 1
24	Boëx C et al / 2021	Case series	Transcranial and subcortical VEP	12	Temporal lobe: 3 Temporo-parietal: 2 Parietal lobe: 2 Temporo-occipital: 2 Sphenoidal: 3	GBM: 5 GG: 1 Meningiomas: 3 AVM: 1 Cavernoma: 1 Hippocampal sclerosis: 1	Not specified	VEP feasibility: 10/12 VEP changes: 2/10	NL: 4 PQ: 2 Q: 1 HH: 2
25	Berro DH et al / 2021	Case series	DES Cortical and subcortical (Modified naming task)	17	Parieto-temporo-occipital junction: 17	LGG	Not specified	Visual disturbances: 12/17	NL: 8 PQ: 0 Q: 9 PH: 0 HH: 0

Table 3

	Age/Sex	Location	Histopathological features:	PreOP VF	Intraoperative tasks	Intraoperative identification of PVP	Post OP VF	EoR	**Follow up**
Patient 1	42 yo / M	R parietal	Anaplastic astrocitoma (G III) - IDH-1: Positive - ATRX: Negative - P53: 30% - Ki67: 5%	NL	Naming Reading Verbal memory Line bisection tet CaPI	No	NL	Subtotal	12 months
Patient 2	17 yo / M	L temporal	Anaplastic astrocitoma (G III) - IDH1: Negative - ATRX: Negative - P53: 5% - Ki67: 15 % - EMA: Negative -L1CAM: Negative -CD34: Negative -Reticulin: Negative -H3K27M: Negative	R superior Q	Naming Reading Verbal memory Episodic memory CaPI	No	NL	Subtotal	12 months
Patient 3	44 yo / F	R occipital	Glioblastoma (GIV) - IDH-1: Negative - PTEN: Positive - p53: 85% - ki67: 60%.	Left PH	Naming Reading Line bisection test CaPI task	1.Left superior Q 2. Left inferior Q	Left HH	Total	12 months

Table 4

Article	Patients	VEP success rate	Sen	Spe	PPV	NPV
Houlden et al	89	86%	100%	97%	25%	100%
Luo et al	46	82,6%	0%	94,28%	0%	91,67%
Gutzwiller et al	29	89,70%	62,50%	94,44%	83,33%	85%
Sasaki et al	100	93,50%	87,50%	98,24%	82,35%	98,82%
Cedzich et al	35	-	71,42%	28,57%	20%	80%
Ota et al	17	82,35%	100%	91,66%	66,66%	100%
Shahar et al	18	77%	57,14%	85,71%	80	66,67%
Boëx et al	12	83,34%	50%	100%	100%	75%

Table 5

	Articles	Patients	VEP feasibility	OP findings	PO VF deterioration	PO H	H patients with OP findings
VEP	12	341	85,34%	19,06%	26,19%*	**13,49%***	70,77%*
DES	12	63	100%	69,84%	53,97%	**1,59%**	2,27%

Figure 1.

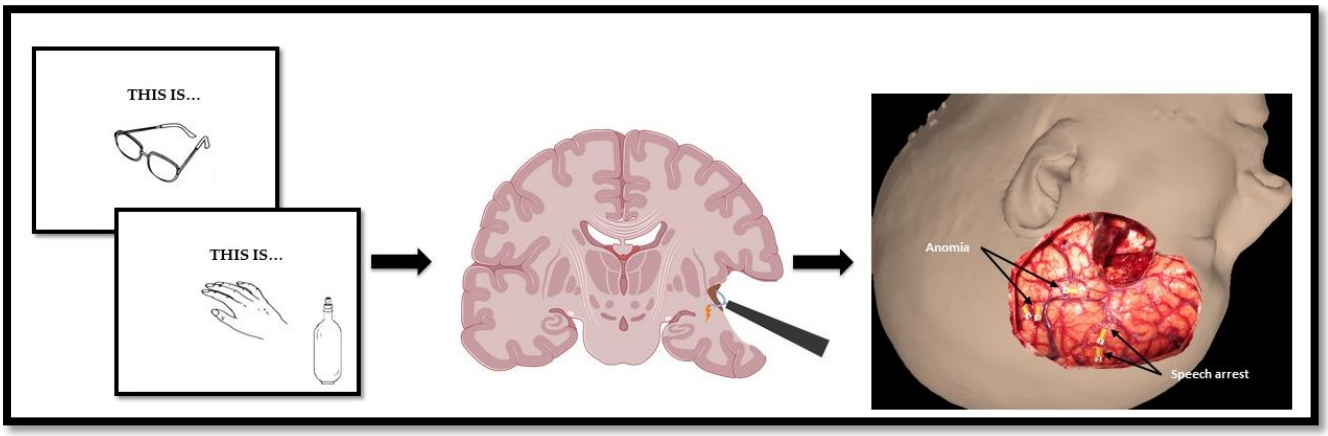


Figure 2.

