Awake surgery for WHO Grade II gliomas within “noneloquent” areas in the left dominant hemisphere: toward a “supratotal” resection

Clinical article

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Object. It has been demonstrated that an extensive resection (total or subtotal) may significantly increase the overall survival in patients with WHO Grade II gliomas (low-grade gliomas [LGGs]). Yet, recent data have shown that conventional MR imaging underestimates the spatial extent of LGG, since tumor cells were found up to 20 mm around MR imaging abnormalities. Thus, it was hypothesized that an extended resection with a margin beyond MR imaging–defined abnormalities—a “supratotal” resection—might improve the outcome of LGG. However, because of the frequent location of LGG within “eloquent” brain areas, it is often difficult to achieve such a supratotal resection. This could nevertheless be possible when LGGs involve “noneloquent” areas, even in the left dominant hemisphere. The authors report on their use of awake electrical mapping to tailor the resection according to functional boundaries, that is, to pursue the resection beyond MR imaging–defined abnormalities, until corticosubcortical eloquent structures are encountered. Their aim was to apply this reliable surgical technique to LGGs located not within eloquent areas but distant from eloquent areas, to take a margin around the LGG visible on MR imaging while preserving brain function.

Methods. Fifteen right-handed patients with a total of 17 tumors underwent resection of WHO Grade II gliomas involving nonfunctional areas within the left dominant hemisphere. In all patients, seizures were the initial manifestation of the tumors. Awake surgery with intraoperative electrostimulation was performed in all cases. The resection was continued until the surgeon reached cortical and subcortical areas crucial for brain function, especially language, as defined by the intrasurgical electrical mapping. The extent of resection was evaluated on postoperative FLAIR-weighted MR images.

Results. Despite transient neurological worsening in 60% of cases, all patients recovered and returned to a normal life. Seizure control was obtained in all patients with a decrease of antiepileptic drug therapy. Postoperative MR imaging showed that total resection was achieved in all 17 tumors and supratotal resection in 15. The average volume of the postoperative cavity (36.8 cm³) was significantly larger than the mean preoperative tumor volume (26.6 cm³) (p = 0.009). Neuropathological examination confirmed the diagnosis of WHO Grade II glioma in all cases. The mean duration of postoperative follow-up was 35.7 months (range 6–135 months). Only 4 of 15 patients experienced recurrence (without anaplastic transformation); the average time to recurrence in these cases was 38 months; radiotherapy was performed 6 years after the relapse in 1 case; no other patients received any adjuvant treatment. This series was compared with a control group of 29 patients who had “only” complete resection: anaplastic transformation was observed in 7 cases in the control group but not in any case in the series of patients who underwent supracomplete resection (p = 0.037). Furthermore, adjuvant treatment was administered in 10 patients in the control group compared with 1 patient who underwent supracomplete resection (p = 0.043).

Conclusions. These findings support the usefulness of awake surgery with intraoperative functional (language) mapping with the attempt to perform supratotal resection of LGGs involving noneloquent areas in the left hemisphere. Indeed, the extent of resection was significantly increased in all cases but 2, with no additional permanent deficit and with control of seizures in all patients. The goal of supracomplete resection is currently to delay the anaplastic transformation, even if it does not (yet) enable a cure. (DOI: 10.3171/2011.3.JNS101333)

Key Words • WHO Grade II glioma • noneloquent areas • supratotal resection • language mapping • awake surgery • oncology

See the corresponding editorial in this issue, pp 230–231.

This article contains some figures that are displayed in color online but in black and white in the print edition.
Supratotal resection of low-grade gliomas

Resection was significantly associated with an increase in overall survival by delaying malignant transformation.1,4,13,24,33,35,36 Thus, maximal resection with preservation of eloquent brain areas is currently the first therapeutic option to consider in LGG.8 However, a recent study using biopsy samples within and beyond MR imaging-defined abnormalities demonstrated that conventional MR imaging underestimated the actual spatial extent of LGGs, since tumor cells were present beyond the area of MR imaging signal abnormalities, up to 20 mm—even when gliomas were well defined on MR images.29 Interestingly, it was suggested that an extended resection of a margin beyond these MR imaging–defined abnormalities might improve the outcome of LGG.29 Although an extensive resection is often difficult because of the frequent location of LGGs within eloquent brain areas,8 a “supratotal” resection—that is, resection extending beyond the area of MR imaging signal abnormalities—could nevertheless be considered in “noneloquent” structures. On the other hand, preoperative determination of the boundary between noneloquent and eloquent brain areas in individuals remains difficult, especially for language areas, due to substantial interindividual anatomo-functional variability26,40 and the lack of reliability in functional neuroimaging methods.13

