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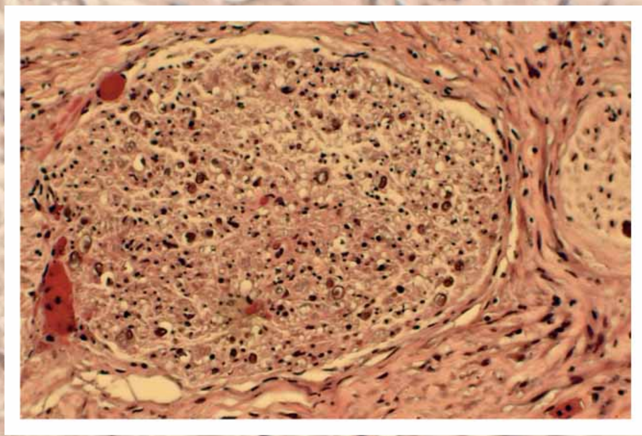

Technological Advances in Glioma Surgery

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Abstract: In the recent past, the impact of surgery has increased because of important technical advances which have significantly improved tumour resection for both high- and low-grade gliomas and at the same time patient quality of life. Today, surgery is asked not only to obtain tissue to reach a precise histological and molecular diagnosis but to influence many functional and oncological endpoints. To reach all these complex issues, surgery has significantly changed in the way it is performed. Surgeons have had the opportunity to incorporate many technical advances, particularly in imaging and intraoperative neurophysiology, which has significantly modified the way resection is conceived and technically performed. The surgeon should be able to critically integrate all these technologies, both at the time of surgical planning and also during surgery. Thanks to these improvements, surgery is today able to impact both survival and quality of life in patients with low- and high-grade gliomas. **Eur Assoc Neurooncol Mag 2011; 1 (1): 13–9.**

Key words: MRI, DTI-FT, fMRI, neuronavigation, brain mapping, glioma

Introduction

Surgery, along with radio- and chemotherapy, has for many years represented one of the main therapeutic tools for the treatment of intrinsic brain lesions. Traditionally, the role of surgery was to remove enough tissue to reach a histological diagnosis and, when considered to be feasible, to resect as much tumour as possible, to relieve symptoms and, particularly, to reduce intracranial pressure. The impact of surgical resection on patient survival was not established and in many cases also questionable. In the recent past, the impact of surgery has increased because of important technical advances which have significantly improved tumour resection for both high- and low-grade gliomas and at the same time patient quality of life. Nowadays, surgery is asked not only to obtain tissue to reach a precise histological and molecular diagnosis but to influence many functional and oncological endpoints. To reach all these complex issues, surgery has significantly changed in the way it is performed. Surgeons have had the opportunity to incorporate many technical advances, particularly in imaging and intraoperative neurophysiology, which has significantly modified the way resection is conceived and technically performed. Thanks to these improvements, surgery is today able to impact both survival and quality of life in patients with low- and high-grade gliomas. We thus aimed to explore and critically analyse the contributions of various technologies currently employed in the routine and upfront clinical practice at the pre- and intra-operative stage in the surgical management of gliomas.

Imaging

The major contribution to the recent improvement of surgical techniques regards imaging. Imaging technologies have been implemented in both the pre- and intraoperative settings, having a substantial impact on surgical planning and performance. Currently, imaging is asked to detect and delineate the tumour mass and its relationship with surrounding vascular or neural structures. Imaging is also asked to provide information on how functions and relevant functional structures at both the cortical and subcortical levels have been modified by the presence of the tumour, and to depict the relationship between the tumour and these structures. In addition, imaging is asked to provide metabolic information with regard to the tumour degree as well as to delineate the tumour's structural heterogeneity. Of course, the surgeon should carefully consider and integrate this huge amount of information in the surgical planning. In addition, selected information can also be incorporated intraoperatively by loading them into the neuronavigation system or similar guiding devices. Furthermore, the same technologies can be used post-operatively to study the effect of surgery and to monitor the tumour's biological behaviour during follow-up.

The Role of MRI

MRI represents the elective neuroradiological procedure for the study of gliomas. Several and different MRI sequences are applied according to the diagnostic query and clinical hints. T1-weighted imaging (T1WI) with and without use of gadolinium contrast, T2WI and fluid-attenuated inversion recovery (FLAIR) sequence are referred to as conventional MRI imaging. The first aim of conventional MRI is, in fact, to obtain an optimal depiction of the physiological and pathological anatomies, ie, the morphological features of the lesion of interest *per se* and its relationship with the surrounding structures [1, 2].

