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Role of the parietooccipital fissure and its implications in the pathophysiology of posterior medial temporal gliomas

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OBJECTIVE The parietooccipital fissure is an anatomical landmark that divides the temporal, occipital, and parietal lobes. More than 40% of gliomas are located in these three lobes, and the temporal lobe is the most common location. The parietooccipital fissure is located just posterior to the medial temporal lobe, but little is known about the clinical significance of this fissure in gliomas. The authors investigated the anatomical correlations between the parietooccipital fissure and posterior medial temporal gliomas to reveal the radiological features and unique invasion patterns of these gliomas.

METHODS The authors retrospectively reviewed records of all posterior medial temporal glioma patients treated at their institutions and examined the parietooccipital fissure. To clarify how the surrounding structures were invaded in each case, the authors categorized tumor invasion as being toward the parietal lobe, occipital lobe, isthmus of the cingulate gyrus, insula/basal ganglia, or splenium of the corpus callosum. DSI Studio was used to visualize the fiber tractography running through the posterior medial temporal lobe.

RESULTS Twenty-four patients with posterior medial temporal gliomas were identified. All patients presented with a parietooccipital fissure as an uninterrupted straight sulcus and as the posterior border of the tumor. Invasion direction was toward the parietal lobe in 13 patients, the occipital lobe in 4 patients, the isthmus of the cingulate gyrus in 19 patients, the insula/basal ganglia in 3 patients, and the splenium of the corpus callosum in 8 patients. Although the isthmus of the cingulate gyrus and the occipital lobe are located just posterior to the posterior medial temporal lobe, there was a significantly greater preponderance of invasion toward the isthmus of the cingulate gyrus than toward the occipital lobe ($p = 0.00030$, McNemar test). Based on Schramm's classification for the medial temporal tumors, 4 patients had type A and 20 patients had type D tumors. The parietooccipital fissure determined the posterior border of the tumors, resulting in a unique and identical radiological feature. Diffusion spectrum imaging (DSI) tractography indicated that the fibers running through the posterior medial temporal lobe toward the occipital lobe had to detour laterally around the bottom of the parietooccipital fissure.

CONCLUSIONS Posterior medial temporal gliomas present identical invasion patterns, resulting in unique radiological features that are strongly affected by the parietooccipital fissure. The parietooccipital fissure is a key anatomical landmark for understanding the complex infiltrating architecture of posterior medial temporal gliomas.

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KEYWORDS posterior medial temporal glioma; parietooccipital fissure; Schramm type D; tractography; cingulum bundle; oncology

THERE is a sulcal boundary between the parietal and occipital lobes at the medial surface of the brain.[1] In the literature, this boundary has a variety of names, such as the parietooccipital sulcus,[2–4] the parietooccipital fissure,[3,5,6] or the anterior part of the calcarine sulcus and parietooccipital sulcus.[1,7,8] A connection between the tip of the parietooccipital fissure and the preoccipital notch, known as the temporooccipital line,[2,5] determines the posterior border of the temporal lobe. Therefore, this fissure is a key landmark to differentiate temporal, occipital, and parietal lobes. Although this fissure is anatomically important and easily recognized on sagittal images, the precise

ABBREVIATIONS CB = cingulum bundle; DSI = diffusion spectrum imaging; DTI = diffusion tensor imaging; EOR = extent of resection; ICBM = International Consortium for Brain Mapping; ROI = region of interest.

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contour on axial images is intricate. The parietooccipital fissure has been reported as a landmark for the posterior interhemispheric surgical approach[9,10] but has rarely been considered a landmark during glioma surgery.

Gliomas are frequently, i.e., rate reaching 30%, located in the temporal lobe.[11] Due to the unique morphology of the temporal lobe, which includes a long anterior to posterior distance, the temporal lobe can be divided into anterior and posterior parts using the widest point of the brainstem.[12,13] The temporal lobe can be further subdivided into lateral and medial parts, which affect the strategy and difficulty of glioma surgery.[12] As long as gliomas are located in the lateral temporal lobe, the anterior or posterior part does not matter for the approach to the superficial tumor. In regard to gliomas located in the medial temporal lobe, known to be challenging tumors for surgery,[13,14] location in the anterior or posterior parts does matter. "Anterior" medial temporal tumors can be removed by the transsylvian approach, anterior two-thirds lobectomy, or temporal pole resection.[13] On the other hand, "posterior" medial temporal tumors have large variations in surgical approaches, such as the suboccipital approach,[12,15] subtemporal approach,[13] occipital interhemispheric approach,[3] supracerebellar transtentorial approach,[15,16] and transcortical approach.[13,17]

The posterior medial temporal lobe comprises the posterior part of the parahippocampal gyrus.[12,13] Just posterior to this gyrus is the parietooccipital fissure subdividing the parahippocampal gyrus into the isthmus of the cingulate gyrus and occipital lobe (lingual gyrus).[3,5,16] Furthermore, as the Klingler white matter fiber dissection technique and diffusion tensor imaging (DTI) have revealed, the parahippocampal gyrus has fiber connections with surrounding structures of the parietal and occipital lobes, retrosplenial cortex, and posterior cingulate cortex.[4,18,19] In this study, we extracted anatomical and radiological features of posterior medial temporal gliomas to address the hypothesis that the parietooccipital fissure strongly affects the invasion pattern of gliomas. Increased understanding of glioma invasion patterns can be applied when choosing surgical strategies.

Methods

This paper was prepared in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.[20]

Study Design, Settings, Participants, and Variables

This study was a multicenter retrospective study with approval of the ethics committees of both the Department of Neurosurgery, Kitasato University School of Medicine, and Tohoku University School of Medicine. The term "parietooccipital fissure" was used to include both the parieto-occipital sulcus and anterior calcarine sulcus. The widest point of the brainstem subdivides the temporal lobe into anterior and posterior parts.[12,13] We used preoperative MR images from records of collected cases of glioma located in the posterior medial temporal lobe to correlate case characteristics with features of parietooccipital fissures. Data for patient demographics, WHO grade, and surgical approach were collected from the medical records. In each medial temporal glioma case, we examined the existence and shape of the parietooccipital fissure and correlated these features to the tumor location. We also examined the tumor invasion patterns of posterior medial temporal gliomas toward the surrounding brain, such as the parietal lobe, occipital lobe, isthmus of the cingulate gyrus, splenium of the corpus callosum, and insula/basal ganglia, based on preoperative MRI.

Schramm and Aliashkevich[13] classified temporal mediobasal tumors into types A, B, C, and D. In brief, types A, B, and C are located only in the medial temporal lobe, whereas type D tumors invade surrounding structures such as the insula and basal ganglia via anatomical connections.[13,14] The clinical importance of this classification is that types A, B, and C are surgically removable, but type D is not a candidate for maximal safe resection.[13,14] As this classification is widely used in other studies,[14,17,21] we differentiated posterior medial temporal gliomas into types A to D.

