ABSTRACT

The petroclival area is a complex region situated at the junction of adjacent parts of sphenoid, temporal and occipital bones. A variety of pathologies may originate in the petroclival area, including meningiomas, schwannomas, chordomas, chondrosarcomas, carcinomas, aneurysms and others. Developments in skull base surgery, neuroradiology and intensive care have led to a breakthrough in the management of petroclival lesions. Different surgical approaches exist to access the petroclival area. Kawase et al described a modification of the middle fossa approach, which is considered a landmark in the history of skull base surgery. The aim of this review is to present a detailed discussion of the technique and relevant surgical anatomy.

KEYWORDS: Kawase approach, anterior petrosectomy, anterior transpetrosal-transtentorial approach, petroclival meningiomas, petroclival tumours, basilar artery aneurysms, Kawase triangle, cerebellopontine angle tumours.

INTRODUCTION

The petroclival area is a complex region situated at the junction of adjacent parts of sphenoid, temporal and occipital bones. An intriguing discussion surrounds the decision regarding the choice of best approach to this region. Different surgical corridors were described in the past and new techniques have arisen in concert with the modern skull base philosophy.

A variety of pathologies may originate in the petroclival area, including meningiomas, schwannomas, chordomas, chondrosarcomas, carcinomas, aneurysms and others. Developments in skull base surgery, neuroradiology and intensive care have led to a breakthrough in the management of petroclival lesions.

Different surgical approaches exist to access the petroclival area. Drake[1] (1965) proposed the subtemporal transtentorial approach to vertebrobasilar aneurysms. However, the approach has major drawbacks such as possible damage to the temporal lobe due to forced retraction and associated sacrifice of the vein of Labbe. Also, the lower part of the basilar artery cannot be reached due to the petrous ridge which obstructs the access to this region. Bochenek and Kukwa[2] (1975) first described an extradural subtemporal approach combined with drilling of the petrous bone. This technique was named as the extended middle fossa approach. It was originally used for removal of acoustic neuromas. This extradural subtemporal approach minimizes the risk of damage to temporal bridging veins. By drilling of petrous bone, an extra space of 10 mm can be gained below the level of the superior petrous sinus. In the extended middle fossa approach, drilling is continued posteriorly, opening the semicircular canals and so jeopardizing the hearing function on ipsilateral side.

Kawase et al[3,4,5] (1985) described a modification of the extended middle fossa approach for treatment of low-lying basilar aneurysms. Drilling of the petrous bone was restricted to the petrous apex, which contains no neurovascular structures. The superior petrous sinus was divided and 10 mm of the adjoining lateral aspect of the tentorium was incised, increasing the surgical field. This resulted in a bone defect about 20 mm wide and 10mm deep, giving access to the preponetine region between the level of the trigeminal nerve and the facial nerve.

Surgical anatomy of the petroclival region

The petroclival area is the region situated between the middle and anterior skull base at the junction of the adjacent parts of sphenoid, temporal and occipital bones. The extradural structures related to the petroclival region that affect the surgical approaches are basically the temporal bone and its petrosal structures. The intradural structures related to the petroclival region can be divided into three spaces[6] — the inferior petroclival space, consisting of the lower clivus and foramen magnum; the middle petroclival space, which comprises the

THE KAWASE APPROACH TO PETROCLIVAL LESIONS OF SKULL BASE: A LANDMARK IN SKULL BASE SURGERY

1*Dr. Jaspreet Singh Badwal, 2Dr. Bharat Kumar S, 3Dr. Saurabh Kumar Sinha, 4Head and Neck Surgeon, Hyderabad, India.

*Corresponding Author: Dr. Jaspreet Singh Badwal
Head and Neck Surgeon, Hyderabad, India.
cerebellopontine angle and prepontine area; and the superior petroclival space, which corresponds to the anterior part of the tentorial incisura, the sella and parasellar regions and the floor of the third ventricle.

The petrous bone is the key extradural structure of the petroclival region. Differing from classic descriptive anatomy, the surgical anatomic scheme divides the petrous bone into anterior and posterior portions, according to the major available transpetrosal approaches.\(^7,8\)

**Anterior Portion of the Petrous Bone**

Major anatomic structures of the anterior portion of the petrous bone include the foramen spinosum with the middle meningeal artery anteriorly; the arcuate eminence posteriorly; the petrous carotid artery, which is mostly only partially covered by a thin bone layer; and the superior petrosal sinus, which runs along the medial border of the upper surface of the petrous bone (Fig. 1, 2, 3).

