The paramedian supracerebellar-transtentorial approach to the entire length of the mediobasal temporal region: an anatomical and clinical study

Laboratory investigation

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Object. The exploration of lesions in the mediobasal temporal region (MTR) has challenged generations of neurosurgeons to achieve an appropriate approach. To address this challenge, the extensive use of the paramedian supracerebellar-transtentorial (PST) approach to expose the entire length of the MTR, as well as the fusiform gyrus, was investigated.

Methods. The authors studied the microsurgical aspects of the PST approach in 20 cadaver brains and 5 cadaver heads under the operating microscope. They evaluated the features, advantages, difficulties, and limitations of the PST approach and refined the surgical technique. They then used the PST approach in 15 patients with large intrinsic MTR tumors (6 patients), tumor in the posterior fusiform gyrus with mediobasal temporal epilepsy (MTE) (1 patient), cavernous malformations in the posterior MTR including the fusiform gyrus (2 patients), or intractable MTE with hippocampal sclerosis (6 patients) from December 2007 to May 2010. Patients ranged in age from 11 to 63 years (mean 35.2 years), and in 9 patients (60%) the lesion was located on the left side.

Results. In all patients with neuroepithelial tumors or cavernous malformations, the lesions were completely and safely resected. In all patients with intractable MTE with hippocampal sclerosis, the anterior two-thirds of the parahippocampal gyrus and hippocampus, as well as the amygdala, were removed selectively through the PST approach. There was no surgical morbidity or mortality in this series. Three patients (20%) with high-grade neuroepithelial tumors underwent postoperative radiotherapy and chemotherapy but needed a second surgery for recurrence during the follow-up period. In all patients with MTE, antiepileptic medication could be decreased to a single drug at lower doses, and no seizure activity has occurred until this point.

Conclusions. The PST approach provides the surgeon precise anatomical orientation when exposing the entire length of the MTR, as well as the fusiform gyrus, for removing any lesion. This is a novel technique especially for removing tumors involving the entire MTR in a single session without damaging neighboring neural or vascular structures. This approach can also be a viable alternative for selective removal of the parahippocampal gyrus, hippocampus, and amygdala in patients with MTE due to hippocampal sclerosis.


Key Words • amygdala • fusiform gyrus • hippocampus • mediobasal temporal region • parahippocampal gyrus • paramedian supracerebellar-transtentorial • semisitting position • diagnostic and operative techniques • skull base

The MTR is actually part of the limbic lobe and includes 2 main portions, the paralimbic areas (mesocortex) and the limbic areas (corticoïd and allocortex). The paralimbic areas consist of the temporal pole and the parahippocampal gyrus, and the limbic areas consist of the amygdala, piriform cortex, and the retrocommissural part of the hippocampal formation.23,24 The MTR is roughly limited medially by the lateral wall of the cavernous sinus and the carotid, crural, and ambient cisterns; anteriorly by the lesser wing of the sphenoid bone; and laterally by the rhinal and collateral sulci. The posterior border of the MTR is the isthmus of the cingulate gyrus and the tip of the cuneus, which is the junction between the parietooccipital and calcarine sulci.6,7,31,34,52,58,61,64 The temporal and occipital neocortical structures cover the MTR and are therefore significant obstacles to surgery of the MTR. The need to incise, resect, or retract the temporal or occipital lobes during surgery of the MTR is a controversial issue.1,3,4,8–10,12,13,15,20,26,27,29,30,33,35–38,42–48,50,57–59,67

This enclosed and extended localization near these highly significant structures renders the MTR a difficult surgical area in some respects. This location necessitates the least traumatic approach without the risk of injury to overlying

Abbreviations used in this paper: EEG = electroencephalography; MTE = mediobasal temporal epilepsy; MTR = mediobasal temporal region; PST = paramedian supracerebellar-transtentorial; ROI = region of interest; TEE = transesophageal echocardiography.
structures, and extended localization may require more than single-session surgery when a lesion involves the entire length of the MTR.

Various approaches to the MTR include the anterior, posterior, lateral, and vertebrobasilar approaches. The features, indications, advantages, and limitations of the PST approach were investigated carefully, one notes that the approaches deemed “less invasive” are restricted to only 1 or 2 portions of the MTR. For example, the lateral transcortical or transsulcal approaches are mainly restricted to the anterior and middle portions of the MTR, and the small petrosal approach is restricted to the middle portion. Although the pterional-transsylvian approach is appropriate for large tumors of the MTR, it is restricted to the anterior and middle portions of the MTR for patients with MTE. The supratentorial infracallosal approach, the lateral occipital subtentorial approach, and the supracerebellar transtentorial approach (E. de Oliveira, personal communication, 2008) are mainly restricted to the posterior portion of the MTR. Selective handling of the MTR has also been used for lesions extending posteriorly, which is appropriate but necessitates staged surgery and requires a combination of 2 different approaches: the pterional-transsylvian approach to the anterior part and the posterior interhemispheric approach to the posterior part of the MTR.

In this manuscript, we describe a novel approach to the entire length of the MTR, selectively, with its anatomical basis, namely, the paramedian supraccerebellar-transtentorial approach. This approach was first defined in cadaveric studies and then used in clinical application.

**Methods**

**Microsurgical Anatomical Study**

Twenty brain specimens obtained from routine autopsies and an additional 5 cadaver heads were used for the microsurgical anatomical study of the PST approach by the senior author (U.T.). The brains were fixed in a 10% formaldehyde solution for a minimum of 2 months. The detailed anatomy of this region was studied through the fiber dissection technique, which has been described previously, and the surgical landmarks of the MTR and fusiform gyrus were investigated. In the formalin-fixed cadaver heads, the bilateral internal carotid and vertebral arteries as well as the jugular veins were dissected at the neck and then were cannulated. After saline irrigation to wash out any residual luminal clots, the arteries and veins were perfused with red and blue silicone, respectively. The microsurgical aspects of the PST approach were carried out under the operating microscope at × 6 to × 25. Particular attention was paid to the relationships between the MTR and the vital neural and vascular structures. The features, indications, advantages, and limitations of the PST approach were investigated and compared with other previously described surgical approaches.

**Clinical Material**

Based on our microsurgical anatomical study and after obtaining institutional board review approval, we used the PST approach in 15 patients in the semisitting position. Six (40%) had large tumors involving the entire MTR, 1 (6.7%) had a lesion in the posterior fusiform gyrus with MTE, 2 (13.3%) had cavernous malformations, and 6 (40%) had drug-resistant MTE due to hippocampal sclerosis. All patients were treated at our institution between December 2007 and May 2010 by the senior author (U.T.). The mean patient age was 35.2 years (range 11–63 years). Eight (53.3%) were male, and 7 (46.7%) were female. Each patient suffered from seizures with a duration of symptoms ranging from 10 days to 21 years. Preoperative radiological examinations included plain radiographs, MR images, MR angiograms, and 3-planar CT scans, along with the use of bone windows and 3D reconstruction. Neuropsychological tests and a visual field study were done preoperatively and 2 months after surgery, except for 1 patient in whom these tests were not possible because she was severely confused and disoriented in the preoperative period (Case 3). Detailed information about these patients is summarized in Table 1.

Presurgical evaluation was done for patients with MTE due to hippocampal sclerosis who had no response to at least 2 antiepileptic drugs. Patients were included if they had unilateral hippocampal sclerosis documented with high-resolution 3-T MR images (Achieva, Philips). Hippocampal sclerosis was defined as atrophy of the amygdala-hippocampus-parahippocampal complex on T1-weighted images and/or increased signal or disruption of the internal architecture of the mediobasal temporal structures on T2-weighted or FLAIR images.

