Conquering the Rock—A Retrospective Single-Center Experience of the Transapical Petrosal Transtentorial (Kawase) Approach: Operative Technique and Impact on Cranial Nerve Function

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Abstract

Since its description in 1985, the transapical petrosal transtentorial or Kawase approach has become a viable option of approaching lesions located in and around the apex of the petrous bone, Meckel's cave, and the anterolateral surface of the brain stem while preserving cranial nerve function. At the Brain Tumor Center, Erasmus MC, 25 patients were treated using the Kawase approach between 2004 and 2018 for various indications, including petroclival meningiomas, chondrosarcomas, pontine cavernomas, trigeminal schwannomas, and posterior circulation aneurysms. Hearing preservation was achieved in all patients; new abducens nerve and trochlear nerve palsies were present in three and six patients, respectively, of which a total of eight required ophthalmological correction. Seven patients experienced a cerebrospinal fluid fistula postoperatively, but this complication appeared self-limiting in all cases, with one patient experiencing secondary meningitis. After modifying our closure technique, the rate of fistulas dropped to zero. The observed direct postoperative mortality was 4% (one patient), although not related to the approach itself. In conclusion, the Kawase approach is a highly complex, but essential middle fossa approach, extremely robust, and able to serve a wide array of pathologies together with its extensions. It is very accurate for performing hearing preservation surgery, but not without caveats and inherent risk of complications.

Keywords

- petrosectomy
- petroclival meningioma
- Kawase approach
- cranial nerve
- anterior

Introduction

In the 1960s, an increased interest arose for the middle cranial fossa approaches and the treatment possibilities that it unlocked with Dolenc in Europe and Hakuba et al in Japan¹. Dolenc focused primarily on the cavernous sinus, Meckel's cave, and parasellar region and famously coined and popularized the intracavernous approach.² Hakuba et al focused their

attention more posteriorly on the petrous bone in an attempt to find a way to more safely approach lesions located in the middle fossa and extending to the posterior fossa without injuring the cranial nerves, especially the caudal ones, but also VII and VIII. After anatomical dissections and observing the work of William House, their group described an extended middle fossa approach with superior opening of the internal acoustic meatus for vestibular schwannomas.³ They observed

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that the safest area to drill in the petrous bone was the apex, as it had reliable landmarks. It offered a wide operating field and offered the surgeon the possibility of approaching the lesions from anterolaterally instead of posteriorly, working between the cranial nerves. Kawase et al defined this approach as it is known today for aneurysms of the lower basilar artery, or basilar trunk aneurysms which were not easily amenable to the usual orbitozygomatic or posterolateral approaches.⁴ Shortly after, the same group showed the relevance of this approach in the treatment of sphenopetroclival meningiomas in 10 patients.⁵ By this time, the Kawase approach, as it is known today, had developed into a straightforward, clear gateway from the middle fossa to the posterior fossa. Across the following decades, it has seen many extensions for various indications, but its relevance has remained high and it has earned its status as a “classic” and “indispensable” middle fossa approach.^{6–10}

However, indications for using this approach remain scarce, and therefore, acquirement of the necessary skills demands practice and a relatively large caseload. In this study, we describe our experience with this approach in a large academic center in the Netherlands, the specific operative technique we use, the results in clinical patients, patient selection, and our training philosophy, as well as its evolution along the years.

Materials and Methods

According to Dutch law, no Institutional Review Board approval was necessary to carry out this study. Between 2004 and 2018, 25 patients at the Brain Tumor Center, Erasmus MC were operated on using the Kawase approach. Surgery in all of these patients was performed by two senior staff members (E.J.D. and R.D.). The electronic patient files were used to extract baseline patient characteristics, radiological imaging, as well as outcomes, reflected in the modified Rankin scale (mRS) scores. mRS scores of 0 to 2 were considered good outcomes. Surgery was carefully planned and performed using extensive magnetic resonance imaging (MRI) pre- and postoperatively, computed tomography imaging, including venography, neuronavigation, and neuromonitoring of cranial nerves.