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**Fig. 1:** Diagram illustrating the various landmarks. ZR – zygomatic root, MMA – middle meningeal artery, FO – Foramen ovale, gspn – greater superficial petrosal nerve, GG – geniculate ganglion, SSC – superior semicircular canal, \(V_3\) – third branch of trigeminal nerve (mandibular), ICA – internal carotid artery, Co – cochlea, IPS – inferior petrosal sinus, BB – Bill’s bar, JB – jugular bulb, IAC – internal auditory canal, GsG – gasserion ganglion, SPS – superior petrosal sinus.

**Fig. 2:** Diagram illustrating the various angles which are measurable between different landmarks. 1 – between gspn and SSC, 2 – between SSC and IAC, 3 – between IAC and SPS, 4 – between IAC and EAC (external auditory canal).
Fig. 3: Diagram illustrating the area of access through the middle fossa approaches to expose cerebellopontine angle through posterior fossa dura. The arrowhead points to inferior border of floor of internal auditory canal.

The greater petrosal nerve passes below the lateral margin of the trigeminal ganglion. Drilling along the course of the greater petrosal nerve in a dorsal direction exposes the geniculate ganglion, which can be followed in a medial direction to expose the labyrinthine portion of the facial nerve through its course into the internal auditory canal.

Opening the internal auditory canal and the dura surrounding the contents of internal auditory canal exposes the transcanalicular portions of the facial and superior vestibular nerves superiorly and the cochlear and inferior vestibular nerves inferiorly. The superior vestibular and facial nerves are separated at the fundus of the internal auditory canal by the vertical crest (the so-called “Bill’s Bar”). The facial and cochlear nerves are in the anterior half, and the superior and inferior vestibular nerves are in the posterior half of the canal. The cochlea lies between the internal auditory canal and the petrous carotid artery, beneath the geniculate ganglion. The labyrinth with the vestibule and the superior semicircular canal lie close posterior to the fundus of internal auditory canal. The length of the internal auditory canal varies from 8 to 12 mm (average 10 mm). The average distance between the posterior semicircular canal and the edge of the canal is 7mm.[6]

The bony area between the greater petrosal nerve anteriorly, and the carotid artery and the cochlea laterally, and the internal auditory canal and semicircular canals posteriorly, has been called the Kawase’s Triangle. Bone removal at that area exposes the posterior fossa and cerebellopontine angle (Fig. 3) from above.

Posterior Portion of the Petrous Bone

The posterior approaches to the petrous bone involve bone removal behind the sigmoid sinus in the retrosigmoid approach and between the wall of external auditory canal and the sigmoid sinus in presigmoid approach.

Decortication of the mastoid and removal of most mastoid air cells exposes the middle fossa plate and the superior petrosal sinus superiorly, the anterior portion of the sigmoid sinus posteriorly and the plate covering the labyrinth block and facial nerve anteriorly.

The otic capsule consists of the vestibule, the semicircular canals and the cochlea. The lateral semicircular canal runs perpendicular to the facial nerve and the posterior semicircular canal runs parallel to the sigmoid sinus. Lateral to the otic capsule lies the antrum and inferior to it the digastric ridge.

The vestibule is separated from the apex of the jugular bulb by an approximately 6 mm of bone. The height of the jugular bulb may vary considerably, sometimes reaching the internal auditory canal. Penetration of a high-lying jugular bulb may be the source of severe bleeding or air embolism during surgery. Preoperative identification and careful intraoperative dissection are essential to control this problem.[9] The vertical segment of the carotid artery runs upward in the carotid canal, then curves anteromedially to form the horizontal segment.

[6]
Knowledge of the various landmarks is indispensable before understanding the surgical technique of Kawase Approach. Sloniewski et al.\[^{10}\] published a morphometric study of the different surgical landmarks for Kawase approach. Important data was obtained in relation to distances between the various surgical landmarks (Table 1), which gives practical orientation for identification of structures during surgery.

