Infarction of the lateral posterior choroidal artery territory after manipulation of the choroid plexus at the atrium: causal association with subependymal artery injury

Clinical article

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Object. The atrium of the lateral ventricle is often affected by tumors, and some patients with these tumors suffer neurological deficits, including hemiparesis after surgery. The authors of this study investigated the possible mechanisms causing the relatively high incidences of ischemic complications associated with surgery approaching the atrium of the lateral ventricle.

Methods. Clinical records and radiological images of 28 patients were retrospectively studied. These patients had their lateral ventricles opened at the atrium during the resection of gliomas as well as other nonbenign brain tumors, and were treated for gliomas at our tertiary referral center in the Tohoku district, Japan, between January 2008 and December 2010.

Results. Routine postoperative diffusion-weighted MR images obtained within 72 hours after surgery detected infarction in the periatrial/periventricular regions in 7 patients, presumably corresponding to the lateral posterior choroidal artery (LPChA) territory. Five of these 7 patients suffered neurological sequelae with varying severities. The choroid plexus at the atrium was coagulated to achieve hemostasis during the surgery in all of these patients. Detailed analysis of microangiograms revealed ventriculofugal arteries arising from the lateral ventricle. Damage of the subependymal artery that supplies the ventriculofugal arteries caused by coagulation of the choroid plexus at the atrium probably resulted in the infarction in these patients.

Conclusions. Neurosurgeons must be aware of the possibility of LPChA territory infarction during surgery in the atrial or periatrial regions caused by subependymal artery obstruction after manipulating or coagulating the choroid plexus near the atrium.

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Key Words • infarction • lateral posterior choroidal artery • atrium • subependymal artery • choroid plexus • vascular disorders

Abbreviations used in this paper: AChA = anterior choroidal artery; LPChA = lateral posterior choroidal artery; MMT = Manual Muscle Test.

Tumors such as gliomas and meningiomas, and vascular diseases such as arteriovenous malformations, occasionally affect the atrium of the lateral ventricle or the adjacent area. Surgical treatment for atrial and periatrial tumors is considered challenging because of the deep location and the relationship to the vascular structures, such as the choroidal arteries and the deep venous system.¹,² Related complications include visual field disturbances, motor deficits, language deficits, cognitive deficits, and others. These postsurgical neurological deficits can be attributed to direct damage to the optic radiations and eloquent language cortex, to extensive retraction during surgery, to obstruction of bridging veins, and so on.¹,³ However, arterial ischemic complications due to surgery have not been extensively studied.

Recently we performed diffusion-weighted MRI within 72 hours after every surgery, and this experience revealed a substantial risk of ischemia in the periatrial/periventricular regions after surgery for atrial and periatrial tumors. Patients who developed such ischemic complications appeared to share a common feature of damage to the choroid plexus at the atrium during surgery. Therefore, we suspected that such ischemic complications might occur in areas supplied by the choroidal arteries of the lateral ventricle.

The present study retrospectively analyzes the findings of patients who had undergone surgery for atrial and periatrial tumors and had suffered postsurgical compli-
Infarction after surgery approaching the atrium cations due to infarction in the periatral/periventricular regions, and discusses the causal association with injury to the subependymal arteries.

Methods

Patient Population

Our hospital (Tohoku University Hospital) acts as a tertiary referral center for patients with gliomas in the Tohoku district, Japan; thus, we treat gliomas as well as other nonbenign brain tumors. We treated 28 cases requiring opening of the lateral ventricle at the atrium during resection of a tumor between January 2008 and December 2010. Clinical records and radiological examinations of these patients were retrospectively analyzed.

Microangiography in Cadavers

Coronal and axial microangiograms of 5 cadaveric brains without gross pathological features, obtained as part of a microangiographic study on the distribution of the basal perforating arteries that had been conducted by 1 of the authors (S.T.) in 1985,13,14 were reanalyzed to examine the subependymal arteries in and around the choroid plexus at the atrium.