In addition, recent advances in MR techniques provide different types of data: the functional specialisation of an area of interest, with particular emphasis on the eloquent regions (fMRI); the normal and pathological anatomies along with the different degrees of involvement of selected subcortical white matter (WM) tracts (Diffusion-Tensor Imaging [DTI] and Fibre Tract [FT] reconstruction); the perfusion pattern described through the analysis of the Brownian motion of water molecules (Diffusion-WI, DWI, and Perfusion-WI, PWI); the metabolic changes detected non-invasively in vivo through biochemical tissue variations (Magnetic Resonance Spectroscopy [MRS]).

Both conventional and advanced MR applications have become a crucial step in the diagnosis of gliomas and a relevant means of support in the preoperative planning of their surgical

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removal. In fact, they represent a fundamental tool to tailor the mapping and monitoring techniques to the individual anatomo-pathological features of the patient and the lesion [3]. The same images can be loaded into the neuronavigation system and made available in an integrated manner during resection.

Conventional MR Imaging

Morphological T1, T2, and FLAIR images, as well as post-contrast T1 images, provide information on the site, location, and structural aspect of the tumour and of peritumoural abnormalities. They determine the relationship of the tumour with major vessels and quantify its volume. Macrocalcifications, cystic areas, intratumoural haemorrhages, and necrosis may orient towards the definition of its nature. These sequences, allowing a first typecasting of the lesion, are relevant in the initial differential diagnosis among a glioma and diverse mass lesions, such as lymphomas, brain metastases, abscesses, or haematomas, especially when combined with clinical and advanced imaging data. Post-contrast T1WI allows for a better definition of blood vessels and provides information on the condition of the blood-brain barrier (BBB), providing a first definition of the grade: low-grade gliomas (LGG) present a normal BBB and do not usually show enhancement in post-contrast images [1]. Furthermore, repetitive measurement on morphological MR images allows for the quantification of the tumour's growth rate, which is suggestive of the tendency towards aggressive biological behaviour [4, 5]: the growth of LGGs amounts to around 4 mm/year, while an increase in diameter > 8 mm/year is suggestive of a high tendency toward malignant transformation, even in the absence of contrast enhancement or modification of FLAIR images.

Advanced MR Imaging: fMRI, DTI-FT, MRS, PWI

Functional MRI and DTI-FT provide information on the site of cortical areas that are active in response to motor or language tasks and a depiction of the connectivity around and inside a tumour by identifying selected WM fiber tracts. Together, they provide information on how the tumour has modified the surrounding brain at both the cortical and subcortical levels and help define the level of plasticity that has been reached by the surrounding brain.

In particular, motor fMRI is employed clinically to depict the cortical motor sites and to understand their relationship with the tumour [6–8]. fMRI with different language tasks is used to build a map of the cortical areas mainly involved in object naming, naming of famous faces, verb generation, and verbal fluency [7–11].

DTI-FT provides anatomical information on the location of motor and several language tracts [12], such as the corticospinal tract (CST), and tracts involved either in the phonologic or semantic components of language, such as the superior longitudinalis fasciculus (SLF), which includes the fasciculus arcuatus and the inferior fronto-occipital (IFO) [7, 13]. The basic DTI-FT map includes the CST for the motor part as well as the SLF and the IFO for the language part [7, 13, 14]. Additional tracts can be reconstructed, such as the uncinatus (UNC) and the inferior longitudinalis (ILF) tracts and the subcallosum fasciculus, upon specific clues obtained by extensive pre-operative neuropsychological evaluation or for research purposes. DTI-FT depicts the relationship between the WM tracts and the tumour mass, describing these tracts as unchanged, dislocated, or infiltrated according to the degree of involvement [15]. Critical aspects for obtaining a reliable reconstruction are the quality of the raw data and an appropriate fraction-of-anisotropy (FA) threshold. Tumour characteristics, such as histology, oedema, and location, can influence tract depiction as well. Indeed, as obtained by intraoperative DTI-FT and DES correlation data, an FA of 0.1 should be used for an optimal visualization of tracts in LGGs [16]. DTI-FT is particularly useful and hence recommended in LGGs since these tumours more likely infiltrate WM fibres than high-grade gliomas (HGG), where DTI-FT can be performed in selected cases only [17].