<table>
<thead>
<tr>
<th>Distances and angles between:</th>
<th>Mean mm or degrees ± OS</th>
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| foramen spinosum and foramen ovale | L: 3.5 ± 1.3  
R: 3.4 ± 1.4 |
| foramen spinosum and trigeminal fossa | L: 12.2 ± 1.9  
R: 12.8 ± 1.5 |
| foramen ovale and trigeminal fossa | L: 11 ± 1.8  
R: 12.2 ± 2.0 |
| foramen spinosum and hiatus of the greater petrosal nerve | L: 13.5 ± 2.7  
R: 12.8 ± 3.5 |
| foramen spinosum and sulcus of the greater petrosal nerve | L: 10.5 ± 2.0  
R: 9.7 ± 2.7 |
| foramen ovale and hiatus of the greater petrosal nerve | L: 18.6 ± 2.0  
R: 18.2 ± 2.5 |
| foramen ovale and sulcus of the greater petrosal nerve | L: 14.7 ± 1.6  
R: 14.3 ± 2.1 |
| hiatus of the greater petrosal nerve and emminencia arquata | L: 11.3 ± 1.8  
R: 12.1 ± 2.6 |
| hiatus of the greater petrosal nerve and sulcus of the upper petrosal sinus | L: 12.8 ± 1.5  
R: 12.8 ± 2.2 |
| the angle: sulus of the upper petrosal sinus and emminencia arquata | L: 91 ± 6.0  
R: 84 ± 7.0 |
| the angle: emminencia arquata and sulcus of the greater petrosal nerve | L: 90 ± 5.0  
R: 85 ± 7.4 |
| the angle: internal acoustic meatus and emminencia arquata | L: 115 ± 9.0  
R: 95 ± 9.0 |

SURGICAL TECHNIQUE OF THE KAWASE APPROACH\[^{3,4,5,10,11}\]
It is pertinent to describe the steps of this surgical technique under two headings – extradural steps and intradural steps.

**Extradural Steps**
The patient is positioned in a supine position with a small pad under the ipsilateral shoulder. A lumbar drain for perioperative drainage of cerebrospinal fluid (CSF) is optional. Cranial nerve monitoring is advisable, depending on the pathology. The head is rotated at 90 degrees and the vertex slightly tilted towards the floor to facilitate gravitational temporal lobe retraction. A U-shaped skin incision is made above the level of external auditory canal and the skin flap is retracted downwards. A vascularized fascia flap is prepared from the temporalis muscle to cover the temporal fossa. Any mastoid cells opened accidentally should be obliterated with bone wax. An alternative is to make a curved frontotemporal incision such as the one used for the standard pterional approach and remove the upper rim of zygomatic arch, or to cut the zygomatic arch anteriorly and posteriorly and pull it downwards with the masseter muscle still attached, to gain more space for the temporal muscle to be reflected downward. In this case, the craniotomy can be extended anteriorly, eventually opening the cavernous sinus when needed.

Under microscopic magnification, the dura is peeled away from the floor of the temporal fossa. The middle meningeal artery, located postero-lateral to the foramen ovale, is divided at the level of the foramen spinosum. The artery should not be divided too close to the foramen, because the proximal part could retract into the foramen and when not properly coagulated, may cause bleeding, which could be difficult to manage. The dura is peeled away from posterior to anterior, avoiding traction on the geniculate ganglion via the greater superficial petrosal nerve (GSPN), which runs from the geniculate ganglion to the pterygopalatine ganglion as the vidian nerve, together with branches from the carotid sympathetic plexus and is responsible for lacrimation.

**Landmarks for Petrous Apex Resection**
Important landmarks during the extradural phase of the Kawase approach are the arculate eminence, covering the superior semicircular canal, which is the posterior border of the area of the petrous apex to be drilled (the Kawase triangle or rhomboid, Fig. 4). The vestibule lies lateral to the superior semicircular canal, and the tegmen tympani can be identified more laterally, lateral to the lateral
The tegmen tympani is a thin layer of bone covering the structures of the middle ear – the head of the malleus, the incus and the tympanic segment of the facial nerve. The lateral border of the Kawase triangle is the pregasserion portion of petrous carotid artery, in the foramen lacerum, and the smaller and greater petrosal nerves running close to the carotid artery. Drilling should not be extended lateral to the carotid artery, because the Eustachian tube might be inadvertently opened or the overlying tensor tympani muscle could be damaged. The geniculate ganglion forms the connection between the GSPN and the labyrinthine portion of the facial nerve. From the geniculate ganglion, the facial nerve runs to the level of the stapes and from that point further downward, below the lateral semicircular canal, becoming the mastoid segment of the facial nerve. Some authors have pointed out the risk of facial nerve palsy due to traction on the geniculate ganglion, even when the GSPN is handled very carefully and a small strip of periosteum is left on the nerve. It has been proposed that the GSPN be divided. Although, this leads to a temporary diminishment of lacrimation of the ipsilateral eye, it usually is compensated for within a few months. The risk of damage to the facial nerve is increased in the 15% of cases where the geniculate ganglion is not covered by bone. The cochlea is located just medial to the geniculate ganglion and deeper in the temporal bone, posterosuperior to the lateral genu of the petrous carotid artery. The cochlea is separated from the petrous carotid by about 2.1 mm (range 0.6 -10 mm) of bone. The frontal border of the Kawase triangle is formed by the third division of the trigeminal nerve. Drilling can be continued under the trigeminal impression downward to the entrance of the abducent nerve in Dorello’s canal. This landmark is, on average, 7 mm anteroinferior to the trigeminal impression (range 5 - 9 mm) and also is the level of the inferior petrosal sinus in the petroclival fissure, which forms the deepest point of petrous apex removal. The medial border of the Kawase triangle or rhomboid is formed by the superior petrosal sinus (SPS).