Before operating on the first patient, the senior author (E.J.D.) had extensive experience in skull base and petrous bone approaches, having visited many skull base centers, including a course given by Kawase himself, and had performed this approach in more than 25 cadavers. Only after thorough preparation, consultations with skull base colleagues and establishing the proper indication, the first patient could be operated on, without complications.

Operative Technique

Our operative technique follows the technique described by Kawase and further established by Roche et al.¹¹

Positioning and Craniotomy

The patients were usually positioned in a supine position with the head rotated 90 degrees with a roll used to elevate

the shoulder. The surgeon should be positioned in front of the vertex. Care should be taken not to compress the jugular vein because this will cause bleeding to be more profuse. The head is also tilted backward to facilitate retraction of the temporal lobe by gravity. A U-shaped incision above the ear is performed, beginning 2 cm before the tragus, extending superiorly to the superior temporal line and ending 2 to 3 cm behind the ear. In more recent operations, we chose a curved frontotemporal incision to gain more space for the inferior retraction of the temporal muscle, as described by Roche et al.¹¹ We did not need to resect the root of the zygomatic arch in any of the procedures, but this is a possibility which may be taken into account, should the need arise. A vascularized temporofascial flap is prepared and a temporal craniotomy is performed using three burr holes, one just above the root of zygoma which is usually enough to detach the dura from the skull, one posteriorly, and one just below the superior temporal line. This creates a craniotomy of $\sim 5 \times 5$ cm. The squamosal part of the temporal bone is drilled flush with the floor of the middle fossa as well as the pterion and flattening of the lateral wall of the orbit to identify the external margin of the superior orbital fissure (SOF).

Under magnification, the dura is then gently peeled away from the floor of the middle skull base. We do this from lateral to medial and from anterior to posterior. It is our opinion that the peeling of the dura from posterior to anterior exerts more tension on the geniculate ganglion/greater superior petrosal nerve (GSPN) and thus may increase the risk of facial nerve palsy. From posterior to anterior, the plane between the dura propria of the temporal lobe and the periosteal dura is also more difficult to identify. Even though it is theoretically possible to dissect underneath the GSPN and avulse it together with the geniculate ganglion, feasibility studies show the anterior to posterior approach is safe.¹²

Dural Peeling

From the SOF posteriorly, the foramen rotundum and V2 (maxillary branch of the trigeminal nerve) and foramen ovale and V3 (mandibular branch) can be identified. The dura is cut with a sharp dissector at the level of the cave of Meckel and under high magnification peeled from the middle fossa. Blood from the cavernous sinus is stopped by injecting fibrin glue.

The foramen spinosum is identified which is situated ~ 3.5 mm (± 1.5 mm) posterolaterally to the foramen ovale. The middle meningeal artery should be coagulated 2 mm above the foramen spinosum to avoid retraction of the middle meningeal artery and bleeding from the foramen spinosum. If this is the case, the bleeding can be controlled with tamponade using bone wax, Gelfoam, or other hemostatic materials available.

The GSPN is identified at the margin of V3 and is best left in a protective sheath of periosteal dura. The dura is then further peeled posteriorly and medially, past the point where the arcuate eminence is identified. Medially, the true and false ridges should be identified (**► Fig. 1**). The Kawase rhomboid should then be exposed as seen in **► Figs. 1 and 2**.

Fig. 1 Dissection performed on a cadaver, illustrating a right-sided approach, in the anatomy research laboratory of the Erasmus MC, Rotterdam. The arcuate eminence (1) and beneath it the superior semicircular canal (6) and foramen spinosum (4) are essential landmarks. The Kawase rhomboid, bordered by the GSPN (3) laterally running together with a branch of the middle meningeal artery, the lateral border of V3 and the Gasserian ganglion (retracted antero-medially to expose the true petrous apex) (2), and roof of the internal acoustic meatus (8). The external acoustic meatus lies at approximately 60-degree angle with the GSPN, and in this angle, we find the cochlea. Extra care needs to be given to the proper identification of the petrous ridge (9) and to differentiate it from the false petrous ridge (7). Also, dissected are the foramen ovale and mandibular branch of the trigeminal nerve (V3), the Gasserian ganglion within the trigeminal impression (2), the lesser petrosal nerve (5), and the artery of the foramen rotundum (10). The two parallel vertical lines show the extent of the exposure of dural peeling from the lateral border of V3 to just beyond the arcuate eminence. GSPN, greater superior petrosal nerve.