All patients with MTE were evaluated using video-EEG monitoring with electrode placement according to the Extended International 10–20 System, with additional anterior temporal electrodes designated T1 and T2 and sphenoidal electrodes (128-channel, Telefactor Beehive). At least 3 seizures were recorded in each patient. Seizure semiology and ictal and interictal EEG findings were used for lateralization and localization. All patients underwent FDG-PET/CT scanning (Achieva, Philips). Neuropsychological tests were also done in all patients. Patients with concordant neuroradiological imaging (both MR imaging and PET CT) and neuropsychological test results were especially selected as candidates for this surgical approach. Patients who had suspected involvement of temporal neocortical or extratemporal areas as the source of seizures were excluded. Intraoperative corticography with subdural strip electrodes and hippocampal depth electrodes was done in all patients to confirm epileptogenic areas.

**Neuroradiological Study.** Before surgery and 2–3 months afterward, all patients underwent imaging using a 3-T MR imaging unit (Achieva, Philips) with an 8-channel sensitivity encoding (SENSE) head coil. Postcontrast T1-weighted 3D turbo field echo was acquired in the sagittal plane (TR 8.5 msec, TE 4 msec, slice thickness 1 mm). Diffusion tensor images were acquired using single-shot spin echo echo planar imaging (TR 10,000 msec, TE 53 msec, EPI factor 67, slice thickness 2.5 mm, gap 0 mm). Sixteen diffusion directions at b = 800 seconds/mm² were acquired in addition to b = 0 images. The acquisition time...
<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Symptoms, Neurological Signs, &amp; Medication</th>
<th>Neuroradiological Diagnosis</th>
<th>Op Approach</th>
<th>Excision</th>
<th>Histopathology/Adjuvant Therapy†</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>42, M</td>
<td>generalized seizure 10 days prior to admission/ neurologically intact</td>
<td>lt-sided tumor along entire length of MTR</td>
<td>lt-sided PST macroscopic total</td>
<td>glioblastoma Grade IV/radio- + chemotherapy</td>
<td>no deficit; reop 13 mos postop for recurrent tumor; died of recurrent tumor 30 mos after 1st op</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>63, F</td>
<td>1-yr Hx of seizures &amp; rt-sided MTR tumor; monitored at another institution; due to tumor growth, she came to our institution; neurologically intact</td>
<td>rt-sided tumor along entire length of the MTR</td>
<td>rt-sided PST macroscopic total</td>
<td>glioblastoma Grade IV/radio- + chemotherapy</td>
<td>no deficit; reop 28 mos after surgery for recurrent tumor</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>37, F</td>
<td>1-mo Hx of seizures &amp; lt hemiparesis; patient was confused, noncooperative, disoriented, &amp; had lt hemiparesis</td>
<td>rt-sided tumor along entire length of the MTR &amp; posterior &amp; middle portions of the cingulate gyrus</td>
<td>rt-sided PST + posterior interhemispheric macroscopic total</td>
<td>diffuse astrocytoma Grade II</td>
<td>no deficit</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>11, M</td>
<td>20-day Hx of seizures; VPA 400 mg/d</td>
<td>lt-sided tumor in posterior fusiform gyrus</td>
<td>lt-sided PST macroscopic total</td>
<td>pleomorphic xanthoastrocytoma Grade II</td>
<td>no deficit</td>
<td></td>
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<tr>
<td>5</td>
<td>24, F</td>
<td>17-yr Hx of intractable seizures (3–4 times/wk); LEV 3000 mg/d, LTG 400 mg/d, TPM 200 mg/d</td>
<td>lt-sided MTS</td>
<td>lt-sided PST sel-AH hippocampal sclerosis</td>
<td>no deficit or seizure LTG 200 mg/d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>40, F</td>
<td>7-mo Hx of seizures</td>
<td>rt-sided tumor along entire length of the MTR</td>
<td>rt-sided PST macroscopic total</td>
<td>anaplastic astrocytoma Grade III/chemotherapy</td>
<td>no deficit; reop 9 mos postop for recurrent tumor</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>21, M</td>
<td>20-yr Hx of intractable seizures (4–5 times/wk); CBZ 900 mg/d, LEV 3000 mg/d, VPA 1000 mg/d</td>
<td>lt-sided MTS</td>
<td>lt-sided PST sel-AH hippocampal sclerosis</td>
<td>no deficit or seizure; CBZ 600 mg/d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>29, F</td>
<td>21-yr history of intractable seizures (1–2 times/mo); CBZ 1000 mg/d, LEV 3000 mg/d</td>
<td>lt-sided MTS</td>
<td>lt-sided PST sel-AH hippocampal sclerosis</td>
<td>no deficit or seizure; CBZ 600 mg/d</td>
<td></td>
<td></td>
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<td>9</td>
<td>37, F</td>
<td>18-yr history of intractable seizures (3–4 times/mo); DPH 400 mg/d, LEV 3000 mg/d</td>
<td>lt-sided MTS</td>
<td>lt-sided PST sel-AH hippocampal sclerosis</td>
<td>no deficit or seizure; CBZ 800 mg/d</td>
<td></td>
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<tr>
<td>10</td>
<td>12, M</td>
<td>11-yr history of intractable seizures (1–2 times/mo); CLZ 2 mg/d, LEV 2500 mg/d, LTG 300 mg/d, ZNS 400 mg/d</td>
<td>rt-sided MTS</td>
<td>rt-sided PST sel-AH hippocampal sclerosis</td>
<td>no deficit or seizure; VPA 1200 mg/d</td>
<td></td>
<td></td>
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<tr>
<td>11</td>
<td>44, M</td>
<td>posterior superior frontal gyrus glioblastoma resection + radiotherapy 3 yrs prior; rt hemiparesis</td>
<td>lt-sided fusiform-parahippocampal gyr tumor</td>
<td>lt-sided PST macroscopic total</td>
<td>glioblastoma WHO Grade IV/ chemotherapy</td>
<td>no new deficit</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>55, M</td>
<td>8-mo Hx of seizures</td>
<td>rt-sided lesion of posterior fusiform gyrus</td>
<td>rt-sided PST macroscopic total</td>
<td>cavernous malformation</td>
<td>no deficit</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>56, F</td>
<td>1-mo Hx of seizures</td>
<td>rt-sided tumor of parahippocampal &amp; fusiform gyr</td>
<td>rt-sided PST macroscopic total</td>
<td>diffuse astrocytoma WHO Grade II</td>
<td>no deficit</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>31, M</td>
<td>8-mo Hx of seizures</td>
<td>lt-sided lesion of posterior para-hippocampal gyrus</td>
<td>lt-sided PST macroscopic total</td>
<td>cavernous malformation</td>
<td>no deficit</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>26, M</td>
<td>20-yr Hx of seizures (2–8 times/mo); LTG 400 mg/d, OXC 600 mg/d, VPA 1000 mg/d</td>
<td>lt-sided MTS</td>
<td>lt-sided PST sel-AH hippocampal sclerosis</td>
<td>no deficit; no seizure; CBZ 600 mg/d</td>
<td></td>
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* CBZ = carbamazepine; CLZ = clonazepam; DPH = diphenylhydantoin; Hx = history; LEV = levetiracetam; LTG = lamotrigine; MTS = mediodasal temporal sclerosis; OXC = oxcarbazepine; sel-AH = selective amygdalohippocampectomy; TPM = topiramate; VPA = valproic acid; ZNS = zonisamide.
† Grades are based on the WHO grading system.
was about 6 minutes. Sixty slices were taken for whole-brain coverage from the vertex to the foramen magnum.

All data were transferred to the MR imaging system’s Release 2.6 Level 3 workstation (Achieva, Philips). The fiber tracking software was used to generate 3D diffusion tensor tractography, which allows virtual dissection of white matter pathways. The direction of color-coding of the fiber tracts in fractional anisotropy maps was as follows: red for left- to right-oriented fibers, blue for craniocaudal-oriented fibers, and green for anteroposterior-oriented fibers. For tracking the white matter fibers, the ROI method was applied. These fibers are generated from multiple ROIs placed on color-coded fiber pathways. The fibers of the anterior commissure (ac, red), uncinate fasciculus (unc, green), posterior thalamic peduncle including the optic radiation (or, yellow), and the frontooccipital fasciculus (fof, blue) were generated. A T1-weighted 3D turbo field echo sequence was used for the background anatomical structure.