Results

Analysis of Patients With Infarctions

Seven of the 28 patients developed infarctions in the periatral/periventricular regions, identified as hyperintense lesions on diffusion-weighted MRI obtained within 3 days after surgery. Two patients remained free of symptoms, whereas 5 patients developed symptoms including deterioration of visual dysfunction, motor weakness, sensory dysfunction, and neuropsychological disturbances (Table 1). All symptoms except for the visual disturbances recovered gradually. Four patients were able to return home and were walking at 1–2 months after surgery, although 1 patient required instrumentation because of foot drop. Another patient required additional rehabilitation because of hemiparesis, but was able to walk afterward.

Analysis of Microangiography Findings

Coronal microangiography of the 5 cadavers showed the presence of ventriculofugal arteries distributed in the periventricular region along the body and atrium of the lateral ventricle (Fig. 1). The infarcted areas found in our series of patients were likely to coincide generally with the supply areas of these arteries.

Illustrative Cases

Case 1

This 58-year-old man had a history of left temporal subcortical hematoma that first occurred in June 2008. He was admitted to a local hospital with recurrent left temporal subcortical hematoma in November 2008. Removal of the hematoma was performed. The histopathological diagnosis of the specimen obtained during surgery was glioblastoma. The patient was referred to our hospital for subsequent treatment. On admission, right homonymous hemianopia, aphasia, alexia, and recent memory disturbance were detected (Table 1). Contrast-enhanced T1-weighted MRI demonstrated the tumor in the left temporal lobe (Fig. 2A and B). Removal of this tumor was performed in January 2009 (Fig. 2C and D). During surgery, the choroid plexus at the atrium was coagulated and cut because of the tumor invasion. After surgery, the patient developed right hemiparesis with an MMT score of 2/5. Postoperative MRI revealed removal of the tumor associated with the high-intensity lesions on diffusion-weighted imaging in areas including the left cerebral peduncle, posterior lateral thalamus, posterior limb of the internal capsule, posterior

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Preop Symptoms</th>
<th>Additional Postop Deficits</th>
<th>Outcome of Additional Symptoms</th>
<th>Manipulation of Choroid Plexus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>58, M</td>
<td>Dyslexia, agraphia, right homonymous hemianopia, short-term memory disturbance</td>
<td>Right hemiparesis (2/5), right sensory disturbance, mild consciousness disturbance, sensory aphasia</td>
<td>Hemiparesis improved to 3–4/5, consciousness level &amp; aphasia recovered</td>
<td>Coagulated, cut at its stem, &amp; partially removed</td>
</tr>
<tr>
<td>2</td>
<td>32, M</td>
<td>Left homonymous hemianopia</td>
<td>Left hemiparesis (3/5)</td>
<td>Hemiparesis improved to 4/5</td>
<td>Coagulated</td>
</tr>
<tr>
<td>3</td>
<td>47, M</td>
<td>Left homonymous hemianopia, left hemiparesis (4/5)</td>
<td>Left hemiparesis (2/5)</td>
<td>Hemiparesis improved to 4/5</td>
<td>Coagulated, cut at its stem, &amp; partially removed</td>
</tr>
<tr>
<td>4</td>
<td>37, F</td>
<td>Left homonymous hemianopia</td>
<td>Mild consciousness disturbance, depression, left hemiparesis (2/5)</td>
<td>Hemiparesis improved to 4/5, consciousness level &amp; depression recovered</td>
<td>Coagulated, cut, &amp; partially removed</td>
</tr>
<tr>
<td>5</td>
<td>65, F</td>
<td>Gerstmann syndrome, left homonymous hemianopia</td>
<td>Mild consciousness disturbance, right hemiparesis (3/5), sensory aphasia</td>
<td>Recovered</td>
<td>Coagulated, cut, &amp; partially removed</td>
</tr>
</tbody>
</table>

* Manual Muscle Test scores are listed within the table for the following categories: preoperative symptoms, additional postoperative deficits, and outcome of additional symptoms (2/5, 3/5, or 4/5).
periventricular region, and posterior hippocampus (Fig. 2E–H). His right hemiparesis gradually recovered, leaving mild to moderate hemiparesis, with MMT scores of 4/5 in the upper limb and 3/5 in the lower limb after 2 months of surgery. He was able to use a wheelchair by himself and was discharged to another hospital for additional rehabilitation.

