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

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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 petrosal 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 = 32), 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, 24.7 mm for schwannoma, 6.8 mm for trigeminal schwannoma, and 3.9 mm for chordoma.

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**Table 1. Diagnosis of patients who underwent ATPA surgery**

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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>
<td>Trigeminal</td>
<td>9</td>
<td>14</td>
<td>9</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Abducens</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Trochlear</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Unclassifiable</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>7</td>
<td></td>
</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>
<td></td>
</tr>
<tr>
<td>Hemangiopericytoma</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>1 (16.7%)</td>
</tr>
<tr>
<td>Cavernous angioma</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td></td>
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<tr>
<td>Cholesterol granuloma</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>1 (50%)</td>
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<tr>
<td>Dermoid</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Chondrosarcoma</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
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</tr>
<tr>
<td>Giant cell tumor</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
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<tr>
<td>Foreign body granuloma</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Hemangioma</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td></td>
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<tr>
<td>Metastasis</td>
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<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
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<tr>
<td>Neurocytoma</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1 (100%)</td>
</tr>
<tr>
<td>Pituitary adenoma</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1 (100%)</td>
</tr>
<tr>
<td>Aneurysm</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>6</td>
<td></td>
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<tr>
<td>CSF leak (1st-time case)</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Trigeminal neuralgia</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>65</td>
<td>118</td>
<td>91</td>
<td>274</td>
<td>23 (8.4%)</td>
</tr>
</tbody>
</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 patient’s symptoms. Complications concerning tumor dissection were not counted in complications related to surgical approach. 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.

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. 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
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.

![Figure 4](image_url)

**FIG. 4.** A case of a large petroclival meningioma in a 38-year-old female patient with hearing disturbance who underwent two-step surgery. A: Gadolinium-enhanced MR image showing a large tumor extended posterior to the IAM. B: Venogram. Initially we considered a combined petrosal approach, but determined that it would be risky because the vein of Labbe runs along the temporal base (arrow). The anterior two-thirds of the tumor was removed with coagulation of feeders from the tentorium, until the facial nerve was confirmed by ATPA. C: Postoperative gadolinium-enhanced MR image. The remaining tumor could be removed by the LSO approach performed after 1 month, when the tumor feeders were coagulated by the first surgery. D: The tumor completely disappeared on the gadolinium-enhanced MR image after the second surgery. The patient had minimal double vision from the sacrifice of the trochlear nerve. No facial palsy persisted. Figure is available in color online only.

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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>
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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. 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. It is possible to expose tumors extending to the infratemporal fossa by additional osteotomy of the zygomatic arch and additional drilling of the middle cranial base, without excessive retraction to the temporal lobe. With the use of ATPA, risks of injury to the facial nerve, vestibulocochlear nerve, and lower CN might be lower than with the LSO approach, because these nerves are pushed back by the tumor, are located outside of the ATPA surgical corridor, and appear after tumor removal in most cases. The LSO also requires retraction of the cerebellum and sometimes causes contusion, but there is no need to retract the cerebellum with the ATPA. The ATPA requires temporal lobe retraction; however, with the ATPA the temporal lobe can be retracted with protection of the dura propria. Enabling the handling of multiple tumor feeders from the meningo-hypophysial trunk and the middle meningeal artery before tumor removal is also a well-known remarkable advantage of the ATPA.

For the original ATPA, our posterior limit was approximately 1 cm posterior from the internal auditory canal (IAC). The petroclival meningioma often extends posteriorly along the superior petrosal sinus. When the tumor extended posteriorly for more than 1 cm of the IAC and the patient’s hearing ability was preserved, we added drilling of Trautmann’s triangle to the surgical procedure. If the patient’s functional hearing was lost, we added partial labyrinthectomy (5 cases in this study) or posterior petrosectomy. The so-called “combined petrosectomy (anterior+posterior)” approach has been beneficial to tumors showing larger extension, but these approaches were excluded from this study. Our inferior limits of the ATPA were the middle clivus and the jugular tuberculum. If the tumor extended more inferiorly to the lower clivus, we planned a two-staged surgery with the LSO (2 cases) and/or transcondylar approach. The zygomatic transtemporal approach (zygomatic osteotomy with ATPA) was the most common modification of the ATPA (19 cases) for large petroclival tumors extending superiorly. Our indication for zygomatic osteotomy was tumor extending 15 mm superiorly from the posterior clinoid process. The frontotemporal approach with ATPA included 6 cases of tumor extending anteriorly. The ATPA is performed with the patient in supine position, and it can be performed as a one-stage surgery with the frontotemporal approach and zygomatic osteotomy.