We used the DSI Studio (http://dsi-studio.labsolver.org) software package to process the DTI data for visualization of the fibers running through the posterior medial temporal lobe.[22] T1-weighted images displayed with the International Consortium for Brain Mapping (ICBM)–152 template[23] were rotated to visualize the parietooccipital fissure. The region of interest (ROI) was manually drawn at the left posterior medial temporal lobe or left posterior parahippocampal gyrus using the coronal image of the ICBM-152. Fiber tracking was defined using the Human Connectome Project (HCP) diffusion MRI population-averaged template (HCP-1065, 1 mm).[24] This template was constructed from diffusion MRI data from a total of 1065 subjects from the HCP. The tracking parameters were as follows: an anisotropy threshold of 0 (random selection between 0.5 and 0.7 of Otsu's threshold),[25] an angular threshold of 0 (random selection from 15° to 90°),[25] a step size of 0 (random selection between 0.5 and 1.5 voxel distance),[25] and minimum and maximum fiber lengths of 20 and 500 mm. The next moving directional estimate of each voxel was weighted by 20% of the previous incoming direction and 80% of the nearest fiber orientation to smooth each tract.[26] We also visualized the fibers running through the posterior medial temporal using preoperative MR diffusion tractography data in iPlan Cranial 3.0 (Brainlab AG). A fractional anisotropy threshold of 0.15 was applied as previously reported.[27]

Surgery

The surgical approach was determined by the tumor location and invasion pattern. If the posterior medial temporal gliomas extended anteriorly, we first removed the anterior part by combining the transsylvian approach, anterior two-thirds lobectomy, and transcortical approach, as we and others have previously reported.[13,14] Through the resection cavity, we subsequently removed the posterior part of the tumor. Localized posterior medial temporal tumors were removed by transcortical, subtemporal, or suboccipital approaches, whereas most posterior medial temporal tumors invading surrounding structures were removed by the transcortical approach. We used Sonopet (Stryker) under a microscope for tumor removal. We utilized 5-aminolevulinic acid (5-ALA) and the navigation-guided fence

TABLE 1. Demographics of posterior medial temporal gliomas

			Invasion Route										
			Anatomical							POF			
Pt No.	Pt Age, Yrs/Sex	Histology/WHO Grade	Parietal	Isthmus	Splenium	Insula/Basal Ganglia	Occipital	Ant or Pst	Schramm's Type	Uninterrupted	Pst Border	Op Approach	EOR, %
1	44/F	G/I	No	No	No	No	No	Pst	A	Yes	Yes	Subtemporal	100
2	7/M	DA/II	No	No	No	No	No	Pst	A	Yes	Yes	OTA	100
3	14/M	PA/I	No	No	No	No	No	Pst	A	Yes	Yes	OTA	100
4	47/M	DA/II	No	No	No	No	No	Pst	A	Yes	Yes	OTA	100
5	54/M	GB/IV	Yes	Yes	Yes	No	Yes	Pst	D	Yes	Yes	Transcortical	100
6	57/M	GB/IV	Yes	Yes	Yes	No	No	Pst	D	Yes	Yes	Transcortical	100
7	47/F	GB/IV	Yes	Yes	No	No	Yes	Pst	D	Yes	Yes	Transcortical	98
8	52/F	GB/IV	Yes	Yes	Yes	No	Yes	Pst	D	Yes	Yes	Transcortical	100
9	66/F	G/I	Yes	Yes	No	No	No	Pst	D	Yes	Yes	Transcortical	100
10	49/M	GB/IV	No	Yes	No	No	No	Pst	D	Yes	Yes	Transcortical	100
11	64/F	GB/IV	Yes	Yes	No	No	No	Pst	D	Yes	Yes	Transcortical	89
12	25/F	AA/III	Yes	Yes	No	No	No	Pst	D	Yes	Yes	OTA	100
13	64/M	GB/IV	No	Yes	No	No	No	Pst	D	Yes	Yes	Transcortical	100
14	50/M	GB/IV	Yes	Yes	No	No	No	Pst	D	Yes	Yes	Transcortical	100
15	27/M	AA/III	Yes	Yes	Yes	No	No	Pst	D	Yes	Yes	OTA	100
16	41/M	GB/IV	No	Yes	No	No	No	Pst	D	Yes	Yes	Transcortical	100
17	69/M	GB/IV	Yes	Yes	Yes	No	No	Ant + pst	D	Yes	Yes	OTA	67
18	56/F	AO/III	No	Yes	No	No	No	Ant + pst	D	Yes	Yes	A2/3	100
19	42/F	AA/III	Yes	Yes	Yes	No	Yes	Ant + pst	D	Yes	Yes	Transcortical	68
20	64/F	GB/IV	Yes	Yes	Yes	No	No	Ant + pst	D	Yes	Yes	A2/3	100
21	58/F	GB/IV	Yes	Yes	Yes	No	No	Ant + pst	D	Yes	Yes	A2/3	89
22	19/F	DA/II	No	Yes	No	Yes	No	Ant + pst	D	Yes	Yes	Transcortical	79
23	55/M	GB/IV	No	No	No	Yes	No	Ant + pst	D	Yes	Yes	A2/3	96
24	65/M	AA/III	No	Yes	No	Yes	No	Ant + pst	D	Yes	Yes	A2/3	74

A2/3 = anterior two-thirds lobectomy; AA = anaplastic astrocytoma; ant = anterior; AO = anaplastic oligodendroglioma; DA = diffuse astrocytoma; G = ganglioglioma; GB = glioblastoma; OTA = occipital transtentorial approach; PA = pilocytic astrocytoma; POF = parietooccipital fissure; pst = posterior; pt = patient.

post procedure to determine the corridor to the tumor.[28] Language mapping under awake surgery was performed in cases with gliomas in the dominant hemisphere. Subependymal arteries running inside the choroid plexus at the atrium may supply the descending motor pathway;[29,30] thus, coagulation of the choroid plexus in this location was avoided. The extent of resection (EOR) was calculated as follows: (preoperative tumor volume − postoperative tumor volume)/preoperative tumor volume × 100.[31] ROI of the tumor was manually drawn based on gadolinium-enhanced T1-weighted images for enhancing tumors and T2-weighted or fluid-attenuated inversion recovery images for nonenhancing tumors.

Results

Patient Characteristics

The study included 24 patients with a glioma located at the posterior medial temporal lobe. Patient demographics, grades of gliomas, and EORs are shown in Table 1. The mean patient age was 47.3 years, and 11 patients (46%) were female. The WHO grade of the tumor was grade I in 3 patients, grade II in 3 patients, grade III in 5 patients, and grade IV in 13 patients. In 8 patients the tumors were long in diameter, occupying both the anterior and posterior parts of the medial temporal lobe, whereas in 16 patients the tumor occupied only the posterior part. Surgical approaches for the posterior medial temporal gliomas were subtemporal in 1 patient, occipital transtentorial in 6 patients, transcortical in 12 patients, and anterior two-thirds lobectomy in 5 patients.

