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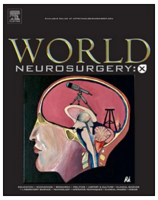

Experience in awake glioma surgery in a South American center. Correlation between intraoperative evaluation, extent of resection and functional outcomes

Guido Caffaratti [a,*], Mauro Ruella [a], Facundo Villamil [a], Greta Keller [b], Darío Savini [c], Andrés Cervio [a]

[a] *Department of Neurosurgery, Fleni, Buenos Aires, Argentina*
[b] *Department of Cognitive Neurology, Neuropsychology and Neuropsychiatry, Fleni, Buenos Aires, Argentina*
[c] *Department of Neurophysiology, Fleni, Buenos Aires, Argentina*

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ABSTRACT

Introduction: Gliomas are the second most frequent primary brain tumors. Surgical resection remains a crucial part of treatment, as well as maximum preservation of neurological function. For this reason awake surgery has an important role.

The objectives of this article are to present our experience with awake surgery for gliomas in a South American center and to analyze how intraoperative functional findings may influence the extent of resection and neurological outcomes.

Materials and methods: Retrospective single center study of a cohort of adult patients undergoing awake surgery for brain glioma, by the same neurosurgeon, between 2012 and 2022 in the city of Buenos Aires, Argentina.

Results: A total of 71 patients were included (mean age 34 years, 62% males). Seventy seven percent of tumors were low grade, with average extent of resection reaching 94% of preoperative volumetric assessment. At six months follow up, 81.7% of patients presented no motor or language deficit.

Further analysis showed that having a positive mapping did not have a negative impact in the extent of resection, but was associated with short term postoperative motor and language deficits, among other variables, with later improvement.

Conclusion: Awake surgery for gliomas is a safe procedure, with the proper training. In this study it was observed that guiding the resection by negative mapping did not worsen the results and that positive subcortical mapping correlated with short term postoperative neurological deficits with posterior improvement within six months in most cases.

1. Introduction

Gliomas represent 24.5% of all primary brain tumors, making them the second most common.[1] Current treatment remains brain function-sparing maximal tumor resection in combination with adjuvant treatment with chemo and radiotherapy, which has been associated with better overall survival.[2,3] Permanent postoperative neurological deficit is linked to worse overall survival, potentially neutralizing the benefits of surgery, mainly due to its profound impact on quality of life.[4]

At present, the combination of awake brain surgery and multimodal intraoperative functional assessment enables more extended resection margins with less neurological deficit.[5–7] Employment of these techniques requires a specialized surgical team, including a neurophysiologist, but not necessarily use of highly expensive equipment, and can even be more cost-effective than using general anesthesia in the long term.[8]

The main objective of this study is to present the experience with awake glioma surgery at a tertiary neurological center in South America, the first series in Argentina. Secondly, to analyze how intraoperative functional findings (motor and/or language responses during the intraoperative neurological examination) may influence the extent of

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* Corresponding author. Fleni, Buenos Aires, Argentina. Montañeses 2325, C1428AQK, Ciudad Autónoma de Buenos Aires, Argentina.
E-mail addresses: gcaffaratti@fleni.org.ar (G. Caffaratti), mruella@fleni.org.ar (M. Ruella), fvillamil@fleni.org.ar (F. Villamil), gkeller@fleni.org.ar (G. Keller), savinid@gmail.com (D. Savini), acervio@fleni.org.ar (A. Cervio).

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Abbreviations list

CI	Confidence Interval
FLAIR	Fluid-attenuated inversion recovery
GTR	Gross Total Resection
iMRI	Intraoperative Magnetic Resonance Imaging
MRI	Magnetic Resonance Imaging
MRC	Medical Research Council
NIHSS	National Institutes of Health Stroke Scale
OR	Odds Ratio
SANDS	Surgically associated neurological deficits
STR	Subtotal Resection

resection and postoperative neurological outcomes.

2. Materials and methods

A single center retrospective study was conducted. The data analyzed corresponds to all the patients undergoing awake surgery for brain glioma by the senior author (Cervio Andrés), between 2012 and 2022, at the Fleni institute of the city of Buenos Aires, Argentina.

Clinical records, imaging, histopathological results and surgical protocols were gathered from the institutional database.

Informed consent was obtained for all the patients.

