Anterior transpetrosal approach: experiences in 274 cases over 33 years. Technical variations, operated patients, and approach-related complications

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OBJECTIVE The anterior transpetrosal approach (ATPA) was initially reported in 1985. The authors’ institution has 274 case records of surgery performed with the ATPA during the period from 1984 to 2017. Although many technical advances and modifications in the ATPA have occurred over those 33 years, to the authors’ knowledge no articles to date have reported a detailed analysis of variations and complications of the ATPA. In this study, the authors analyzed their patient series to elucidate improvements over time in ATPA methodology while highlighting unresolved problems and evaluating how to avoid surgical complications.

METHODS All surgical cases (274 patients) using the ATPA at the authors’ institution during the period from 1984 to 2017 were analyzed retrospectively using charts, clinical summaries, operative records, and operative videos. Obtained parameters were patient age and sex, diagnosis, size of tumors, location of disease, operative date, neurological symptoms before and after surgery, radiographically identified brain injury, and other surgical complications. The most common diagnosis was petroclival meningioma (n = 158), followed by trigeminal schwannoma (n = 32), chordoma (n = 25), epidermoid tumor (n = 21), other tumor (n = 27), aneurysm (n = 6), and other (n = 5).

RESULTS The original ATPA was performed in 239 cases. In an additional 35 cases, a modified ATPA was performed. Zygomatic osteotomy with ATPA was a common modification that was used in 19 of the 35 cases to decrease retraction damage to the temporal lobe for high-positioned tumors. Brain injury by temporal lobe retraction without venous hemorrhage still occurred in 8 of the 19 cases (3.1%) with surgical death in 1 of these cases (0.4%) of reoperation with sacrifice of the petrosal vein. Symptomatic CSF leak was the most frequent complication noted and was observed in 35 cases (13.5%). In most of these cases the patients were cured by observation or lumbar drain, but in 6 cases (17.1%) reoperation was needed. Facial nerve damage related to surgical approach decreased from 6.2% to 3.5% after 2010; however, the incidence of CSF leaks (13.5%) has not improved.

CONCLUSIONS There have been several modifications and advancements made in the ATPA to increase tumor removal and decrease surgical complications. However, complications related to surgical approach occurred, such as venous occlusion–related brain injury and facial nerve damage at pyramid resection. CSF leak remained an unsolved problem related to the ATPA procedures. Preoperative assessment of venous variation of the middle fossa, pneumatization of the temporal bone, and intraoperative monitoring of cranial nerves are important procedures to decrease these complications.


KEYWORDS transpetrosal; anterior; complication; skull base

THE anterior transpetrosal approach (ATPA) was initially performed for surgical management of aneurysms at the Mihara Memorial Hospital and reported in 1985 by Kawase et al.¹ This technique has since been applied to petroclival tumors to increase the degree of tumor removal and to decrease surgical complications associated with more traditional approaches, such as subtemporal or suboccipital routes. Our institution (Keio University) has recorded data for 274 cases utilizing the ATPA between 1984 and 2017.¹⁻³ The ATPA is now well known worldwide, and its techniques and pitfalls have been widely recognized.⁴⁻⁷
There have been many technical advancements over the 33 years during which the study patients underwent surgery with the ATPA approach, including the opening of Meckel’s cave and the combination of ATPA with zygomatic osteotomy (zygomatic petrosal approach, subdural ATPA, and ATPA with partial posterior petrosectomy). However, no previous article has reported the history and objective of technical modifications and detailed analysis of complications of the ATPA, and there have been no large published case series on the ATPA. In this study, we characterized the ongoing technical variations of the ATPA at our institution and the surgical complications related to these surgical approaches, including chronological changes in complications.

**Methods**

All surgical cases (274 cases) in which patients underwent surgery performed with the ATPA approach from 1984 to March 2017 at the School of Medicine, Keio University were analyzed retrospectively using charts, clinical summaries, operative records, and operative videos. Most surgeries were performed by two of the authors at this university (T.K. and K.Y.). The definition of ATPA used for data analysis was an operative method that includes drilling of Kawase’s triangle. We excluded the so-called “combined petrosal approach,” or posterior petrosectral approach, because ATPA was developed to spare complications that might occur by posterior petrosectomy, i.e., hearing loss, facial nerve injury, CSF leak, or venous infarction by injury to the vein of Labbe. However, cases of ATPA performed with partial posterior petrosectomy (4 cases) were included in this study because the surgical complication risk of partial posterior petrosectomy was negligible.