MR spectroscopy (MRS) allows for the evaluation of intratumoural areas where the metabolism is more or less pronounced, according to the differential proton MR-spectral output of the analysed regions of interest (ROI) [18]. The differential representation in this spectra of choline, creatinine, and their ratio, n-acetyl-aspartate (NAA), lipids, lactic acid, and, occasionally, other metabolites, such as myo-inositol, can provide a presumptive diagnosis and grading of the lesion [19]. This is particularly crucial in case of tumour-mimicking masses [20], when a refinement of the differential diagnosis is required to choose an appropriate treatment protocol, for instance when a distinction between treatment-induced changes and recurrence or between a glioma and lymphoma is required. This is also of great help in guiding the tissue sampling at the time of surgery for histological and molecular diagnoses. Selected MRS images can be loaded into the neuronavigation system and integrated with conventional MR images for this purpose.

Perfusion-weighted imaging (PWI) studies the arterial and capillary vascular beds by analysing the paramagnetic effects of the contrast medium on the MR signal. Perfusion maps can be designed upon these data, providing information regarding the biological behaviour of the tumour. In fact, LGGs and HGGs display a different behaviour in this aspect [21], with hyperperfusion being suggestive of a more malignant nature. Areas of high perfusion in an LGG can be targeted to obtain a more precise histological and molecular diagnosis.

These different imaging modalities produce an impressive amount of information. These data constitute a complex map of the cortical and subcortical eloquent structures and of areas with different metabolic and perfusion assets, thus allowing for the establishment of anatomical and functional boundaries along with the metabolic and perfusion assets determined by the tumour. All these data are thus critical for pre-operative surgical planning and the evaluation of risks but become even more relevant when they are loaded into the neuronavigation system. These MR applications are a valuable intraoperative aid yielding a series of advantages: reduced operative time, more prompt and accurate choice of site of direct electrical stimulation (DES) with a resultant reduced number of stimulations needed for safe identification of eloquent structures and decreased likelihood of intraoperative seizure occurrence and, finally, decreased patient's fatigue [3, 17].

Multimodal Neuronavigation System: From the Pre-operative to the Intra-operative Stage

Morphologic volumetric T1WI, T2WI, or FLAIR images, along with motor and language fMRI and DTI-FT images are usually loaded into a frameless neuronavigation system. Neuronavigation is a set of computer-assisted technology enabling the integration of 3-dimensional anatomical and functional data and the match of the pre-operative imaging data with the intraoperative identification of a target. It thus represents an aid during surgery to localise the tumour and to find the relationship between the tumour and the surrounding functional and anatomic structures, both at cortical and subcortical levels [13].

Functional MRI and DTI-FT are usually loaded into the neuronavigation system and co-registered with anatomical MR images and reference points applied on the skull of the patient. For a reliable use of fMRI and DTI-FT data in this setting, 2 issues are critical: (1) data transfer to the neuronavigation system and (2) use of adjustments during surgery to maintain a global accuracy, as described elsewhere. The problem of brain shift has to be buffered, as will be addressed later.

The reliability of fMRI and DTI-FT images, thus their sensitivity and specificity in depicting the structures of interest, has been investigated by intraoperative brain DES studies correlating intraoperative findings with MRI data [7]. These investigations demonstrated that motor fMRI usually matches with data obtained with DES, although the extent of the functional activations is larger than the area defined with intraoperative mapping, and can guide in the choice of a safe cortical entry point. Being aware of a larger fMRI representation of a specific motor area, motor fMRI can be safely used for planning and performing surgery. In case of language tasks, results are instead variable and different with suboptimal correlation with intraoperative brain mapping results [11, 22, 23]. This is due to larger activation depicted by fMRI when compared with DES, which, conversely, demonstrates only essential language sites. Therefore, the use of exclusively language fMRI could not be recommended in critical decision-making without employing direct brain mapping in the awake surgery setting. On the contrary, language fMRI is reliable in establishing language laterality and can effectively replace the Wada test.

In the corresponding author's experience, the combined use of DTI-FT and DES is a feasible approach that can be effectively and safely applied in daily activity according to clinical and surgical requirements [7, 13, 17]. When loaded into the neuronavigation system, DTI-FT helps in decreasing the time of surgery, guiding the surgeon to the point of the tract where the stimulation can be started and, then, to proceed with a precise resection [3].

Remarks on Multimodal MRI Neuronavigation

The main limitation of the use of a neuronavigation system, particularly in case of large tumours or at the subcortical level, is the occurrence of brain shift. Brain shift is the displacement of the cerebrum from its normal position, especially in relation to its position at the time of the acquisition of the pre-operative MRI study loaded for intraoperative neuronavigation [6, 7, 24].

