Absence of movement disorders after surgical resection of glioma invading the right striatum

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Object. Despite the high frequency of striatal lesions, the rate of movement disorders reported in the literature is lower than expected (<10%). To maximize the extent of resection in low-grade gliomas invading the right striatum, the authors performed a striatal resection in a series of 14 patients, observed the lack of movement disorders following these procedures, and discuss herein the mechanisms likely to explain these findings.

Methods. Fourteen patients harboring a low-grade glioma that was infiltrating the right nondominant striatum, and in whom the results of neurological examination were normal, underwent surgery in which intraoperative electrical mapping was used, allowing the identification of pyramidal pathways. The striatum was resected in all procedures, and corticospinal tracts were systematically detected and preserved. Ten patients presented with a transient postoperative motor deficit, and nine with a loss of interest and affect. These symptoms all resolved within 3 months, except for one case of persistent hemiparesis. No postoperative movement disorder was noted, even transitorily. All resections were categorized as either total or subtotal on control magnetic resonance images.

Conclusions. These findings show that the nondominant striatum can be removed in cases of glioma invasion without inducing even transitory movement disorders. This phenomenon could be explained by the combined resection of the two classes of striatal neurons, an associated pallidal and thalamocortical resection, or a compensatory recruitment of parallel networks. Thus, these results may allow the surgeon to maximize the extent of removal of low-grade gliomas involving basal ganglia. Striatal resection may induce transient hemiparesis and “athymhormic syndrome,” however, necessitating that the patient be clearly informed before surgery.

KEY WORDS • striatum • low-grade glioma • movement disorder • intraoperative electrical stimulation

In addition to the many observations reported for neurodegenerative diseases, 1,11,27,34,50,57,79 movement disorders such as hemichorea, 18,35,38,45,73,84 hemiballismus, 20,29,40,41 athetosis, 20,29,35,38,45,73,84 or tonic spasms 61 were also extensively described in stroke involving the striatum alone 32,35,38,58,76,84 or the striatum in association with other basal ganglia: GP, thalamus, and STN. 17,18,51,57,60

These abnormal movements rarely occur, however, in comparison with the high rate of stroke involving the basal ganglia; 64 they are present in only 8% of focal lesions of the basal ganglia (6% in caudate lesions) 5 and are even absent in some series. 12,15,19 In the same way, in the rare studies of neurological symptoms associated with tumors involving the gray nuclei, although a high incidence of movement disorders might be expected because of the major role of these structures in the control of movement, 6,69 they were infrequently observed—ranging from 1 to 9% in the main series published in the last two decades, 11,36,40,41 noted in some case reports, 20,42,66 and sometimes not even mentioned. 7 Moreover, movement disorders were occasionally described after resection of tumors located in the basal ganglia. 39 Nevertheless, although functional surgery (performed using electrical stimulation and/or lesioning) was widely used at the level of the thalamus, the GP, and even the STN (but not in the striatum) for the treatment of movement disorders, 9,5, only a few reports of deep tumor surgery are available in the literature. 36,39,52,60 Most often, these series described thalamic gliomas, with no systematic, clear statement about striatal removal.

We describe a series of 14 patients in whom we performed a right striatal resection to treat an infiltration by a low-grade glioma, without inducing movement disorders after the procedure. Although our primary surgical aim was to maximize the quality of tumor removal, which was reported to be correlated with a better prognosis by many authors, 9,12,25,59,70,71,78,80,82 our main goal in this present study was not to investigate outcome related to extent of glioma resection, or to attain seizure control. Rather, the essential aim was to document the immediate postoperative functional consequences, then the recovery patterns after tumor surgery involving the nondominant striatum, and to discuss the mechanisms likely to explain these findings, in particular the lack of movement disorders.

Clinical Material and Methods

Between November 1998 and November 2000, 14 patients underwent surgery for a cortical–subcortical low-
The topography of the tumor was accurately analyzed on a preoperative MR image (spoiled-gradient images in the three planes, with the anterior commissure–posterior commissure as the reference plane). In all surgical procedures, intraoperative motor cortical–subcortical mapping was performed using direct electrical stimulation, as previously described by the surgeons (H.D. and L.C.).24 to track and preserve the pyramidal pathways. Briefly, a bipolar electrode with 5-mm spaced tips delivering a biphasic current (pulse frequency 60 Hz, single-pulse phase duration 1 msec, amplitude 6–18 mA) (Ojemann Cortical Stimulator 1, Radi- onics, Inc., Burlington, MA) was applied to the brain after induction of general anesthesia. Stimulation of every motor structure induced an involuntary movement of the con-tralateral hemibody at each level of the corticospinal tract, allowing us to detect in particular the corona radiata and the internal capsule.22,23 Consequently, to perform the most complete tumor removal possible, with preservation of the functional areas, all resections were conducted using functional boundaries, that is, pursued until motor pathways were encountered. Intraoperative glioma identification was also systematically obtained using ultrasonography and/or neuronavigation.