Parietooccipital Fissure, Radiological Features, and Invasion Patterns of Posterior Medial Temporal Gliomas

Anatomically, the parietooccipital fissure is located posterior to the medial temporal lobe (Fig. 1A), followed by either the isthmus of the cingulate gyrus or occipital lobe (Fig. 1B).[16] Figure 1 was created with DSI Studio using axial and sagittal T1-weighted images aligned to the ICBM template.[23] The parietooccipital fissure marks the medial aspect of the hemisphere and has a width as visualized on the axial image (Fig. 1C). First, we examined the presence of the parietooccipital fissure in our cohort. All patients presented with the fissure as an uninterrupted straight sulcus reaching from the cerebellar tentorium to the brain surface (Table 1; white arrows in Figs. 2, 3, and

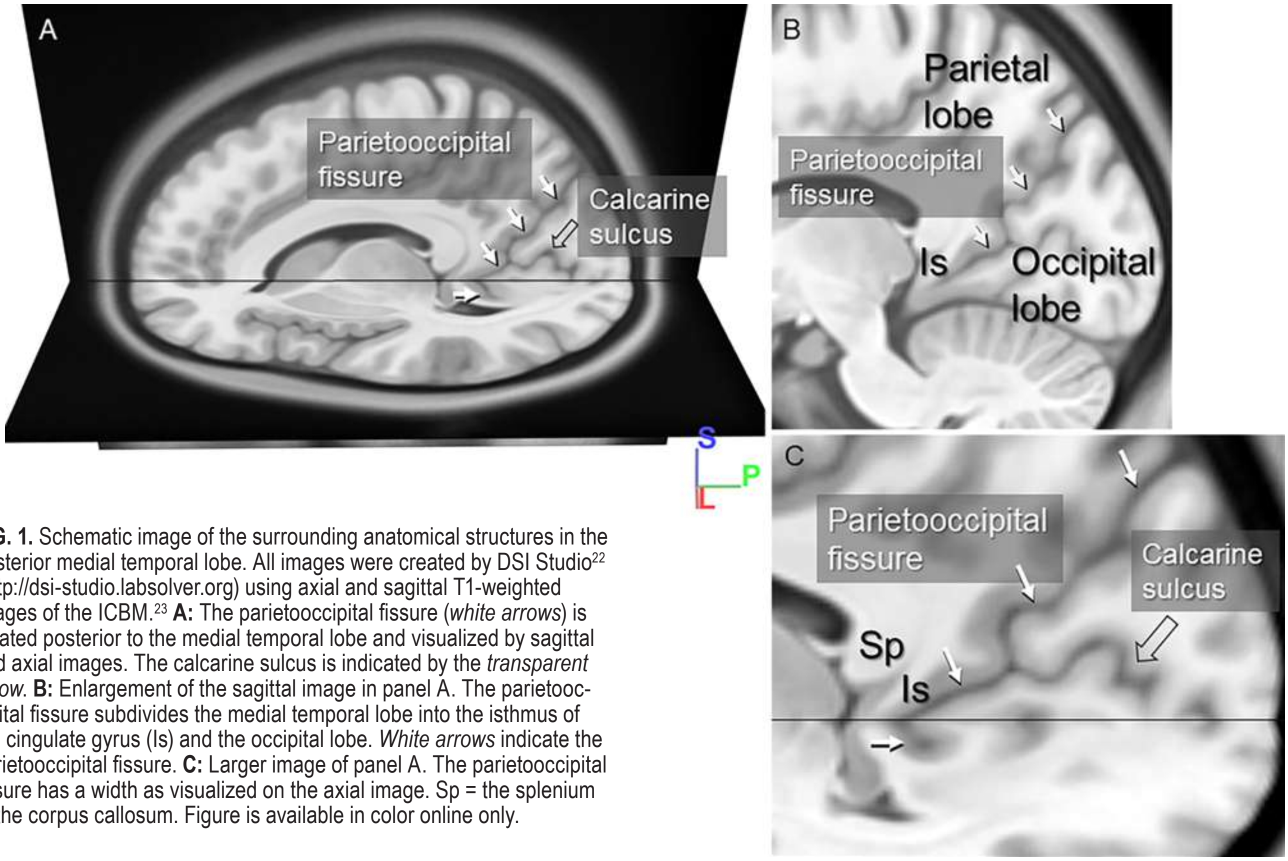

FIG. 1. Schematic image of the surrounding anatomical structures in the posterior medial temporal lobe. All images were created by DSI Studio[22] (http://dsi-studio.labsolver.org) using axial and sagittal T1-weighted images of the ICBM.[23] **A:** The parietooccipital fissure (*white arrows*) is located posterior to the medial temporal lobe and visualized by sagittal and axial images. The calcarine sulcus is indicated by the *transparent arrow.* **B:** Enlargement of the sagittal image in panel A. The parietooccipital fissure subdivides the medial temporal lobe into the isthmus of the cingulate gyrus (Is) and the occipital lobe. *White arrows* indicate the parietooccipital fissure. **C:** Larger image of panel A. The parietooccipital fissure has a width as visualized on the axial image. Sp = the splenium of the corpus callosum. Figure is available in color online only.

4A). Next, we assessed the anatomical architecture between the tumor location and the fissure in each patient. Of note, the anterior end of the parietooccipital fissure was always the posterior border of the tumor (Table 1; white arrows in Figs. 2, 3, and 4A). Of 24 patients, 4 patients had gliomas that were relatively small in size and remained in the posterior medial temporal lobe (Table 1, patients 1–4; Fig. 2A–D), whereas the other 20 patients presented with tumor invasion toward surrounding structures (Table 1, patients 5–24; Figs. 2E–K, 3, and 4A). The invasion patterns of the gliomas in the 20 patients included invasion toward the parietal lobe in 13 patients, toward the isthmus of the cingulate gyrus in 19 patients, toward the splenium of the corpus callosum in 8 patients (Figs. 2 and 3, triangles), toward insula/basal ganglia in 3 patients (Fig. 3J–L, transparent triangles), and toward the occipital lobe in 4 patients (Figs. 2E, 2G, 3G, and 4A, transparent arrows). Both the isthmus of the cingulate gyrus and the occipital lobe are located just posterior to the posterior medial temporal lobe, but there was a significantly greater preponderance of glioma invasion toward the isthmus of the cingulate gyrus (in 19 of 20 patients) than toward the occipital lobe (in 4 of 20 patients) ($p = 0.00030$, McNemar test). Eight patients had large tumors occupying both the anterior and posterior of the medial temporal lobe (Fig. 3E–L).

MRI of the 20 patients with glioma invasion showed a clear posterior border on the axial images (Figs. 2, 3, and 4A). Sagittal images showed that the tumor invaded along and anterior to the parietooccipital fissure (Figs. 2, 3, and 4A), resulting in the clear posterior border observed with axial imaging. Four gliomas with occipital invasion showed a high-intensity lesion on T2-weighted images that barely reached the occipital lobe after detouring around the outside bottom of the parietooccipital fissure (Figs. 2E, 2G, 3G, and 4A, transparent arrows). Figure 2G presents a cystic component, or trapped ventricle, that reached the occipital lobe and detoured the parietooccipital fissure. Overall, the medial aspect of the occipital lobe was free from tumor invasion. Compared to posterior medial temporal gliomas, we identified a glioblastoma located posterior to the parietooccipital fissure (at the anterior tip of the cuneus) (Fig. 4B). Since the parietooccipital fissure was the anterior border of this tumor, there was a clear anterior radiological border, and the anteriorly invading tumor had to detour around the outside bottom of the parietooccipital fissure in a posterior to anterior direction.