The frontooccipital fasciculus connects the occipital and frontal lobes. To define this tract, the first ROI was defined in the frontal lobe and the second in the occipital lobe on the fiber pathways in the coronal plane. The anterior commissure connects the anterior and ventral temporal lobes of the 2 hemispheres. For tracking the fibers of the anterior commissure, 2 ROIs were defined 10 mm away from the left and right sides at the point where the anterior commissure is seen in the midsagittal plane. The uncinate fasciculus connects the anterior temporal lobe with the medial and lateral orbitofrontal cortex. To set the uncinate fasciculus, the first ROI was defined in the anterior temporal lobe white matter, and the second was defined around the white matter of the anterior basal portion of the frontal lobe in the coronal plane. The optic radiation connects the lateral geniculate body to the occipital cortex. The first ROI was outlined on the occipital visual cortex in the coronal plane, the second ROI was defined on the lateral geniculate body in the sagittal plane, and the third was defined on the optic tract in the coronal plane.

Anesthesiology Considerations. All patients were examined preoperatively by a cardiologist and were evaluated using transthoracic echocardiography to exclude anyone with atrial or ventricular septal defects, as these defects contraindicate the use of the semisitting position.

Results

Microsurgical Anatomical Study

The MTR is separated into 3 portions: the anterior, middle, and posterior portions. The anterior portion starts from the piriform cortex and extends to the tip of the uncus. The temporal incisura and the rhinal and collateral sulci form the lateral border of the anterior portion. This portion consists of the amygdala, uncus, and head of the parahippocampal gyrus and hippocampus. The middle portion extends to the collicular level of the midbrain. The collateral sulcus is the lateral border of the middle portion of the MTR. The posterior portion extends posteriorly from this level. We divided the posterior portion of the MTR into superior and inferior parts, as the anterior calcarine sulcus separates these structures naturally. The superior portion (parahippocampocingulate) is separated from the cingulate gyrus by the isthmus cinguli. The superior portion contains the gyri Andrea Retzius, gyrus fasciolaris, and the fasciola cinerea. The isthmus cinguli forms the transition between the posterosuperior parahippocampal gyrus and the posterior cingulate gyrus below and below the splenium of the corpus callosum. The inferior portion (parahippocampolinguai) is connected with the anterior lingual gyrus, and an imaginary line between the preoccipital notch and the tip of the cuneus forms the posterior border of the MTR. The lingual (medial occipitotemporal) gyrus is demarcated from the fusiform (lateral occipitotemporal) gyrus by the posterior portion of the collateral sulcus, and from the cuneus by the calcarine sulcus. The intralingular sulcus separates the lingual gyrus into 3 portions: superior, inferior, and anterior. The anterior portion, which we call the parahippocampolingual gyrus, belongs to the posterior portion of the MTR, while the superior and inferior portions belong to the occipital lobe. The collateral sulcus forms the lateral margin of the posterior portion of the MTR (Fig. 1).

The MTR is deeply enclosed and is close to highly vital neural and vascular structures. These are the optic tract and the lateral geniculate body; the oculomotor and trochlear nerves; the midbrain; the internal carotid, and posterior cerebral arteries; the basal vein of Rosenthal and its tributary medially; and the sublentiform portion of the internal capsule. This portion of the internal capsule includes the frontopontine, temporopontine, and occipitopontine fibers; the inferior thalamic peduncle; and the posterior thalamic peduncle, which includes the optic radiation (Appendix). By using the fiber dissection technique, these significant anatomical structures of the temporal lobe and their relations to the surrounding formations can be seen (Figs. 2 and 3). The visual cortex (Brodmann areas 17–19) is located posterior to the MTR, and the basal language area in the fusiform gyrus is located lateral to the MTR.

The features, advantages, and limitations of the PST approach were investigated, and we found that the approach is feasible for exposing the entire length of the MTR as well as the fusiform gyrus, even with cadaver specimens (Figs. 4–7).

Surgical Technique

Preparing and Positioning. In the operating room, antiembolic stockings and a pneumatic sequential compression device are applied to the patient’s legs to prevent deep venous thrombosis. After endotracheal intubation, the patient undergoes placement of a TEE probe to monitor for possible air embolism. Before the positioning, a “bubble test” with the Valsalva maneuver is done to further evaluate for any possible shunting from the right to the left atrium. This bubble test is crucial because transthoracic echocardiography, which is done in the preoperative period, may miss atrial or ventricular septal defects, and it is imperative to confirm that there are no such defects. Transesophageal echocardiography provides de-
Paramedian supracerebellar-transtentorial approach

Fig. 1. The inferolateral view of the left cerebral hemisphere in a cadaver brain showing portions of the MTR, which are separated by dotted lines. The arrows indicate posterior extensions of the parahippocampal gyrus to the isthmus of the cingulum (superior) and to the lingual gyrus (inferior). No exact border shows where the MTR ends. The asterisk indicates the tip of the cuneus. Abbreviations with white letters denote the sulci and fissures. A = anterior portion of the mediotemporal region; cas = calcarine sulcus; cas-a = anterior calcarine sulcus; cc-s = splenium of the corpus callosum; cig = cingulate gyrus; cos = collateral sulcus; cp = cerebral peduncle; cun = cuneus; fg = fusiform gyrus; ils = inferior lingual sulcus; ist = isthmus cinguli; lg-a = anterior lingual gyrus; lg-i = inferior lingual gyrus; lg-s = superior lingual gyrus; lgb = lateral geniculate body; M = middle portion of the mediotemporal region; ots = occipitotemporal sulcus; P = posterior portion of the mediobasal temporal region; pc = piriform cortex; pon = preocipital notch; pos = parietooccipital sulcus; rs = rhinal sulcus; s = subiculum; sups = subparietal sulcus; tp = temporal pole; uc = uncus; us = uncal sulcus; II = optic nerve.

tailed real-time information about the heart, great vessels, and every air bubble entering the blood circulation during surgery. Thus, it is possible to detect air inflow at an early stage and prevent any complications with appropriate maneuvers (Fig. 8A and B).

With the patient in the supine position, the skull clamp of the Mayfield-Kees 3-point fixation device is applied to the head. One skull pin is fixed to the mastoid process of the contralateral side, and 2 pins are fixed to the ipsilateral frontal and parietal regions. While the surgeon holds the patient’s head securely, silicone cushions and large soft pillows are placed to position the patient’s legs approximately 90° to the torso with the knees flexed 90°. The seat section of the operating table should be parallel to the ground and the back section tilted up approximately 25°. This smaller degree of tilt helps prevent complications associated with air embolism and preserves the surgeon’s comfort when the operating table is elevated and the surgeon’s armrest is used. This modification recreates the semisitting position. After the patient is in the desired position, the Mayfield crossbar adaptor is fitted to the accessory rail of the back section of the operating table to allow changes in the degree of elevation of the back without having to go under the drapes to disconnect the Mayfield system during surgery. The patient’s head is then fixed in a neutral-straight position with moderate flexion. Extreme flexion of the head must be avoided, especially in elderly patients. When positioning the patient’s head, the surgeon flexes the neck as necessary to increase the intracranial venous pressure during fixation of the headholder. Flexing the leg to increase the intraabdominal pressure can also help to increase venous blood return to the heart. Hyperextension or hyperflexion of the leg must be avoided to prevent nerve damage. In the preoperative period, the patient should be examined to delineate the normal range of motion.

To preserve the intravascular volume of the patient in this semisitting position, we avoid the use of diuretics. Also, we did not use positive end expiratory pressure in our series. Avoiding spontaneous ventilation is also important to prevent air embolism.