All patients were clinically examined immediately, 3 months, and 1 year postoperatively by the same neurologist. A control MR image was obtained in all cases, immediately and 3 months after surgery, first to evaluate the quality of glioma removal by using the classification reported by Berger, et al.,30 and second to estimate the percent volume resected of each striatal structure (>90%).

Results

The clinical, radiological, and surgical characteristics of the 14 patients are summarized in Table 1.

### Table 1

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Presenting Symptoms</th>
<th>Location of Glioma on Preop MR Image</th>
<th>Op (% of resection)</th>
<th>Clinical Results</th>
<th>Extent of Resection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>29</td>
<td>F</td>
<td>partial seizures: dur 2 yrs, freq 4/mo</td>
<td>temporoinsular glioma inv HCN, put, &amp; ALIC</td>
<td>temporoinsular op: HCN (&lt;50%), put (&lt;50%), &amp; ALIC</td>
<td>no deficit</td>
<td>subtotal</td>
</tr>
<tr>
<td>2</td>
<td>36</td>
<td>M</td>
<td>partial seizures: dur 5 yrs, freq 4/mo</td>
<td>frontal glioma inv HCN, anterior put, &amp; ALIC</td>
<td>frontal op: HCN (&lt;50%), anterior put (&lt;50%), &amp; ALIC</td>
<td>no deficit</td>
<td>subtotal</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>M</td>
<td>gen seizures: dur 3 mos, freq 1/mo</td>
<td>frontotemporal glioma inv HCN, put, GPe, &amp; ALIC</td>
<td>frontotemporal op: HCN (&lt;50%), put (&gt;90%), GPe (&lt;50%), &amp; ALIC</td>
<td>hemiparesis 1/5 &amp; LOI resolving w/in 3 mos</td>
<td>total</td>
</tr>
<tr>
<td>4</td>
<td>41</td>
<td>F</td>
<td>partial seizures: dur 6 mos, freq 4/mo</td>
<td>frontotemporal glioma inv HCN, put, GPe, &amp; ALIC</td>
<td>frontotemporal op: HCN (&gt;90%), put (&gt;90%), GPe (&gt;50%), &amp; ALIC</td>
<td>hemiparesis 2/5 &amp; LOI resolving w/in 2 mos</td>
<td>subtotal</td>
</tr>
<tr>
<td>5</td>
<td>43</td>
<td>F</td>
<td>partial seizures: dur 13 mos, freq 1/day</td>
<td>frontotemporal glioma inv HCN, put, GPe, &amp; ALIC</td>
<td>frontotemporal op: HCN (&gt;90%), put (&gt;90%), GPe (&gt;50%), &amp; ALIC</td>
<td>hemiparesis 3/5 &amp; LOI resolving w/in 1 mos</td>
<td>subtotal</td>
</tr>
<tr>
<td>6</td>
<td>50</td>
<td>M</td>
<td>partial seizures: dur 2.5 yrs, freq 2/mo</td>
<td>frontotemporal glioma inv HCN, put, GPe, &amp; ALIC</td>
<td>frontotemporal op: HCN (&gt;90%), put (&gt;90%), GPe (&gt;50%), &amp; ALIC</td>
<td>hemiparesis 2/5 &amp; LOI resolving w/in 3 mos</td>
<td>subtotal</td>
</tr>
<tr>
<td>7</td>
<td>27</td>
<td>M</td>
<td>gen seizures: dur 10 mos, freq 1/mo</td>
<td>frontotemporal glioma inv HCN, put, &amp; ALIC</td>
<td>frontotemporal op: HCN (&gt;90%), put (&gt;90%), &amp; ALIC</td>
<td>hemiparesis 2/5 &amp; LOI resolving w/in 3 mos</td>
<td>subtotal</td>
</tr>
<tr>
<td>8</td>
<td>38</td>
<td>F</td>
<td>gen seizures: dur 3 yrs, freq 3/day</td>
<td>frontotemporal glioma inv HCN, put &amp; ALIC</td>
<td>frontotemporal op: put (&gt;90%) &amp; ALIC</td>
<td>no deficit</td>
<td>subtotal</td>
</tr>
<tr>
<td>9</td>
<td>37</td>
<td>M</td>
<td>2 gen seizures in past mo</td>
<td>frontotemporal glioma inv HCN, put, GPe, &amp; ALIC</td>
<td>frontotemporal op: HCN (&gt;90%), put (&gt;90%), GPe (&gt;50%), &amp; ALIC</td>
<td>hemiparesis 3/5 &amp; LOI resolving w/in 2 mos</td>
<td>total</td>
</tr>
<tr>
<td>10</td>
<td>33</td>
<td>M</td>
<td>gen seizures: dur 1 yr, freq 3/yr</td>
<td>temporoinsular glioma inv put</td>
<td>temporoinsular op: put (&gt;90%)</td>
<td>no deficit</td>
<td>total</td>
</tr>
<tr>
<td>11</td>
<td>24</td>
<td>M</td>
<td>2 gen seizures in past 2 mos</td>
<td>frontotemporal glioma inv HCN, put, GPe, &amp; ALIC</td>
<td>frontotemporal op: HCN (&gt;90%), put (&gt;90%), GPe (&gt;90%), &amp; ALIC</td>
<td>brachiofacial paresis 3/5 &amp; LOI resolving w/in 2 wks</td>
<td>total</td>
</tr>
<tr>
<td>12</td>
<td>32</td>
<td>M</td>
<td>partial seizures: dur 10 mos, freq 1/mo</td>
<td>frontotemporal glioma inv HCN, put, GPe, &amp; ALIC</td>
<td>frontotemporal op: HCN (&gt;90%), put (&gt;90%), GPe (&gt;90%), &amp; ALIC</td>
<td>postop hemiplegia w/ residual spastic hemiparesis after 3 mos</td>
<td>subtotal</td>
</tr>
<tr>
<td>13</td>
<td>35</td>
<td>M</td>
<td>partial seizures: dur 9 mos, freq 1/mo</td>
<td>frontotemporal glioma inv HCN, put, GPe, &amp; ALIC</td>
<td>frontotemporal glioma inv HCN (&lt;50%), put (&gt;90%), GPe (&gt;50%), &amp; ALIC</td>
<td>hemiparesis 3/5 &amp; LOI resolving w/in 1 mos</td>
<td>subtotal</td>
</tr>
<tr>
<td>14</td>
<td>57</td>
<td>M</td>
<td>gen seizures: dur 5 mos, freq 1/mo</td>
<td>frontal glioma inv HCN &amp; ALIC</td>
<td>frontal op: HCN (&gt;90%) &amp; ALIC</td>
<td>hemiparesis 1/5 &amp; LOI resolving w/in 3 mos</td>
<td>subtotal</td>
</tr>
</tbody>
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* Results of all clinical examinations were normal. Abbreviations: dur = duration; freq = frequency; gen = generalized; inv = invading; LOI = loss of interest; put = putamen.
Clinical Presentation

