# Awake Surgery for Gliomas within the Right Inferior Parietal Lobule: New Insights into the Functional Connectivity Gained from Stimulation Mapping and Surgical Implications

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■ OBJECTIVE: **Little is known about the functional role of the white matter connections running within and around the right inferior parietal lobule (IPL). We used direct electrostimulation during awake surgery to investigate this connectivity and to avoid permanent deficit after resection for right IPL gliomas.**

■ METHODS: **We reviewed patients who underwent awake mapping for a glioma involving the right IPL. Resection was achieved up to functional corticosubcortical boundaries detected by electrostimulation. Results of the intraoperative mapping were confronted to preoperative and postoperative magnetic resonance imaging to perform anatomofunctional correlations.**

■ RESULTS: **Fourteen consecutive patients were enrolled (9 men; mean age, 44 years). Cortically, the resection was limited anteriorly by the retrocentral somatosensory area (11 patients) or by the precentral motor cortex (3 patients). Subcortically, the thalamocortical pathways were identified anteriorly in all patients. Articulatory disturbances were elicited anteriorly and laterally (6 patients) corresponding to the superior longitudinal fasciculus part III. Deeper and superiorly, stimulating the superior longitudinal fasciculus part II or the arcuate fasciculus induced spatial disorders (6 patients). More laterally and posteriorly, disrupting the inferior fronto-occipital fasciculus induced nonverbal semantic disorders (7 patients). Six patients had visual deficits while the optic radiations were stimulated. A total or subtotal resection was achieved in all patients but one. There were no permanent impairments, except an expected left superior quadrantanopia in 4 patients.**

■ CONCLUSIONS: **This is the first surgical series focusing on right IPL gliomas. The complex functional connectivity detected within and around this region fully supports the use of intraoperative multimodal functional mapping for optimizing outcomes.**

## INTRODUCTION

The right hemisphere, often referred to as "nondominant", has been long neglected for the benefit of its left "dominant" homolog.[1] A paradigmatic example of the eloquent region is the left inferior parietal lobule (IPL), which represents a major crossroad in which several crucial white matter tracts run, explaining why both cortical and subcortical awake mapping are performed for glioma in this region,[2] whereas only cortical mapping was advocated for some time.[3] However, the right IPL is also formed by critical neural networks the disruption of which may result in dramatic consequences in everyday life,

**Key words**
- Awake surgery
- Direct electric stimulation
- Functional connectivity
- Glioma
- Right inferior parietal lobule

**Abbreviations and Acronyms**
**DES**: Direct electric stimulation
**FLAIR**: Fluid-attenuated inversion recovery
**IPL**: Inferior parietal lobule
**MNI**: Montreal Neurological Institute
**MRI**: Magnetic resonance imaging
**PPTT**: Pyramids and Palm Trees Test
**SLF**: Superior longitudinal fasciculus
**WHO**: World Health Organization

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especially after surgery for a brain tumor.[4,5] Yet, despite scarce reports in the literature, little is known about the functional connectivity of the right IPL and its surgical implications, especially for glioma resection. Even although anatomic studies using fiber tract dissection and tractography have allowed a better understanding of the structural organization of the white matter underneath the right inferior parietal cortex,[6,7] these techniques do not permit the functions that may be associated with these fiber pathways to be probed. Intraoperative direct electric stimulation (DES) in awake patients offers a unique opportunity to map not only the cortex but also the subcortical connectivity.[8] In addition, in glioma surgery, the use of electric stimulation mapping led to an increase of the extent of resection and significantly decreased the rate of severe permanent deficits, notably when the tumors are located in the so-called eloquent brain structures.[9]

Here, we report for the first time to our best knowledge a homogeneous and consecutive series focusing specifically on patients who underwent awake surgery for a glioma involving the right IPL. The aim was both to investigate the functional anatomy within and around this poorly studied region with the use of cortical and axonal stimulation mapping and to apply these findings to the optimization of surgical outcomes.

## METHODS

### Selection of Patients

From a prospective database, we performed a review of patients who underwent awake surgery with intraoperative DES mapping for a glioma involving the right IPL in our department between March 2009 and June 2016. All surgeries were performed by the senior author (H.D.). Information regarding sociodemographic and clinical characteristics (i.e., age at treatment, gender, presenting symptoms, handedness, and neurologic status), radiologic features, intraoperative mapping results, extent of resection, and functional outcomes was collected and analyzed.