**Patient Backgrounds**

The ATPA was performed in a total of 274 patients (178 females and 96 males). The mean ± SD patient age was 49.7 ± 14.7 years. The most common diagnosis in patients who underwent the ATPA was meningioma (n = 158), followed by trigeminal schwannoma (n = 41), chordoma (n = 25), and epidermoid tumor (n = 21) (Table 1). Nontumor cases were very rare and comprised 6 aneurysm cases, 2 trigeminal neuralgia cases, and 2 CSF leaks by meningocele. Although there were only 11 ATPA cases in the 1980s, there have been 12–15 cases consistently each year since 2000. The ATPA as a second surgery was done in 23 cases of tumor regrowth, including 7 cases of chordoma, which had the highest incidence of reoperation due to tumor regrowth.

The size of the tumor was also analyzed on the 4 most common tumors. The average sizes were 31.1 mm for meningioma, 20.5 mm for schwannoma, 17.3 mm for trigeminal schwannoma, and 22.0 mm for chordoma.

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<tbody>
<tr>
<td>Meningioma</td>
<td>36</td>
<td>67</td>
<td>55</td>
<td>158</td>
<td>8 (5.1%)</td>
</tr>
<tr>
<td>Schwannoma</td>
<td>10</td>
<td>17</td>
<td>14</td>
<td>41</td>
<td>3 (7.3%)</td>
</tr>
<tr>
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<td>9</td>
<td>14</td>
<td>9</td>
<td>32</td>
<td></td>
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<tr>
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<td>0</td>
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<td>1</td>
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<td>Trochlear</td>
<td>0</td>
<td>0</td>
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<td>1</td>
<td>3</td>
<td>3</td>
<td>7</td>
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</tr>
<tr>
<td>Chordoma</td>
<td>5</td>
<td>17</td>
<td>3</td>
<td>25</td>
<td>7 (28%)</td>
</tr>
<tr>
<td>Epidermoid</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>21</td>
<td>1 (4.8%)</td>
</tr>
<tr>
<td>Other tumors</td>
<td>4</td>
<td>8</td>
<td>7</td>
<td>19</td>
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<tr>
<td>Hemangiopericytoma</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>1 (16.7%)</td>
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<td>0</td>
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<tr>
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<td>0</td>
<td>1</td>
<td>2</td>
<td>1 (50%)</td>
</tr>
<tr>
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<td>1</td>
<td>0</td>
<td>2</td>
<td></td>
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<td>0</td>
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<td>1</td>
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<td>1</td>
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<td>1</td>
<td>0</td>
<td>1</td>
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<td>0</td>
<td>1</td>
<td>1</td>
<td>1 (100%)</td>
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<tr>
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<td>0</td>
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<td>1</td>
<td>1 (100%)</td>
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<tr>
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<td>2</td>
<td>1</td>
<td>6</td>
<td></td>
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<td>CSF leak (1st-time case)</td>
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<td>0</td>
<td>2</td>
<td>2</td>
<td></td>
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<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>65</td>
<td>118</td>
<td>91</td>
<td>274</td>
<td>23 (8.4%)</td>
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</table>

Values are presented as number of patients or number (%).
ningiomas (n = 153), 31.7 mm for trigeminal schwannomas (n = 28), 31.0 mm for chordomas (n = 25), and 21.0 mm for epidermoid tumors (n = 21). Meningiomas were large (≥ 30 mm) in 95 cases and small (< 30 mm) in 58 cases. Trigeminal schwannomas were large (≥ 30 mm) in 18 cases and small (< 30 mm) in 10 cases.