The series included 10 men and 4 women, ranging in age from 24 to 57 years (mean 37 years). All patients were right-handed, as established by neuropsychological examination and fMR imaging. The presenting symptoms were seizures in all cases (chronic partial epilepsy lasting for at least 2 years, despite treatment with two or more antiepileptic drugs in four patients; Table 1). The results of preoperative clinical testing were normal in all patients, with no movement disorders. The Mini-Mental State Examination score was 30/30 in all cases.

Preoperative MR Imaging

All tumors were hypointense on T1-weighted and hyperintense on T2-weighted MR images; no enhancement was seen after gadolinium administration. The locations in the right hemisphere were distributed as follows: there were two frontal tumors extending deeply in the HCN (two cases), the anterior part of the putamen (one case), and the ALIC (two cases); and there were two temporal–insular and 10 frontotemporoinsular gliomas involving the HCN in 10 cases, the putamen in 12, the ALIC in 11, and also the GPe in eight (Figs. 1–3). The thalamus and the STN were never invaded in this series.

Surgical Findings

Intraoperative direct subcortical electrical stimulation allowed the detection and preservation of the pyramidal pathways in the PLIC in all patients: the anterior part of the PLIC constituted the posterior limit of the resection in frontal gliomas (after removal of the ALIC, HCN, and/or the putamen) and the lateral part of the PLIC constituted the posteromedial limit of the resection in temporal–insular gliomas (after removal of the putamen, and even of the GPe).

Consequently, the HCN was removed in 12 cases, the putamen in 13 (the anterior part in three cases, the whole putamen in 10), the GPe in eight, and the ALIC in 13. The thalamus and STN were never resected, even partially.