Schramm's Classification of Posterior Medial Temporal Gliomas and Surgery

The 24 posterior medial temporal gliomas were grouped by Schramm's classification. Based on Schramm's classification, 4 tumors that remained in the posterior temporal lobe were posterior type A (Fig. 2A–D). The other 20 tumors had invasion toward surrounding structures (Figs. 2E–K, 3A–L, and 4A). Based on the original Schramm's classification, type D has to invade the insula/basal ganglia.[13] Only 3 patients (patients 22–24) had tumors which occupied both the anterior and posterior parts of the medial temporal lobe and presented invasion toward the insula/basal ganglia from their anterior part, fulfilling the criteria

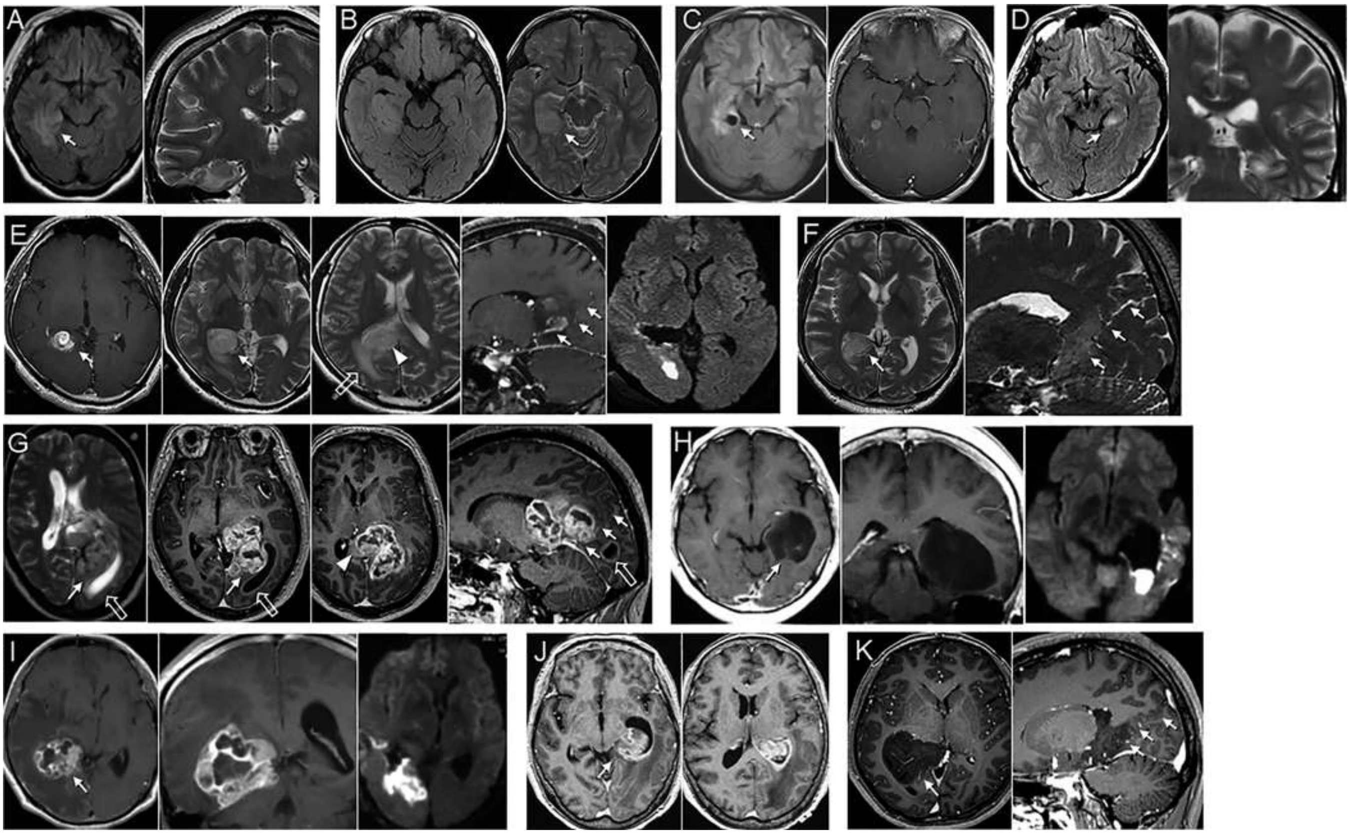

FIG. 2. Axial, coronal, and sagittal MR images of posterior medial temporal gliomas. *White arrows* indicate the parietooccipital fissure. *White triangles* indicate corpus callosum invasion, and *transparent arrows* indicate occipital invasion. All MR images showed a clear posterior border of the tumor determined by the parietooccipital fissure. Panels E, H, and I include postoperative DWI to demonstrate ischemic changes at the occipital lobe. Panels A–F correspond to patients 1–6, respectively, and panels G–K correspond to patients 8–12, respectively (patient 7 is shown in Fig. 4A). **A–D:** Small tumors restricted to the posterior medial temporal lobe, classified as Schramm's type A. **E–K:** Tumors presenting invasion of one or more of the parietal lobes, the isthmus of the cingulate gyrus, the splenium of the corpus callosum (*white triangles*), insula/basal ganglia (*transparent triangles*), and the occipital lobe (*transparent arrows*).

of type D (Table 1; Fig. 3J–L, transparent triangles). In the other 17 patients there was no tumor invasion toward the insula/basal ganglia, indicating that these tumors did not meet Schramm's definition but had invasion toward either the parietal lobes, the isthmus of the cingulate gyrus, the splenium of the corpus callosum, or the occipital lobe (Table 1; Figs. 2E–K, 3A–I, and 4A). Comparison of EOR between type D with and without insula/basal ganglia invasion revealed a significantly higher EOR in the latter ($p = 0.030$).

DTI Tractography

DSI Studio software enabled us to visualize white matter fibers running through the posterior medial temporal lobe (Fig. 5A–C). DTI tractography showed 1) fibers running toward the parietal lobe, 2) fibers running toward the occipital lobe, 3) fibers running toward the cingulate gyrus, and 4) fibers running toward the contralateral hemisphere via the splenium of the corpus callosum. Of note, fibers running toward the occipital lobe made a detour to avoid the parietooccipital fissure, resulting in running laterally of the outside bottom of the parietooccipital fissure to reach the occipital lobe (Fig. 5C). We obtained preoperative DTI data from patients 6 (Fig. 2F) and 7 (Fig. 4A). As demonstrated by the diffusion spectrum imaging (DSI) scans, these 2 patients also showed tractography fibers running toward the occipital lobe detouring the parietooccipital fissure (Supplementary Fig. 1). Overall, combining the invasion pattern and tractography data, Fig. 5D demonstrates a scheme to visualize how the posterior medial temporal gliomas invade surrounding structures.

Discussion

Key Results and Interpretation

The parietooccipital fissure is a key anatomical landmark for differentiating the temporal, parietal, and occipital lobes; however, to our knowledge no attention has been given to it in relation to the pathophysiology of gliomas. In our series, preoperative MR images of posterior medial temporal gliomas of different patients presented similar radiological features, with a clear posterior border, frequent tumor invasion of the isthmus of the cingulate gyrus, and infrequent invasion toward the occipital lobe. Detailed investigation of our series revealed that the parietooccipital fissure is the key anatomical structure deter-