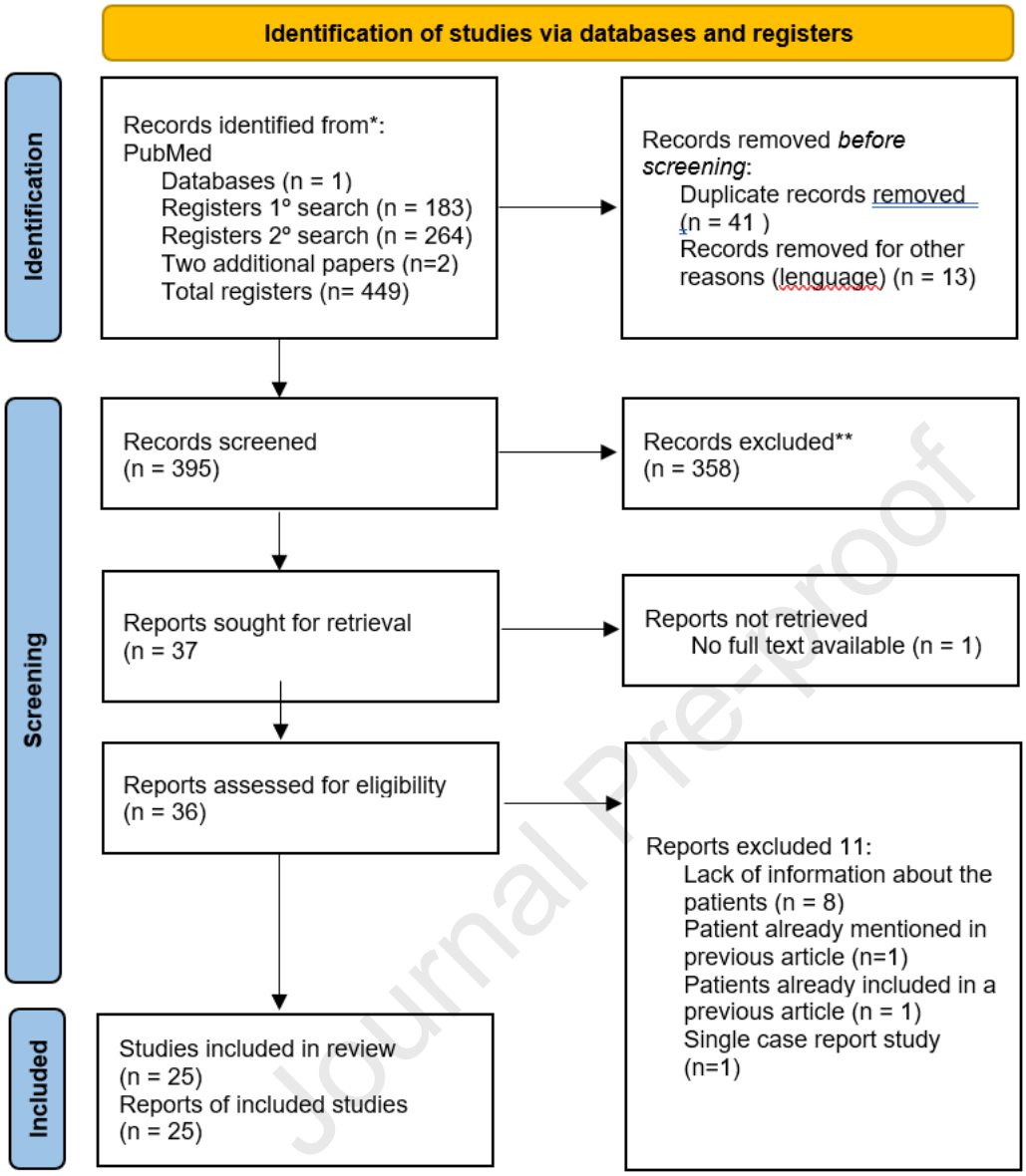


Figure 3.

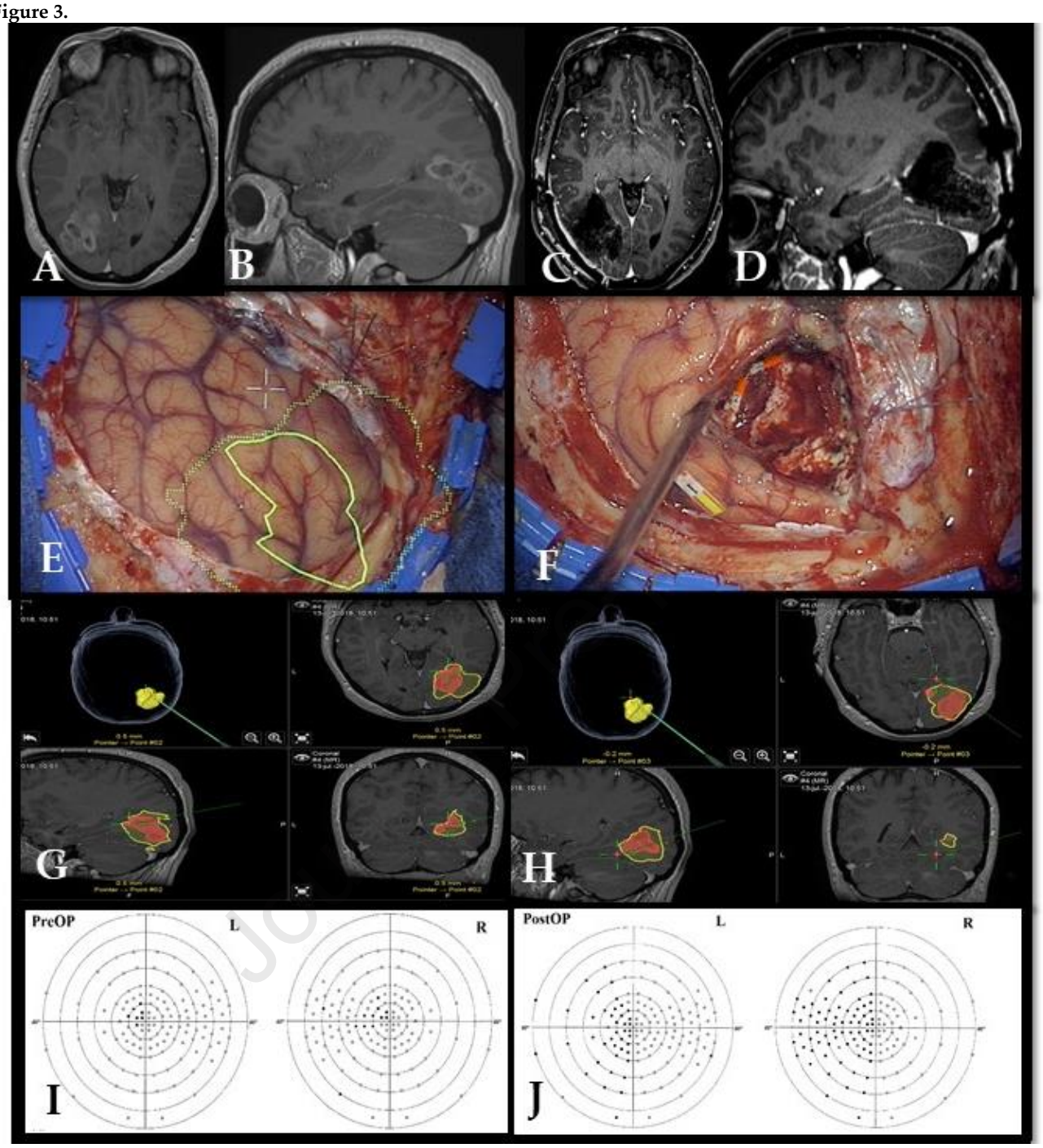


Figure 4.