Clinical Results

There was no operative or postoperative death. Ten patients experienced an immediate postoperative motor deficit with motor neglect, which totally resolved within 3 months or less (within 2 weeks in two cases, within 1 month in two, within 2 months in two, and within 3 months in three), except in one patient who suffered a deep ischemia involving the PLIC (attributable to a lenticulostriate artery injury).

In nine cases an inertia with loss of interest and affect was also observed, despite the preservation of intellectual function. Again, these symptoms resolved in all patients within 3 months or less. No movement disorders were noted (even transitorily), either subtle ones that might be seen during the careful objective neurological examination, or those discovered during questioning of the patient.

All patients except one returned to a normal social and professional life after the 3rd month postsurgery. One year after surgery, all patients were examined. There was no residual motor deficit, except in the patient with the deep ischemia, who still had spastic hemiparesis (but who can...
walk with the aid of crutches). All neuropsychological evaluations showed a Mini-Mental State Examination score greater than 28 of 30 (30 of 30 in nine patients). There were no movement disorders. The overall definitive neurological morbidity rate in this series was thus reduced to 7%. Note that seizures were improved in 11 patients (78%); nine without epilepsy and two with rare seizures, whereas three patients still have regular seizures despite medical treatment.

Histological Results

On histopathological examination we diagnosed a low-grade glioma (World Health Organization Grade II) in all cases. No complementary radiotherapy or chemotherapy was administered.

Radiological Results

Four glioma resections were considered total (with no residual signal abnormality), according to evaluations of immediate and delayed MR images obtained postoperatively, and 10 resections were subtotal (< 10 cm³ of tumor remaining; Figs. 1–3).¹⁰ The estimate of the percent volume resected for each striatal structure is given in Table 1.

Discussion

Despite the frequency of nondegenerative striatal lesions reported in the literature, the rate of movement disorders observed in these lesions—more often stroke,²³,²⁴,²⁶,²⁸,³⁶,³⁸,³⁹,⁷⁶,⁸⁴ more rarely vascular malformations,²⁸,⁴⁹ brain injury,⁷⁷,⁸³ and tumor⁴¹,³⁶,⁴⁵,⁴⁸—is surprisingly very low (< 10%). Indeed, a high percentage of movement disorders might be expected, as classically described in striatal degeneration such as Huntington disease, because the striatum plays a major role in the control of movement.²,⁷⁰,⁶⁰ Moreover, movement disorders were occasionally noted after surgery involving this structure, and in most cases were transitory.⁷⁰

Our series confirms that striatal removal in cases of glio-infiltration, at least in the right, nondominant side, does not induce transient or definitive movement disorders, independently of the occurrence of a motor deficit. To try to explain these findings, it seems necessary to recall that the striatum represents the entry of the basal ganglia, that it receives afferents from the cortex and substantia nigra (pars compacta), and that it projects to the GPe and pars reticulata of the substantia nigra (both inhibiting the thalamus and thalamocortical efferents) via two pathways. The first is a direct inhibitory pathway consisting of specific γ-aminobutyric acid (and dynorphinergic) striatal neurons, and the second is an indirect excitatory pathway (in which the inhibition of the GPe itself inhibits the excitatory STN) consisting of other specific γ-aminobutyric acid (and enkephalinergic) striatal neurons.⁶,⁶⁰ It has been shown that experimental lesioning of the striatum in animals has induced an imbalance between the different afferents projecting to the GPe, releasing motor sequences that are not part of the motor program established at the cortical level, and then generating movement disorders.¹⁶,⁶⁵ In the same way, it is well known now that in Huntington disease, hemichorea is caused by an imbalance between these two pathways, that is, by facilitation of the direct pathway and inhibition of the indirect pathway, resulting in an abnormal suppression of the inhibitory GPe, which explains the occurrence of involuntary movements after release of the thalamocortical circuitry.⁵⁵,⁶⁷

In case of striatal glioma resection, this phenomenon does not occur, likely because of several mechanisms. First, in Huntington disease, the degeneration involves the enkephalinergic neurons projecting onto the GPe rather than the dynorphinergic neurons projecting onto the GPi, thus favoring the overexpression of the direct pathway inhibiting the GPe.¹,²,⁵,²⁶ The resection does not allow such an imbalance to be created, because it involves the two types of striatal neurons equally.