Fig. 2 Own drawing of the senior author (E.J.D.). The Kawase rhomboid is pictured together with the essential structures, which need to be identified during surgery, namely, the foramen spinosum and middle meningeal artery, the GSPN, the petrous carotid, the geniculate ganglion, the cave of Meckel, the arcuate eminence, and the internal acoustic meatus with the cochlear angle.

The geniculate ganglion may or may not be covered with bone, and when the bone above it is dehiscant, the risk of facial nerve palsy postoperatively increases by ~15%.¹³

Drilling

When the Kawase rhomboid is fully exposed (► **Fig. 2**), the drilling should begin. The essential landmarks are: the lateral edge of V3 (mandibular branch of the trigeminal nerve) and the Gasserian ganglion with the trigeminal fibrous ring anteriorly, laterally the GSPN running above the petrous carotid, and posteriorly the roof of the internal acoustic meatus. The medial border also poses another caveat, as there is a “false” petrous edge immediately lateral to the true petrous edge, which needs to be exposed before drilling commences, as shown in ► **Fig. 1**.

The dura is held in place by tack-up stitches placed on the underside side of the temporal lobe dura above the surface of the middle fossa and held in place by hemostats. We do not use any type of fixed retraction during the entire course of the procedure. We begin drilling with a 5-mm cutting burr and switch to a 3-mm cutting when drilling the compact bone in contact with the posterior fossa dura. We have noticed in cadaver courses that trainees sometimes show reluctance to drill deep in the petrous apex and instead end up drilling laterally in Kawase’s triangle, injuring the carotid. Drilling should be perpendicular and deep, layer by layer. It is facilitated by a pneumatized petrous apex and should be deep enough to distinguish the bluish tinge of the inferior petrosal sinus. When cancellous bone makes way for compact bone again, drilling should be very careful to not prematurely open the dura protecting the structures of the posterior fossa or to injure the inferior petrosal sinus.

To gain a wider exposure, one could open the foramen ovale by drilling it and mobilizing the Gasserian ganglion anteromedially after sharp division of the trigeminal carotidodural fold, to detach the tip of the os petrosum similar to removal of the tip of the anterior clinoid process (ACP) in extradural ACP resections. The tip is held in place firmly by the petrosphenoidal and petrolingual ligaments, and a wide exposure underneath the Gasserian ganglion needs to be achieved to detach them (usually not necessary). It is advisable not to drill more than 10 mm under Meckel’s cave medially on the side of the clivus to reduce the risk of injury to the abducens nerve, running under Gruber’s ligament in Dorello’s canal. Alternatively, if needed, the roof of the internal meatus can be opened, expanding the petrosectomy more posteriorly. This can be done safely in the porus part where the nerves are furthest away from the roof of the meatus, but the chance of peroperative damage of the nerves increases the more drilling is done toward the fundus. The extent of resection can be appreciated in ► **Fig. 3**.

Dural Opening and Tentorial Division

It is essential to check the position of Labbe’s vein and of the superior petrosal (Dandy’s) veins on preoperative imaging. The risk of postoperative complications due to occlusion of these veins is relatively low, but the possibility of crucial venous impairment exists, around 30%. An essential step in

Fig. 3 Postoperative CT showing extent of resection of a right-sided petrosectomy for a petroclival meningioma. Note the proximity of the cochlea. In this case, as shown on this CT image, the true apex (under the Gasserian ganglion) did not need removal. CT, computed tomography.

preoperative planning, therefore, is the evaluation of these veins and their drainage patterns.¹⁴