Fig. 4: Diagram illustrating the surgical view after extradural steps of Kawase approach have been completed, exhibiting the rhomboid area to be drilled.
The internal auditory meatus (IAM) can be found by two methods, the Fisch\textsuperscript{12} and the House\textsuperscript{13} techniques. In the House technique, the GSPN is followed towards the geniculate ganglion, from which point the labyrinthine portion of the facial nerve is followed to the internal acoustic meatus. In the Fisch method, two virtual lines are drawn, one line representing the course of the GSPN and another line representing the arcuate eminence. The angle between these lines is 120 degrees (Fig. 2). This angle is divided in two equal angles of 60 degrees and the resulting virtual line represents the course of the IAM. The Fisch method is considered the safer one. The roof of the IAM, which is, on average 5 mm thick (range 3 - 7 mm) is drilled carefully from medial to lateral, leaving the dural sheath intact. In the lateral part of the IAM, the cochlear and inferior vestibular nerves are separated by a transverse bony crest from the facial nerve and superior vestibular nerve, and the facial nerve and superior vestibular nerve are separated by a vertical bony crest.

Nasal liquorhea might occur when mastoid air cells, the tegmen tympani or the Eustachian tube are accidentally opened. Defects should be carefully closed and covered. Deafness invariably occurs when the cochlea is opened. It occurs in about 20% of cases when the semicircular canals are partially opened. Blue-lining of the cochlea and the superior semicircular canal offers the maximum space, but it also risks opening these structures and so jeopardizing hearing function. It is safer to drill until the consistency of the bone of the petrous apex changes from relatively soft to very hard. This thin shell of hard bone covers the structures of the inner ear. After drilling is completed, the dura under the level of the SPS is opened, thus exposing the posterior fossa.

**Intradural Steps**

The temporal dura is opened basally, parallel to the cranial base. Two small retractors are placed under the temporal lobe and the temporal lobe is gently retracted. The tentorial edge is identified, as well as the trochlear nerve in its subarachnoidal course, running parallel to the tentorial edge and entering the tentorium more anteriorly. A cut of about 10 mm is made on the tentorium medial and perpendicular to the SPS. The SPS is divided between two hemoclips as far posterior as possible to avoid damage to the trigeminal nerve. Care must be taken to include the superior petrosal vein (Dandy’s vein) in the posterior part of the divided SPS. However, there is ample space to do this in only about 20% cases. In other cases, the entry of the superior petrosal vein is at the level of Meckel’s cave or at a point somewhere between Meckel’s cave and the IAM. The risk of permanent vascular complications from sacrificing the superior petrosal vein probably is very low, so when the superior petrosal vein hinders visibility, it is best to coagulate and divide it. A later modification of the approach was to cut the tentorium from the tentorial edge medially, behind the entry point of the trochlear nerve, towards the SPS at the posterior level of the trigeminal nerve and hold the two tentorium flaps aside with stitches. MacDonald et al\textsuperscript{14} advised opening the dura in an inverted Y shape, pulling one dura flap down, so as to be able to put a retractor under the temporal lobe, flush to the temporal cranial base. Additional space is gained by cutting the tentorium twice – one cut starts just behind the entry of the trochlear nerve, traversing posterolaterally medial to the SPS and the petrous ridge; while one smaller cut is made perpendicular to the first in an anterolateral direction, running laterally to the trigeminal nerve and dividing the SPS just lateral to the trigeminal nerve. One tentorium flap containing the trochlear nerve can be retracted anteriorly with a stitch and the posterior tentorium flap can also be retracted posteriorly with a stitch (Fig. 5). If necessary, the parasellar region can be reached by opening the sylvian fissure.
Fig. 5: Diagram illustrating the surgical view after the extradural and intradural steps of Kawase approach have been completed.

CONFLICT OF INTERESTS
The authors declare that there is no conflict of interests that could influence this work.

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