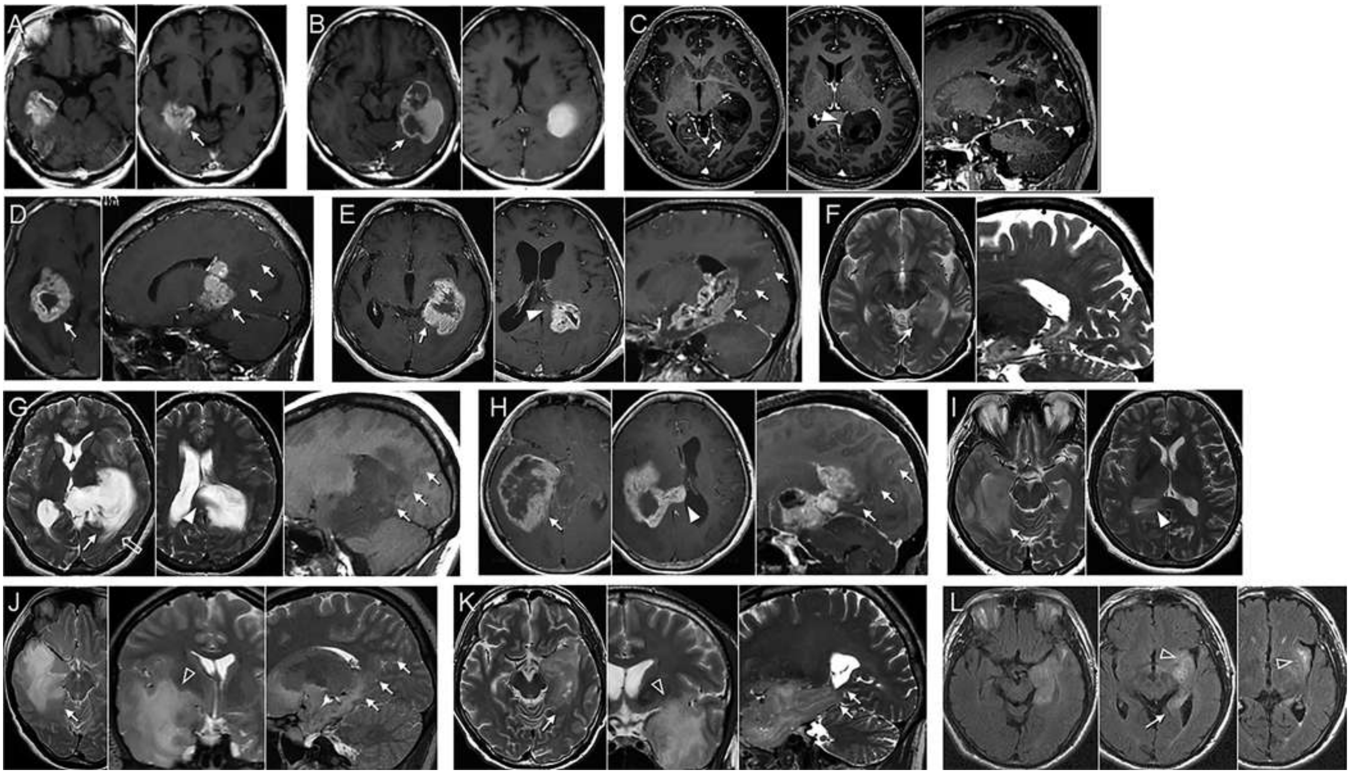

FIG. 3. Axial, coronal, and sagittal MR images of posterior medial temporal gliomas (patients 13–24). *White arrows* indicate the parietooccipital fissure, which creates a *clear posterior border* of the tumor. **A–L:** Patients 13–24, respectively. All patients presented with invasion of one or more of the parietal lobe, the isthmus of the cingulate gyrus, the splenium of the corpus callosum (*white triangles*), insula/basal ganglia (*transparent triangles*), and the occipital lobe (*transparent arrows*). E–L: Tumors occupied both anterior and posterior parts of the medial temporal lobe.

mining the pathophysiology of posterior medial temporal gliomas. Although the occipital lobe is located just posterior to the posterior medial temporal lobe (parahippocampal gyrus), gliomas in this region did not show direct invasion toward the occipital lobe. We discuss our data from four perspectives: the parietooccipital fissure, Schramm's classification, cingulum bundles (CBs), and surgery.

Parietooccipital Fissure

Although the brain's surface is a collection of wide variations in fissures, gyri, and sulci, the parietooccipital fissure has roughly no variation. A total of 92.9% of this fissure had an extension on the lateral surface, and the extension patterns were T-shaped, Y-shaped, or ramified to several branches.[1] Therefore, the anterior endpoint, or parietooccipital fissure origin, always exists as an uninterrupted large main fissure,[1] including all cases in our series. The parietooccipital fissure faces the tentorium and delineates the medial aspect of the brain; thus, this fissure is a valley running just posterior to the posterior medial temporal lobe. Our series demonstrated that posterior medial temporal gliomas have to detour this valley to reach the occipital lobe, resulting in significantly less frequent invasion toward the occipital lobe. In other words, the parietooccipital fissure, located just behind the posterior medial temporal lobe, acts as an obstacle to glioma cells showing invasion toward the occipital lobe. To support our hypothesis, axial MR images showed a clear posterior border of the tumor, and our tractography data and DTI imaging clearly showed that white matter fibers detoured the parietooccipital fissure laterally to reach the occipital lobe. To exclude the selection bias that our series may harbor, MR images of several posterior medial temporal gliomas in previous reports also demonstrated this fissure as the posterior border.[12,16,32] The medial temporal lobe is an anatomically complex region, but by focusing on the parietooccipital fissure we were able to understand the anatomical architecture and invasion pattern of gliomas in this region (Fig. 5D). In addition to the role of a landmark, the parietooccipital fissure is a key component in determining the direction of invasion.

Schramm's Classification

Based on the original classification of temporal mediobasal tumors, Schramm type D involves invasion toward the insula/basal ganglia.[13] In their report, Schramm and Aliashkevich[13] identified 8 cases (3.4%) in which tumors were classified as posterior type D. However, because there is an anatomical gap between the posterior medial temporal lobe and insula/basal ganglia, posterior type D does not logically exist. We assumed that posterior type D would be a large tumor occupying both anterior and posterior parts and that the anterior part would invade the insula/basal ganglia. Our series had 3 cases that met this assumption. Other posterior medial temporal gliomas invaded toward the isthmus of the cingulate gyrus, parietal and occipital lobes, and occasionally the splenium of the corpus callo-