The dura needs to fit with the bony exposure to not require excessive temporal lobe retraction and a restricted working corridor. The dura is sectioned horizontally above the superior petrosal sinus (SPS) from Meckel's cave to just behind the level of the meatus. Opening too posteriorly puts the vein of Labbe in jeopardy. The posterior fossa dura is cut parallel to the SPS from the trigeminal fibrous ring at the porus and stopping just before the meatus. The SPS can then be divided by coagulation (sometimes this step entails profuse blood loss and blood loss should be controlled every step of the way with cottonoids or hemostatic material). This allows the tentorium to be sectioned toward its free edge. This needs to be done not too close to the porus trigeminus (to avoid trochlear nerve injury—6 mm average distance).^{15,16} However, division of the tentorium too oblique posteriorly might lead to venous impairment and damage to the bridging veins. Tack-up sutures at both edges of the cut section help by widening the operating field.

Now, the approach focuses on the root entry zone of the trigeminal nerve at the lateral level of the ventral pons.

CSF Leak Avoidance

Possible points where cerebrospinal fluid (CSF) may leak are the mastoid cells posteriorly or the tegmen tympani, a thin and sometimes dehiscent area of bone of the middle skull base covering the structures of the middle ear—the head of the malleolus, the incus, the tympanic segment of the facial nerve, and the chorda tympani. These bony defects need to be closed with fat grafts, bone wax, fascia lata, vascularized

flaps in more difficult cases, and fibrin glue. Furthermore, postoperative CSF drainage via lumbar drains needs to be promptly initiated when necessary. Epidural drains should be avoided to not create a CSF fistula.

Results

In our department, 25 patients were operated on using the Kawase transapical transpetrosal approach from 2004 up to 2018 (► **Table 1**). The median follow-up was 4 years, with two patients expiring from systemic disease and all others receiving long-term follow-up.

Functional Outcome

The 30-day postoperative mortality was 1 of 25 patients (4%). At 6 months, 21 of the 25 (84%) patients had a very good outcome (mRS 0–2) and one patient had an mRS of 4, reflecting the preoperative status and progression of the systemic disease (metastatic melanoma). Also, at 6 months, two patients had died and one was in a vegetative state (► **Table 2**).

Cranial Nerve Presentation and Outcomes

No patients experienced loss of hearing.

Six of the 25 patients presented with trigeminal hypesthesia preoperatively. Other six patients complained of trigeminal neuralgia with an intact trigeminal function. The most common postoperative complaint was trigeminal hypoesthesia (11 of the 25, 44%), with 1 patient (4%) also suffering corneal erosions. Five of these were new and three were worse postoperatively. Most of these (8 of the 11) recovered during the follow-up period, needing an average of 3 months before subjective recovery was felt by the patients.

Ocular motor deficits consisted preoperatively of two trochlear nerve palsies, six abducens nerve palsies, and one oculomotor palsy (► **Table 1**). Postoperatively, there were six new trochlear nerve palsies (24%). Five of the eight patients with trochlear nerve palsy needed operative correction. All of these were new deficits as a result of manipulation of the nerve.

Three new abducens nerve palsies occurred postoperatively. From the nine total abducens nerve palsies, six recovered spontaneously (those pre-existent), while the three iatrogenic injuries of the nine had successful operative correction by the ophthalmologist (► **Table 3**).

Preoperative facial palsy was seen in five patients. Postoperatively, three new facial palsies occurred and worsened in two patients. One patient had a House–Brackmann grade VI facial palsy preoperatively which did not improve after the surgery. These surgically related postoperative facial palsies were likely caused by manipulation of the geniculate ganglion and were all House–Brackmann grade III, save for one House–Brackmann V that worsened to a House–Brackmann VI. Most of them partially recovered after surgery, but one patient required a facial reanimation surgery using a gracilis graft. The facial nerve outcomes have improved significantly along the years, as 4 of the 25 complications happened before

Table 1 Baseline characteristics and symptoms upon presentation of the patients in the series