Inclusion criteria.

- Age over 18 years.
- Histological diagnosis of glioma regardless of grade. Tumors were classified according to the 2021, WHO Classification of Tumors of the Central Nervous System.[9]
- Supratentorial location.
- Thin-sliced pre and post operative MRI (Magnetic Resonance Imaging) for volumetric analysis.
- Preserved language function preoperatively (with or without corticoid therapy).
- Awake surgery performed by the senior author and team in Fleni institute.
- Minimum follow up of 6 months.

The total number of awake surgery glioma patients was 82, but considering the previous criteria the finally included sample was 71.

R 4.1.2 software was used for statistical analysis of findings. Categorical variables are presented as absolute and relative frequencies, and continuous variables as averages and standard deviations. Correlation between variables was analyzed using: Fisher's exact test for qualitative dichotomous variables, Wilcoxon signed-rank test for continuous variables and Pearson's Chi square for assessing goodness of fit. p values < 0.05 were considered statistically significant. Multivariate linear regression was applied to examine numerical variables (percentage of resection) and their relationship to different independent variables. Model presuppositions were verified before the analysis and $p < 0.05$ values used as cutoff value for significance. Categorical dependent variables (extent of resection, complications, surgically associated neurological deficits or "SANDS") were analyzed using multivariate logistic regression and p values < 0.05 considered significant.

Tables 1 and 2 list the variables examined.

3. Neurological examination

All patients were evaluated pre and postoperatively. Motor function was classified according to the MRC scale.[10] Language was assessed using a protocol that includes nomination, repetition, task comprehension, reading and writing. Patients were categorized using the NIHSS[11] scale in order to simplify interpretation due to heterogeneity of records.

Table 1
Demographic and clinical characteristics.

Variable	$n = 71$[a]
Sex	
Male	44 (62%)
Female	27 (38%)
Age (years)	34 (29, 45)
Clinical presentation	
Seizures	50 (70%)
Aphasia	8 (11%)
Incidental finding	6 (8.5%)
Headache	5 (7.0%)
Motor deficit	2 (2.8%)
Location	
Frontal	27 (38%)
Insular involvement	19 (27%)
Parietal	13 (18%)
Temporal	12 (17%)
Side	
Left	57 (80%)
Right	14 (20%)
Preoperative volume	51.6 (16, 54)
Resection percentage	94 (83, 100)
Extent of resection	
GTR	41 (58%)
STR	30 (42%)
Intraoperative MRI	22 (31%)
Neuronavigation	68 (96%)

[a] Median (IQR); n (%).

4. Imaging

All patients were studied by means of a volumetric MRI, both pre and postoperatively (1 month), before the onset of adjuvant treatment.

Volumetric analysis was performed by the same operator, using the Smartbrush tool from Brainlab Elements software, by manually drawing interest areas over the tumor on thin slice MRI with T2/FLAIR for low grade tumors or contrasted T1 sequences for high grade tumors.

Location was determined by considering the area with larger involvement by the tumor as follows: frontal, temporal, parietal, occipital and insular. Those with considerable (more than 50% of total volume) insular involvement were considered as insular, regardless of extension into other lobules.

Extent of resection was determined according to two variables, a numerical percentage according to pre and postoperative volumetric analysis; and a dichotomous categorical variable, namely: a) gross total resection (GTR) (0% tumor present on postoperative MRI) of hyperintense area for low grade tumors using FLAIR sequences, or of gadolinium-enhanced area for high grade tumors in T1; or b) subtotal resection (STR). All cases without a 100% resection were considered as STR. No patient was operated only for diagnostic purposes. Volumetric analysis was made taking into consideration the preoperative and 1 month postoperative MRI.

31% of patients underwent iMRI. Selection criteria involved, but were not limited to patients age, BMI, eloquence and preoperative imaging grade and volume of the tumor.

5. Intraoperative evaluation

Language assessment was carried out by a neuropsychologist using a digital screen only in left sided tumors. The core neuropsychological assessment battery for intraoperative evaluations included: confrontation tasks, language comprehension assessments, phonological and semantic word fluency tests, and reading tasks, which are widely utilized in this context (Appendix). For motor assessment the patient was instructed to do alternating movements with his contralateral hand and foot. Because patients gradually grow fatigued during the procedure it is

Table 2
Intraoperative findings and neurological outcome at follow-up.