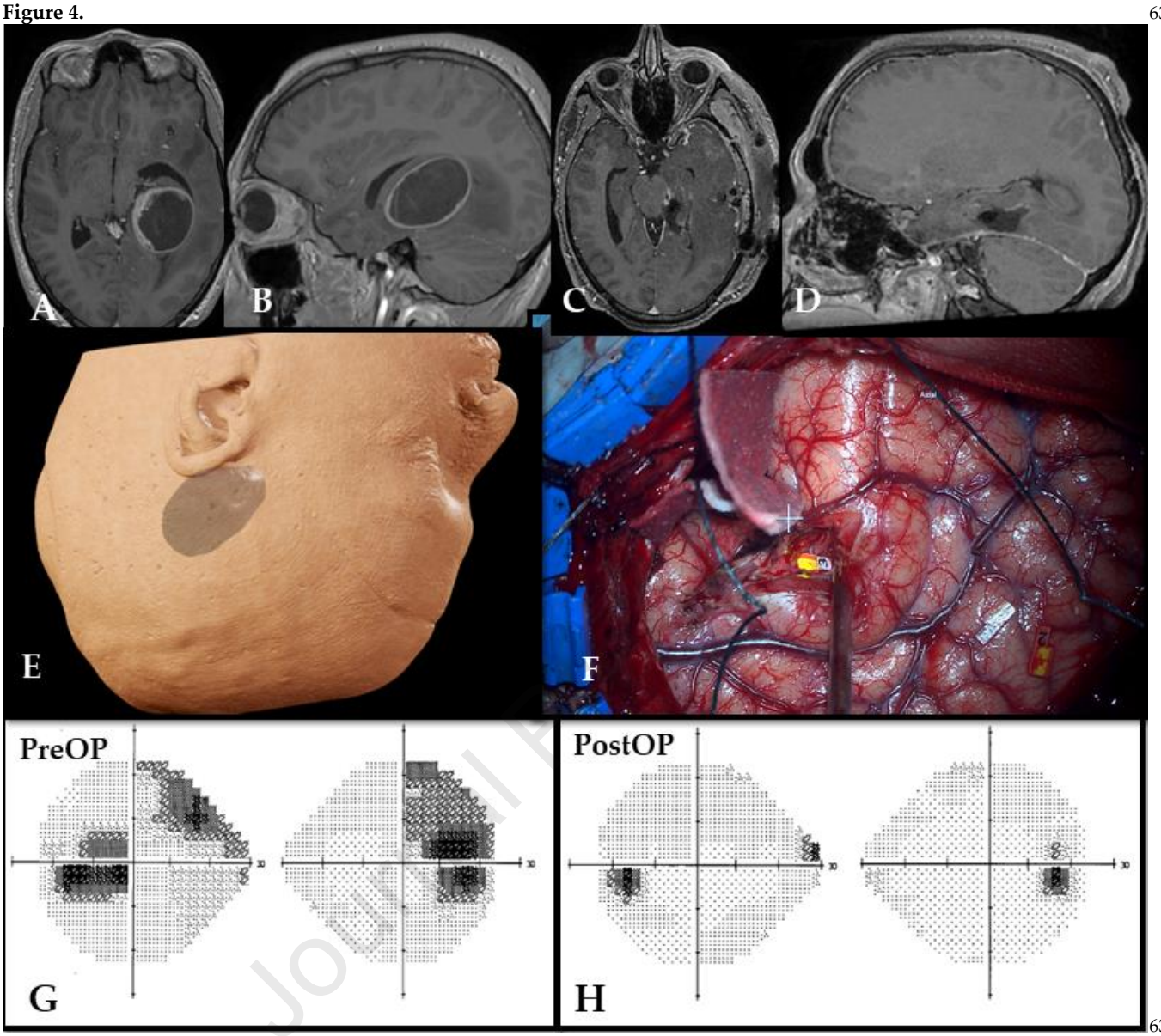
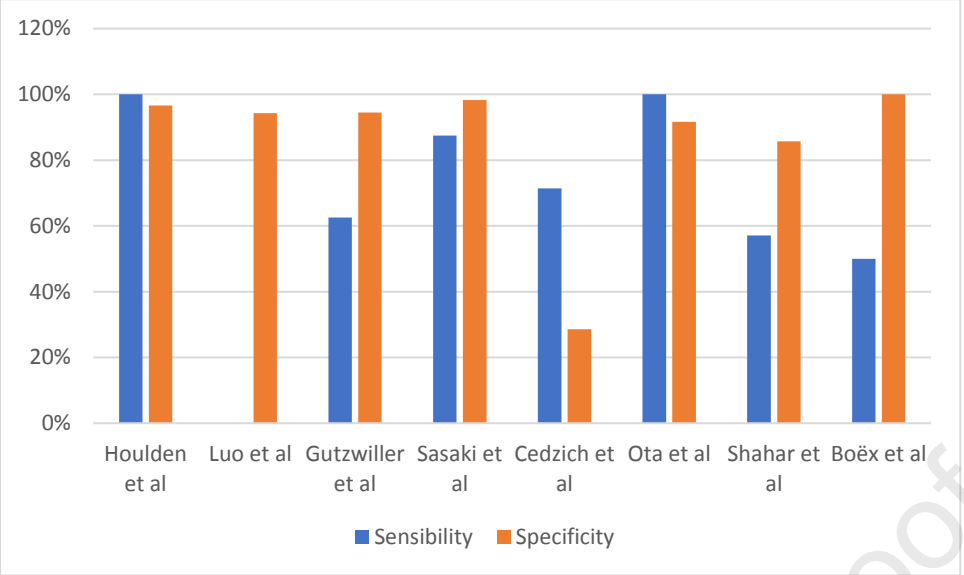


Figure 5.



Visual mapping systematic review inclusion criteria	
PICOS criteria	**Inclusion criteria**
Participants	Patients diagnosed with brain tumor or epileptic foci near the PVP.
Interventions	Surgical resection done with intraoperative visual mapping procedures.
Comparisons	No comparison with other treatments was made.
Outcomes	1º Visual function outcomes from each procedure. 2º Ability to identify the visual pathway from each procedure.
Study design	Observational studies and systematic review.

Table 1. PICOS: participants, interventions, comparisons, outcomes, and study design.