Incision. A vertical, linear paramedian incision is made. It passes through the midpoint of an imaginary line between the external occipital protuberance and the mastoid process. The incision extends one-third above and two-thirds below the superior nuchal line (Fig. 8B). Depending on the patient’s skin thickness and muscle mass, the incision may be extended superiorly and inferiorly, but a 12-cm incision is generally sufficient for exposure. The occipital artery is usually encountered twice, initially superficial to the occipital belly of the occipitofrontalis muscle, and later while dissecting the suboccipital muscles. Next, we split the occipital belly of the frontocipital muscle, and the suboccipital muscles are separated with electrocautery in line with the incision. The occipital artery beneath the splenius capitis muscle should be coagulated and divided. The muscle mass is retracted using 2 Whitlenar retractors, one curved superiorly and the other straight inferiorly. The external occipital protuberance should be exposed medially and the asterion laterally to allow sufficient exposure for subperiosteal dissection. There is no need to expose the foramen magnum region.

Craniotomy. Three bur holes are then made. The first is placed in line with the skin incision and 2 cm above the superior nuchal line, as this is the most superior aspect of the exposure. The second hole is placed just lateral to the external occipital protuberance right over the transverse sinus just lateral to the confluence of sinuses, and the third hole is placed on the asterion (corresponding approximately just medial to the junction of the transverse and sigmoid sinuses). A dural dissector is then passed to separate the dura and the transverse sinus from the bone, and the bone flap is turned with the craniotome, which extends one-third above the transverse sinus and two-thirds below the transverse sinus. Placing the craniotomy well above the transverse sinus helps in 2 ways: the exact location of the transverse sinus varies, and the transverse sinus sometimes needs to be pulled up depending on the tentorial angle. We try not to expose the mastoid air cells and, irrespective of opening air cells, we apply bone wax to the bone edges to prevent a CSF leak. With this exposure, we usually have approximately 6 cm of bone exposed in the mediolateral plane and 5 cm in the superoinferior plane. This space is necessary to achieve a wide mediolateral corridor, which allows excellent visualization and enough room for maneuvering during the operation (Fig. 8C).

Dural Opening. At this stage, the operating microscope is introduced. It is critical to mention that we use a surgical microscope with a 300-mm objective lens with-
out autofocus and zoom functions (OPMI 1 FC, Zeiss). The counterweight-balanced microscope stand is controlled with a pistol-grip hand switch and mouth switch (Contraves).62 We make 2 openings in the dura. The first is a transverse opening about 15 mm long placed right over the lower aspect of the craniotomy to access the cisterna magna. Cerebrospinal fluid is then released to relax the posterior fossa and allow the supracerebellar infratentorial corridor to open. A cottonoid is left here, allowing access to the cisterna magna to release more CSF as necessary. The transverse and occipital sinuses should not be opened. Before the second incision, a micro-Doppler probe (Mizuho America, Inc.) is used to confirm the exact location and extension of the transverse sinus. A curvilinear opening in the dura is made about 15 mm below the transverse sinus. This opening is parallel to the transverse sinus in the center of the exposure. At the ends of the exposure, the dural incision curves up closer to the transverse sinus. It is important to open the dura wide from the midline to the lateral aspect of the opening to create a wide mediolateral corridor. This corridor allows visualization of the supracerebellar space to work between the tentorial draining veins without sacrificing them. This wide corridor also allows visualization of the medial temporal structures beyond the “napkin ring” formed by the midbrain medially and the petrous ridge laterally.

When the surgeon approaches the transverse sinus during the second dural opening, a small, inadvertent opening may appear in the transverse sinus, which might lead to air inflow to the blood circulation. Thus, we alert...
our anesthesia team to watch for that phenomenon. After the dural opening, adhesions of arachnoid villi are commonly found from the most posterosuperior aspect of the cerebellum to the dura. We release these arachnoid villi adhesions, a maneuver that opens the supracerebellar operative corridor. After it is opened, the dura is placed over the transverse sinus. At this point, the patency of the transverse sinus is checked again with a micro-Doppler probe to make sure that tenting of the dura did not compromise flow.

Exploring the Supracerebellar Space. The superior (tentorial) surface of the cerebellum is dissected from the tentorium (Fig. 8D). The supracerebellar space is then explored, and special attention is paid to understand any venous variations. Generally, 1 small vein in the supracerebellar paramedian region drains to the tentorium. In our first 4 patients (26.7%), we sacrificed these veins to allow a sufficient working space. Although there were no clinical or radiological problems with this sacrifice, in the remaining 11 patients (73.3%) we preserved these veins even if there were multiple ones. We were able to mobilize the veins and modify the tentorial incision according to the venous variations to open enough space. The surgeon must not sacrifice the lateral petrosal vein or the tentorial veins around the midline, which are the main veins draining the posterior fossa.

Dissection is carried forward to open the posterior aspect of the quadrigeminal cistern and the ambient cistern all the way to the lateral aspect of the ambient cistern.

During dissection of the arachnoid to uncover ambient and quadrigeminal cisterns, care must be taken to identify the trochlear nerve. The trochlear nerve advances between the posterior cerebral artery and superior cerebellar artery after emerging from the dorsal aspect of the crus cerebri. Before tentorial opening, the trochlear nerve should be followed until it pierces the tentorium. Although the trochlear nerve remains below the trajec-

**Fig. 3.** A: In a formalin-fixed cadaveric brain specimen, the left hemisphere was almost totally dissected away by using the fiber dissection technique; the MTR and all portions of the internal capsule were preserved. B: Further dissection was done, and the left-sided internal capsule, diencephalon, brainstem, and cerebellum (cer) were also removed. The left MTR has been preserved. Abbreviations with white letters denote the sulci and fissures. ab = amygdaloid body; ac = anterior commissure; ahi = alveus of the hippocampus; alic = anterior limb of the internal capsule; alv = atrial portion of the lateral ventricle; ap = ansa peduncularis; cc-b = body of the corpus callosum; cc-s = splenium of the corpus callosum; cig = cingulate gyrus; cos = collateral sulcus; cv = cerebellar vermis; f-b = body of the fornix; f-c = column of the fornix; f-cr = crus of the fornix; fi = limenia; fm = foramen of Monro; fma = forceps major (radiation of the corpus callosum); lg = lingual gyrus; m = midbrain; pg = parahippocampal gyrus; plic = posterior limb of the internal capsule; po = pons; sa = subcallosal area; slic = sublentiform portion of the internal capsule; sp = septum pellucidum; th = thalamus.

**Fig. 4.** The left paramedian sagittal section through the hippocampal formation of a formalin-fixed cadaveric head is shown. The figure shows the paramedian supracerebellar transtentorial approach for selective amygdalohippocampectomy. The arrow indicates the route of the surgical approach. Abbreviations with white letters denote sulci and fissures. ab = amygdaloid body; ac = anterior commissure; cer = cerebellum; chp = choroid plexus; cos = collateral sulcus; cr = corona radiata; hi = hippocampus; ocp = occipital pole; pu = putamen; slic = sublentiform portion of the internal capsule; te = tentorium; trs = transverse sinus.
Tentorial Opening. After the trochlear nerve is clearly identified, the tentorium is coagulated and incised. An incision is made about 2–3 cm posterolateral from the posterior portion of the tentorial incisura, right in the center of the exposure. A cottonoid is placed above this opening to protect the supratentorial structures. The incision is then gently carried toward the tentorial hiatus to the lateral and posterior aspects of the quadrigeminal cistern. The incision is then extended from the starting point anteriorly to the midpoint of the petrous ridge. After the tentorium has been cut in this fashion, the anterior leaflet of the tentorium is retracted downward with 3 sutures, with Dandy forceps hanging from the tails of the sutures. To prevent the sutures from biting into the cerebellum, the tentorial surface of the cerebellum is padded with cotton patties. The cerebellum hangs by gravity, and the self-retaining retractor is never used in any part of the surgery. Next, the posterior leaflet is pulled up in a similar fashion. Tack-up sutures are then placed to help elevate the upper leaflet of the tentorium to displace the transverse sinus. This maneuver opens more space for visualization and manipulation. In some patients, we modify this tentorial incision because of venous variations. We leave a cuff of dura around the tentorial draining vein; hence, we are able to preserve the vein in most patients (Fig. 8E).