Variable	$n = 71$[a]
Intraoperative mapping	
Positive language cortical stimulation	7 (9.9%)
Positive motor cortical stimulation	9 (13%)
Positive subcortical language stimulation	10 (14%)
Positive subcortical motor stimulation	10 (14%)
Intraoperative neurological examination	
Intraoperative language deficit	26 (37%)
Intraoperative motor deficit	13 (18%)
No deficit	37 (52%)
Motor AND Language deficit	5 (7%)
Histopathology	
Astrocytoma	32 (45%)
Oligodendroglioma	18 (25%)
Ganglioglioma/P. Xanthoastrocytoma/Glioneuronal	5 (7.0%)
Glioblastoma	16 (23%)
Complications	
None	61 (87%)
Surgical site infection/Meningitis	4 (5.7%)
Bleeding	2 (2.9%)
Ischemia	3 (4.3%)
SANDs at short term	
Language SANDs	
No	41 (59%)
Mild-Moderate	21 (30%)
Severe	7 (10%)
Global-Mutism	1 (1.4%)
Motor SANDs	
None	43 (61%)
Mild	16 (23%)
Moderate	6 (8.6%)
Severe	5 (7.1%)
SAND at mid/long term	
At 3 months follow-up	
Stable	3 (6.5%)
Complete recovery	25 (54%)
Improvement	18 (39%)
Worsening	0 (0%)
NA (No initial SAND reported)	25
At 6 months follow-up	
Stable	2 (4.3%)
Complete recovery	33 (72%)
Improvement	10 (22%)
Worsening	1 (2.2%)
NA (No initial SAND reported)	25
Follow-up	22 (6, 44)

[a] Median (IQR); n (%).

advisable to design the language assessment preoperatively, and tailor it to tumor location.[12]

6. Surgical technique

“Asleep-awake-asleep” protocols were used in all cases.[5] Patients were administered oxygen through a nasal cannula (during the entire procedure, we do not use a laryngeal mask routinely) and remifentanil/propofol was used to achieve a state of conscious sedation. Uncomfortable procedures were performed while patients were completely unconscious, including positioning the head holder (prior scalp block was performed), bladder catheterization, as well as surgical incision, craniotomy and wound closure.

Patient positioning depended on tumor site, taking into consideration that patients need to feel comfortable throughout the procedure and be able to interact easily during intraoperative evaluations. Semilateral decubitus with ipsilateral shoulder padding was the most common position used.

Neuronavigation was used to plan the incisions and bone flaps (Image 1). The area was then infiltrated with 0.1% lidocaine/epinephrine and 0.5% bupivacaine.

After the craniotomy, cottonoids soaked in 0.5% lidocaine were applied on the dura prior to opening (see image 1), after which a 4 electrode strip was placed over the motor area, to monitor motor evoked potentials and electrocorticography.[13] Patients were awakened during dural opening.

Subsequently, the tumor was located with neuronavigation (and/or ultrasound) and next, cortical mapping was performed with a bipolar probe. Two different stimulation patterns were administered, one for language and another for motor mapping (Images 2 and 3). Subcortical mapping was performed during the in depth resection in order to map for long association fibers. During stimulation, neurological functions were assessed according to location.

7. Stimulation technique

Language mapping, both cortical and subcortical, was performed with bipolar stimulation using biphasic square wave pulses, 0.5 ms duration at a pulse rate of 50–60 Hz, starting with 2 mA and increasing by 1 mA up to a recommended maximum of 8–12 mA, for 2–4 s. Maximum values for this parameter vary in the literature.[14,5] Areas of stimulation were spaced every 5 mm. In the current model for language processing,[15,16] mapping of areas corresponding to the dorsal pathway may result in speech arrest (inability to speak), phonological paraphasias (phoneme substitution) and/or hesitation (longer time required to execute an order), in addition to alteration of repetition. The ventral pathway is usually characterized by semantic paraphasias (word switching) and difficulties in semantic interference tests.[5]