This event is due to intraoperative brain deformation, caused by mass removal, brain swelling, and cerebrospinal fluid leaks. The extent of brain shift of major WM tracts, for instance, can reach up to 8–10 mm [25, 26]. To reduce the effects of brain shift during resection, some countermeasures can be adopted [2].

Yet, other imaging techniques are also available to increase the accuracy of proper structure identification and thus of surgery, producing an ongoing depiction of resection at the intraoperative stage, such as ultrasound and intra-operative MRI.

Intra-operative Ultrasound

Ultrasound has been employed in a range of neurosurgical procedures [6, 26, 27]. It is also useful for intraoperative visualization of gliomas and employed for mapping. Advances in ultrasound technology have improved image quality [28]. Integrating the intraoperative ultrasound with neuronavigation represents an efficient, affordable, and flexible tool for intraoperative imaging and surgical guidance since it succeeds in outwitting the issue of brain shift, thus having direct consequences on intraoperative strategies and decisions [29]. Brain shift detected with intraoperative ultrasound could be used to update pre-operative image data such as fMRI and DTI-FT to increase the value of this information throughout the operation, especially at the subcortical level. Nevertheless, the ability of these methods to reveal tumour remnants is lower than that of intraoperative MR systems. Overall, initial studies demonstrated the clinical usefulness of the ultrasound technique in updating the neuronavigation system and leading towards a safer and wider resection [28, 30].

Intra-operative MRI (ioMRI)

Although all the above-mentioned methods enable the surgeon to correctly identify and spare eloquent structures and to complete the operation without tumour remnants, it is critical to meet one of the goals of surgery as well. Over the last 15 years, MRI has entered into the operating rooms to allow real-time imaging during surgery. Intraoperative MRI (ioMRI) has been used for surgical treatment of LGGs using both low (0.2 T or 0.5 T) or high (1.5 T, 3 T) magnetic fields [29]. High-field magnets have the potential for improved image quality and for the acquisition of advanced sequences [31], thus providing not only data on the EOR [29, 32] and on the localization of tumour remnants but also an updated depiction of metabolic changes, tumour invasion, and localization of functional eloquent cortical and deep-seated brain areas. The advantage of ioMRI is to have a precise judgment of surgical performance with the patient still in the operating room. In addition, ioMRI is a further worthy resource to overcome brain shift, since it enables us to acquire morphological images by performing repeated acquisition during surgery and then to load them into the neuronavigation system uploading its initial dataset [25]. IoMRI also enables the early detection of intraoperative complications.

The main limitation of the ioMRI system are its costs: of the machine itself, its equipment, and maintenance. Besides, especially with high-field magnets, titanium neurosurgical tools are mandatory. Given the gantry sizes, patient positioning can be altered to allow for a proper scan. In addition, the need to move the patient during surgery can increase operative time and compromise sterility. Finally, artefacts due to blood or air can disturb image reading.

Additional Imaging Techniques: PET and Intraoperative Tumour Fluorescence-based Technologies

Along with information provided by MRI, 2 other sets of imaging techniques have contributed to the substantial improvement of surgery: (1) PET and (2) intraoperative fluorescence techniques.

Nuclear medicine-based imaging techniques, particularly (11)C-MET PET and (18)F-FDG PET, have been widely used in brain tumours [33–35]. They are used to differentiate tumour recurrence from radiation necrosis. MET is useful in detecting and delineating the extent of the tumour, but not in evaluating the tumour grade and proliferative activity. The FDG uptake ratio correlates well with tumour grade and proliferative activity. Preoperative PET studies with FDG and MET play complementary roles in the planning of glioma surgery, and integrated information from both tracers helps us to plan the extent of tumour resection. In addition, they provide the surgeon with important metabolic information which can help in planning and performing targeted tumour biopsy, particularly in case of large and diffuse lesions. These have been proven to better define tumour structural characterization and, when loaded intraoperatively into the neuronavigation system, significantly help in performing tissue sampling and improving histological and molecular diagnoses.