Age, sex	Operation year	Lesion	Symptoms upon presentation
58, F	2005	Petroclival meningioma WHO I	Trigeminal neuralgia
51, F	2006	Petroclival meningioma WHO I	Headache, nausea, gait disturbance, deafness
60, F	2009	Petroclival meningioma WHO I	Abducens nerve palsy, trigeminal dysesthesia, gait, and balance disturbances
60, M	2013	Petroclival meningioma WHO I	Headache, tremor of the left hand
24, M	2015	Petroclival meningioma WHO I	Trigeminal neuralgia
62, F	2016	Petroclival meningioma WHO I	Trigeminal neuralgia
38, F	2017	Petroclival meningioma WHO I	Tumor growth on serial MRI scans
55, F	2017	Petroclival meningioma WHO I	Trigeminal neuralgia, diplopia
51, F	2017	Petroclival meningioma WHO I	Trigeminal neuralgia
46, F	2018	Petroclival meningioma WHO I	Trigeminal neuralgia
36, M	2006	Hemangioendothelioma brainstem	Coordination impairment, blurred vision, facial paralysis, coma
48, F	2008	Metastasis malignant melanoma mesencephalon	Spastic hemiparesis, abducens nerve palsy and facial palsy, dysarthria
50, F	2007	Pontine cavernoma	Headache, trigeminal dysesthesia
28, F	2009	Pontine cavernoma	Eye movement and gait disturbances, headache, ataxia
27, F	2016	Pontine cavernoma	–
33, F	2011	Trigeminal schwannoma	Trigeminal hypesthesia, headache
53, F	2016	Trigeminal schwannoma	Trigeminal hypesthesia, bilateral abducens nerve palsy
11, F	2014	Malignant peripheral nerve sheath tumor petroclival	Abducens nerve palsy, facial nerve palsy, headache
56, F	2009	Clival chondrosarcoma WHO II	Abducens nerve palsy and gait disturbances, headache, ataxia, impaired swallowing
34, M	2011	Clival chondrosarcoma WHO II	Oculomotor palsy, trigeminal dysesthesia
35, M	2012	Clival chordoma	Gait and balance disturbance, hemiparesis, facial nerve palsy
64, F	2012	Clival chordoma	Abducens nerve palsy, trigeminal dysesthesia
44, F	2017	Clival chordoma	Diplopia
58, M	2006	Superior cerebellar artery aneurysm	Spastic paresis, facial nerve palsy, headache, gait and balance disturbance
60, M	2008	Basilar apex aneurysm	Subarachnoid hemorrhage, no neurological focal signs (WFNS gr 1)

Abbreviations: MRI, magnetic resonance imaging; WHO, World Health Organization.

2012 and only 1 after 2012, illustrating the increased surgical experience of our team.

Surgical Outcomes

Among the different pathologies in this case series, in 4 of the 10 patients with petroclival meningiomas, we were able to achieve Simpson grades I to III resections, and these were followed by yearly repeat MRIs (► **Table 2**). One patient showed growth and was referred to radiotherapy. Four other patients were referred to radiotherapy immediately post-operatively, one patient with a meningioma, one patient with malignant peripheral nerve sheath tumor, and two patients with chondrosarcomas. The aneurysms were completely excluded from the circulation, and the pontine cavernomas and the hemangioendothelioma in the brain stem showed no recurrence. The chondrosarcomas and the

chordoma could be resected more than 95% and have shown no recurrence so far.

CSF fistulas were encountered in seven patients (28%), despite our best efforts to properly close all skull base defects, and were especially prominent in patients with a dehiscent tegmen tympani. In one patient, secondary meningitis occurred. Three CSF leaks were self-limiting and four received external lumbar drainage for 5 to 7 days with no reoperations necessary.

Mortality

The first patient who died of a surgical complication was a 60-year-old woman presenting with progressive abducens nerve palsy and trigeminal neuralgia caused by a clival tumor showing imaging characteristics of a chordoma. Resection at that time, in 2007, was considered impossible by another

Table 2 Surgical outcome, postoperative radiotherapy, and outcomes of the patients