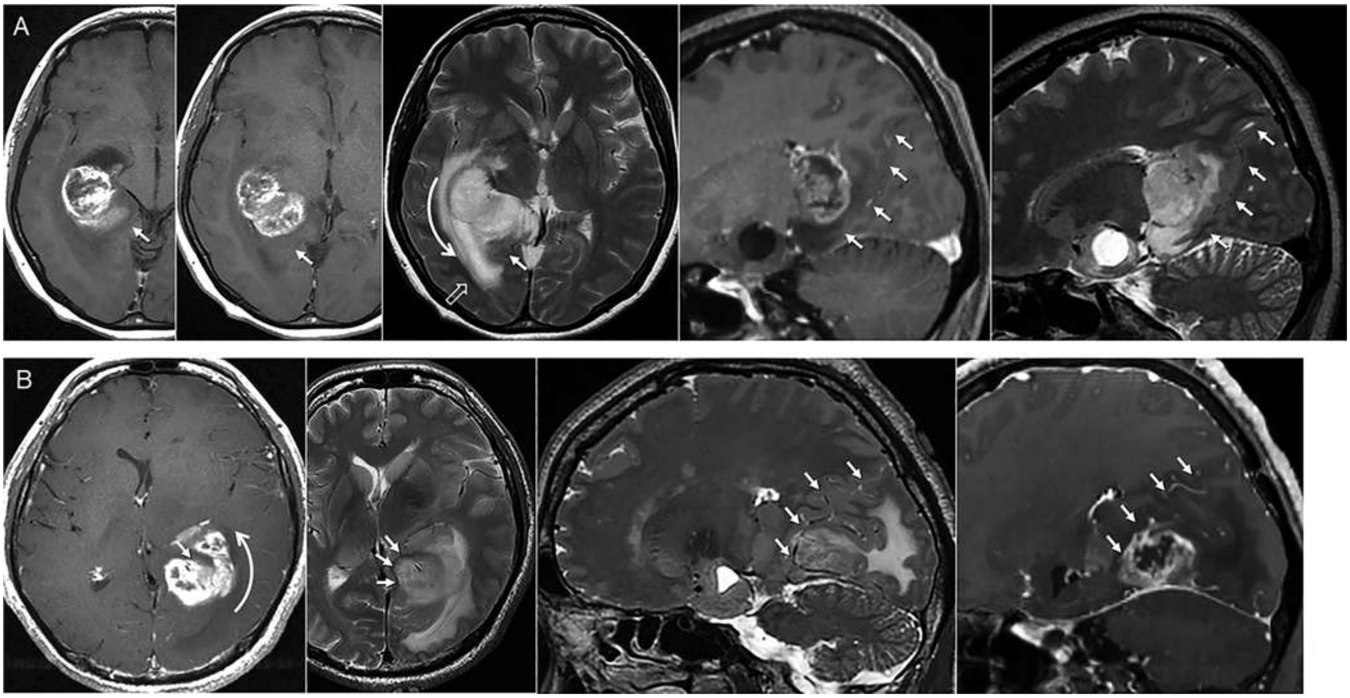

FIG. 4. Representative MR images of two glioblastomas located at the posterior medial temporal lobe and cuneus. **A:** Images obtained in a 47-year-old female patient (patient 7) with a right posterior medial temporal glioblastoma presenting invasion toward the isthmus of the cingulate gyrus and the parietal and occipital lobes (*transparent arrow*). The parietooccipital fissure comprised the posterior border of the tumor (*white arrows*). The *curved arrow* indicates the direction of the invasion detouring the parietooccipital fissure laterally to reach the occipital lobe. **B:** Images obtained in a 47-year-old male patient with a glioblastoma in the left cuneus. The parietooccipital fissure comprised the anterior border of the tumor (*white arrows*). Axial and sagittal T2-weighted images show flow voids corresponding to the parietooccipital artery running through the parietooccipital fissure. Anterior tumor invasion detoured around the parietooccipital fissure (*curved white arrow*).

sum without insula/basal ganglia invasion (Fig. 5D). Given that the nature of type D in Schramm's classification[13] included medial temporal tumors not restricted within the medial temporal lobe, our cases fulfilled the definitions of type D with a unique and unrecognized invasion pattern toward surrounding structures. Therefore, type D includes a more comprehensive range of medial temporal tumors than has been recognized. Schramm and Aliashkevich mentioned that type D is not a candidate for maximal safe resection due to invasion toward the insula/basal ganglia, but type D without insula/basal ganglia invasion can be a candidate for resection. In our series, type D without insula/basal ganglia invasion presented a significantly higher EOR than insula/basal ganglia invasion ($p = 0.030$).

Cingulum Bundles

All neurosurgeons share some impression that gliomas invade in a certain direction. Giese and Westphal reported in 1996 that the pattern of glioma invasion followed the path of blood vessels and myelinated axons rather than being a random phenomenon.[33] To date, other reports have also indicated that glioma and glioblastoma cells invade in certain directions via white matter fibers.[34–37] Due to the unique radiological features of posterior type D, we placed an ROI at the posterior medial temporal lobe (posterior parahippocampal gyrus) to interpret invasion patterns by DSI tractography. DSI tractography revealed four components running toward the parietal lobe, occipital lobe, cingulate gyrus, and contralateral hemisphere. The first three components are part of the CBs. CBs comprise five segments, CB-I to CB-V, and CB-II and CB-V stem from the parahippocampal gyrus.[18,38] CB-V is also called the parahippocampal cingulum.[18] Fibers from the parahippocampal gyrus to the superior frontal gyrus along the cingulate gyrus are CB-II,[18] and fibers interconnecting the parietal lobe, occipital lobe, posterior cingulate cortex, and medial temporal lobe are CB-V.[4,18,39] The fourth set of fibers from the posterior medial temporal lobe to the contralateral hemisphere are transcallosal fibers connecting the splenium (region V) and the inferior temporal lobe.[40–42] Therefore, fibers running through the posterior medial temporal lobe have been well investigated and matched the invasion pattern of the posterior medial temporal gliomas in the present study.

To our surprise, none of these previous studies focused on how the fibers ran toward the occipital lobe. The tractography data demonstrated that the trajectory from the posterior medial temporal lobe toward the occipital lobe detoured around the parietooccipital fissure. To support this finding, we observed 4 cases with occipital invasion, but the invasion was from the outside bottom of the parietooccipital fissure (Figs. 2E, 2G, 3G, and 4A). The parietooccipital fissure exists as a physical obstacle to posterior medial temporal gliomas to reach the occipital lobe, resulting in a greater preponderance of invasion toward the isthmus of the cingulate gyrus than the occipital lobe.