Second, in eight patients in our series, the striatal removal was associated with resection of part of the GP. Because the surgery in the basal ganglia was conducted anteriorly to posteriorly and/or laterally to medially, then was stopped when the internal capsule (posterior limb) was identified using the subcortical electrical stimulations, the GPe was resected preferentially on the GPi, likely in part preserved in its medial portion close to the internal capsule (as confirmed on postoperative MR imaging; Fig. 1). This could result in the continuance of an inhibitory activity of the remaining GPi on the thalamus, and even a reinforcement of this activity by an increased excitatory effect of the STN (which was never removed in our experience), because this structure, which is known to induce severe dyskinesias or ballism when damaged,⁹ could not be inhibited anymore by the resected GPe. In this way, it was previously reported that a pallidal lesion was able to induce the interruption of preexisting movement disorders;¹⁴,¹⁵ this concept is the foundation of GPi surgery for dyskinesias generated by levodopa in parkinsonism. Nevertheless, it is notable that the inhibitory effect of the GPe on the STN is currently under discussion again.

Third, the ALIC was also resected in 13 patients, because it is anatomically located between the HCN medially and the anterior part of the putamen laterally, and therefore is often invaded by the infiltrating glioma. The thalamocortical pathways run in this ALIC. Thus, we can hypothesize that the removal of these fibers may prevent the expression of...
the striatal imbalance at the cortical level, with or without a transient associated motor deficit.

Fourth, it was already demonstrated at the cortical level, by using functional neuroimaging and intraoperative electrical stimulations that low-grade glioma may generate compensatory plasticity mechanisms based on functional network reshaping. It seems likely that a similar phenomenon may occur at the subcortical level, by recruitment of parallel circuits such as the pallidal–luousal– pallidal, striate–nigral–striate, cortical–striate–nigral–thalamocortical, and cortical–luousal networks. This hypothesis could explain the lack of transient movement disorders in our series; it may be caused by a preoperative long-term functional reorganization induced by the slow-growing glioma, although in acute stroke, many authors have described transient movement disorders with rapid recovery likely due to the recruitment of accessory circuits as mentioned earlier.

Consequently, plasticity phenomena caused by preexisting involvement of striatum by a long-present tumor would lead one to be cautious when speculating about pathophysiological features. To improve the understanding of these mechanisms, we could suggest performing an fMR imaging study of the basal ganglia before and after surgical resection of the glioma; such a work is currently in progress at our institution.

In summary, in this work we have shown that resection of nondominant striatum invaded by glioma can be performed without inducing either transient or definitive movement disorders. Thus, these findings may allow improvement in the quality of tumor resection.

Some modifications should be considered, however, because in 71% of cases a transient hemiparesis and/or a motor neglect occurred. These may be explained in part by the ALIC removal (partial lesion of the thalamocortical pathways) and a postoperative PLIC edema: by the resection of the insular lobe in some patients, which is known to represent a secondary motor area and also perhaps by the striatal removal itself, taking into account the major involvement of this structure in the voluntary movement already described. It is notable that in the four patients with no postoperative deficit, the surgical removal involved either only one gray nucleus (namely the putamen only; Cases 8 and 10) or two deep structures (HCN and putamen, not the GPe) with partial resection (<50% for Cases 1 and 2).

All other patients who presented with a deficit underwent a resection involving three structures (HCN, putamen, and GPe; Cases 3–6, 9, and 11–13) or two deep nuclei almost completely (>90% for both; Case 7), except in one case, the oldest patient in this series (Case 14), maybe due to a decrease of the plastic potential.

In 64% of cases, patients presented with transitory inertia with loss of interest and affect, without deterioration of intellectual function. These symptoms seem to constitute an “athymhormic syndrome,” which has been previously reported in cases of stroke or lacunar lesions of the striatum, and is likely explained by the interruption of a cortical–subcortical striatal–limbic loop including striatal afferents from the limbic frontal cortex, the striatum itself (especially its limbic component), the GP, and the dorsomedial thalamic nucleus. These results show that the basal ganglia play an important role in the control of emotion and behavior. Finally, it is important to emphasize that all the resections in this series involved exclusively the right, nondominant striatum, because of the essential participation of the left, dominant basal ganglia in language.

Conclusions

Our findings show that the right, nondominant striatum can be removed in case of glioma invasion, without inducing movement disorders, even transitory ones. This phenomenon could be explained by the combined resection of the two types of striatal neurons, by an associated pallidal and thalamocortical resection, and likely by compensatory recruitment of parallel networks. Thus, these results may allow us to maximize the extent of removal of low-grade glioma located in basal ganglia.

Due to the important role of the striatum in movement and behavior, however, its resection may induce transient hemiparesis, motor neglect, and even athymhormic syndrome, necessitating that the patient be clearly informed before surgery.

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References


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