Analysis of Clinical Data

Clinical data for the study patients were available for parameters including patient age and sex, diagnosis, location of disease, size of the tumor, operation date, variation of ATPA, and neurological symptoms before and after surgery. The presence or absence of brain injury caused by surgical approach (contusion, infarction, hemorrhage) was evaluated on postoperative MRI and/or CT studies. CSF leak, exudative otitis media, and wound infection were counted as complications by surgical approach. Data regarding complications involving cranial nerves (CNs) were obtained from both surgical records and postoperative MRI and/or CT studies. The parameter “approach-related facial palsy” includes any facial palsy, even House-Brackmann grade II mild palsies. "Hearing disturbance" also includes any hearing disturbance more severe than Gardner-Robertson class 2. Diagnoses of patients who underwent ATPA and had approach-related complications were analyzed to compare each of the three distinct time periods (1980–1999, 2000–2009, and 2010–2017). This retrospective study was approved by the Institutional Review Board of the School of Medicine, Keio University (20130379). The chi-square test was used to compare the incidence rates of CSF leak in the presence and absence of the parameters listed above. Analyses were performed with IBM SPSS Statistics (IBM Corp.).

Results

Preoperative Neurological Symptoms

Preoperative neurological symptoms were analyzed in all first-time surgical cases and for each of the four most common tumor entities (Table 2). Trigeminal nerve (CN V) symptoms were the most common of all neurological symptoms and were seen in 42.2% of cases. Tumor size was not related to the preoperative trigeminal nerve symptom rate associated with meningiomas and trigeminal schwannomas. The preoperative neurological symptoms seen with small trigeminal schwannomas were mostly trigeminal nerve symptoms only. Diplopia was observed in 28.2% of cases. Many patients with chordoma (52.0%) complained of diplopia preoperatively, mostly attributable to abducens nerve (CN VI) palsy. The rate of abducens nerve symptoms in all cases was 21.5%, and it was the second most common preoperative CN deficit in our series. Many chordoma cases showed abducens nerve deficit (48%). Oculomotor nerve (CN III) deficit was seen in 9.7% of all cases, and large-meningioma cases (> 3 cm) had a higher preoperative oculomotor deficit rate than small-meningioma cases (< 3 cm). Preoperative trochlear nerve deficit (CN IV) was rare in all cases (3.8%), but often occurred in chordoma patients (16.0%). Preoperative facial nerve deficit (CN VII) was seen in 8.4% of the patients. Symptoms related to the vestibulocochlear nerve (CN VIII), such as hearing disturbance, dizziness, or vertigo, were seen in 19.4% of all cases. The incidence of preoperative hemiparesis was 6.3%. Hemisensory disturbances were relatively rare (1.3%) in all ATPA cases. Preoperative cerebellar symptoms were seen in 9.7% of all cases.

Historical Advancement of ATPA

The original ATPA was used in 239 cases; however, the surgical method has gradually transformed into today’s method. For the first several cases that involved basilar aneurysms, Meckel’s cave was not opened. Starting in 1998, the opening of Meckel’s cave allowed extension of the surgical field for larger tumors. The posterior cavernous sinus (CS) could be opened by this approach, and meningiomas invading the CS could be removed by opening the CS until 1997, with sacrifice of ophthalmic function. However, tumors in the CS were not surgically removed thereafter, but treated with Gamma Knife surgery. The combination of zygomatic osteotomy and ATPA began to be used in...
1992 in order to expand the surgical field. ATPA was applied to trigeminal schwannomas from 1994, and the parasellar part of the tumor has been accessed epidurally since 1996.\textsuperscript{12}

**Surgical Variations of ATPA**

Variations of ATPA were performed in 35 patients, and the approach was chosen on the basis of tumor size and direction of tumor extension.\textsuperscript{13} The site of bone resection of the original ATPA and its variation are shown in Fig. 1.

**ATPA With Zygomatic Osteotomy**

The most frequent variation was zygomatic osteotomy with ATPA (19 cases). It was used to decrease retraction to the temporal lobe, by reflection of the temporal muscle more inferiorly. Zygomatic osteotomy was indicated for dumbbell trigeminal schwannomas with parasellar extension (2 cases) (Fig. 2) or petroclival meningiomas showing high extension over the posterior clinoid process (13 cases). The zygoma was cut at the part of the arch only, and a wide infratemporal field was obtainable with about 20 minutes of dissection. For schwannomas, an epidural subtemporal approach was used.

**ATPA With Frontotemporal Approach**

The combination of ATPA with a frontotemporal approach was used in 8 cases of tumors with suprasellar extension, such as parasellar chordoma (1 case), central skull base meningioma (6 cases), or suprasellar epidermoid (1 case) (Fig. 3). In some cases, a two-staged surgery was performed to decrease the operation time.