We recently showed that it is possible to use awake surgery with intraoperative mapping to remove invasive LGGs within language areas according to functional boundaries—that is, to continue the resection until functional boundaries have been encountered with no margin—without increasing the rate of permanent deficit.11,14 Here, for the first time, we apply this concept to diffuse LGGs located in presumed noneloquent areas within the left dominant hemisphere. Indeed, we performed awake craniotomy with intrasurgical functional mapping (particularly language mapping) to remove the parenchyma beyond the area of MR imaging signal abnormalities, known to be invaded by tumoral cells, until eloquent structures were detected by both cortical and subcortical direct electrostimulation. Our objective was to achieve a supratotal resection while preserving the patient’s quality of life.

Methods

Selection of Patients

We analyzed a consecutive series of right-handed adult patients (older than 18 years at the time of diagnosis), who underwent awake surgery for an LGG located in a presumed nonfunctional area—that is, at least 5 mm from functional areas—within the dominant left hemisphere. In all cases, surgery was performed by the senior author (H.D.) between December 1998 and February 2010.

Definition of Noneloquent Areas

A functional area was defined according to the recent UCSF (University of California, San Francisco) classification, including the sensorimotor areas (precentral and postcentral gyri), perisylvian language areas in the dominant hemisphere (superior temporal, inferior frontal, and inferior parietal gyri), basal ganglia, internal capsule, thalamus, and visual cortex around the calcarine sulcus.3

The presumed noneloquent areas were defined as all brain structures not belonging to the regions mentioned above. They were therefore determined on the basis of preoperative anatomical MR imaging.

Evaluation Methods

Information concerning the following parameters was obtained for all patients: sex, age at diagnosis, first symptom, tumor location, preoperative tumor volume and surgically resected volume (evaluated on pre- and postoperative MR imaging, respectively), neuropathology, administration of radiotherapy and/or chemotherapy, time to progression, and survival.

In addition, the patients’ neurological status and language functions were evaluated pre- and postoperatively (at 3 months after surgery and every 6 months thereafter). Handedness was assessed using the Edinburgh inventory.27 Language evaluation was performed using the Boston Diagnostic Aphasia Examination16 and a test of picture naming (DO80 test).23 Finally, each patient’s status was systematically evaluated by means of the KPS before and after the surgery.

Magnetic Resonance Imaging Evaluation

Preoperatively, the tumor volume was calculated on the basis of the 3 largest diameters (D1, D2, and D3) of areas of signal abnormality on FLAIR or T2-weighted MR images according to the 3 orthogonal planes (axial, sagittal, and coronal). An estimation of tumor volume was calculated by the ellipsoid approximation ((D1 × D2 × D3)/2), as already reported.22 Postoperatively, the volume of the residual tumor (if any) was calculated using the same method on the FLAIR-weighted MR images obtained 3 months after surgery. According to the Berg er classification, resection was defined as “total” when no residual signal abnormalities were present.3 In these cases, to quantify the extent of the “supratotal” resection, the volume of the surgical cavity was calculated with the same technique, and compared with the preoperative tumor volume. In patients who underwent total or supratotal resection, a relapse was defined as the occurrence of any FLAIR-weighted MR imaging abnormality.

Surgical Procedure

In all cases intraoperative functional electrostimulation mapping was performed using the “asleep-awake-asleep” protocol, as already reported.11,12 In the first stage, the tumor and cerebral sulci and gyri were identified using ultrasonography. Cortical mapping was then performed to detect the eloquent areas, using a bipolar electrode with a 5-mm space between the tips (Nimbus, Newmedic) and delivering a biphasic current (pulse frequency 60 Hz, single-pulse phase duration 1 msec, amplitude 1.5–4 mA). In all cases in which the central region was exposed, sensorimotor mapping was first performed to confirm a positive response (movement and/or paresthesias). The current intensity used for individual patients...
was determined by progressively increasing the amplitude in 1-mA increments (from a baseline of 2 mA) until a functional response was elicited. Then the patient was asked to perform counting (in a regular rhythm from 1 to 10, over and over) and picture-naming tasks, with the goal to identify the essential cortical language sites known to be inhibited by stimulation. Before naming each picture, the patient was asked to read a short phrase, namely the French translation of “this is a …,” to check that there were no seizures generating complete speech arrest if the patient was not able to name the picture. For the picture-naming task, we used the DO80 test pre- and postoperatively. Mapping of spatial cognition was also performed in parietal lesions, using a line-bisection task.