For cortical motor mapping bipolar stimulation was used with high frequency pulses (500 Hz) delivered in trains of 4–6 Hz with variable stimulation intensity. Clinical responses were recorded using subcutaneous electrodes in the corresponding contralateral muscles. Subcortical motor mapping was performed with a monopolar probe (we used a suction cannula/stimulator of our own design, useful during subcortical resection of lesions close to motor fibers. See image 1. E).[17] High frequency pulses (500 Hz) were applied in trains between 4 and 6 Hz at a stimulation intensity starting at 10 mA. The anodal stimulation train had a square stimulus of 200–500 μs pulse width and 2–4 ms gap between stimuli. According to the literature, It is considered that there is a relationship between the stimulation intensity and the distance to the corticospinal tracts, where 1 mA corresponds to 1 mm.[18,19] Taking this into consideration, we consider a safety limit for resection when stimulation is positive at 5 mA. If no positive response is elicited, image guidance is used and the possibility of iMRI is considered.

During resection, use of bipolar coagulation was kept to a minimum to avoid potential thermal damage or altering of neurophysiological monitoring. Subcortical resection limits were defined according to neuronavigation and intraoperative functional findings. In this regard, findings taken into consideration as “red flags” are the following.

- Clinical:
- Motor deficit.
- Repeated language errors in 2 different tasks consistent with anatomical location.
- Neurophysiological:
- Motor evoked potentials decrease of 50% or more in amplitude.

If any of these are encountered, resection is halted for 5 min, the cavity is irrigated with warm saline and arterial blood pressure is raised. If the deficit does not improve the resection is finished.

As previously stated, an intraoperative MRI (iMRI) was used in certain cases. At our institution, we do not have an MRI scanner in the operating room, so we use the iMRI technique described by Ramina et al.[20]

8. Postoperative neurological evaluation

SANDs were defined as new neurological deficits derived from the surgical procedure. These were grouped into motor and language.

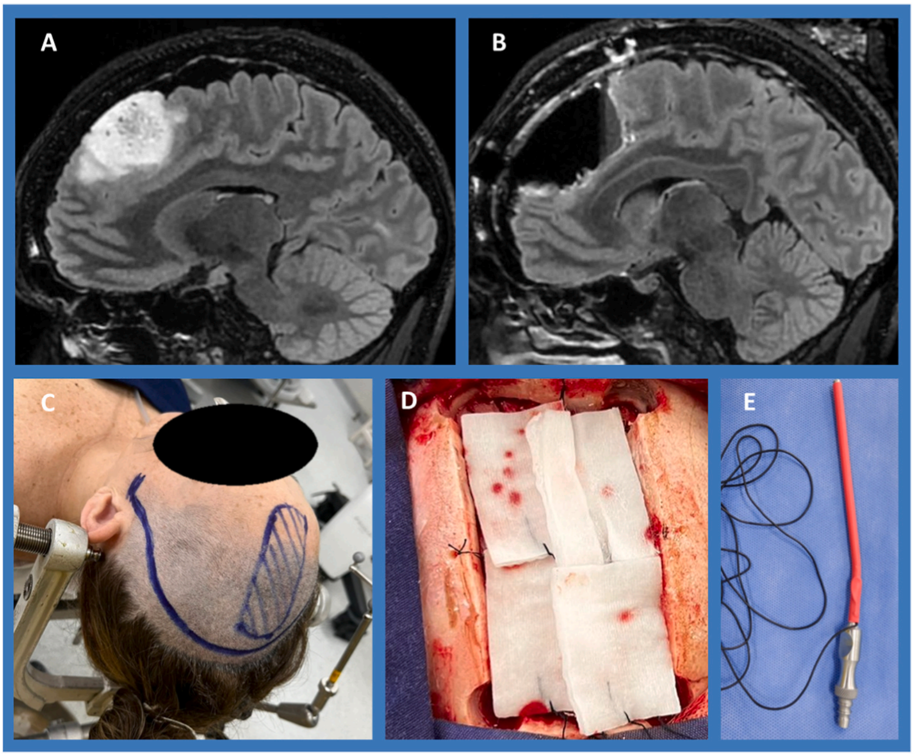

Image 1. Case example of low grade glioma. A: Preoperative FLAIR sequence MRI showing parasagittal left frontal hyperintense lesion. B: Postoperative FLAIR sequence MRI showing complete resection. C: Position of the patient, planning of the incision and craniotomy. D: Placement of cotton pads with anesthetic on the dura mater. E: Aspiration and stimulation cannula with electrical insulation.