**ATPA With Partial Posterior Petrosectomy**

The ATPA with partial posterior petrosectomy was indicated in 4 patients with meningiomas or chordomas extending minimally over the internal auditory meatus (IAM), with larger tumors considered for a combined petrosal approach and not included in this series. The objective of the variation was complete tumor removal and preservation of the patient’s auditory function. Bone resection was extended toward the posterior pyramidal ridge and/or Trautman’s triangle, where functional organs were not present. The anterior semicircular canal was sometimes opened, but to preserve auditory function the middle ear and labyrinth were not opened.

**Planned Two-Staged Operation Using Other Approaches**

Four cases were treated by a two-staged operation using other approaches. One was a case of ATPA combined with a lateral suboccipital (LSO) approach for meningioma showing inferior extension. The combined petrosal approach was not indicated in this case, because of the

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**FIG. 1.** Variation of the ATPA to access petroclival tumors and larger tumors, spare injury to auditory organs, and shorten operation time. **A:** ATPA indicated for tumors with attachment located anterior to the IAM. (A, dotted area) indicates the site of bone resection medial to the greater superficial petrosal nerve (GPN) and anterior to the arcuate eminence and labyrinth (LB). For tumors showing high extension of more than 15 mm over the posterior clinoid process, zygomatic osteotomy (Z) was combined with the ATPA. **B:** ATPA with partial posterior pyramid resection (opening of the anterior semicircular canal) for tumors extending posterior to the IAM, indicated for patients without useful hearing. Resection of Trautman’s triangle (TT) was one option for patients with useful hearing. **C and D:** Two-step surgery for petroclival tumors showing large extension over the pyramid. By the first surgery of ATPA (A, dotted area), the tumor part anterior to the facial nerve was removed, including detachment of feeders from the meningo-hypophyseal trunk (C). The posterior part could be removed by the retrosigmoid approach (dotted area) in the second surgery, because the tumor was devascularized by the first surgery (D). CH = cochlea; FM = foramen magnum; SS = sigmoid sinus. Copyright Takeshi Kawase, School of Medicine, Keio University, Neurosurgery. Published with permission. Figure is available in color online only.
**FIG. 2.** A case of a huge trigeminal schwannoma in a 26-year-old male patient who complained of mild ataxia and underwent ATPA+zygomatic osteotomy. **A:** Gadolinium-enhanced MR image showing a dumbbell tumor compressing the brainstem and engulfing the internal carotid artery and basilar artery. **B:** Surgical drawing demonstrating ATPA with zygomatic osteotomy (zygomatic petrosal approach). The dashed line shows the incision of the periosteal dura to access the tumor. **AE** = arcuate eminence; **FO** = foramen ovale; **FR** = foramen rotundum; **GSPN** = greater superficial petrosal nerve; **MMA** = middle meningeal artery; **SOF** = superior orbital fissure. **C:** Drawing of the exposure of the tumor. **SPS** = superior petrosal sinus. **D:** Postoperative MR image showing no damage to the temporal lobe, because the subtemporal epidural approach was made more inferior by use of the zygomatic osteotomy. The patient had no complications after surgery. Panels B and C copyright Takeshi Kawase, School of Medicine, Keio University, Neurosurgery. Published with permission. Figure is available in color online only.

**FIG. 3.** A case of a basal epidermoid in a 54-year-old male patient without symptoms who underwent a combined ATPA and frontotemporal approach. **A and B:** MR images before surgery. The tumor invaded from the suprasellar to posterior (post) fossa. **C:** Surgical drawings of the suprasellar tumor seen after pterional craniotomy (upper) and the posterior fossa tumor removed by ATPA (lower). The tumor was completely removed without complications. **AICA** = anterior inferior cerebellar artery; **BA** = basilar artery; **ICA** = internal carotid artery; **PCA** = posterior cerebral artery; **Pcom** = posterior communicating artery; **SCA** = superior cerebellar artery; **SPS** = superior petrosal sinus. Panel C copyright Takeshi Kawase, School of Medicine, Keio University, Neurosurgery. Published with permission. Figure is available in color online only.
anterior presence of the vein of Labbe (Fig. 4). ATPA combined with an infratemporal fossa approach was used for a case of trigeminal schwannoma that had invaded the infratemporal fossa.