Age, sex	Year when surgery took place	Lesion	Extent of resection (if applicable)/ recurrence on follow-up	Radiotherapy postoperative	Postoperative Complications	mRS preoperative	mRS 6 mo	mRS last follow-up
58, F	2005	Petroclival meningioma WHO I	Simpson IV (rest on the trochlear nerve)/no growth	None	IV palsy	1	1	0
51, F	2006	Petroclival meningioma WHO I	Simpson IV/died on follow-up	None	Death due to hemorrhagic diathesis	1	6	6
60, F	2009	Petroclival meningioma WHO I	Simpson IV (rest on the brain stem)/no growth	None	Deterioration of VII palsy	2	2	1
60, M	2013	Petroclival meningioma WHO I	Simpson IV (rest on the brain stem)/no growth	30 × 1.8 Gy	Transitory VI palsy, V hypesthesia, VII palsy	0	1	1
24, M	2015	Petroclival meningioma WHO I	Simpson IV (rest on the meatus)/growth	30 × 1.8 Gy in 2018	V hypesthesia	1	1	0
62, F	2016	Petroclival meningioma WHO I	Simpson II/no recurrence	None	IV palsy	1	1	1
38, F	2017	Cavernopetroclival meningioma WHO I	Simpson IV (rest in cavernous sinus)/no growth	None	IV palsy	0	2	1
55, F	2017	Petroclival meningioma WHO I	Simpson II/no recurrence	None	Transitory III palsy	2	2	2
51, F	2017	Petroclival meningioma WHO I	Simpson I/no recurrence	None	V hypesthesia	2	1	1
46, F	2018	Petroclival meningioma WHO I	Simpson III/no recurrence	None	IV palsy	2	2	2
36, M	2006	Hemangioperithelioma brain stem	Near-complete resection/no recurrence	None	Transitory worsened hemiparesis	5	5	2
48, F	2008	Metastasis malignant melanoma mesencephalon	Near-complete resection/died on follow-up	None	Transient III palsy, V hypesthesia, worsened VII palsy	4	4	6
50, F	2007	Pontine cavernoma	Complete resection/no recurrence	N/A	None	1	0	0
28, F	2009	Pontine cavernoma	Complete resection/no recurrence	N/A	None	1	0	0
27, F	2016	Pontine cavernoma	Complete resection/no recurrence	N/A	IV palsy, GSPN (impaired lacrimation)	3	2	1
33, F	2011	Trigeminal schwannoma	Complete resection/no recurrence	None	Transitory III palsy, VI palsy, V hypesthesia	1	1	0
53, F	2016	Trigeminal schwannoma	Subtotal removal/no growth	None	V hypesthesia	2	2	1
11, F	2014	Malignant peripheral nerve sheath tumor petroclival	Near-complete removal/no recurrence	Proton beam therapy	IV palsy	1	1	1

(Continued)

Table 2 (Continued)

Age, sex	Year when surgery took place	Lesion	Extent of resection (if applicable)/recurrence on follow-up	Radiotherapy postoperative	Postoperative Complications	mRS preoperative	mRS 6 mo	mRS last follow-up
56, F	2009	Clival chondrosarcoma WHO II	Subtotal removal/recurrence 2012	Carbon ion therapy	VII palsy, worsened V hypesthesia	2	1	6
34, M	2011	Clival chondrosarcoma WHO II	Subtotal removal/no recurrence	Carbon ion therapy	VI palsy, V hypesthesia	1	1	1
35, M	2012	Recurrent clival chordoma	Near-total removal/recurrence in 2017	None	VI palsy	0	2	0
64, F	2012	Clival chordoma after radiotherapy	Subtotal removal/died before follow-up	Carbon ion before surgery	Infarction of left hemisphere, VII palsy, death 1.5 y later	1	5	6
44, F	2017	Clival chordoma	Near-total removal (rest in cavernous sinus)/no recurrence	None	Transitory III palsy, light VII palsy	2	2	1
58, M	2006	Superior cerebellar artery aneurysm	Complete occlusion	N/A	None	3	2	0
60, M	2008	Basilar apex aneurysm	Complete occlusion	N/A	Transitory hemiparesis	0	1	0

Abbreviations: GSPN, greater superior petrosal nerve; mRS, modified Rankin scale; N/A, not applicable; WHO, World Health Organization.