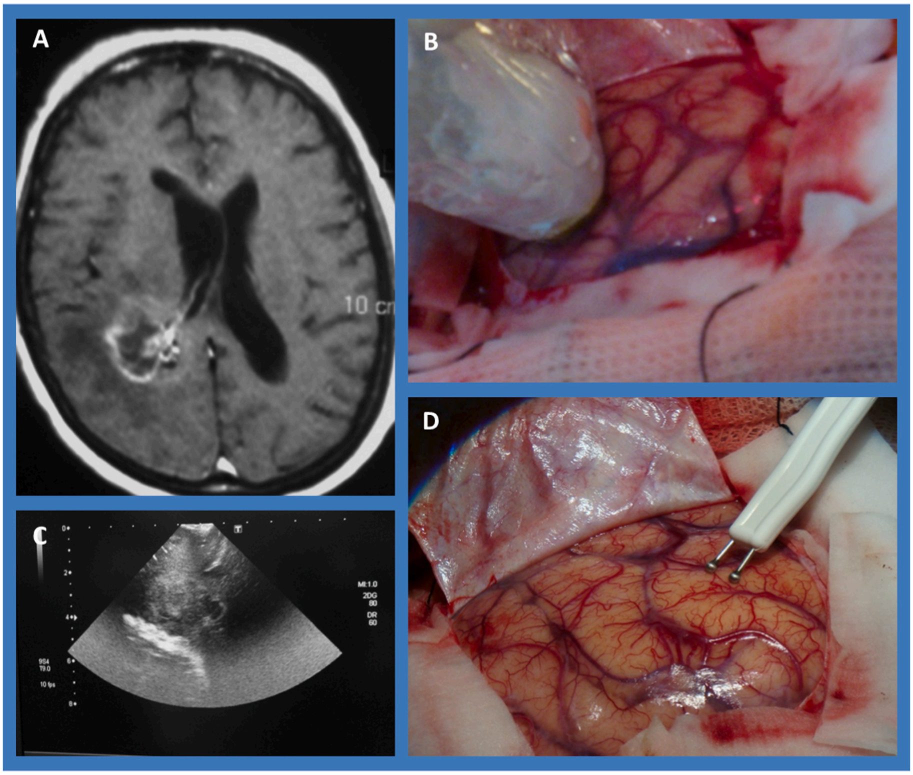

Image 2. Case example of high grade glioma. A: Contrast MRI showing a lesion with both heterogeneous contrast-enhancing areas and cystic/necrotic appearance, involving the area of the motor tract projections in depth. B: In this case, ultrasound was used to localize the lesion. C: Ultrasound image showing an area of heterogeneous echogenicity that corresponds to the tumor. D: Cortical stimulation to locate the motor area.