The patient was never informed when the brain was stimulated. The duration of each stimulation was about 4 seconds. At least 1 picture presentation without stimulation separated each stimulation, and in order to avoid seizures, no site was stimulated twice in succession. Each cortical site of the entire cortex exposed by the bone flap was tested 3 times and all areas where a response was obtained were stimulated at least 3 times for confirmation. In all cases, a speech therapist was present in the operating room during the stimulation and classified the type of language disturbance using a system previously developed for the classification of language disturbances. Specifically, the disturbances were classified as speech arrest, anoma, phonetic paraphasia, phonemic paraphasia, semantic paraphasia, slowness with initiation disturbances, and perseverations. Each eloquent area was marked by a sterile number tag on the brain surface and its location was correlated with the anatomical landmarks previously identified by ultrasonography. An intraoperative photograph of the cortical map was routinely made before resection.

During a second surgical stage, the glioma was removed by alternating resection and subcortical stimulations. Using the same parameters of stimulation, the functional pathways were followed progressively from the cortical eloquent sites already mapped to the depth of the resection. The patient had to continue the naming and/or line-bisection (movement) task when the resection came close to the subcortical eloquent structures, which were also identified by functional inhibition during stimulation as at the cortical level. Thus, the white matter tracts involved in language, motor, somatosensory, and/or visual functions could be detected in the deeper brain parenchyma. Again, the type of functional disturbance was detailed by a speech therapist throughout the resection.

To optimize the tumor removal, with preservation of function, all resections were pursued until eloquent structures were encountered around the surgical cavity. Thus, resection was performed according to functional cortical and subcortical boundaries. This means that there was no margin left around the eloquent areas, both within the gray and the white matter. As a consequence, when possible, the resection was extended beyond the tumor’s limits visible on preoperative MR imaging (and on intraoperative ultrasonography).

**Comparison With a Control Group**

A control group of patients who underwent a complete (not supracomplete) resection under local anesthesia, using the same operative technique of awake mapping, for an LGG involving eloquent areas in the left dominant hemisphere was compared with the patients who underwent supracomplete resection regarding the following parameters: sex, age, first symptom, preoperative neurological examination, median duration of follow-up, rate of recurrence, rate of anaplastic transformation, and adjuvant treatments.

**Statistical Analysis**

A Kolmogorov-Smirnov test was used to study the distribution of the variables, and P-P and Q-Q charts were used to confirm it. The variables did not follow a normal distribution, and nonparametric tests were used for comparisons. An intrasubject Wilcoxon signed-rank test was used to determine if there were differences between the pre- and postoperative tumor volumes. A significance level of 5% (p < 0.05) was accepted in all cases. SPSS software version 15.0 was used for the statistical analysis.

**Results**

**Clinical and Radiological Presentation**

Patient characteristics are summarized in Table 1. Our series consisted of 15 right-handed patients (8 men and 7 women) with a mean age of 36.4 years (range 24–59 years). The first clinical symptom was seizure in all patients. The average time between the onset of symptoms and the surgical treatment by our team was 28.5 months (range 1–222 months). Three patients had undergone previous surgery with partial resection performed by another team using general anesthesia. One of these patients had also been treated with adjuvant chemotherapy. In these 3 cases, the average time between the 2 surgeries was 14 months (range 6–24 months).

Preoperatively, no patient had sensorimotor deficit or intracranial hypertension. Mild language and/or cognitive disorders were found in 12 patients (80%). The preoperative KPS score was 90 or greater in all patients but one, who had a KPS score of 80 due to verbal working memory disorders.

All gliomas were located in noneloquent areas within the left dominant hemisphere (for details, see Table 1) (Fig. 1). It is worth noting that a bifocal multicentric glioma was present in 2 patients. These lesions also involved noneloquent areas in both cases (left presupplementary motor area and posterior part of the superior parietal lobule in the first case; left prefrontal and temporopolar lobes in the second case).

The average presurgical volume was 26.6 cm³ (range 1–68.8 cm³).

In summary, 17 lesions were removed, including 11 in the frontal lobe, 4 in the temporal lobe, and 2 in the parietal lobe.