Intraoperative tumour fluorescence provided by the chemical compound 5-aminolevulinic acid assists surgeons in identifying the true tumour margin during resection of glial neoplasms, consequently increasing the extent of resection [36]. 5-aminolevulinic-derived tumour fluorescence strongly correlates with anaplastic foci of anaplastic gliomas and glioblastomas seen on post-contrast MR or PET imaging. When used intraoperatively in high-grade gliomas, 5-aminolevulinic acid (5-ALA) has been shown to help visualize tumour tissue intraoperatively and significantly improve the possibility of achieving gross total resection of malignant brain tumours, strongly influencing patient survival. Unfortunately, the power in low-grade gliomas is limited.

Intraoperative Neurophysiology or So-called Brain Mapping Techniques

The term intraoperative mapping refers to a group of techniques which allow to safely and effectively remove lesions located in so-called eloquent or functional areas. Although the entire brain can be inferred as eloquent, eloquent areas usually and traditionally include those which are involved in motor, language, visual, or visuospatial control. Surgical removal of such a lesion aims at maximizing surgical removal while minimizing post-operative morbidity. This can be achieved by identification and preservation at the time of surgery of cortical and subcortical sites involved in specific functions [3, 37, 38]. The concept of detecting and preserving the essential functional cortical and subcortical sites has been recently defined as “surgery according to functional boundaries”, and it is performed using the so-called brain mapping technique. Brain mapping techniques are generally applied for the surgical resection of intrinsic lesions, in particularly low-grade gliomas [3, 13, 38–40]. Occasionally, they can also be utilized during removal of cavernoma or meningioma, whenever these lesions are located in or in close vicinity of functional areas of the brain.

To achieve the goal of satisfactory tumour resection associated with the full preservation of the patient’s abilities, a series of neuropsychological, neurophysiological, neuroradiological, and intraoperative investigations has to be performed [37]. Performing brain mapping requires a series of pre-operative evaluations and intra-operative facilities which involve different specialists. A complete neuropsychological evaluation is generally the first step of the process to select suitable patients and to individualize intraoperative testing. Then, sophisticated imaging techniques including fMRI and DTI-FT provide the opportunity to attentively plan surgical strategies. In addition, these images can be loaded into the neuronavigation system, thus becoming available peri- and intraoperatively for orientation (Figure 1). Intraoperative MR can be used as well, if available. Finally, and most importantly, a series of neurophysiological techniques are employed at the time of surgery to precisely guide the surgeon in the tumour removal. These include cortical and subcortical direct electrical stimulation, motor-evoked potentials (MEP), multichannel electromyography (EMG), electroencephalography (EEG) and electrocorticography (ECoG) recordings [3, 13, 37].

Neuropsychological evaluation comprises a large number of tests for the assessment of various neurological functions such as the cognitive, emotional, intelligence, and basic language functions. Such a broad spectrum evaluation provides information on how the tumour impacts the social, emotional, and cognitive life of the patient, which is frequently intact or only mildly impaired at the time of neurological examination. Testing must be done most extensively because the tumour, which grows along fibre tracts, may alter the connectivity between separate areas of the brain, resulting in the impairment of functions which might not be documented if the examination is limited to the testing of those functions strictly related to the area of the brain in which the tumour has grown. When this extensive testing is administered, some alterations in the aspects of the neuropsychological exams can be documented in > 90 % of the patients with low-grade gliomas, and in > 70 % with high-grade gliomas [37–39, 41, 42]. These data represent the baseline with which the effect of surgical and future treatments should be compared. Additionally, when the tumour involves language or visuospatial areas or pathways, a more extensive specific evaluation should also be added. Other than better defining the preoperative status of the patients, the neuropsychological assessment allows to build up a series of tests, composed of various items, which will be used