**Case 2**

This 32-year-old man with an 8-year history of intracranial low-grade fibromyxoid sarcoma underwent his sixth surgical removal of recurrent tumor surrounding the atrium of the lateral ventricle (Fig. 3A).11 Previously he had suffered left homonymous hemianopia and slight left-sided motor weakness (Table 1), and visited a local hospital in September 2009. The axial T1-weighted MRI with contrast enhancement revealed a tumor occupying the space from the right temporal area to the insuloopercular area (Fig. 4A). He was referred to our hospital and underwent removal of the tumor in October 2009. During surgery the choroid plexus at the atrium was coagulated, cut at its stem, and partially removed together with the tumor. He developed left hemiparesis with an MMT score of 2/5 after surgery. Postoperative MRI revealed removal of the tumor with the high-intensity lesions on diffusion-weighted images in the posterolateral thalamus and posterior parts of the periventricular region (Fig. 4B–E). His hemiparesis improved to an MMT score of 4/5. One and a half months after surgery, he was walking and was discharged home.

**Discussion**

Surgical removal of clearly circumscribed lesions in
Infarction after surgery approaching the atrium

**Fig. 3.** Case 2. Axial T1-weighted MR images with contrast enhancement obtained before (A) and after (B) surgery. Diffusion-weighted images obtained within 72 hours of surgery (C–E) revealed high-intensity areas at the dorsolateral aspect of the right side of the thalamus.

**Fig. 4.** Case 3. Axial T1-weighted MR images with contrast enhancement before (A) and after (B) surgery. Diffusion-weighted images obtained within 72 hours of surgery (C–E) revealed high-intensity areas at the posterolateral thalamus and posterior parts of the caudate nucleus.
the atrial and periatrial regions, including meningiomas, metastases, and cavernomas, resulted in an 11% incidence of motor deficits.\textsuperscript{4} Mild to moderate hemiparesis is not uncommon after excision of a large atrial tumor via a middle fossa transcortical approach, presumably as a result of retraction pressure, and will resolve gradually.\textsuperscript{2} However, the incidence of permanent motor loss has been as high as 30\% in some patient series.\textsuperscript{9} Therefore, motor weakness as a complication after surgery for tumors located in or around the atrium is acceptable, although no clear explanation of the cause, including imaging data, has been proposed. Diffusion-weighted MRI obtained within 72 hours after surgery revealed infarctions in our series of patients. These findings provided indicators of the cause of motor weakness associated with surgery in the atrial and/or periatrial region. All of our patients who developed postsurgical infarction underwent coagulation of the choroid plexus at the atrium. We did not identify any other procedures that could be related to infarction of the posterior periventricular region. On the other hand, coagulation of the choroid plexus was performed in 11 of 28 cases. Seven of 11 patients developed infarction, and 5 of 7 were symptomatic.

The ventriculofugal arteries consist of 2 types of vessels: terminal branches of the striate arteries around the frontal horn and body of the lateral ventricle, and terminal branches originating from the choroidal arteries in the atrium and posterior horn of the lateral ventricle.\textsuperscript{15,16} Although the existence of these tiny vessels was once refuted,\textsuperscript{8} the second type of ventriculofugal branches was again described as arising from the choroidal arteries and supplying the lateral wall of the lateral ventricle, under the term subependymal arteries.\textsuperscript{8} Our review of microangiograms also demonstrated the ventriculofugal distribution pattern.\textsuperscript{12} The walls of the atrium of the ventricle are predominantly nourished by the ventriculofugal arteries or the subependymal arteries of the LPChA (65\%), and less frequently by the same fine branches of the AChA (35\%).\textsuperscript{5} The choroidal arteries in the atrium of the lateral ventricle are predominantly supplied by the LPChA, compared with the AChA in most cases.\textsuperscript{3} The subependymal arteries supply the walls of the lateral ventricle and its adjacent white matter,\textsuperscript{5,15,16} although the exact vascular supply of the vessels is unknown.