Since 1984, the petroclival meningioma has been the most common indication for the ATPA (57.7%) at our institution. The second most common diagnosis was trigeminal schwannoma (11.7%). These two tumors comprised the most appropriate indications for this approach due to their location. Although most of the indications for the ATPA were tumors, there were also rare indications, such as lower basilar aneurysms. However, surgically performed clipping of basilar aneurysms has recently been replaced by endovascular techniques. Other indications for 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., sphenobasal and spheno-petrosal patterns) should be carefully studied before surgery (Fig. 5), because in the case of a sphenobasal pattern, epidural coagulation of venous routes around the foramen ovale can cause stagnation of the SMCV. 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 sphenobasal vein, spheno-petrosal 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. 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
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) 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.

adhered can be difficult to isolate, and sacrifice of this vein might cause fatal infarction if other drainage routes have been occluded by former surgery.

Injury to the Facial Nerve and Cochlea

The risk of facial palsy was 6.2% in our series. 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 of the greater superficial petrosal nerve (GSPN), which is an important landmark because it is located on the posterior extension line of the GSPN. The GSPN not only is an accurate landmark for Kawase’s triangle drilling 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 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.

surgical damage after 2000. We also reported that electro stimulation was useful for GSPN detection. This antidromic GSPN stimulation monitoring technique detects the GSPN location with a high level of accuracy.25 Hearing disturbance after ATPA might be attributable to damage to the cochlea and middle ear by extensive resection of the pyramid. Our series showed a 3.9% incidence of hearing disturbance after ATPA. Extensive opening of the IAC might cause cochlear injury, and opening the middle ear might cause exudative otitis media, leading to conduction deafness. Confirmation of hard bone around the cochlea anterior to the IAM is important to spare injury to the cochlea. Overdrilling the pyramid to the clivus may have caused abducens palsy at Dorello’s canal, but this could not be discriminated from complications occurring at tumor dissection.

CSF Leakage

CSF leak is a common complication of the ATPA. A CSF leak to bony air cells may result in exudative otitis media and hearing disturbance. Petrosectomy often opens air cells in the petrous bone, and packing of the opened air cells is not always easy. We usually use an autologous fat graft and fibrin glue for packing of the opened air cells, and the temporal base is covered by a fascia flap of the temporal muscle. However, the occurrence rate of CSF leaks has not improved over time but has persisted at around 14% since the 1980s, with about 17% of patients with CSF leak requiring reoperation. The CSF leak is still an unsolved problem of the ATPA, and it must be resolved in the next decade. Tamura et al. reported that assessment of an abnormal pneumatization pattern around the antrum of the temporal bone is important to estimate the risk of CSF leak.26 Preoperative bone imaging studies of the pyramid and complete packing of the opened air cells using an appropriately sized fat graft that covers the whole drilled surface are important for cases of high-risk pneumatization patterns, because it is nearly impossible to have visual contact with all of the opened air cells of the drilled surface due to the visual axis of the microscope. The endoscope may be useful to visualize opened air cells, but packing of all the drilled surfaces with fat grafts might be the most practicable solution. Air cells at the rim of the temporal craniotomy also caused CSF leaks in a few cases in series;26 they can be recognized and packed during closure, so the operator must carefully check opened air cells along the craniotomy rim.

Conclusions

This study provides data from the long history at the authors’ institution of ATPA development and ongoing variations to minimize surgical complications during removal of petroclival lesions. However, we still could not neglect surgical complications such as brain injury with venous hemorrhage, facial palsy, and CSF leakage. Detailed anatomical studies of pyramidal apex and epidural venous drainage patterns, as well as CN monitoring, contributed to technical improvement to decrease such surgical complications. However, the incidence of CSF leakage
does 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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