**Approach-Related Complications and Their Decade Change**

Complications related to surgical approach (Table 3) included brain injury with or without venous hemorrhage, CSF leakage, hearing disturbance, facial nerve injury during bone resection, and wound infection. Temporal lobe injury including contusion, infarction, and hemorrhage occurred in 8 cases (3.1%). Retraction of the temporal lobe with or without sacrifice of epidural/subdural venous route was the main cause of the complication. A surgical death occurred in 1 case (0.4%). The cause of death in this large-meningioma case (> 5 cm) was hemorrhagic infarction by venous occlusion. The patient in this case was operated on two times at another institution, so the ATPA surgery included in this study was not the original but actually the third surgery. The incidence of temporal lobe injury was 4.9% during 1983–1999, 2.7% in 2000–2009, and 2.3% in 2010–2017. Symptomatic CSF leak requiring specific management after surgery (bed rest, spinal drainage, and reoperation) was the most frequent complication noted.

**TABLE 3. Yearly change of approach-related complications**

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<tbody>
<tr>
<td>Surgical death</td>
<td>0% (0/61)</td>
<td>0.8% (1/113)</td>
<td>0% (0/87)</td>
<td>0.4% (1/261)</td>
</tr>
<tr>
<td>Temporal lobe injury</td>
<td>4.9% (3/61)</td>
<td>2.7% (3/113)</td>
<td>2.3% (2/87)</td>
<td>3.1% (8/261)</td>
</tr>
<tr>
<td>CSF leak</td>
<td>14.8% (9/61)</td>
<td>11.6% (13/112)</td>
<td>14.9% (13/87)</td>
<td>13.5% (35/260)</td>
</tr>
<tr>
<td>CSF leak needed op</td>
<td>1.6% (1/61)</td>
<td>0.9% (1/112)</td>
<td>4.6% (4/87)</td>
<td>2.3% (6/260)</td>
</tr>
<tr>
<td>Exudative otitis media</td>
<td>4.9% (3/61)</td>
<td>6.3% (7/112)</td>
<td>5.7% (5/87)</td>
<td>5.8% (15/260)</td>
</tr>
<tr>
<td>Wound infection</td>
<td>0% (0/61)</td>
<td>0% (0/112)</td>
<td>1.1% (1/87)</td>
<td>0.4% (1/260)</td>
</tr>
<tr>
<td>Approach-related facial palsy</td>
<td>5% (3/60)</td>
<td>8.9% (10/112)</td>
<td>3.5% (3/85)</td>
<td>6.2% (16/257)</td>
</tr>
<tr>
<td>Hearing disturbance</td>
<td>3.3% (2/60)</td>
<td>5.4% (6/112)</td>
<td>2.4% (2/85)</td>
<td>3.9% (10/257)</td>
</tr>
</tbody>
</table>

Values are presented as percentage of affected patients (no. of affected patients/total no. of patients in group).
and was observed in 34 cases (13.8%). Six cases of CSF leak required a revision surgery. No decrease in the incidence of CSF leak has been noted since 1983. Some cases of exudative otitis media and meningitis were related to CSF leaks. Exudative otitis media after ATPA occurred in 15 cases (5.8%). ATPA approach–related facial palsy occurred in 16 cases (6.2%). Yearly incidence rates of facial nerve injury during bone resection were 5% (1983–1999), 8.9% (2000–2009), and 3.5% (2010–2017). Hearing disturbance after ATPA surgery occurred in 10 cases (3.9%). Wound infection occurred in only 1 case (0.4%).

Discussion

Advantages and Indications of the ATPA and Its Variations

The ATPA has several advantages as an operative approach to certain parts of the skull base. An advantage of the ATPA is that it provides a wide surgical view to the trigeminal nerve area from the brainstem to Meckel’s cave, the anterior aspect of the pons, and the clivus region with preserved hearing.2,3 However, the surgical field is limited. Opening and removing tumor from Meckel’s cave enlarges the surgical space, allowing tumor removal from the parasellar space.3,14 It is possible to expose tumors extending from the middle cranial base to the infratemporal fossa by additional osteotomy of the zygomatic arch and zygomatic transpetrosal approach,16,17 because these nerves are pushed back by the nerve, and lower CN might be lower than with the LSO. ATPA included pontine cavernomas and trigeminal neuralgia, which can be treated by ATPA in cases inaccessible by the LSO.