The extent of infarction was quite variable in our patients, but included the lateral part of the pulvinar nuclei, dorsolateral part of the thalamus, posterior periventricular wall of the lateral ventricle, part of the lateral geniculate body, and the hippocampal formation, and generally coincided with the vascular supply area of the LPChA and its subependymal arteries.\textsuperscript{7,15} The variations in the occurrence and extent of the lesion, and in the severity of neurological sequelae, may depend on the rich anastomoses between the LPChA and AChA within or around the choroid plexus, as well as many connections between the LPChA and medial posterior choroidal artery.\textsuperscript{2,10,17} Additionally, the lesion in the hippocampus found in Case 1 may be explained by the fact that hippocampal arteries sometimes arise from the LPChA.\textsuperscript{32} Therefore, we suggest that the infarcts found in our series of patients were probably caused by surgical damage to the choroidal arteries within or around the choroid plexus at the atrium of the lateral ventricle, especially the LPChA.

Surgical procedures for diseases located at or around the atrium often approach the atrium and thus cause bleeding from the choroid plexus. In such situations, many neurosurgeons coagulate the choroid plexus to achieve hemostasis, but substantial damage to the choroid plexus may result in ischemic complications. Moreover, the surgical approach to intraxial tumors located around the atrium is often planned via routes including the tumor location, ultimately opening the atrium. In such situations, the approach route may be enlarged, thus resulting in more severe damage to the vessels at the atrium.

Our series of (mainly) glioma cases included 7 patients with complications of periatral/periventricular territory infarctions among the 28 patients whose atriums were opened during removal of tumors surrounding the atriums. Five of these 7 patients experienced motor weakness. The observed symptoms in our series of patients were similar to those reported in cases of isolated LPChA infarction, reflecting the area of infarction.\textsuperscript{10} Three neurological features have been suggested as the main symptoms of LPChA infarction: visual field defect, sensorimotor dysfunction, and neuropsychological disturbances.\textsuperscript{7} Associated hemiparesis is reported to be usually slight and transient. Speech disturbances and memory impairment are also often not severe and transient. Accordingly, the neurological deficits in our series of patients gradually improved with time.

Whether or not the subependymal arteries really supply the adjacent white matter, including the pyramidal tract, remains unclear. This group of vessels and their supply distribution require further studies. However, surgery approaching the atrium of the lateral ventricle obviously carries the risk of damaging these vessels. Neurosurgeons must be aware of the relatively high incidences of LPChA territory infarction when planning surgery, with the possibility of opening the atrium of the lateral ventricle and damaging the choroid plexus. Coagulation of the choroid plexus should be avoided, especially at the stem of the plexus, as the subependymal arteries most often arise from the plexal segment of the AChA and LPChA, at the level of the choroid fissure.

Conclusions

The present patient series illustrates the ischemic complications found after surgery for tumors at or around atrium of the lateral ventricle. After surgery to open the atrium, patients can develop infarction in the LPChA territory that is frequently symptomatic. Damage to the subependymal arteries caused by coagulation of the choroid plexus may be the cause of such sequelae. Surgeons must be aware of the possibility of ischemic complications during surgery in the atrial or periatrial regions.

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
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include the following. Conception and design: Kumabe, Saito, Sonoda, Takahashi. Acquisition of data: Kumabe, Saito, Sonoda, Kanamori, Mugikura, Takahashi. Analysis and interpretation of data: Kumabe, Saito, Sonoda, Kanamori, Mugikura, Takahashi. Drafting the article: Kumabe, Saito, Takahashi. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Kumabe. Administrative/technical/material support: Kumabe, Sonoda, Kanamori, Mugikura, Takahashi. Study supervision: Kumabe, Tominaga.

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