### Preoperative and Postoperative Magnetic Resonance Imaging Study

The topography of the tumor was accurately analyzed on preoperative magnetic resonance imaging (MRI) (T1-weighted and spoiled gradient images obtained before and after gadolinium enhancement in the 3 orthogonal planes, T2-weighted axial images, and fluid-attenuated inversion recovery [FLAIR]-weighted axial images). Preoperative tumor volume was calculated based on FLAIR-weighted MRI signal abnormalities in diffuse low-grade gliomas and based on T1-weighted contrast enhancement in high-grade gliomas. Tumor volume was assessed using a dedicated software (Myrian [Intrasense, Montpellier, France]).

Postoperative MRI (T1-weighted, T2-weighted, and FLAIR-weighted imaging) was performed within 24 hours after surgery to assess the extent of resection, at 3 months, and then every 6 months thereafter. For low-grade gliomas, complete removal of the hyperintense area on postoperative FLAIR-weighted MRI sequences was considered as total resection, whereas a residual volume of $\leq$10 mL on FLAIR imaging was defined as subtotal resection. For high-grade glioma, only complete removal of the enhancement on postoperative gadolinium T1-weighted MRI was considered to be total resection. All other cases were considered to be a partial resection.

### Preoperative and Postoperative Neuropsychological Assessment

All patients benefited from an assessment of spatial cognition before, 5 days after, and 3 months after surgery, with 2 well-used behavioral tasks: the bell test[10] and the line bisection task.[11] One half of the patients were more comprehensively assessed with other neuropsychological tasks (a systematic and comprehensive neuropsychological examination of patients with a right tumor has been performed only since 2011 in our institution). To maintain homogeneity, these neuropsychological data are not reported.

### Intraoperative Electrostimulation Mapping

All surgical procedures were performed using an asleep awake asleep technique with DES mapping, a method extensively described in other studies.[8,12-14] A large craniotomy exposing the sylvian fissure, the frontal operculum, the central region, the IPL, the superior parietal lobule, and the posterior part of the superior and middle temporal gyri was performed with the patient under sedation. The tumor margins were verified with ultrasonography in relation to the sulcal and gyral brain surface anatomy. Sterile letter tags marked the cortical boundaries of the glioma.

Before glioma resection, cortical mapping was achieved in the awake condition to avoid damage to critical areas. A bipolar electrode (Nimbus [Innopsys, Carbonne, France]) with 5-mm inter tip spacing was used to apply electric stimulation with a biphasic current intensity ranging from 1.5 to 3 mA (stimulation parameters, 60 Hz pulse frequency; 1 millisecond single pulse phase; 4-second tissue contact) while the patient performed functional tasks. First, cortical mapping was performed, by stimulating the primary sensory motor areas and the ventral premotor cortex during a dual task (counting from 1 to 10 repeatedly in concert with contralateral arm movement). This mapping was achieved starting at 1 mA and increasing up by steps of 0.5 mA until a reproducible functional response was elicited (i.e., elicitation or disruption of movement, dysesthesia, or articulatory disturbances). This optimal threshold of stimulation was used for the rest of the cortical and axonal mapping. A cortical site was considered as responsive when the same functional disturbance was elicited 3 times in a nonsequential manner, followed by normalization after stimulation. To avoid seizures, the same site was never stimulated twice in succession.[12]

Before tumor removal, cortical mapping of the following functions was achieved[15]: motor cognition,[16,17] somesthetic function,[2] spoken language,[18,19] spatial cognition,[20] visual functions,[18] and nonverbal semantic cognition[21,22] (see later discussion for the details of the tasks). The same trained neuropsychologist (G.H.) monitored patients' functions and assessed the behavioral consequences of stimulation during surgery. To maintain a good level of objectivity, both the patient and the neuropsychologist were fully blind to the time of stimulation. Numbered sterile tags marked the eloquent areas. A photograph was taken before resection to capture the cortical map.

After completion of cortical mapping, glioma removal started. Axonal stimulation was regularly alternated with resection using the same electric parameters as those at the cortical level.[8] If the