Approach-Related Complications During ATPA

Many of the nonneurological complications, such as brain injury, which was mainly caused by temporal lobe retraction without venous infarction, CSF leak including exudative otitis media, and wound infection, were approach-related complications of ATPA.

Retraction Injury and Venous Complication

With the current subtemporal or subtemporal-transtentorial approach, retraction injury to the temporal lobe had been a significant problem that frequently included damage to the vein of Labbe. The epidural approach of the ATPA decreased the risk of temporal lobe contusion (3.1%). However, we sometimes encountered severe epidural bleeding during surgery and postoperative swelling of the temporal lobe, even with the ATPA. The main cause of temporal lobe injury might have been epidural venous occlusion during the ATPA. Drainage routes of the superficial middle cerebral vein (SMCV) must be preserved. The drainage pattern of the SMCV (e.g., sphenopetrosal patterns) should be carefully studied before surgery (Fig. 5), because in the case of a sphenopetrosal pattern, epidural coagulation of venous routes around the foramen ovale can cause stagnation of the SMCV.20,22 The vein of Labbe is well known to be preserved by the subtemporal approach or posterior petrosal approach, but other venous variation of the middle fossa, including the sphenopetrosal vein, sphenopetrosal vein, and tentorial veins, should be attempted before ATPA. The use of recently developed imaging modalities (multislice CT angiography, MR venography) can create detailed venous patterns for assessment. Shibao et al. classified venous drainage patterns and established several technical tips for venous preservation.23,24 Preservation of the petrosal vein, which if occluded can cause brainstem injury, is important and possible by ATPA, but caution is needed if the patient has had prior surgery or radiosurgery. A fatal complication in our series was due to brainstem hemorrhage and infarction caused by occlusion of the petrosal vein, which when...
The facial nerve at the geniculate ganglion (GG) courses very superficially in the pyramid, and careless drilling over the GG of the facial nerve was a main cause of facial nerve injury. The GG can be preserved by identification and preservation during surgery and/or postoperative venous hemorrhage in the temporal lobe. These types of sphenopetrosal vein (SPV) and tectorial veins may cause similar risks by vein occlusion. The vein of Labbe (VL), commonly located more posteriorly, has a low risk of occlusion by ATPA. PV = petrosal vein. Copyright Takeshi Kawase, School of Medicine, Keio University, Neurosurgery. Published with permission. Figure is available in color online only.

FIG. 5. Venous variation of the middle fossa. The superficial middle cerebral vein (SMCV) commonly drains into the CS. In this type of sphenopetrosal vein (SPV), the SMCV drains into the sphenopetrosal vein through the foramen ovale (FO), flowing epidurally around the trigeminal nerves (V2 and V3). With this type or anatomical arrangement, epidural dissection around the FO by ATPA has a risk of severe venous bleeding. During surgery and/or postoperative venous hemorrhage in the temporal lobe, these types of SPV may cause similar risks by vein occlusion. The vein of Labbe (VL), commonly located more posteriorly, has a low risk of occlusion by ATPA. PV = petrosal vein.
has not decreased but remains an unsolved problem that must be resolved by further technical advancement.

References


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: Tomio, Horiguchi, Kawase. Acquisition of data: Tomio, Tamura, Yoshida, Kawase. Analysis and interpretation of data: Tomio, Kawase. Drafting the article: Tomio, Horiguchi, Borghesi-Razavi, Kawase. Critically revising the article: Tomio, Horiguchi, Borghesi-Razavi, Yoshida, Kawase. Reviewed submitted version of manuscript: Tomio, Borghesi-Razavi, Tamura, Yoshida, Kawase. Approved the final version of the manuscript on behalf of all authors: Tomio. Statistical analysis: Tomio, Tamura. Administrative/technical/material support: Tomio, Tamura, Yoshida, Kawase. Study supervision: Tomio, Horiguchi, Yoshida, Kawase.

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