After this maneuver, various anatomical structures can be identified as landmarks to help with orientation during the rest of the surgery. The quadrigeminal and posterior portions of the ambient cisterns should be well opened to create a large working space. The inferior colliculus, the trochlear nerve, the main stem and branches of the posterior cerebral and superior cerebellar arteries, the galenic venous system with the basal vein of Rosenthal, and the superior petrosal vein should be explored. Large portions of the MTR and fusiform gyrus become

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**Fig. 5.** A: The superior view of a cadaver brain reveals the MTR on both sides to show their relationship to the ventricles and the surrounding vascular structures. The dotted lines designate the portions of the hippocampal formation from the superior view that correspond to portions of the MTR. B: After resection of the remaining temporal lobe, the middle fossa is revealed. The tentorium was dissected away to demonstrate how the middle fossa relates to the cerebellum, midbrain, and anterior fossa. The head of the hippocampus sits on the lateral wall of the cavernous sinus at the medial border of the middle fossa. A1 = precommunicating (first) segment of the anterior cerebral artery; ab = amygdaloid body; af = anterior fossa; alv = atrial portion of the lateral ventricle; ce = collateral eminence; cer = cerebellum; cp = cerebral peduncle; fi = fimbria; hi-b = body of the hippocampus; hi-h = head of the hippocampus; hi-t = tail of the hippocampus; ica = internal carotid artery; ico = inferior colliculus; M1 = sphenoidal (first) segment of the middle cerebral artery; mf = middle fossa; ot = optic tract; P2 = second (ambient) segment of the posterior cerebral artery; pc = piriform cortex; pr = petrous ridge; ps = pituitary stalk; sca = superior cerebellar artery; sco = superior colliculus; sr = sphenoidal ridge; sts = straight sinus; su = subiculum; te = tentorium; tee = tentorial edge; tp = temporal pole; u = uncus; vg = vein of Galen; II = optic nerve; III = oculomotor nerve; IV = trochlear nerve; V = trigeminal nerve; VI = abducent nerve; VII = facial nerve; VIII = vestibulocochlear nerve.
Paramedian supracerebellar-transtentorial approach

visible. The collateral sulcus, which separates the para-hippocampal gyrus and the fusiform (lateral tempor-occipital) gyrus, should be identified. In patients with hippocampal sclerosis, because of atrophic mediobasal structures, the uncus and third cranial nerve may be disclosed at this step. In patients with tumors, however, it may be dangerous to try to expose these structures because of the voluminous tumor tissue in this step. These various landmarks guide the surgeon during the rest of surgery; this is the great advantage of the PST approach.

Removal of the Para-hippocampal Gyrus, Hippocampus, and Amygdala. To remove these structures, intraoperative surface EEG is done first and then a depth electrode is passed into the hippocampus and the parahippocampal gyrus. Recordings are made in all cases. In our experience, contrary to that of patients with hippocampal sclerosis, we did not find epileptic EEG activity within the tumor.

The inferior colliculus is the main landmark for the starting point of the parahippocampal gyrus resection. In patients with MTE, the inferior colliculus is also the posterior limit of resection because of the need to preserve the anterior extension of the visual cortex. In patients with tumors, however, if the lesion extends behind this point, then the tumor is dissected anterior to this point initially. We then reach and resect the posterior portion at the end of the surgery. The collateral sulcus, which marks the lateral limit of resection, is identified next. The choroidal fissure and midbrain form the medial limit of resection.

A perpendicular posterior parahippocampal incision is made with bipolar forceps at the level of the inferior colliculus, which is limited by the collateral sulcus laterally. Subpial dissection is done, taking care to preserve the major inferior temporal arteries originating from the P3 and P2 segments of the posterior cerebral artery. Next, subpial resection of the posterior aspect of the subiculum is done and is carried forward to the uncus medially. The hippocampal arteries originating from the P3 and P2 segments of the posterior cerebral artery are identified, coagulated, and cut. The uncal arteries are then identified, coagulated, and cut. Subpial dissection is continued posteriorly to identify the collateral sulcus and, with gentle dissection of the inferior aspect of the parahippocampal gyrus just medial to the collateral sulcus, the dentate gyrus is identified by its distinct grayish color. The alveus is then dissected and the posterior aspect of the temporal horn, near the atrium, is entered.

Unique to this exposure is that the roof of the temporal horn is in the line of sight. The choroidal fissure is identified in the temporal horn of the lateral ventricle and dissection is carried forward to the tip of the temporal horn. Dissection is done between the fimbria and the choroid plexus. At this point, the body and most of the
head of the hippocampus are ready to be delivered without damage, allowing for detailed pathological examination of the hippocampus in patients with MTE (Fig. 8F). In patients with tumors, the hippocampus and parahippocampal gyrus are removed in piecemeal fashion with bipolar forceps, suction tubes, and ultrasonic surgical aspiration.

The remainder of the head of the hippocampus, the uncus, and the amygdala are then resected, taking care to stop at the point where the lateral wall meets the roof of the temporal horn near the collateral eminence. Resection of the amygdala is begun at the junction of the amygdala and the tail of the caudate nucleus; the amygdala is identified clearly by its nutmeg color under the ependymal layer. This technique prevents injury to the visual fibers within the Meyer loop. Care must be taken during subpial resection of the medial aspect of the amygdala as both the optic tract and the anterior choroidal artery are at risk. We prefer to use only gentle suction at this stage of the procedure, when we can identify the crural cistern subpially and the point where the anterior choroidal artery departs the internal carotid artery. At this point, the high-definition neuroendoscope (Aesculap) is introduced to visualize the inferior and anterior aspects of the parahippocampal gyrus. This area is not well seen through the microscope, as it is hidden from view by the petrous ridge. This phenomenon is truer in patients with tumors than in those with MTE, in whom we try selective amygdalohippocampectomy.

The technique of placing a cotton ball below the parahippocampal gyrus brings it into view; therefore, resecting the most anterior and inferior aspects of the parahippocampal gyrus becomes possible. With the high-definition neuroendoscope and a suction tube with a curved tip, we continue to resect the remaining tissue in this region, attaining hemostasis. The internal carotid artery with its perforators, the anterior choroidal artery, the posterior communicating artery, the third and fourth cranial nerves, the roof of the temporal horn with the choroid plexus and the tail of the caudate nucleus, the P₂ and P₃.
Fig. 8. **A:** Lateral view of the patient in the semisitting position. The seat section (ss) of the operating table is parallel to the ground and the back section (bs) is tilted up approximately 25°. The head is flexed in the neutral position without any rotation or tilt. The back section’s accessory rail is used for the Mayfield crossbar adaptor (cba). With this modification, the position of the back section can be changed easily without having to go under the drapes to disconnect the Mayfield system from the operating table adapter during surgery. **B:** A vertical linear incision, approximately 12 cm long, is made through the midpoint between the mastoid process and the external occipital protuberance (eop). One-third of the incision is above the transverse sinus while two-thirds is below. During the operation, any possible air embolism is monitored using the TEE monitor (tee-m). **C:** The anatomical landmarks necessary to localize the craniotomy and the operative field after the dural opening are shown. The vertical dashed line indicates the skin incision. Note the small dural opening just above the inferior border of the craniotomy, which is made to reach the cisterna magna to release CSF. The ideal spots for the 3 bur holes are demarcated. The first bur hole is placed 2 cm above the superior nuchal line, the second bur hole is placed just lateral to the external occipital protuberance right over the transverse sinus, and the third bur hole is placed on the asterion just medial to the junction of the transverse and sigmoid sinuses. Care must be taken not to open the mastoid air cells to prevent a CSF leak. The asterisk indicates the tentorial incision. **D:** Illustration showing the inferior view of the middle portion of the left MTR (M) and the midbrain after the tentorial opening. The exposure is wide enough without retraction of the cerebellum. The anterior leaflet of the tentorium is retracted downward with 3 holding sutures and Dandy forceps, and the posterior leaflet is retracted upward. **E:** The illustration of the surgical field after the selective removal of the left amygdala, hippocampus, and parahippocampal gyrus is shown. **F:** The head (hi-h) and body (hi-b) of the hippocampal formation can be removed in 1 piece through the PST approach. These portions correspond to the anterior and middle portions of the MTR. **G:** The endoscopic view of the surgical field after the selective removal of the left amygdala, hippocampus, and parahippocampal gyrus is shown. The asterisk indicates the bed of the amygdala. (See Video 1.) **H:** The surgeon’s position during excision of the amygdala; the foremost point of the surgical field, is demonstrated. With the small head of the surgical microscope (without autofocus and zoom functions) and correct instrumentation, (continued)→
segments of the posterior cerebral artery with their main branches, the superior cerebellar artery, and the basal vein of Rosenthal should be seen (Fig. 8G, Video 1).