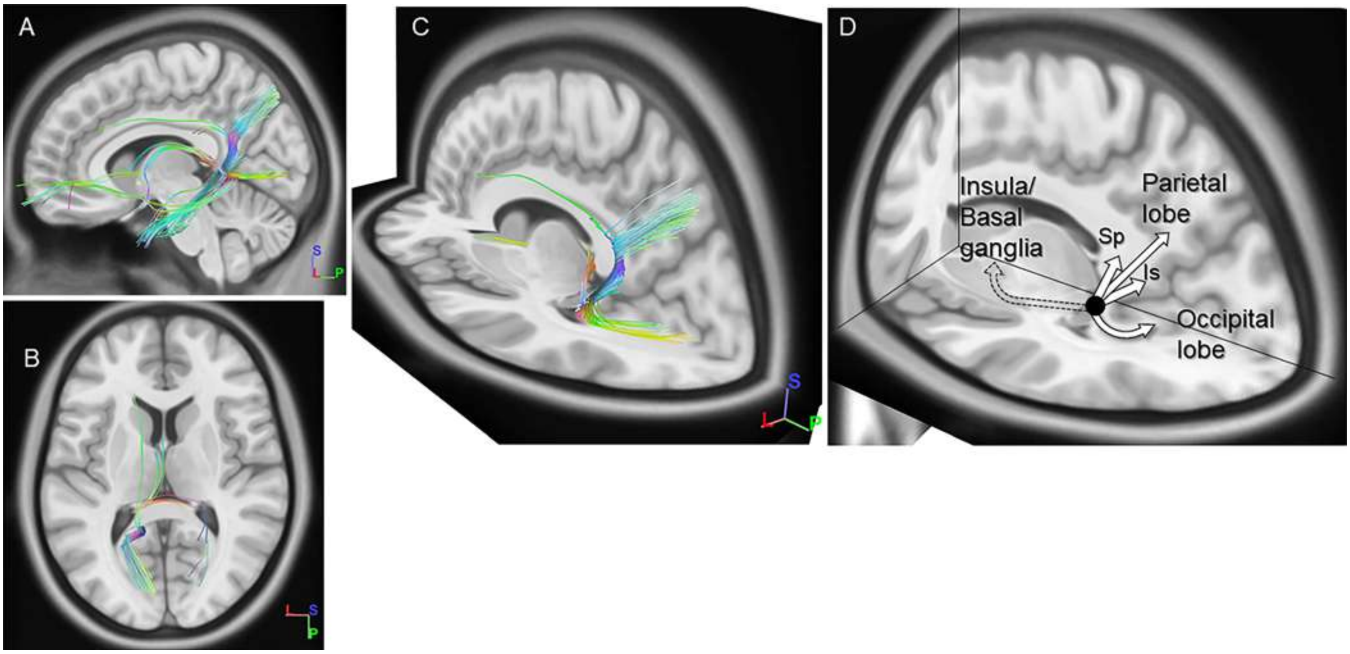

FIG. 5. DT images created by DSI Studio[22] (http://dsi-studio.labsolver.org). The ROI was placed at the posterior medial temporal lobe (posterior parahippocampal gyrus) to visualize fibers running through this region. **A–C:** Tractography fibers were registered on the axial and sagittal T1-weighted images of the ICBM.[23] Four components were visualized: fibers running toward the parietal lobe (A and C), the occipital lobe (A and C), the cingulate gyrus (A and C), and the contralateral hemisphere via the splenium of the corpus callosum (B). Fibers running toward the occipital lobe make a detour to avoid the parietooccipital fissure and as a result run lateral of the parietooccipital fissure to reach the occipital lobe (C). **D:** A schematic showing the direction of potential invasions. The *black circle* indicates the posterior medial temporal lobe. The five *arrows* indicate, in a clockwise order, invasions toward the splenium of the corpus callosum (Sp), parietal lobe, isthmus of the cingulate gyrus (Is), occipital lobe, and insula/basal ganglia through anterior medial temporal lobe.

Interestingly, our glioblastoma case located in the cuneus presented with the opposite invasion route, showing a detour around the parietooccipital fissure to invade anteriorly (Fig. 4B). Wu et al. tried without success to expose the fibers running from the parahippocampus to the occipital lobe by fiber dissection.[18] Such fibers wind medially to laterally due to the parietooccipital fissure; thus, dissection and exposure of these particular fibers from the medial aspect is almost impossible.

Surgery

The anatomical architecture of posterior medial temporal gliomas is complex due to the functional pathways, deep locations, and vascular anatomy.[15,17] As our series showed, frequent invasion toward surrounding structures further increased their complexity. In general, understanding the anatomy and invasion pattern of gliomas is essential for neurosurgeons to determine surgical strategies. According to our observations, the parietooccipital fissure always forms the posterior border of posterior medial temporal gliomas. Occipital invasion did occur but always required a detour around the fissure before reaching the occipital lobe. In this manner, focusing on the parietooccipital fissure enabled us to more easily understand the anatomical complexity of posterior medial temporal gliomas. This fissure is also important for developing surgical strategies because the parietooccipital artery branching from the posterior cerebral artery runs through the parietooccipital fissure,[43] which enables us to easily identify this fissure preoperatively using MRI or during surgery. We experienced 3 cases with postoperative ischemic changes at the occipital lobe, affected by the branches of the parietooccipital artery. These cases indirectly supported that the parietooccipital artery runs just posterior to the tumor. Overall, anterior two-thirds lobectomy is suitable for gliomas occupying both anterior and posterior parts, and the occipital transtentorial approach is suitable for relatively small tumors. The transcortical approach can be generalized to all invasion types and is particularly suitable to those invading toward splenium and parietal lobe, which need a large vertical surgical view from the tentorium to the upper end of tumor.

Study Limitations

There are several limitations to this study. First, we presented only 24 cases of posterior medial temporal tumors; thus, the study cohort was small. However, compared to the previous large series of medial temporal tumors, our cohort included the largest posterior medial temporal gliomas.[13,17] Second, our results are based on the tumor extension pattern and tractography data. Although we could not conduct fiber dissection to support our findings, a previous report supported the notion that fiber dissection and DTI have good correlations.[44] Finally, we proposed that glioma cells invade in particular directions; however, further studies are warranted from biological and molecular perspectives.

Generalizability

The temporal lobe is a frequent location of gliomas; thus, understanding the anatomy, radiological features, and physiology of temporal gliomas is important. We found that the parietooccipital fissure is an important landmark in relation to posterior medial temporal gliomas. The reason why little attention has been directed to the parietooccipital fissure is its difficult recognition on axial MRI, whereas it can be easily identified using sagittal MRI. The importance of this fissure can be applied to other gliomas located in the cuneus and medial parietal lobe.

Conclusions

The parietooccipital fissure exists as an uninterrupted main sulcus and comprises the posterior border of posterior medial temporal gliomas. Therefore, this fissure is a key landmark for understanding the anatomical architecture and invasion pattern of posterior medial temporal gliomas during preoperative analysis.

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References

1. Gürer B, Bozkurt M, Neves G, Cikla U, Hananya T, Antar V, et al. The subparietal and parietooccipital sulci: an anatomical study. *Clin Anat*. 2013;26(6):667-674.
2. Reis CV, Yagmurlu K, Elhadi AM, Dru A, Lei T, Gusmão SN, et al. The anterolateral limit of the occipital lobe: an anatomical and imaging study. *J Neurol Surg B Skull Base*. 2016;77(6):491-498.
3. Campero A, Tróccoli G, Martins C, Fernandez-Miranda JC, Yasuda A, Rhoton AL Jr. Microsurgical approaches to the medial temporal region: an anatomical study. *Neurosurgery*. 2006;59(4)(suppl 2):ONS279-ONS308.
4. Skandalakis GP, Komaitis S, Kalyvas A, Lani E, Kontrafouri C, Drosos E, et al. Dissecting the default mode network: direct structural evidence on the morphology and axonal connectivity of the fifth component of the cingulum bundle. *J Neurosurg*. 2020;134(3):1334-1345.
5. Chau AM, Stewart F, Gragnaniello C. Sulcal and gyral anatomy of the basal occipital-temporal lobe. *Surg Radiol Anat*. 2014;36(10):959-965.
6. Ovalioglu AO, Ovalioglu TC, Canaz G, Emel E. Morphologic variations of the collateral sulcus on the mediobasal region of the temporal lobe: an anatomical study. *World Neurosurg*. 2018;118:e212-e216.
7. Thompson PM, Schwartz C, Lin RT, Khan AA, Toga AW. Three-dimensional statistical analysis of sulcal variability in the human brain. *J Neurosci*. 1996;16(13):4261-4274.
8. Alonso-Vanegas MA, Freire Carlier ID, San-Juan D, Martínez AR, Trenado C. Parahippocampectomy as a new surgical approach to mesial temporal lobe epilepsy caused by hippocampal sclerosis: a pilot randomized comparative clinical trial. *World Neurosurg*. 2018;110:e1063-e1071.
9. Wang S, Salma A, Ammirati M. Posterior interhemispheric transfalx transprecuneus approach to the atrium of the lateral ventricle: a cadaveric study. *J Neurosurg*. 2010;113(5):949-954.
10. Yaşargil MG, Abdulrauf SI. Surgery of intraventricular tumors. *Neurosurgery*. 2008;62(6)(suppl 3):1029-1041.
11. Larjavaara S, Mäntylä R, Salminen T, Haapasalo H, Raitanen J, Jääskeläinen J, Auvinen A. Incidence of gliomas by anatomic location. *Neuro Oncol*. 2007;9(3):319-325.
12. Faust K, Schmiedek P, Vajkoczy P. Approaches to temporal lobe lesions: a proposal for classification. *Acta Neurochir (Wien)*. 2014;156(2):409-413.
13. Schramm J, Aliashkevich AF. Temporal mediobasal tumors: a proposal for classification according to surgical anatomy. *Acta Neurochir (Wien)*. 2008;150(9):857-864.
14. Shibahara I, Hanihara M, Miyasaka K, Sato S, Hide T, Kumabe T. Temporal glioblastoma mimicking basal ganglia invasion: distinguishing removable and unremovable tumors. *World Neurosurg*. 2019;130:e213-e221.
15. Jittapiromsak P, Deshmukh P, Nakaji P, Spetzler RF, Preul MC. Comparative analysis of posterior approaches to the medial temporal region: supracerebellar transtentorial versus occipital transtentorial. *Neurosurgery*. 2009;64(3 suppl): ons35-ons43.
16. Weil AG, Middleton AL, Niazi TN, Ragheb J, Bhatia S. The supracerebellar-transtentorial approach to posteromedial temporal lesions in children with refractory epilepsy. *J Neurosurg Pediatr*. 2015;15(1):45-54.
17. Morshed RA, Young JS, Han SJ, Hervey-Jumper SL, Berger MS. The transcortical equatorial approach for gliomas of the mesial temporal lobe: techniques and functional outcomes. *J Neurosurg*. 2018;130(3):822-830.
18. Wu Y, Sun D, Wang Y, Wang Y, Ou S. Segmentation of the cingulum bundle in the human brain: a new perspective based on DSI tractography and fiber dissection study. *Front Neuroanat*. 2016;10:84.
19. De Simoni S, Grover PJ, Jenkins PO, Honeyfield L, Quest RA, Ross E, et al. Disconnection between the default mode network and medial temporal lobes in post-traumatic amnesia. *Brain*. 2016;139(Pt 12):3137-3150.
20. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Lancet*. 2007; 370(9596):1453-1457.
21. Quinones-Hinojosa A, Raza SM, Ahmed I, Rincon-Torroella J, Chaichana K, Olivi A. Middle temporal gyrus versus inferior temporal gyrus transcortical approaches to high-grade astrocytomas in the mediobasal temporal lobe: a comparison of outcomes, functional restoration, and surgical considerations. *Acta Neurochir Suppl*. 2017;124:159-164.
22. Yeh FC, Verstynen TD, Wang Y, Fernández-Miranda JC, Tseng WY. Deterministic diffusion fiber tracking improved by quantitative anisotropy. *PLoS One*. 2013;8(11):e80713.
23. Lancaster JL, Tordesillas-Gutiérrez D, Martinez M, Salinas F, Evans A, Zilles K, et al. Bias between MNI and Talairach coordinates analyzed using the ICBM-152 brain template. *Hum Brain Mapp*. 2007;28(11):1194-1205.
24. Yeh FC, Panesar S, Fernandes D, Meola A, Yoshino M, Fernandez-Miranda JC, et al. Population-averaged atlas of the macroscale human structural connectome and its network topology. *Neuroimage*. 2018;178:57-68.
25. Yeh FC. Shape analysis of the human association pathways. *Neuroimage*. 2020;223:117329.
26. Fernández-Miranda JC, Wang Y, Pathak S, Stefaneau L, Verstynen T, Yeh FC. Asymmetry, connectivity, and segmenta-