In all patients, the cortical and subcortical functional areas were detected by intraoperative stimulation. These cortical and subcortical functional structures represented the limits of resection (Fig. 2).
Supratotal resection of low-grade gliomas

Postoperative Results

In the immediate postsurgical period, a transient worsening was noted in 9 patients (60%). There were 2 supplementary motor area syndromes and 7 mild language disorders, which improved after rehabilitation in all cases. Three months after surgery, there was no severe permanent deficit. A slight somatosensory deficit and a quadrantanopia persisted in 2 patients with parietal and posterior basal temporal lesions, respectively, but with no consequence on the quality of life. All 15 patients returned to a normal life.

Relief of seizures was obtained in all 15 patients postoperatively. The doses of the antiepileptic drugs have been reduced in all cases in which the follow-up period was longer than 9 months. In 4 cases, the antiepileptic treatment has been stopped.

All 15 patients have resumed their social activities. Professional activities have also been resumed by all patients but one, who had a preoperative working memory disorder, which persisted following surgery.

The KPS score was 90 or greater in all cases but one (in which it was 80).

The resection was total in all cases—that is, with no neurological deficit except for very mild disturbances of the verbal episodic memory detected by an extensive neuropsychological assessment. Note that the tumor is far from the ventricle.

Comparison With the Control Group

The control group of patients who underwent a complete (not supratotal) resection for an LGG involving eloquent areas in the left dominant hemisphere consisted of 29 patients (19 men and 10 women) with a mean age of 37 years (range 17–61 years). The first symptom was seizure in all patients, with no neurological deficit. The mean postoperative follow-up duration was 36 months (range 6–132 months). Thus, there was no significant difference with respect to these parameters between the control group and the series of 15 patients who had a supratotal resection.

The control group had a higher rate of recurrence, 41% versus 26% in the series of patients who underwent supratotal resection, although the difference was not statistically significant. In addition, anaplastic transformation was observed in 7 cases in the control group but not in any case in the series of patients who underwent supratotal resection (p = 0.037). Furthermore, adjuvant treatment was administered in 10 patients in the control group. The adjuvant treatment was administered in 10 patients in the control group.

TABLE 1: Clinical and radiological characteristics of 15 patients*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs),†</th>
<th>Sex</th>
<th>Preop Deficit</th>
<th>Time Btw Sx Onset &amp; Op (mos)</th>
<th>Tumor Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26, M</td>
<td>none</td>
<td>9</td>
<td>pre-SMA</td>
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<tr>
<td>2</td>
<td>32, F</td>
<td>MLD</td>
<td>12</td>
<td>pre-SMA, SPL</td>
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<tr>
<td>3</td>
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<tr>
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<td>59, M</td>
<td>MLD</td>
<td>1</td>
<td>frontal pole</td>
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<tr>
<td>5</td>
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<td>MLD</td>
<td>28</td>
<td>pre-SMA</td>
<td></td>
</tr>
<tr>
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<td>26, F</td>
<td>MLD</td>
<td>2</td>
<td>SMA</td>
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<td>7</td>
<td>27, M</td>
<td>MLD</td>
<td>40</td>
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</tr>
<tr>
<td>8</td>
<td>39, F</td>
<td>MLD</td>
<td>9</td>
<td>SPL</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>54, M</td>
<td>MLD</td>
<td>42</td>
<td>temporal pole</td>
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<td>2</td>
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<td>24, M</td>
<td>MLD</td>
<td>7</td>
<td>temporal pole, frontal pole</td>
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<tr>
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<td>MLD</td>
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<td>frontal pole</td>
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<tr>
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<td>29, F</td>
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<td>14</td>
<td>pre-SMA</td>
<td></td>
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<tr>
<td>15</td>
<td>45, F</td>
<td>none</td>
<td>222</td>
<td>pre-SMA</td>
<td></td>
</tr>
</tbody>
</table>

* MLD = mild language disorder (on Boston Diagnosis Aphasia Examination); SMA = supplementary motor area; SPL = superior parietal lobule.
† Patient age at time of surgery.
group compared with 1 patient who underwent supracomplete resection (p = 0.043).

Discussion

Low-Grade Glioma Surgery and the Concept of Supratotal Resection

Several decades ago, it was demonstrated, using multiple stereotactic biopsies in high-grade gliomas, that tumor cells invaded most of the hemisphere (or even the contralateral side through the corpus callosum), far beyond the tumor visible on imaging studies (CT scanning and then MR imaging). These results explained why it was impossible to cure glioblastoma, even with extensive resection.