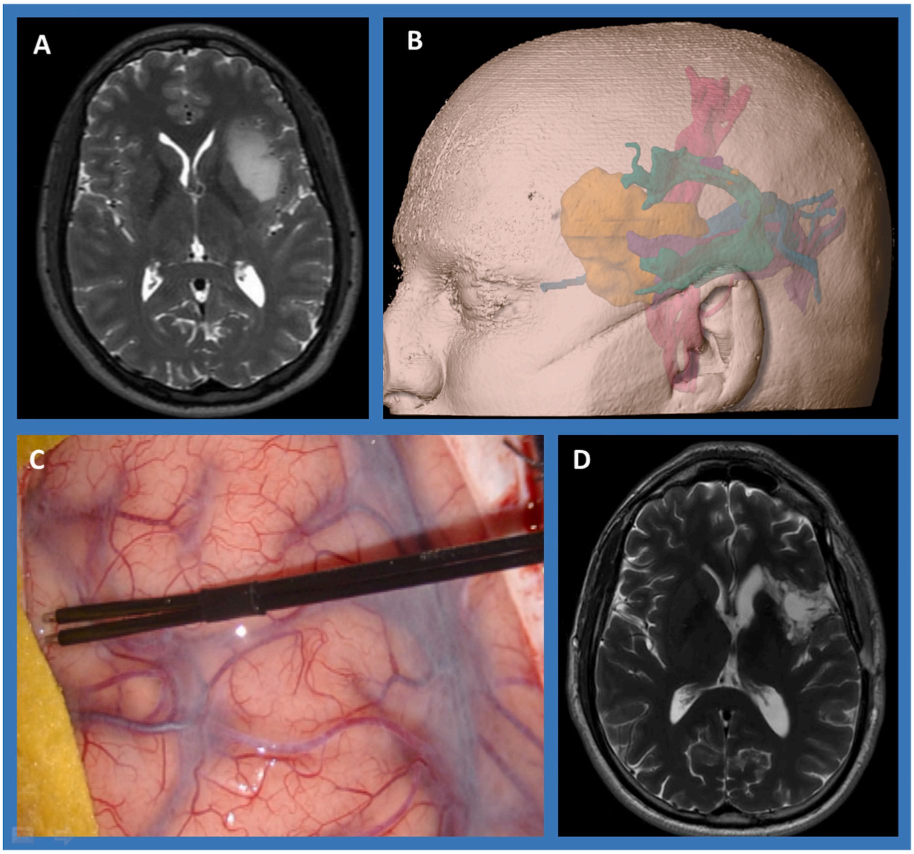

Image 3. Case example of low-grade insular glioma. A: T2 sequence MRI shows hyperintense left fronto-insular lesion. B: 3D reconstruction with skin projection of the lesion, in orange, and the surrounding tracts: corticospinal in fuchsia, optic in light blue, arcuate in green and in violet the lower fronto-occipital. C: cortical mapping with bipolar probe. D: Postoperative T2-weighted MR with minimal remnant adjacent to the frontal horn of the lateral ventricle.

Evaluations were performed at time of hospital discharge, and at 3 and 6 months. Patients without deficit postoperatively that did not worsen during follow up were designated as “NA (not applicable)”.

NIHSS scales were used to characterize language deficit levels as: mild-moderate, severe, or global mutism or aphasia. Motor deficits were scored based on the MRC scale as mild (4 or 4+/5 deficit), moderate (3/5) and severe (2/5 or 1/5).

9. Results

A total of 71 patients were included in the study, (average age 34 years, 62% males). The most frequent form of presentation were seizures, with 80% of tumors located on the left side of the brain, 38% of these involving the frontal lobe, and 27% the insula. Seventy seven percent of the tumors were low-grade (Table 1).

10. Intraoperative variables

Neuronavigation was used in 96% of patients and iMRI was obtained in 31%. Cortical mapping was negative in 77% and subcortical stimulation was positive in 28%. During resection, 37% of patients presented language deficits and 18% motor ones. Only three patients (4.2%) experienced a seizure during the procedure, none of which made stopping the operation necessary (Table 2).

11. Postoperative variables

Overall, 25 patients (35.2%) showed no immediate deficit. Language was unaffected in 59% of patients and deficit was mild-moderate in 30%. Motor function was preserved in 61% and mild-moderate deficit was observed in 26%. GTR was possible in 58% of surgeries, with an average resection of 94% of the previous volumetric value (Table 2).

12. Follow-up

Full recovery from either type of deficit was observed in 54% at 3 months and 72% at 6 months. Ultimately, 81.7% presented no motor or language deficits 6 months after the intervention.

Table 3
Statistical analysis of variables associated with the EOR and SANDs after multivariate analysis.

Variable	OR	CI	*p* value
Extent of resection			
Intraoperative MRI	1.4	1.13; 1.49	0.05
Insular involvement	−1.47	−5.8; −1.2	0.01
SANDs: Motor			
Positive subcortical motor response	1.17	1.1; 2.2	0.03
Insular involvement	4.57	1.4; 5.37	0.02
STR	3.49	1.4; 3.78	0.05
Complications: Hematoma	1.39	1.6; 8.4	0.04
SANDs: Language			
Positive subcortical language response	1.2	1.14; 9	0.05
Location: Parietal	1.2	1.1; 1.27	0.04
Insular involvement	1.6	1.38; 4.7	0.05
Side: Right	−6.2 (Protective)	−7.1;-1.7	0.04
Complications			
Preoperative tumor volume	9.4	1.2; 9.9	0.05

13. Statistical analysis

The results of the multivariate analysis are shown in Table 3.

Multivariate linear regression analysis (R2 57%) showed that variables related to extent of resection were: use of iMRI, which increased resection by 20% (p 0.04) and insular involvement, which had a negative impact, reducing the resection by 5.5% (p 0.01).