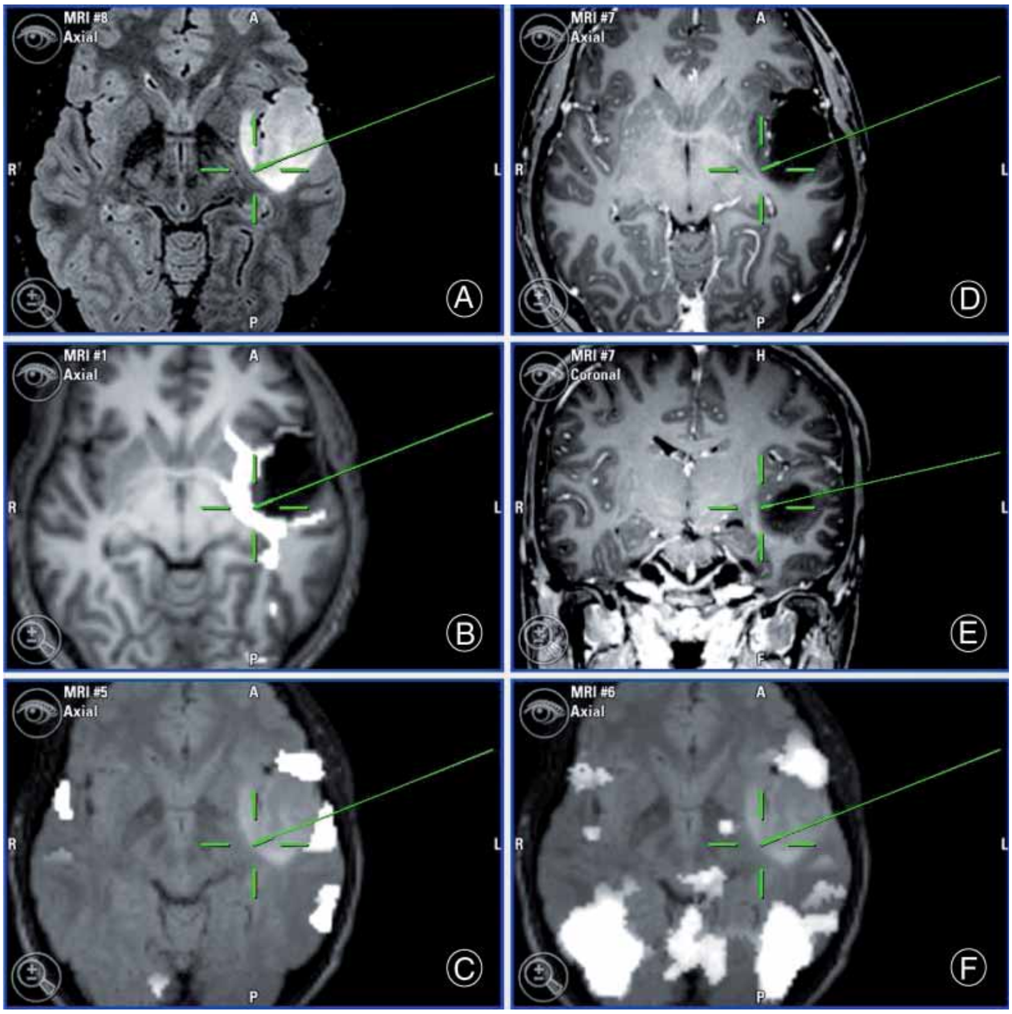

Figure 1. Example of integration in the operating theatre of various types of imaging in a case of left temporo-insular low-grade glioma: **(a)** volumetric FLAIR; **(b)** DTI FT reconstruction of IFO (white) superimposed onto a post-contrast T1-weighted MR image; **(c)** spots of activation for denomination (in white) obtained with fMRI, superimposed onto FLAIR images; **(d)** axial and **(e)** coronal post-contrast-T1 weighted images, and **(f)** spots of activation for verbal generation (in white) obtained with fMRI, superimposed onto FLAIR images. All these images were loaded into the neuronavigation system, co-registered, and fused together to be available during surgery. Surgery was performed in awake anaesthesia and the patient was continuously submitted to object-naming tests by the neuropsychologist during resection. The green cross indicates a subcortical site where semantic paraphrasia was induced by DES, at this site corresponded to the IFO as indicated in **(b)** and to the medial deep border of the tumour, as shown by FLAIR images **(a)**.

intraoperatively, and the brain mapping of various functions, among which memory, language in its various components, and visuospatial orientation are most important [3, 13, 37, 38].

As described, imaging gives the opportunity to carefully plan surgical strategies. In addition, images can be loaded into the neuronavigation system to be available peri- and intraoperatively for orientation. Imaging provides information based on probabilistic measurements, and although they may have a relatively high sensitivity or specificity, they still carry a certain amount of limitations. This is the reason why neuroradiological information loaded into the neuronavigation system always has to be supported during surgery by brain mapping results.

Once the preoperative work-up according to the site and the characteristics of the tumour, the results of the neuropsychological evaluation and of the functional and anatomic imaging are completed, each patient is offered an individualized surgical and monitoring strategy. The protocol includes mapping (DES) and monitoring (EEG, ECoG, MEP) procedures [3, 13, 37]. Intraoperative neurophysiology using DES allows to detect functions located at the cortical and subcortical levels. Detection of motor functions is generally performed in the asleep setting; identification of cortical and subcortical sites for language requires the patient to be awakened during the procedure and to be fully collaborative and actively interact with the in-house neuropsychologist and surgeon. Monitoring procedures allow to detect the intraoperative occurrence of seizures (EEG, ECoG) or of ischaemic events (MEP) (Figure 2).