Recently, it was also shown using multiple biopsy samples that LGG invaded the brain beyond the abnormalities visible on conventional MR images. This study demonstrated that tumor cells were present at a distance of 10–20 mm from the tumor boundaries defined by MR imaging, but that their number was significantly less beyond 20 mm. These results explained why it was impossible to cure glioblastoma, even with extensive resection.

In parallel, the development of intraoperative stimula-
tion in awake patients has been extensively demonstrated to allow a dramatic decrease in permanent deficits, with a rate of sequelae currently lower than 1.5%.8,11,34 Interestingly, awake surgery also enabled a significant increase of the extent of resection while operating in eloquent areas, as shown in patients who underwent 2 consecutive surgeries, the first under general anesthesia and the second under local anesthesia with an optimization of the LGG removal.5

As a consequence, our goal in this series of cases was to apply this reliable surgical technique to LGGs located not within eloquent areas but distant from eloquent areas, to take a margin around the LGG visible on MR imaging while preserving brain functions (that is, resection according to functional and not anatomical boundaries).

Surgery for Low-Grade Gliomas at a Distance From Functional Areas

To our knowledge, the role of brain stimulation under local anesthesia in LGG within noneloquent areas in the left dominant hemisphere has never been studied in the literature. Indeed, in patients with LGGs in presumed noneloquent areas, resection is traditionally performed under general anesthesia, thus with no language mapping, despite the involvement of the left hemisphere. Interestingly, 3 of our patients who underwent a previous resection under general anesthesia in another institution had only partial resection, while it has been possible to perform not just a total but a supratotal resection during a second surgery with these patients awake—with no neurological worsening. These data confirm the limits of the conventional surgery, in which the neurosurgeon stops the resection prematurely to avoid language disorders in the dominant hemisphere. Indeed, it has been clearly demonstrated that without functional mapping the anatomical landmarks are not reliable enough to identify the cortical and subcortical structures crucial for language.31 Therefore, these results in noneloquent areas support the findings already reported in eloquent areas, that is, the significant increase of the extent of resection thanks to the use of awake mapping.5,13

In addition to the fact that a complete resection was obtained in all cases, intraoperative electrostimulation under local anesthesia enabled us to perform a supratotal resection in 15 (88%) of the 17 lesions, as demonstrated by comparing the preoperative tumor volume and the postsurgical cavity volume (p = 0.009). Indeed, the volume of the postoperative cavity reflects the volume of the brain tissue that was removed, tissue that was invaded by tumor cells even if this infiltration was not visible on presurgical MR imaging. In 2 patients, the volume of the cavity was nevertheless smaller than the presurgical tumor volume, despite the absence of signal abnormalities on the postoperative FLAIR-weighted MR imaging. This postoperative volume may be underestimated because of parenchymal retraction. Even with this underestimation of the extent of resection, the mean postoperative volume has been enlarged by 10.8 cm³ (38%), due to the awake mapping, which allowed resection until functional boundaries were reached. It means that we increased the resection by more than 10 cm³ in comparison with a “classic” surgery conducted according to oncological limits—that is, based on neuronavigation or even on intraoperative MR imaging—since the goal, according to this principle, in essence is to remove only the MR imaging–defined abnormalities.

From a functional point of view, a transient clinical worsening occurred in 60% of cases after surgery, especially with respect to language function. Such results are not surprising due to the absence of margin between functional cortico-subcortical structures and the edge of the surgical cavity, even if the (visible) glioma was a priori located in noneloquent areas. It must be emphasized that according to classic recommendations, a margin of security of about 5–10 mm around the area detected by functional brain stimulation is generally preserved in the surgical series reported in the literature. However, we recently demonstrated in a series with 162 patients who underwent surgery for an LGG in the left dominant hemisphere that resection to the point of contact with eloquent areas was possible without increasing the rate of postoperative definitive deficits (less than 2%), despite a transitory impairment in the immediate postoperative period.14 Here, we confirm that all patients recovered their preoperative neurological status within a few weeks of surgery, with specific functional rehabilitation, and that they returned to a normal social and professional life (except for 1 patient who did not work preoperatively due to cognitive disorders). Moreover, seizures were controlled in all cases with decrease or cessation of antiepileptic drug therapy.