When resection was analyzed categorically (GTR vs STR) using a multivariate logistic regression model, similar results were observed. Use of iMRI increased GTR by 40% (OR 1.4 CI 1.13–1.49; p 0.05), while insular involvement presented a negative OR of 1.47 (CI 1.2–5.8), i.e. decreasing likelihood of total resection by 47% (p 0.01). Intraoperative cortical and subcortical positive stimulation results did not have a negative impact in the extent of resection.

For the analysis of SAND results, a multivariate logistic regression model was applied. Having a positive response during subcortical motor stimulation was associated with an increase of motor-type SANDs by 17% (OR 1.17 - CI 1.1–2.2) with a $p = 0.03$. Other variables that showed correlation with this variable were: insular involvement, which increased the risk 4.57 times (OR 4.57 - CI 1.4–5.37; p 0.02); STR which was linked to a 3.49-fold increase (OR 3.49 - CI 1.4–3.78; p 0.05); and complications such as postoperative hematoma which was associated with a 1.39-fold increase (OR 1.39 - CI 1.6–8.4; p 0.04).

A positive response during subcortical stimulation for language was related to a 20% increase in language-type SANDs (OR 1.2 - CI 1.14–9; p 0.05). Tumor location also correlated with this finding. Parietal involvement showed a 20% increase in risk (OR 1.2 - CI 1.1–1.27; p 0.04); insular involvement increased it 1.6 times (OR 1.6 - CI 1.38–4.7; p 0.05); and left hemisphere tumors were also linked to higher risk, as demonstrated by the “protective” effect of right-sided location, where a 6-fold reduction in risk of language SANDs was observed (OR -6.2 - CI 1.7–7.1; p 0.04).

Finally, multivariate analysis corresponding to tumor volume was associated with an increased risk of postoperative language impairment (OR 1.12 - CI 1–1.6; p 0.05) unlike what occurred in motor type SANDs.

Variables correlating with postoperative neurological deficit at 3 months were: insular involvement, which increased it 1.7 times (OR 1.7 - CI 2.3–5.6; p 0.02); and positive subcortical stimulation, which increased it 5.8 times (OR 5.8 - CI 2.03–3.8; p 0.05).

Conversely, multivariate logistic regression of variables linked to complications, only showed significant correlation with preoperative tumor volume (OR 9.4; CI 1.2–9.9; p0.05)

14. Discussion

We present a series of 71 patients diagnosed with brain gliomas, operated by a single surgeon with awake technique. Tumors were located in eloquent areas, with clear predominance on the left side of the brain and a significant percentage in the insula. We considered these criteria to support indicating this technique, however the literature shows different viewpoints regarding this.[21] Some authors advocate using awake surgery in all glioma patients regardless of location,[22,23] whereas others prefer to limit it to tumors within classically functional areas.[4,21] On the other hand, it was mostly used for tumors that appeared to be low-grade on preoperative images, since it potentially would enable to extend resection margins with greater safety in patients with an expected greater survival and due to the lower possibility of intraoperative complications such as bleeding and edema.[3] Nevertheless, in selected cases, this technique has also been used for high-grade tumors involving areas with elevated risk of postoperative neurological deficit, to attempt optimal resection whilst preserving the quality of life.[17,24,25]

With respect to the surgical technique, cortical mapping was positive in 10% of cases for language, and 13% for motor function. This could be interpreted as secondary to our preference for custom craniotomies and for guiding the resection following negative cortical mapping. Although the use of larger craniotomies would improve recognition of functional areas, smaller craniotomies and limited resection guided by negative mapping are also considered safe.[25–27] In this series, our preference responded to reducing procedure duration and possible approach related complications (only 4 patients presented wound infections/meningitis, however this was not thoroughly analyzed). Moreover, we believe that limiting cortical stimulation might reduce the incidence of intraoperative seizures, but we have no data to support such affirmation. It is worthy of mention that in some cases, such as left insular tumors and other prolonged cases, fatigue with decreased responsiveness has been encountered by the end of the resection.

GTR was possible in 58% of cases, with the average resection reaching 94% in the MRI volumetric analysis. Only 18.3% of the patients presented motor and/or language deficit 6 months after surgery. Finally, only 4.2% presented intraoperative seizures, without having to abort any procedure for this reason, and clinical/surgical complications occurred in 13%, including ischemia, hematoma, and infection. These results are similar to those of other published series and support awake surgery as a safe procedure.[5,27] It is of interest that in our series intraoperative seizures occurred during cortical stimulation and in patients that had seizures at presentation.