	Author / Year	Type of article	Visual mapping method	Patients	Lesion location	Tumor or lesion	PreOp Visual field	Intraoperative findings	PostOp Visual field
1	Cedzich C et al / 1987	Case series	Transcranial VEP	35	Orbit: 3 Perisellar: 25 Retroquiasmatic: 7 Intraventricular: 4 Occipital: 2 Pineal: 1	Hemangioma: 1 Glioma: 1 Pituitary adenoma: 15 Craniopharyngioma: 6 Meningioma: 8 Germinoma: 2 Angioma: 1 GBM: 1	Not specified	VEP feasibility: 19/35 VEP changes: 25/35	Q: 4 PH: 2 HH: 19
2	Curatolo JM et al / 2000	Case report	Subcortical VEP + ERG	2	Occipital: 2	Epileptic focus: 2	PQ: 1 PH: 1	VEP feasibility: 2/2 VEP changes: 0	Q: 1 HH: 1
3	Duffau H et al / 2004	Case report	DES Cortical and subcortical (subjective sensation)	1	Temporal lobe	LGG	N	Visual disturbances: 1/1	Q: 1
4	Kamada K et al / 2005	Case series	Transcortical VEP Cortical VEP	2	Parietal Temporal	Epileptic focus GBM	N	VEP feasibility: 2/2 VEP changes: 1/2	N: 1 HH: 1
5	Sasaki T et al / 2010	Prospective case series	Transcranial VEP + ERG	100	Parasellar: 28 Temporal: 16 Parietal: 6 Occipital: 5 Frontal: 2 Orbital: 1 Vascular aneurism: 42	Tumor: 53 AVM: 5 Aneurism: 42	Not specified	VEP feasibility: 187/200 eyes VEP changes 39/200 eyes	Q: 3 HH: 8
6	Ota T et al / 2010	Case series	Cortical VEP	17	Temporal 5 Occipital 12	Epilepsy 4 GBM 4 Hemangioma 2 Metastasis 2 Meningioma 1 AVM 1 Radionecrosis 1 Ganglioglioma 1 Cryptococcal granuloma 1	N: 9 P Q: 1 Q: 6 HH: 1	VEP feasibility: 14/17 VEP changes: 4/14	N: 8 PQ: 1 Q: 5 PH: 0 HH: 3
7	Nguyen HS et al / 2011	Case report	DES cortical and subcortical (Colour dots on screen)	1	Occipital lobe	AA (G III)	N	Visual disturbances: 1/1	N: 1
8	Gras-combe G et al / 2012	Clinical article	DES cortical and subcortical (Modified picture naming task).	14	Temporo-ocipito-parietal junction: 10 Temporal lobe: 2 Occipital lobe: 2	ODs (GII): 11 ODs (GIII): 2 Angiocentric glioma GI: 1	N: 14 PQ: 0 Q: 0 PH: 0 H: 0	Visual disturbances: 11 / 14	N: 1 PQ: 2 Q: 10 PH: 0 HH: 1

9	Steno A et al / 2012	Case report	DES Cortical and subcortical (Dog on screen task)	1	Temporal lobe	LGG (GII)	N	Visual disturbances: 1/1	PQ: 1
10	Torres C et al / 2012	Case report	Cortical VEP	1	Occipital	Metastasis	Q	VEP change 1/1	Q: 1
11	Fernández -Coello A et al / 2013	Case report	DES Cortical and subcortical (Modified naming task)	1	Temporo-occipital junction	LGG (GII)	N	Visual disturbances: 1/1	Q: 1
12	Chan-Seng E et al / 2014	Case series	DES cortical and subcortical (Modified picture naming task).	8	Temporo-occipito-periatrial junction (SS): 8	LGG (GII): 8	Normal: 8	Visual disturbances: 5/8	N: 3 PQ: 0 Q: 5 PH: 0 HH: 0
13	Sarubbo S et al / 2015	Case series	DES Cortical and subcortical (Modified naming task)	3	Optic radiation	LGG 2 HGG 1	N	Visual disturbances: 3/3	N: 0 PQ: 1 Q: 2 HH: 0
14	Luo Y et al / 2015	Case series	Transcortical VEP + ERG	46	Parieto-Occipita junctionl: 2 Occipital lobe: 1 Temporo-occipital juncton: 5 Parietal lobe: 1	Linfoma: 1 Astrocytoma: 1 Hemangioma: 1 Metastasis: 2 GBM: 2 Glioma: 2	N: 16 Q: 4 H: 14 Other: 12	VEP feasibility: 38/46 VEP changes 2/38	N: 14 Q: 5 HH: 17 Other: 10
15	Mazerand E et al / 2017	Clinical trial	DES Cortical and subcortical (Modified Esterman test on virtual reality headset)	1	Inferior parietal lobe	GBM (GIV)	N	Visual disturbances: 1/1	N: 1
16	Shahar T et al / 2018	Case series	VEP transcranial, cortical, and subcortical	18	Parietal: 8 Parieto-temporal: 3 Temporal: 6 Temporo-occipital: 1	AA: 6 Metastasis: 2 GBM: 7 OD: 2 Anaplastic OD: 1	N: 13 PQ: 0 Q: 1 PH: 3 H: 1	Cortical VEP feasibility: 14/18 Subcortical VEP feasibility: 10/13 VEP changes not mention	N: 9 PQ: 0 Q: 2 PH: 2 HH: 5
17	Rolland A et al / 2018	Case series	DES cortical and subcortical (Modified picture naming task).	14	Inferior parietal lobe: 14	- LGG (GII): 11 - AA (GIII): 1 - GBM (GIV): 1	Normal: 14	Visual disturbances: 6/14	N: 10 PQ: 0 Q: 1 PH: 0 HH: 0
18	Joswig H et al / 2018	Case report	DES cortical (subjective sensations marked with laser on perimetry chart)	1	Occipital lobe	Epileptic foci.	N	Visual disturbances: 1/1	N: 1
19	Gutzwiller	Prospective	Transcranial and	29	Temporal: 14	Gliomas: 14	Not	VEP feasibility:	No

	EM et al / 2018	case series	subdural VEP + ERG		Parietal: 8 Frontobasal: 7	DNET: 3 Metastasis: 3 AVM: 2 Meningioma: 7	specified	26/29 VEP changes 6/26	changes: 18 PQ: 3 Q: 1 HH: 5
20	Houlden DA et al / 2019	Case series	Transcortical VEP + ERG	89	Temporal: 8 Parietal: 4 Occipital: 11 Frontal: 2 Sellar / suprasellar: 39 Sphenoid: 10 Intraventricular: 1 Nasopharynx: 3 Ethmoid: 9 Arterial aneurisms: 7 Spinal: 3	Aneurysm: 7 AVM: 6 Cavernoma: 2 Craneopharyngioma: 9 Meningioma: 29 Abscess: 1 Epidermoid cyst: 1 Glioma: 3 Metastasis: 7 Subependymoma: 1 Adenoma: 19 Angiofibroma: 2 Adenocarcinoma: 2 Carcinoma: 1 Chordoma: 1 Rathke's cleft cyst: 1 Encephalocele: 1 Glomangiopericytoma: 2 Sarcoma: 4 Teratoma: 1 Spine degenerative: 3	Not specified	VEP feasibility: 77/89 VEP changes: 4/77	Not specified
21	Qerama E et al / 2019	Case report	Transcranial VEP + ERG	1	Ventricle	Meningioma	N	VEP changes: 1/1	N: 1
22	Talabaev M et al / 2020	Case report	DES cortical and subcortical (Subjective sensation).	1	Occipital lobe	DNET	Not specified	Visual disturbances: 1/1	N: 1
23	Mammadkhanli O et al / 2020	Case series	VEP not secify	8	Occipital lobe: 8	Not specified	Normal: 8	VEP feasibility: 8/8 VEP critical changes: 0	N: 7 PQ: 0 Q: 0 PH: 0 HH: 1
24	Boëx C et al / 2021	Case series	Transcranial and subcortical VEP	12	Temporal lobe: 3 Temporo-parietal: 2 Parietal lobe: 2	GBM: 5 GG: 1 Meningiomas: 3 AVM: 1	Not specified	VEP feasibility: 10/12 VEP changes: 2/10	N: 4 PQ: 2 Q: 1 HH: 2