group without primary expertise in skull base surgery, so she was referred to the ENT specialists for a transsphenoidal biopsy, which confirmed the diagnosis chordoma. The next step was carbon ion radiotherapy, which ensured that the tumor remained stable for the following 4 years. The clivus chordoma showed a recurrence in 2011 and her neurological status progressively worsened. During surgery, at the antero-inferior border of the tumor, we encountered an uncontrollable hemorrhage from within the tumor, which in retrospect seemed to be originating from the cavernous carotid artery. The Gasserian ganglion and the cavernous carotid were fully embedded in the tumor. We were ultimately forced to apply two permanent clips on the carotid artery at the foramen lacerum. We initially observed very good backflow, and we were not prepared to perform a Fukushima type I bypass.¹⁷ The patient ultimately developed a large middle cerebral artery infarction and remained comatose and hemiplegic, being transferred to a nursing home in a persistent vegetative state and ultimately died without improving, 1.5 years after surgery. After this, we changed our operative philosophy to prepare for a salvage bypass if necessary.¹⁷

The second patient was a 51-year-old woman with Ehlers-Danlos' syndrome, with a mechanical aortic valve and an aortic root conduit presenting with a large petroclival meningioma with progressively worsening symptoms. After uneventful surgery through a Kawase approach, a Simpson grade IV resection could be achieved. However, the mechanic aortic valve required immediate restart of anticoagulation medication on the first day postoperatively. Within 36 hours, she developed an acute subdural hematoma, which was evacuated in an emergency setting. The anticoagulation was then commenced again and her situation remained stable. However, after 5 days, she again developed an acute subdural hematoma. After the second successful evacuation of a subdural hematoma, she developed a middle cerebral artery infarction due to an embolus from a clot on her mechanical aortic valve. She ultimately died 10 days after the initial surgery.

Illustrative Case

A 29-year-old woman presented with severe ataxia, abducens nerve palsy, and gait disturbance, which got progressively worse. MRI revealed an extensive hematoma from a left lateral pontine cavernoma extending from the pontopeduncular to the pontomedullary sulci (►Fig. 4). Through a Kawase approach, evacuation of the hematoma and resection of the cavernoma were performed successfully through a small myelotomy in the safe entry zone represented by the trigeminal root area. The postoperative result was very favorable showing complete resection and resolving symptoms without any complications (►Fig. 5).

Discussion

We present 25 patients in whom we performed surgery via an anterior (transapical, transtentorial) petrosal Kawase approach for different pathologies. Twenty-one patients

Table 3 Cranial nerve outcomes

Cranial nerve	Preoperative palsy	Postoperative palsy (pre-existent, new and worse)	Needing correction/treatment
Trigeminal	6/25 (hypesthesia), 6 trigeminal neuralgia without hypesthesia	11/25 (3 pre-existent, 5 new, 3 worse)	1 corneal erosion
Trochlear	2/25	8/25 (2 pre-existent, 6 new)	5/8 ophthalmologic correction, all new deficits
Abducens	6/25	9/25 (6 pre-existent, 3 new)	3/9 ophthalmologic correction
Facial	5/25	8/25 (3 pre-existent, 2 worse, 3 new)	One House–Brackmann grade V preoperative, grade VI postoperative had a facial reanimation with gracilis flap
GSPN	0/25	1/25 (1 new)	None

Abbreviation: GSPN, greater superior petrosal nerve.

Fig. 4 Preoperative MRI, T2 sequence. Notice the large lateral pontine cavernoma located inferolateral to the root entry zone of the trigeminal nerve. We found this lesion perfectly amenable to a Kawase approach. MRI, magnetic resonance imaging.

Fig. 5 Postoperative MRI, T2 sequence. Notice the postoperative effects and the absence of the apex of the petrous bone. The cavernoma was fully resected, without postoperative complications or recurrence. MRI, magnetic resonance imaging.

experienced a favorable outcome on follow-up. We observed one postoperative mortality related to hemorrhagic diathesis and one severe complication.