tion of the arcuate fascicle in the human brain. *Brain Struct Funct*. 2015;220(3):1665-1680.
27. Wende T, Kasper J, Wilhelmy F, Dietel E, Hamerla G, Scherlach C, et al. Assessment of a reliable fractional anisotropy cutoff in tractography of the corticospinal tract for neurosurgical patients. *Brain Sci*. 2021;11(5):650.
28. Yoshikawa K, Kajiwara K, Morioka J, Fujii M, Tanaka N, Fujisawa H, et al. Improvement of functional outcome after radical surgery in glioblastoma patients: the efficacy of a navigation-guided fence-post procedure and neurophysiological monitoring. *J Neurooncol*. 2006;78(1):91-97.
29. Hanihara M, Sato S, Shibahara I, Saito R, Kanamori M, Sonoda Y, et al. Intraoperative visualization of subependymal arteries at the atrium supplying the descending motor pathway. *World Neurosurg*. 2017;101:296-303.
30. Saito R, Kumabe T, Sonoda Y, Kanamori M, Mugikura S, Takahashi S, Tominaga T. Infarction of the lateral posterior choroidal artery territory after manipulation of the choroid plexus at the atrium: causal association with subependymal artery injury. *J Neurosurg*. 2013;119(1):158-163.
31. Bush NAO, Young JS, Zhang Y, Dalle Ore CL, Molinaro AM, Taylor J, et al. A single institution retrospective analysis on survival based on treatment paradigms for patients with anaplastic oligodendroglioma. *J Neurooncol*. 2021;153(3):447-454.
32. Türe U, Harput MV, Kaya AH, Baimedi P, Firat Z, Türe H, Bingöl CA. The paramedian supracerebellar-transtentorial approach to the entire length of the mediobasal temporal region: an anatomical and clinical study. Laboratory investigation. *J Neurosurg*. 2012;116(4):773-791.
33. Giese A, Westphal M. Glioma invasion in the central nervous system. *Neurosurgery*. 1996;39(2):235-252.
34. Latini F, Fahlström M, Hesselager G, Zetterling M, Ryttlefors M. Differences in the preferential location and invasiveness of diffuse low-grade gliomas and their impact on outcome. *Cancer Med*. 2020;9(15):5446-5458.
35. Drumm MR, Dixit KS, Grimm S, Kumthekar P, Lukas RV, Raizer JJ, et al. Extensive brainstem infiltration, not mass effect, is a common feature of end-stage cerebral glioblastomas. *Neuro Oncol*. 2020;22(4):470-479.
36. Hide T, Shibahara I, Kumabe T. Novel concept of the border niche: glioblastoma cells use oligodendrocytes progenitor cells (GAOs) and microglia to acquire stem cell-like features. *Brain Tumor Pathol*. 2019;36(2):63-73.
37. Saito R, Kumabe T, Kanamori M, Sonoda Y, Tominaga T. Insulo-opercular gliomas: four different natural progression patterns and implications for surgical indications. *Neurol Med Chir (Tokyo)*. 2010;50(4):286-290.
38. Andrews-Hanna JR, Reidler JS, Sepulcre J, Poulin R, Buckner RL. Functional-anatomic fractionation of the brain's default network. *Neuron*. 2010;65(4):550-562.
39. Jones DK, Christiansen KF, Chapman RJ, Aggleton JP. Distinct subdivisions of the cingulum bundle revealed by diffusion MRI fibre tracking: implications for neuropsychological investigations. *Neuropsychologia*. 2013;51(1):67-78.
40. Witelson SF. Hand and sex differences in the isthmus and genu of the human corpus callosum. A postmortem morphological study. *Brain*. 1989;112(Pt 3):799-835.
41. Hofer S, Frahm J. Topography of the human corpus callosum revisited—comprehensive fiber tractography using diffusion tensor magnetic resonance imaging. *Neuroimage*. 2006;32(3):989-994.
42. Xue K, Wang D, Wang T, Li Y. Posterior corpus callosal integrity based on automated fiber quantification predicts age-related decline of cognitive performance. *Annu Int Conf IEEE Eng Med Biol Soc*. 2019;2019:446-449.
43. Párraga RG, Ribas GC, Andrade SE, de Oliveira E. Microsurgical anatomy of the posterior cerebral artery in three-dimensional images. *World Neurosurg*. 2011;75(2):233-257.
44. Flores-Justa A, Baldoncini M, Pérez Cruz JC, Sánchez Gonzalez F, Martínez OA, González-López P, Campero Á. White matter topographic anatomy applied to temporal lobe surgery. *World Neurosurg*. 2019;132:e670-e679.

Disclosures

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

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

Supplemental Information

Online-Only Content

Supplemental material is available with the online version of the article.

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