Video 1. High-definition endoscopic recording demonstrating the surgical field after the selective removal of the left amygdala, hippocampus and parahippocampal gyrus using a left-sided PST approach. The asterisk indicates the bed of the amygdala (same case as in Fig. 8G). cer = cerebellum; cp = cerebral peduncle; ICA = internal carotid artery; lgb = lateral geniculate body; M1 = first segment of middle cerebral artery; P2 = second segment of the posterior cerebral artery; P3 = third segment of posterior cerebral artery; pt = pulvinar of the thalamus; rth = roof of the temporal horn; te = tentorium; tee-p = probe of the TEE; trs = transverse sinus; zpr = zygomatic process; 3 = inferior posterior temporal artery; 4 = inferior temporooccipital artery; II = optic nerve; III = oculomotor nerve; IV = trochlear nerve.

A critical factor in the success of the PST approach is to have a small optical head for the surgical microscope. For the surgeon to work in the depth of a small space with both hands continuously, without stretching his or her arms, the use of a surgical microscope without autofocus and zoom functions that can be controlled with a mouth switch is crucial. The hydraulic armrest is also important equipment for the surgeon’s comfort (Fig. 8H).

Closure. After hemostasis is achieved, the tentorial sutures are released and reapproximated to reconstruct the anatomical position of the tentorium. The small inferior and large superior incisions of the dura of the posterior fossa are closed watertight and the bone flap is replaced with skull-fixation devices. The occipital belly of the occipitofrontal muscle is reapproximated and the suboccipital muscles are brought together with 0 Vicryl. The wound is then closed.

Patients are extubated in the operating room at the end of the procedure, and they are then transferred to the ICU until the next morning. In the ICU, the patient is kept with the head elevated 30°. Postoperative MR imaging is done the morning after surgery. A detailed MR imaging study with fiber tractography is repeated routinely 2–3 months after surgery.

Surgical Results and Outcome

The PST approach provided excellent exposure and safe resection of various lesions in the MTR and/or fusiform gyrus in 9 patients. This approach also ensured selective removal of the anterior two-thirds of the parahippocampal gyrus and hippocampus, and the amygdala in 6 patients with MTE due to hippocampal sclerosis. The mean operation time was 4 hours 55 minutes (range 3 hours 20 minutes to 7 hours 10 minutes), and the mean time spent under the microscope was 2 hours 8 minutes (range 1 hour 33 minutes to 3 hours 10 minutes). There were no intraoperative or postoperative complications. Minimal air inflow in a short period of time was detected by TEE in 6 patients (40%). No airflow was detected in the remaining 9 patients (60%). None of the patients had any clinical sign of air embolism, such as a sudden decrease in end-tidal CO2, desaturation, a decrease in arterial blood pressure, ventricular dysrhythmia, or an increase in central venous pressure.

Postoperatively, imaging studies revealed that the lesions had been totally resected macroscopically (Figs. 9 and 10). The postoperative follow-up period ranged from 10 to 39 months (mean 21.4 months) (Table 1). Patients with high-grade tumors (Cases 1, 2, 6, and 11) received adjuvant radiotherapy and/or chemotherapy in the postoperative period. Three of these patients (Cases 1, 2, and 6), however, underwent repeated surgery 13, 28, and 9 months after the first surgery, respectively, because of recurrent tumors. One of these patients (Case 1) died due to recurrence 30 months after the first surgery. In Case 3, the tumor extended to the posterior and middle portions of the cingulate gyrus; therefore, we combined the PST approach with the posterior interhemispheric approach in the same session with a modified craniotomy. In all patients with hippocampal sclerosis, antiepileptic drugs could be gradually decreased to 1 drug, and there had been no seizure activity at the time of this writing. The postoperative visual field remains intact in all patients with MTE.

Detailed information regarding the characteristics of patients and their surgical results and outcomes are summarized in Table 1.

Illustrative Cases

Case 2

This 63-year-old woman experienced epileptic seizures 1 year prior to her presentation at another institution. An MR imaging study disclosed a right-sided MTR tumor, and the patient was subsequently observed. Because of the growth pattern of the tumor during the observation period, the patient was referred to our institution. The MR images disclosed a tumor at the MTR extending from the piriform cortex to the isthmus cinguli, which enhanced minimally after contrast injection (Fig. 9A). A preoperative study of the visual field showed peripheral narrowing with left-sided homonymous hemianopia. Surgery was recommended, and gross-total resection of the tumor was achieved in 1 session by using a right-sided PST approach (Fig. 9B). The patient’s postoperative course was uneventful, and the histopathological diagnosis yielded a glioblastoma (WHO Grade IV). The patient received adjuvant radiotherapy and chemotherapy in the postoperative period. At the 3-month follow-up, MR imaging...
disclosed no residual or recurrent tumor (Fig. 9C). The patient underwent a second surgery 18 months afterward for recurrent tumor.

**Case 4**

This 11-year-old boy was admitted to our clinic with seizures that started 20 days before admission. During the seizures, he asked meaningless questions but never remembered this event. He had a history of afebrile convulsions at the age of 5 years. Magnetic resonance imaging disclosed a left-sided posterior fusiform gyrus lesion (Fig. 10A). During video-EEG monitoring, the ictal and interictal findings showed that the clinical and electrophysiological seizures originated in the left anterior temporal lobe. He had bitemporal inferior quadrantanopia (pie-on-the-floor), but he was otherwise neurologically intact. The lesion was totally removed through a left PST approach (Fig. 10B). Intraoperative electrocorticography was done with a strip electrode placed onto the parahippocampal gyrus, and a depth electrode was placed into the hippocampal formation in the sagittal plane. Epileptiform activity was detected in the hippocampal formation. Therefore, we carried out a selective amygdalohippocampectomy. The patient’s postoperative period was uneventful, and the histopathological diagnosis was pleomorphic xanthoastrocytoma (WHO Grade II). Histopathological tests of the hippocampal specimen revealed dispersion and neuronal loss at the CA1 to CA3 regions of the Ammon horn. The 2-month postoperative MR imaging studies demonstrated radical resection of the tumor with selective removal of the amygdala, the hippocampus, and the parahippocampal gyrus. No adjuvant therapy was

**Fig. 9.** Case 2. **A:** Preoperative axial FLAIR and T1-weighted postcontrast MR imaging sections in coronal and sagittal planes at different levels showing the MTR lesion extending from the piriform cortex to the isthmus cinguli. The early diagnosis was a neuroepithelial tumor. **B:** Endoscopic view of the surgical field after resection of the large, right-sided MTR tumor. The internal carotid artery (ICA), anterior choroidal artery (ach), choroid plexus (chp), posterior communicating artery (pc), third cranial nerve (III), and cerebral peduncle (cp) are shown. **C:** Three months after surgery, MR imaging studies show no residual or recurrent tumor and the neighboring structures have been preserved. L = left; rth = roof of the temporal horn.

**Fig. 10.** Case 4. **A:** Axial FLAIR and T1-weighted postcontrast MR imaging studies obtained in coronal and sagittal planes at different levels showing a left-sided (L) lesion located in the posterior portion of the fusiform gyrus (lateral temporoccipital gyrus) and the MTR, which minimally enhances after contrast injection. **B:** Three months after surgery, MR imaging studies show the resection of the fusiform gyrus and selective amygdalohippocampectomy for seizure control through the PST approach.
recommended. The patient has not had a seizure since the surgery.