					Temporo-occipital: 2 Sphenoidal: 3	Cavernoma: 1 Hippocampal sclerosis: 1			
25	Berro DH et al / 2021	Case series	DES Cortical and subcortical (Modified naming task)	17	Parieto-temporo-occipital junction: 17	LGG	Not specified	Visual disturbances: 12/17	N: 8 PQ: 0 Q: 9 PH: 0 HH: 0

Table 2. Articles included in systematic review. visual evoked potentials (VEP), electroretinogram (ERG), direct electrical stimulation (DES), normal (N), patial quadrantanopia (PQ), quadrantanopia (Q), partial homonimous hemianopia (PH), homonimous hemianopia (HH), low grade glioma (LGG), high grade gliomas (HGG), Anaplastic astrocytoma (AA), Oligodendroglioma (OD), ganglioglioma (GG), Glioblastoma (GBM), arteriovenous malformation (AVM) and dysembryoplastic neuroepithelial tumor (DNET).

	Age/Sex	Location	Histopathological features:	PreOP VF	Intraoperative tasks	Intraoperative identification of PVP	PostOP VF	EoR	**Follow up**
Patient 1	42 yo / M	R parietal	Anaplastic astrocitoma (G III) - IDH-1: Positive - ATRX: Negative - P53: 30% - Ki67: 5%	N	Naming Reading Verbal memory Line bisection tet CaPI	No	N	Subtotal	12 months
Patient 2	17 yo / M	L temporal	Anaplastic astrocitoma (G III) - IDH1: Negative - ATRX: Negative - P53: 5% - Ki67: 15 % - EMA: Negative - L1CAM: Negative - CD34: Negative - Reticulin: Negative - H3K27M: Negative	Right superior Q	Naming Reading Verbal memory Episodic memory CaPI	No	N	Subtotal	12 months
Patient 3	44 yo / F	R occipital	Glioblastoma (GIV) - IDH-1: Negative - PTEN: Positive - p53: 85% - ki67: 60%.	Left PH	Naming Reading Line bisection test CaPI task	1. Left superior Q 2. Left inferior Q	Left HH	Total	12 months

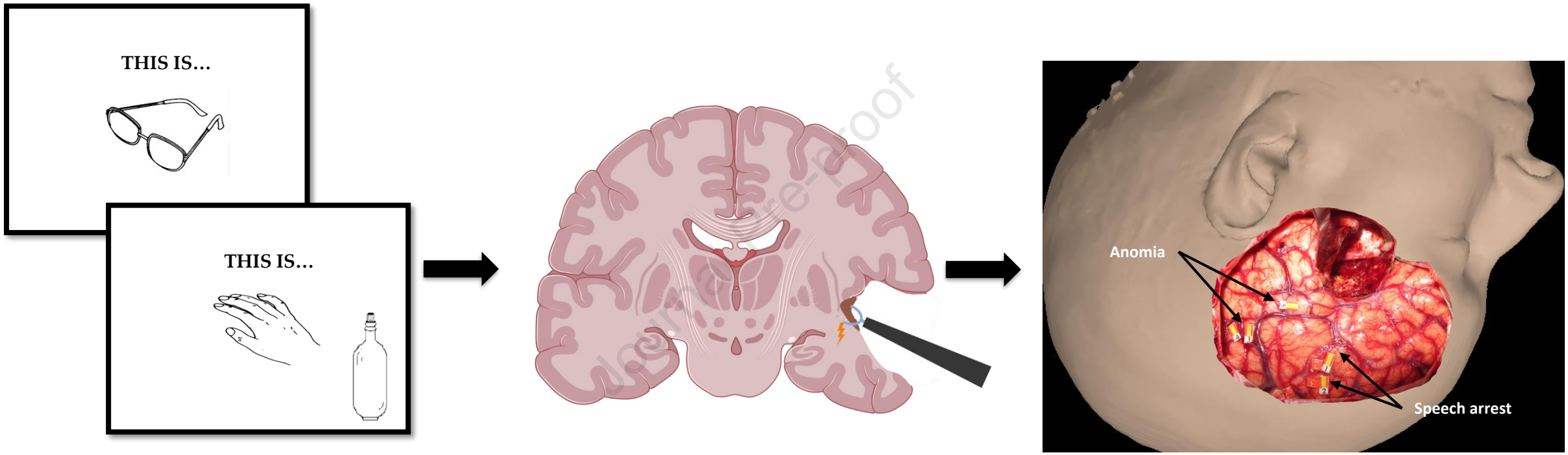
Table 3: Patient characteristics. visual function (VF), posterior visual pathway (PVP), extent of resection (EoR), central and peripheral image task (CaPI), Male (M), Female (F), right (R), left (L), normal (N), homonimous hemianopia (HH) and quadrantanopia (Q).