As also reported elsewhere, we observed that use of iMRI was associated with increased extent of tumor resection,[28,29] and a decrease when the insula was involved, likely secondary to its anatomically challenging area, surrounded by multiple tracts resulting in intraoperative stimulation findings. Moreover, the benefits of awake surgery in improving outcomes for insular tumors is undoubted in the literature.[30] A comparative analysis determining the influence of cortical and subcortical mapping vs not mapping, in terms of EOR was not performed in our study as all of the patients were mapped, since we consider it a standard of care. However we could identify that positive cortical or subcortical mapping responses did not statistically decrease the resection rates.

The multivariate analysis showed that postoperative motor deficit was associated with positive subcortical motor stimulation, iMRI, insular involvement, subtotal resection, and postoperative bleeding. This may be interpreted as resulting from proximity to functional areas, where the neurosurgeon will normally limit both resection and use of bipolar cautery. Postoperative hematoma development would also worsen neurological outcomes. This highlights the importance of achieving an excellent hemostasis, without the use of bipolar cautery because of the possibility of damaging nearby tracts. With respect to postoperative language deficits, similar findings were observed for tumors with insular or parietal location, and cases with positive subcortical stimulation. Association with tumor volume and laterality were to be expected, expressing the validity of the analysis. Correlation between postoperative deficit and positive mapping has also been observed in other series.[30,31,24]

Interestingly, cortical mapping did not have a negative impact on short and long term SANDs as subcortical did. This could be related to the fact that cortical areas might be more simply avoided during the initial resection of the tumor, while white matter tracts preservation imply a more difficult task. A positive subcortical mapping is to be interpreted as proximity to functional tracts which would help to preserve them, however, this proximity could also increase the risk of injury due to bleeding and edema/swelling. In the latter scenario, it should be expected that neurological deficits would improve over time. In our analysis, we could identify a relationship between short/mid term postoperative neurological deficit and positive subcortical stimulation. However, in the long term most of the patients recovered completely (81.7% with no deficit at 6 months). These results enforce the importance of subcortical stimulation for tract mapping during resection and that many times surgical manipulation may result in immediate postoperative deficit, nevertheless, if the tracts were correctly identified the patient would have a high probability of recovering during follow up.

15. Study limitations

We acknowledge limitations to this analysis that include the retrospective design of the study which is subject to selection and recall bias, and the fact that the series included cases operated on during the first years of experience using the technique, resulting in heterogeneity in the register of data, such as intraoperative drawbacks, which may have been insufficiently recorded. Furthermore, for these reasons some of the clinical scores used for the analysis had to be interpreted according to the records.

16. Conclusion

Awake glioma resection appears to be a safe surgical technique that could be applied in most neurosurgical centers, after adequate training.

Surgical outcomes suggest that extent of resection could be positively influenced by using iMRI and negatively by having insular location and might not be negatively influenced by having positive stimulation findings. On the other hand, negative mapping could be an acceptable strategy for guiding resection. Furthermore, proximity to functional tracts identified as positive stimulation might correlate with higher rates of short/mid term postoperative neurological deficits. Identification and preservation of tracts during resection would be fundamental for postoperative neurological improvement with rehabilitation.

Declaration

The authors declare no conflict of interests.

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CRediT authorship contribution statement

Guido Caffaratti: Writing – review & editing, Writing – original draft, Data curation, Conceptualization. **Mauro Ruella:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Facundo Villamil:** Writing – review & editing, Writing – original draft, Data curation. **Greta Keller:** Writing – review & editing. **Darío Savini:** Writing – review & editing. **Andrés Cervio:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

APPENDIX

Intraoperative protocol.

List of tasks
Reading regular and irregular words
Oral diadochokinesis
WAB
Automatic series
Completing sentences
Recognition of spelled words
Reading
Repetition
Orders
Verb naming
Auditory-verbal discrimination
Direct Digit Span
Reverse Digit Span
Trail Making Test oral version

WAB = Western Aphasia Battery.

Source: Authors. Translated from Keller et al.[32]

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