Case 5

This 24-year-old woman was admitted with a 17-year history of intractable MTE. She had automotor seizures without consciousness 2–3 times a week while she was taking levetiracetam (2 × 1500 mg per day), lamotrigine (2 × 200 mg per day), and topiramate (2 × 100 mg per day). Ictal and interictal EEG findings revealed that the seizures originated in the left frontotemporal region. The MR imaging findings disclosed left-sided hippocampal sclerosis, especially in the posterior part, with hyperintensity on T2-weighted images and volume loss on T1-weighted images (Fig. 11A). On PET-CT scanning, hypometabolism was located especially around the left hippocampus, whereas the neocortical regions were spared. With successful experience from previous cases and especially because the patient had posteriorly located hippocampal sclerosis, we decided to use the PST approach for selective amygdalohippocampectomy. An intraoperative strip electrode was placed on the left MTR, and a depth electrode in the left hippocampus verified abnormal electrical activity. Selective removal of the left parahippocampal gyrus, the hippocampus, and the amygdala was done, and the postoperative course of the patient was uneventful. The postoperative MR images obtained at 2 months showed selective removal of the amygdala, hippocampus, and parahippocampal gyrus on the left side (Fig. 11B). Postoperative fiber tractography also showed preservation of the major fiber tracts of the left temporal lobe (Fig. 11C), and a visual field study showed that the visual field remained intact (Fig. 11D). The patient has not suffered a seizure or aura during the postoperative period (29 months) with lamotrigine (2 × 100 mg per day).

Discussion

The MTR is deeply located and extended, and there remain some controversies regarding surgical approaches to it. The main reason for this controversy is that the MTR is such a long structure anteroposteriorly and is curved around the midbrain, which further complicates the ability to reach the entirety of its length in a single surgical session. The various approaches for resecting lesions of the MTR can be classified as anterior, lateral (subtemporal or transcortical), and posterior.42 Other authors prefer to carry out an anterior temporal lobectomy or anteromedial temporal lobectomy to approach lesions located in the MTR.43,44,45 Yañagisawa introduced the pterional-transsylvian approach and demonstrated that it is suitable for removing the anterior two-thirds of the MTR in patients with MTE due to hippocampal sclerosis.46,47 Its usage also was shown to be appropriate for many patients with large tumors involving the entire length of the MTR.48

Lateral approaches are other alternatives to reaching the MTR and may be divided into subtemporal and transcortical approaches. The subtemporal approaches include the subtemporal,12,27 zygomatic,45 petrosal,53 and transcoccygus temporal sulcus.5 The lateral-transcortical approach described by Niemeyer40 for resecting the amygdala and hippocampus was followed by some modifications through the temporal gyri and sulci.15,33 However, all of these approaches have limitations in exposing the entire length of the MTR and necessitate more or less temporal lobe retraction or incisions, which endanger the optic radiation.

The posterior interhemispheric approach is very useful for lesions located in the posterior portion of the MTR.60 Other alternatives for such lesions are the supracerebellar infratentorial approach46 and the lateral occipital subtemporal approach.57 These latter two approaches were also used to reach the middle portion of the MTR; however, extensive retraction of the occipital lobe is necessary and endangers the occipital basal and posterior temporal veins.

The supracerebellar transtentorial approach was developed by Yañagisawa to remove posterior hippocampal cavernous malformations without injuring the optic radiation.56 Later, he used this approach in 2 patients with posterior parahippocampal dysplasia and 1 patient with an oligodendroglioma.59 The supracerebellar transtentorial approach was revitalized by Yonekawa and colleagues60 to approach the posterior portion of the MTR. De Oliveira (E. de Oliveira, personal communication, 2008) and Moftakhar et al.28 also used this approach for the posterior portion of the MTR. Yañagisawa62 developed the idea of a PST approach for selective amygdalohippocampectomy. His main concern was the possible difficulty of removing the amygdala and piriform cortex using the PST approach.

Since the first such posterior procedure was performed in 1968, I am continually reflecting on the issue and suggesting to colleagues that this approach could be applied routinely for selective [amygdalohippocampectomy]. It would be quite difficult to access the amygdala and temporal pole areas along the semicircular trajectory around the cerebral peduncle. Nevertheless, if experts in the field of epileptology could determine with certainty that only the hippocampus and parahippocampal gyrus should be removed, I would not hesitate to use the supracerebellar approach.64

Following extensive cadaveric studies, we found that it is possible to remove the amygdala and piriform cortex using the PST approach. However, we did not submit this study for publication until we had the experience of surgical application, and we had to wait 10 years to perform the first surgery. This delay was due to the need to understand in greater detail the anatomy of the fiber system and the microsurgical anatomy of the MTR region and to gain enough experience with tumor and epilepsy cases involving the MTR region. We first used this approach to remove a tumor in the entire length of the MTR and then applied it in patients with MTE due to hippocampal sclerosis.

The PST approach offers several advantages for selectively removing lesions involving various portions of the MTR. In lesions involving the entire length of the MTR, the senior author (U.T.) had previously performed a second procedure using the posterior interhemispheric approach if there was residual tumor in the posterior portion of the MTR after the pterional-transsylvian approach. However, the PST approach allows surgery to be completed in a single session rather than 2, and it is
the least invasive technique for removing these lesions. Consequently, we now prefer this approach. For extended tumoral lesions of the MTR, the PST approach provides an excellent panoramic view of the entire MTR without disturbing the neighboring structures.

For lesions restricted to the posterior portion of the MTR, the PST is a good alternative to the posterior interhemispheric approach. However, exposing the superior part of the posterior portion may be difficult because of obstruction by the galenic venous system. If the lesion is located in the posterior and middle portions, or restricted to the middle portion, the PST approach is most suitable. Although the PST is a posterior approach, it is more useful for removing not only the posterior but also the middle and anterior portions of the MTR as well as the amygdala. Table 2 summarizes the various locations of the MTR lesions and appropriate approaches to these lesions.

The PST discloses excellent landmarks during the entire surgery, which may be surprising, as the PST is not a difficult approach compared with others. Of course, it does require a different perspective of the MTR region, but this perspective can be learned through cadaver dissections and it provides excellent orientation with precise landmarks. The brainstem and major vascular structures near the MTR are located medially and the vascular course with its branches is visualized intracisternally, which prevents major injury to these structures during

Fig. 11. Case 5. A: Axial T2-weighted and FLAIR images obtained through the hippocampal formation and coronal inversion recovery sequences showing left-sided (L) hippocampal sclerosis, especially in the posterior portion. B: Postoperative axial T2-weighted (upper left) and T1-weighted (upper right), coronal T2-weighted (center row), and sagittal T1-weighted (lower row) images showing left-sided selective amygdalohippocampectomy through the PST approach. C: Postoperative fiber tractography demonstrates that the major fiber systems (in various colors) of the temporal lobe have been preserved; green = uncinate fasciculus; red = anterior commissure; blue = frontooccipital fasciculus; yellow = posterior thalamic peduncle, which includes the optic radiation. D: A postoperative visual field study demonstrated a normal visual field.
resection of the MTR. Neither the visual cortex nor the optic radiation is related to the surgical trajectory, and therefore, the risk of injury to these structures is minimal. Nonetheless, the surgeon should be aware of the location of the lateral geniculate body when opening the choroidal fissure.

For patients with MTE, the advantages may be even greater. This technique makes possible real selective removal of MTR structures with a more posterior resection. This avenue may be an advantage for more successful seizure control and better neuropsychological and psychosocial outcome in patients with posteriorly located hippocampal sclerosis. However, this difference should be verified through further studies.