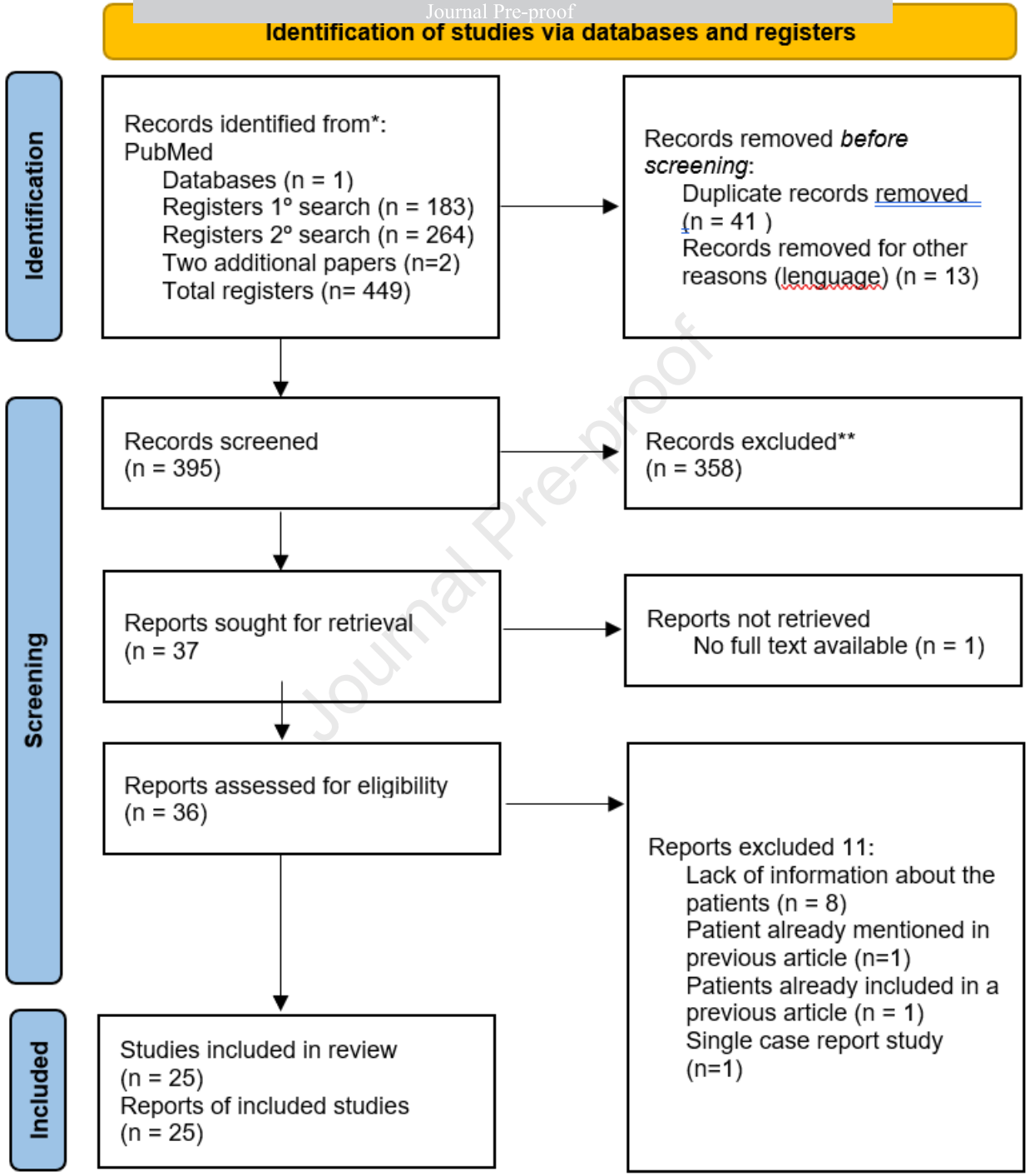
Article	Patients	VEP success rate	Sen	Spe	PPV	NPV
Houlden et al	89	86%	100%	97%	25%	100%
Luo et al	46	82,6%	0%	94,28%	0%	91,67%
Gutzwiller et al	29	89,70%	62,50%	94,44%	83,33%	85%
Sasaki et al	100	93,50%	87,50%	98,24%	82,35%	98,82%
Cedzich et al	35	-	71,42%	28,57%	20%	80%
Ota et al	17	82,35%	100%	91,66%	66,66%	100%
Shahar et al	18	77%	57,14%	85,71%	80	66,67%
Boëx et al	12	83,34%	50%	100%	100%	75%

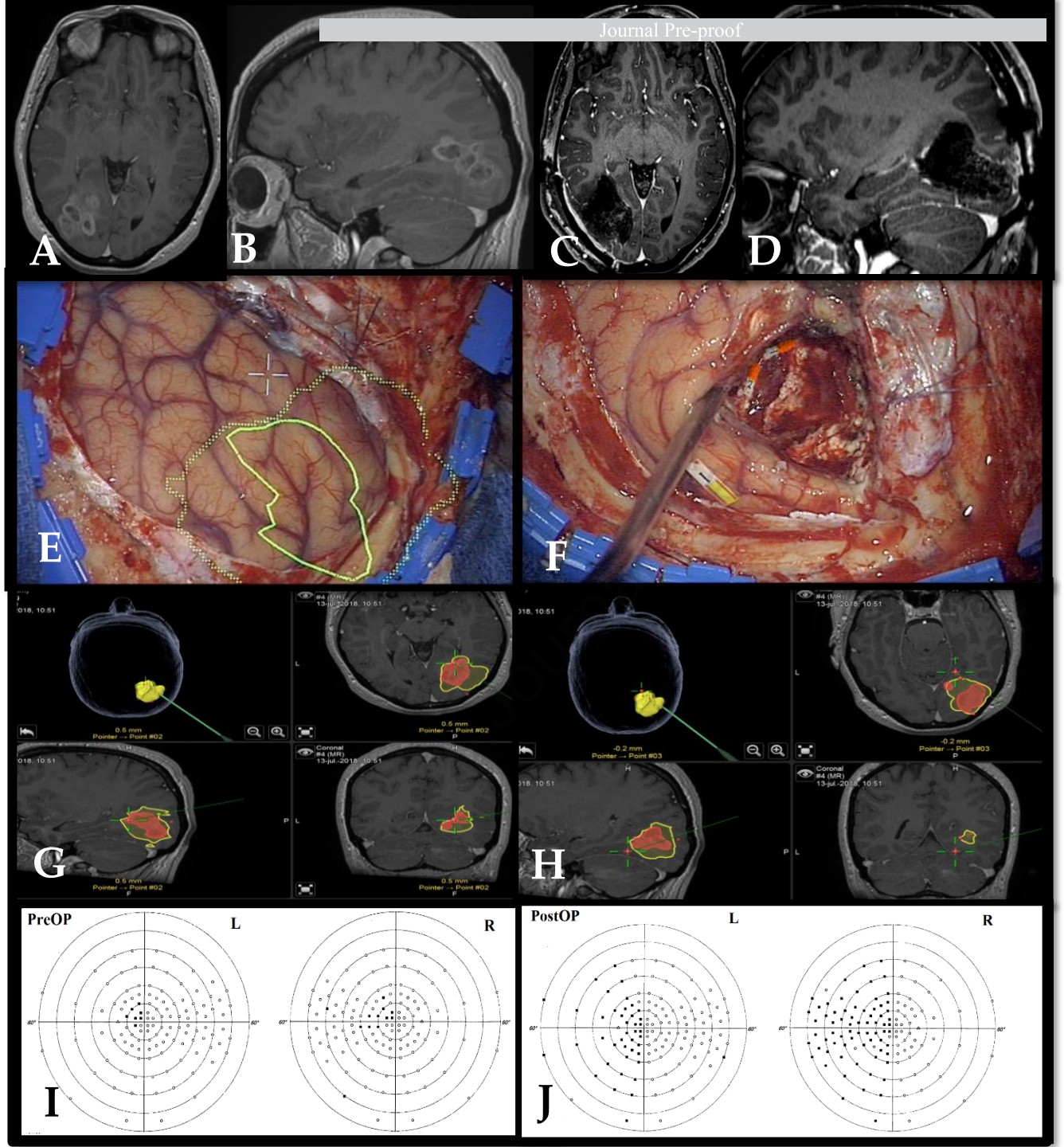
Table 4: reviewed VEP article results analysis. Sensibility (Sen), Specificity (Spe), Positive predictive value (PPV), Negative predictive value (NPV).