Limitations and Perspectives

The main limitations of our study are the small number of patients and a short duration of postoperative follow-up for some of them. Indeed, the mean duration of follow-up is only 3 years, due to the inclusion of 5 patients with only 6 months of follow-up. However, it is worth noting that 8 patients have been followed up for 2–11 years, without any case of death or anaplastic transformation (without adjuvant treatment in all cases but one), supporting a possible impact of the supracomplete resection on the long-term course of the disease. Indeed, comparison with the control group of patients who had “only” a complete resection (no supracomplete resection due to the fact that the LGG involved eloquent areas) showed a higher rate of recurrence in the control group (41% versus 26% in the patients who underwent supracomplete resection), although the difference was not statistically significant. Interestingly, anaplastic transformation was observed in 7 cases in the control group, compared with no cases in the series of patients who underwent supracomplete resection (p = 0.037). Furthermore, adjuvant treatment was given in 10 patients in the control group, but only in 1 patient who underwent supracomplete resection (p = 0.043). Thus, these results support the hypothesis that a supracomplete resection may significantly delay anaplastic transformation with no adjuvant chemotherapy or radiotherapy, even if it does not prevent LGG recurrence.

Indeed, we must also emphasize that a relapse occurred in 4 of the 15 patients, indicating that the primary goal of the supratotal resection remains to delay malignant transformation and thus to increase the median
survival while preserving (or improving) brain function. Although the quality of life was not evaluated using validated instruments (except the KPS) in the present series, no patient suffered additional permanent neurological deficit, and seizures have been controlled in all patients. Of course, we do not claim to be able to cure patients with LGG, even when performing suprachallenge resection. Indeed, these recurrences might mean that it was not possible to take at least 20 mm of margin all around the tumor in all patients, due to the functional structures (even if distant from the glioma). Interestingly, although the ages of the 4 patients with recurrence and their tumor volumes were not significantly different from those of the 11 other patients with no recurrence, it is nonetheless worth noting that this subgroup includes the 2 patients with a postoperative cavity volume smaller than the preoperative tumor volume. As a consequence, we can suggest that the margin around the FLAIR signal abnormality was less than in the other patients, likely explaining a quicker relapse. The relapses might also mean that the technique used in the study by Pallud et al.29 (MBI-1 immunostaining based on the detection of proliferating cells) might not be sensitive enough in LGG. It is possible that tumor cells not identified by MBI-1 immunostaining exist in the perilesional parenchyma beyond a margin of 2 cm around the MR imaging–defined abnormalities.

On the other hand, it is interesting to note that some patients in our series had a relapse after 18 months while others had no recurrence with 135 months of follow-up after the sole surgery. This could be explained by the fact that some LGGs are more “invasive” whereas other LGGs are more “proliferative.” It is likely that surgery, especially supratotal resection, by definition has a better chance of controlling the latter than the former. In the future, advances in MR imaging might allow for better selection with respect to indications for suprachallenge resection. Indeed, it has been suggested that MR spectroscopy and perfusion MR imaging could be more effective than conventional MR imaging for evaluating actual LGG infiltration. Metabolic imaging might be more sensitive than morphological MR imaging based on T2/FLAIR signal abnormalities, and could be closer to the neuropathological tumor infiltration.20,37,42 However, these techniques still lack reliability and need to be validated. Another method could be to use the new biomathematical models of proliferation and diffusion, based on at least 2 sets of MR images acquired 3–6 months apart, before any treatment.17,22,32

Conclusions

Our findings support the usefulness of awake surgery with intraoperative functional (language) mapping with the attempt to achieve a supratotal resection of LGG involving noneloquent areas in the left hemisphere. Indeed, the extent of resection was significantly increased in all but 2 cases, with no additional permanent neurological deficit and with seizure control despite a decrease of antiepileptic drugs in the 15 patients. The goal would be to delay the anaplastic transformation and to delay the use of adjuvant therapy, without claiming to cure patients. These preliminary results need to be validated by increasing the number of patients and the follow-up period, using prospective multicenter studies.

Disclosure

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

Author contributions to the study and manuscript preparation include the following. Conception and design: Duffau. Acquisition of data: Duffau, Moritz-Gasser. Analysis and interpretation of data: all authors. Drafting the article: Duffau, Yordanova. Critically revising the article: Duffau, Yordanova. Approved the final version of the paper on behalf of all authors: Duffau. Administrative/technical/material support: Duffau, Moritz-Gasser. Study supervision: Duffau.

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