The long history, discussions and controversies over iatrogenic visual field defect after epilepsy surgery\(^4,8,11,20,25,38-40\) will come to an end with the use of the PST approach. With precise knowledge of surgical anatomy and microsurgical technique, surgeons have achieved excellent results with the pterional-transsylvian approach without visual field defects.\(^5\) The senior author (U.T.) has had the same experience when using that approach for selective amygdalohippocampectomy.\(^51\) After using the PST approach more frequently for tumor cases, however, we are more comfortable using it for MTE cases as well, especially if hippocampal sclerosis is evident in the posterior portion. The PST approach may be preferable as it allows more posterior resection compared with the pterional-transsylvian approach. We must mention, however, that removing a sclerotic hippocampus in MTE cases is much easier than removing MTR tumors because a tiny and atrophied hippocampus and an evident temporal horn make the surgery less complicated, and even removing the hippocampus in one piece becomes possible for the sake of research studies. We recommend the PST approach as an alternative for those who have difficulty with selective amygdalohippocampectomy through the pterional-transsylvian approach.

One possible criticism of the PST approach for MTE patients is the difficulty of temporal pole resection, if it is necessary. As we gained more experience using this approach in tumor cases, however, we noticed that it is possible to remove the temporal pole. Recurrent seizures after anterior selective amygdalohippocampectomy may be due to iatrogenic damage to the temporal neocortex, sylvian region, or temporal pole. However, none of these areas is damaged during the PST approach. This difference also needs further evaluation and studies in large series.

Like many other approaches, the PST approach has potential problems and difficulties. For example, the semisitting position needs special attention from the neurosurgeon, anesthesiologist, nurses, technicians, and the entire operating team.\(^14,21,62\) However, modern neuroanesthesiology with TEE and modern monitoring methods have made this position safe. It is important to mention that the absence of any septal defect must be confirmed with TEE through the bubble test, as transthoracic echocardiography may miss small defects. In one of our patients with MTE, a small atrial septal defect was detected using TEE before the patient was positioned. Therefore, we used the pterional-transsylvian approach for selective amygdalohippocampectomy. The semisitting position makes the PST approach possible. We do not recommend performing it in any other position.

The patient should be positioned in a stepwise fashion, checking the hemodynamics and other parameters and also adjusting the depth of anesthesia appropriately. Padded cushions should be kept under areas vulnerable to nerve compression. An experienced anesthetist and his or her assistant must be present throughout the entire surgical procedure. Instead of discarding this method because of the risk of air embolism, we can concentrate on discovering the reasons for them through the surgical area, as well as ways to prevent or minimize them while developing advanced techniques to determine the admission of air. Using TEE helps detect airflow to the blood circulation in the early stage of surgery, making it possible to make necessary changes before any problems occur. One maneuver is to decrease the degree of elevation of the back section, which is possible only when the back section’s accessory rail is used for the Mayfield crossbar adaptor (Fig. 8A). Approximately 25° of head elevation provides adequate exposure when the surgical table is raised as necessary. Modifying the semisitting position with flexion of the patient’s head and elevating the legs make the semisitting position safe. In our series, we did not encounter any complications related to air embolism.

### TABLE 2: Options for the surgical approach to various locations in the MTR

<table>
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<tr>
<th>Tumor Location*</th>
<th>Pterional-Transsylvian</th>
<th>PST</th>
<th>Posterior Interhemispheric</th>
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<td>only in the anterior portion (A)</td>
<td>X</td>
<td></td>
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</tr>
<tr>
<td>anterior &amp; middle portions (A+M)</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>anterior, middle, &amp; posterior portions (A+M+P)</td>
<td>X†</td>
<td>X</td>
<td></td>
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<tr>
<td>only in the middle portion (M)</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>middle &amp; posterior portions (M+P)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>only in the posterior portion (P)</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>posterior portion &amp; isthmus cinguli</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

* The abbreviations in this column refer to locations in Fig. 1.
† In some cases, the pterional-transsylvian approach may be limited for these lesions. In this situation, a second session should be done with a posterior interhemispheric approach.
Paramedian supracerrebellar-transtentorial approach

Another possible problem with having the patient in the semisitting position is that modern microscopes with autofocus and zoom systems are not suitable because of the large optical head of the surgical microscope, which necessitates extreme stretching of the surgeon's arms. This problem is solved by using a surgical microscope with a small optical head controlled by a mouth switch and using an armrest.62 The mouth switch frees up the surgeon's hands, especially for the semisitting position, in which long instruments are used. This device allows the surgeon to move the microscope in various directions while working with 2 hands at great depth without interfering with the surgery.

The tentorial bridging veins between the superior surface of the cerebellum and the tentorium are a topic worthy of discussion. Releasing CSF from the cisterns and dissecting the superior or tentorial surface of the cerebellum from the tentorium provides enough space to remove the entire length of the MTR. The major components of the tentorial bridging veins are located in the midline, and the surgeon must certainly preserve these vermillion bridging veins to prevent cerebellar edema, venous infarction, or hemorrhage in certain instances.52,41,49 Rather than a midline trajectory, using the paramedian approach allows the surgeon to preserve these major supracerrebellar veins. A few and generally minor bridging veins also exist in the paramedian part of the supracerrebellar tentorial region. In 4 of our early patients (26.7%), we sacrificed these veins to gain enough exposure. Even though we did not see any clinical or neuroradiological signs, we tried to preserve these veins in later cases. By mobilizing the veins and modifying the tentorial incision, depending on the variations of these veins, preservation became possible, and we have succeeded in preserving these veins in the later cases (73.3%).

The PST approach makes it difficult to visualize and reach the inferior surface of the anterior parahippocampal gyrus with the microscope because of the obstruction created by the petrous ridge. The main reason for this difficulty is variations in the shape of the skull, which change the angle relationship between the transverse sinus and petrous ridge. To overcome this difficulty, we placed cotton sponges in the middle fossa underneath the parahippocampal gyrus to bring the hidden part into view, making removal of these areas possible. The high-definition neuroendoscope and a suction tube with a curved tip are of great help in visualizing and resecting residual tissue in this blind spot at the anteromedial part of the middle fossa.

In our experience, the PST approach is very appropriate for removing various MTR lesions with patients in the semisitting position. Releasing CSF from the cistern magna and the quadrigeminal and ambient cisterns pulls the cerebellum downward, so no cerebellar or supratentorial retraction is needed. The PST approach also allows precise anatomical orientation, and resection of even the anterior portion of the MTR is possible and comfortable for the surgeon.

Conclusions

The PST approach allows for safe removal of large MTR tumors extending from the piriform cortex to the isthmus of the cingulate gyrus in a single session without disturbing neural and vascular structures. This approach appears to be superior to previously described approaches as well as to 2-session surgery, which combines the pterional transsylvian and posterior interhemispheric approaches. More significantly, selective removal of the amygdala and hippocampus could be done for patients with MTE due to hippocampal sclerosis. This approach is a good alternative to other amygdalohippocampectomy techniques because there is no danger of injuring the major white matter structures, such as the uncinate fasciculus; anterior commissure, inferior and posterior thalamic peduncles (including the optic radiation); and the frontopontine, temporopontine, and occipitopontine fasciculi. Furthermore, there is no danger of damage to the superficial and deep sylvian veins, the middle cerebral artery and its branches, and especially the temporal pole and temporal neocortex. The posterior portions of the hippocampus and parahippocampal gyrus can be removed through this approach, possibly allowing better seizure control, especially in patients with posterior hippocampal sclerosis. Nonetheless, larger series and long-term follow-up are needed to confirm the advantages of the PST approach for patients with MTE. This approach also seems to be the best option for removing lesions in the fusiform gyrus, especially in the posterior portion.

Appendix

Major White Matter Fiber System of the Temporal Lobe

1. Short association (U) fibers
2. Superior longitudinal fasciculus (inferior arm)
3. Uncinate fasciculus
4. Occipitofrontal fasciculus
5. Anterior commissure
6. Sublenticular part of the internal capsule
   I. Temporopontine fibers
   II. Occipitopontine fibers
   III. Inferior thalamic peduncle
   IV. Posterior thalamic peduncle (includes optic & auditory radiations)
7. Tapetum
8. Inferior longitudinal fasciculus
9. Alveus-fimbria-fornix
10. Cingulum (inferior arm)

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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