The mortality in our series, we believe, is not due to the choice of approach itself. It reflects, in our opinion, the new challenges that a skull base surgeon has to face nowadays, with more patients having had treatment strategies, which may hamper surgeries and make them riskier. Resection of a

previously irradiated tumor poses much more difficulties with more adhesions and often encased blood vessels, including the internal carotid¹⁸ and thus more risk for the patient. It also reflects the prerequisites a skull base surgeon should have mastered.

Next to the mandatory (neuro)anatomical knowledge, a large experience not only in oncological neurosurgery but also in vascular neurosurgery must be available,^{19,20} either

by the skull base surgeon or within the team that then should be on standby during such procedures. We believe that in cases where preoperative imaging shows compromise of large arteries by tumors, especially if irradiated previously, the surgical planning should incorporate the availability of performing acute high-flow bypass surgery.

The careful selection of patients is essential, and while many pathologies may also be successfully treated using other surgical approaches²⁰ (extended retrosigmoidal or endoscopic), we find that the best results depend on the approach which is most comfortably performed by the surgeon. The senior author has a broad experience in skull base approaches and anatomy and before carrying out the first Kawase approach, many years of training in the anatomy laboratory and cadaver dissections were necessary.

The true relevance and strength of the Kawase approach consist of avoiding cranial nerve injury from the surgical entrance route. With this approach not only preservation of hearing but also facial palsy can be avoided. This is also reflected in our series, where no patient experienced hearing impairment secondary to manipulation of the eighth nerve or of the cochlea. Abducens, trochlear, and facial nerve palsies attributable to the surgical manipulation amounted to 25%, especially with patients having no bony covering of the geniculate ganglion and tumors extending all the way to Dorello's canal, but most of them recovered in the postoperative period. All of the patients with abducens nerve palsy postoperatively and almost all patients with trochlear nerve palsy required ophthalmologic correction, a testament to the susceptibility to injury of these nerves and that even fine microsurgical technique may lead to iatrogenic injury needing correction.

Although postoperative CSF fistulas may be a problem in all skull base approaches, and even though they only lead to meningitis in one patient (4%), and they were mostly self-limiting and/or treated with a lumbar drainage, the proper meticulous closing of all defects is paramount, especially in a particularly difficult region such as the middle fossa, where so many cavities communicate with each other. In this regard, careful and minute study of preoperative imaging, including CTs with 0.75 mm slices and accurate reconstructions is a must and a responsibility of all skull base surgeons to be able to predict and correctly close the defects during surgery.

Several reports show the benefit of skull base approaches for pathologies located in and around Meckel's cave, suggesting the benefit in terms of cranial nerve outcomes and extent of resection.^{9,21–23} Reports of the outcomes of the Kawase approach alone are scarce, as these are mostly reported together with other approaches for a particular indication.^{9,21} The reported prevalence of CSF fistulas is 10.5%,⁹ with 2.3% needing surgical repair. The authors also report always being able to achieve hearing preservation when this was intended through the use of middle fossa approaches, as we also show in this series.

This single-center experience aims to show the necessary prerequisites which need to be fulfilled to perform skull base approaches in general and those involving the middle fossa in particular. The combination of extensive anatomical knowledge

experienced by performing numerous cadaver dissections, appraisal of the neuroimaging details such as the particular anatomy of the patients caused by the change in anatomy, which is attributable to the pathology itself, and training under supervision are key elements to achieving good outcomes.

Conclusion

The Kawase approach has evolved into one of the mainstays of middle fossa skull base surgery, offering an elegant way of conquering the rock (the petrous bone) solely through the removal of its tip, with preservation of hearing, but it is associated with a certain degree of cranial nerve pathology. With careful preoperative planning of imaging, intraoperative anatomical orientation and oncological, as well as vascular neurosurgical expertise, good outcomes for the patients may be achieved. Furthermore, when having acquired the knowledge and the skills to achieve this, it becomes relatively easy to combine the Kawase approach with other skull base approaches to create surgical space for safe resection of a variety of pathological processes of the skull base and around the brain stem. Each large neurosurgical center focusing on oncology and vascular neurosurgery should have this expertise.

Conflict of Interest

None.

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