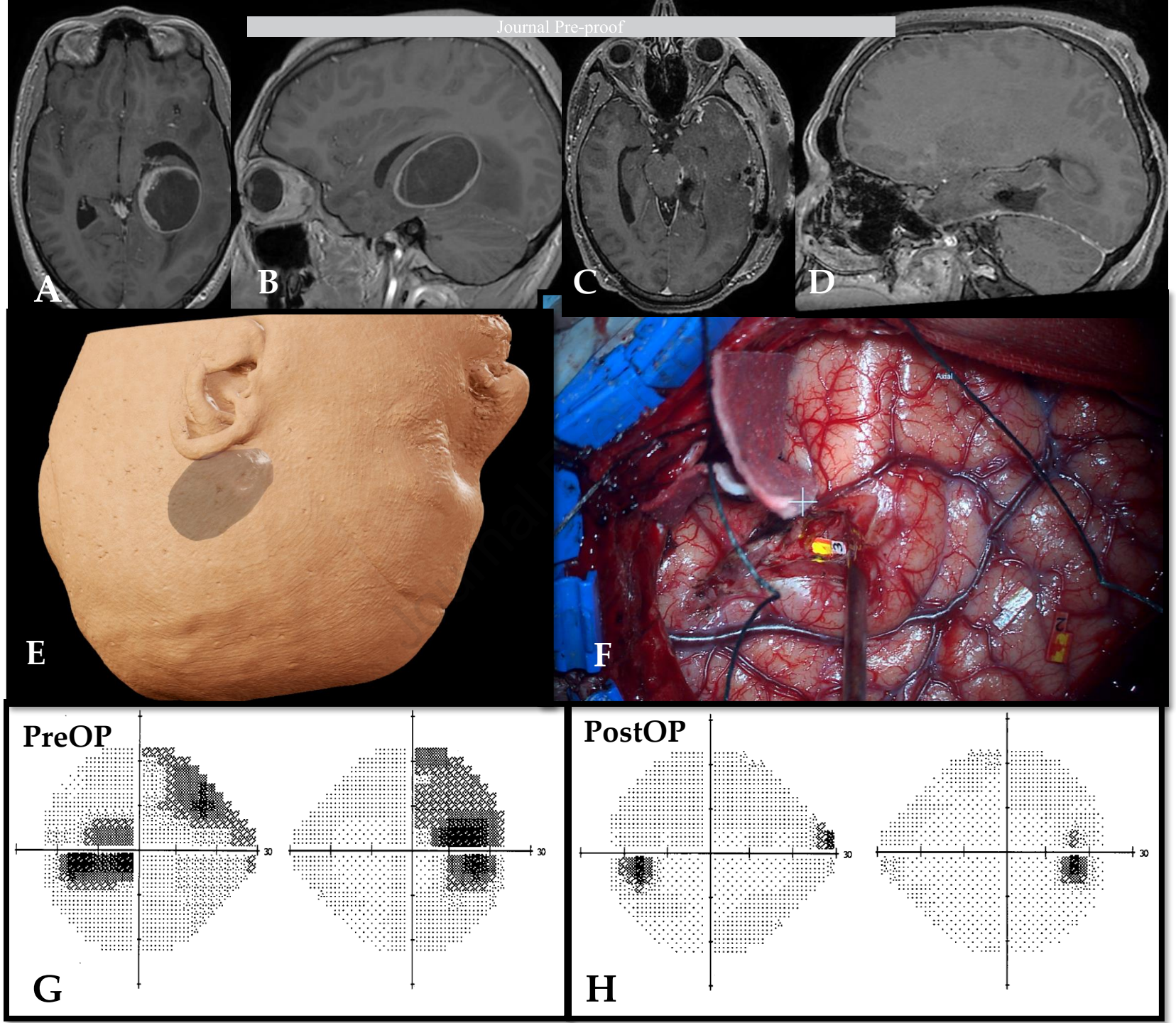
	Articles	Patients	VEP feasibility	OP findings	PO VF deterioration	PO H	H patients with OP findings
VEP	12	341	85,34%	19,06%	26,19%*	**13,49%***	70,77%*
DES	12	63	100%	69,84%	53,97%	**1,59%**	2,27%

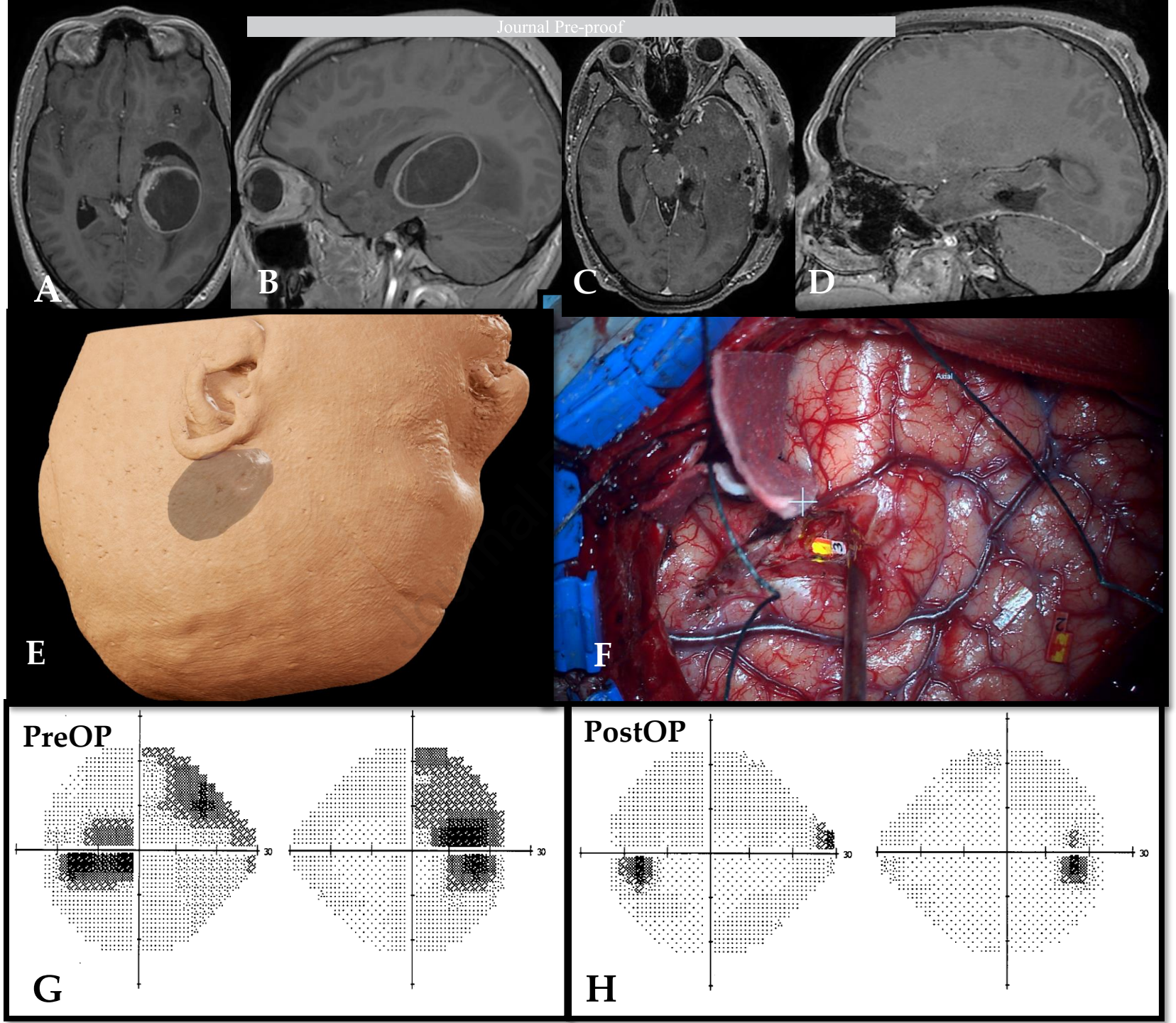
Table 5: Compared analysis of VEP and DES. * For the analysis 85 patients from Houlden et al were not included due to not specify postoperative visual field. VEP: Visual Evoke Potentials (VEP), Direct Electrical Stimulation (DES), Operative findings (OP), Visual function (VF), Post-Operatie (PO) and Hemianopia (H).