Resection margins are usually kept very close to essential cortical sites and are usually coincident with subcortical sites. When this is achieved, motor or language deficits develop in the immediate postoperative period in 72.8 % and 65.4 % of cases, respectively. When we considered the results of the long-term postoperative neuropsychological evaluation, we found that 79.5 % of the patients had a long-term postoperative normal language, 18.6 % showed mild disturbances still compatible with normal daily life, and only 2.3 % incurred long-term impairment [13, 17, 37–39, 42]. Surgery performed with the aid of brain mapping techniques allows to reach several oncological endpoints, particularly in case of low-grade gliomas [9, 43–46]. It allows to obtain a large amount of material which helps the pathologist in the histological and molecular diagnosis. It increases the number of cases submitted to surgical treatment: in accordance with previous reports in the literature, this percentage in our series rose from 11 % of cases, when mapping was not available, to

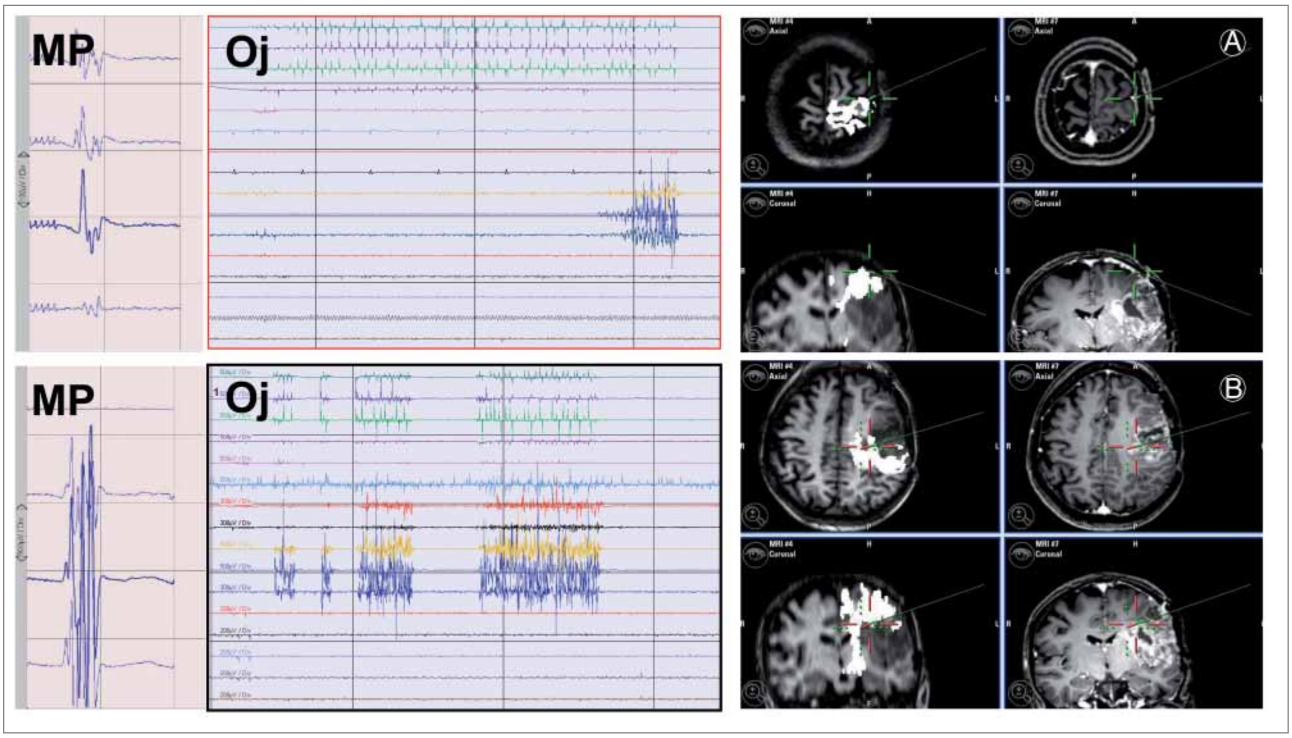

Figure 2. Example of integration of intraoperative neurophysiology with advanced MR imaging (DTI-FT) in a case of a left rolandic tumour. In this case, at the beginning of the resection the surgeon should integrate information coming from DES cortical mapping **(a)** (left and middle panel showing hand motor responses from the hand obtained by train of 5 techniques [left panel]) and 60 Hz probes [middle panel]), to those obtained by DTI-FT. The right panel shows the DTI-FT reconstruction for CST (in white) superimposed onto post-contrast T1-weighted images. The green cross indicates the position of the cortex where DES found hand motor responses. The site corresponded to the CST as indicated by DTI-FT images. The same type of integration is shown during resection at the subcortical level **(b)**. The green cross indicates the site where DES (with both train of 5 techniques and 60 Hz) located hand responses from the subcortical of the CST, which corresponded to the same position in the DTI-FT images**.**

81 % when mapping was applied, with a significant decrease in the number of cases submitted to biopsy only. Moreover, it decreases the percentage of permanent postoperative deficits, which fell from 33 % to 2.3 % either for language or motor functions [13, 17, 37, 38, 42]. Another important effect is the decrease in the incidence of seizures, particularly in low-grade glioma patients with a long epileptic history and affected by insular tumours. Seizure control is more likely to be achieved after gross-total resection than after subtotal resection/biopsy alone. Lastly, the use of brain mapping techniques increased the percentage of patients in whom a total and subtotal resection was achieved. This is particularly evident in low-grade gliomas. In our series of low-grade gliomas, the percentage of total and subtotal resections rose from 11 % in the pre-mapping period to 69,8 % in the time in which brain mapping techniques were applied [13, 17, 37, 38, 42].