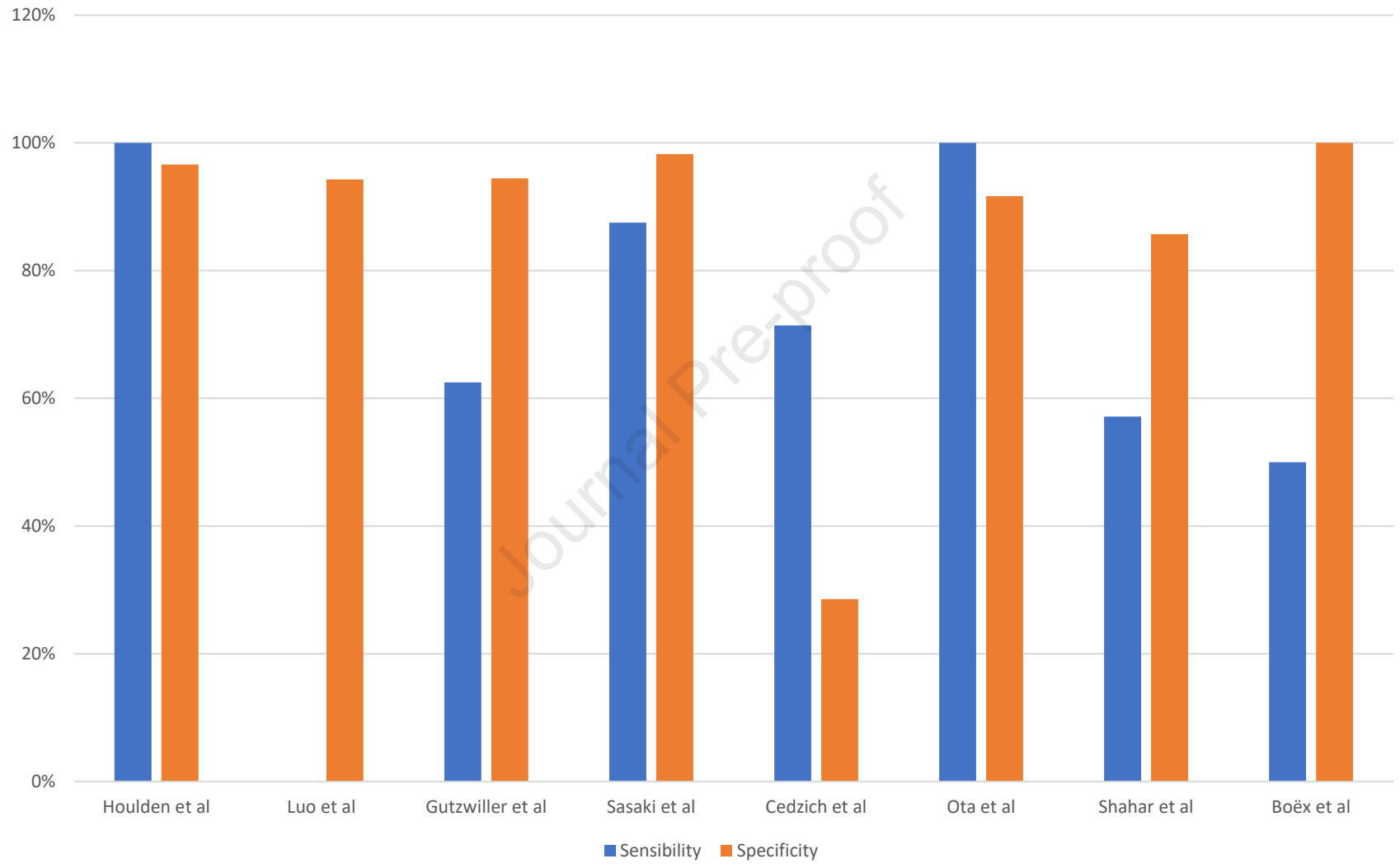

THIS IS…
THIS IS…
Anomia
Speech arrest











Abbreviations:

Visual evoked potentials (VEP). Direct electrical stimulation (DES). Extent of resection (EoR). gross total resection (GTR). Posterior visual pathway (PVP). Optic radiation (OR). Central and Peripheral Image (CaPI). Intraoperative electrical stimulation (IES). Ventral premotor area (VPM). Anterior visual pathway (AVP). Normal (NL). Partial quadrantanopia (PQ). Complete quadrantanopia (Q). Partial hemianopia (PH). Complete hemianopia (H). Standard flash VEP (FVEP). Light emitted diodes (LED). Optic nerve (ON). First negative (N). First positive (P). Sensitivity (Sen). Specificity (Spe). Positive predictive value (PPV). Negative predictive value (NPV). Virtual reality headset (VRH). Electroretinogram (ERG). Intraoperative optical imaging (IOI).

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The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

The paper or portions of the paper have not been published previously.

Carlos Santos.
(on behalf of the authors)