An important observation that helps in planning surgery is the occurrence of the phenomenon of brain plasticity [37, 38]. Cerebral plasticity could be defined as the continuous processing allowing short-, middle-, and long-term remodelling of the neurono-synaptic organization. Plasticity may occur in the preoperative period in low-grade gliomas and in this case is the result of the progressive functional brain reshaping induced by these slowly growing lesions. The most important observation time for the occurrence of brain plasticity is the postoperative period. This has been shown by submitting patients recovered from postoperative deficit status to fMRI, demonstrating the activation of different areas of the brain, close or remote to those involved in the preoperative period. Plasticity may occur either at a cortical level, or, although less frequently, at a subcortical level, where it can be explained by the recruitment or unmasking of parallel and redundant subcortical circuits. The occurrence of plasticity allows for an extension of surgical indications: at the time of first surgery, by extending resection until functional boundaries are encountered, and by allowing the patient to recover in the postoperative period due to the activation of redundant functional areas; at the time of second surgery, when the functional reshaping induced by initial surgery can be used to perform second surgery with the aim to remove areas of the brain initially essential for function but losing their essentiality in terms of function after functional reshaping has been induced by initial surgery or to the continuous slow growth of the tumour. This phenomenon of functional reshaping can be observed up to a period of 6 months after initial surgery and allows to perform a more radical second surgery with an increase in the oncological benefit for the patient. In addition, plasticity can also be enhanced by means of chemotherapy when used in a preoperative setting [47].

Brain mapping techniques require the combined efforts of a multidisclipinary team of neurosurgeons, neuroradiologists, neuropsychologists, and neurophysiologists who contribute together in the definition of the location, extension, and extent of functional involvement that a specific lesion has induced in a particular patient. Each tumour induces particular and specific changes of the functional network that vary among patients. This requires that each treatment plan should be tailored to the tumour and to the patient. When this is achieved, surgery should be accomplished based on functional and anatomical boundaries with the aim of maximum resection with maximum preservation of patient functionality. This can be reached at the time of initial surgery, depending on the functional organization of the brain, or may require additional surgeries, eventually intermingled with adjuvant treatments. The use of so-called brain mapping techniques extends surgical indications, improves the extent of resection with greater oncological impact, minimizes morbidity, and increases quality of life.

Conclusive Remarks

Surgery has significantly changed in the recent past, mostly due to the progress in imaging and intraoperative neurophysiology. Surgeons should have the ability to critically use different types of imaging, to integrate them in surgical planning and directly incorporate them into the operating theatre. In addition, the surgical procedure requires the active contribution of various professional groups, such as neurophysiologists and neuropsychologists, who all help the surgeon to safely and effectively perform the resection. By means of these developments, surgery is nowadays able to influence patient survival and at the same time to maintain a high level of functional integrity and quality of life.

Conflict of Interest

The authors have no conflict of interest to disclose.

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