For more than a century, surgeons have been trying to develop and define safe surgical approaches to large skull base lesions of the CPA and ventrolateral brainstem and clivus. Anterior approaches through the anterior petrous bone or subtemporal region provide some exposure, but often require significant elevation of the temporal lobe. Traditional posterior suboccipital approaches provide access to the CPA, but exposure of the ventral brainstem and clivus are extremely limited unless the cerebellum is retracted significantly or the posterior dural sinuses are ligated. Finally, transmastoid approaches were developed as a more direct route to the lateral brainstem, but it is difficult to access the supratentorial space through these approaches. Therefore, surgeons have logically thought to combine them to achieve the benefits of each approach while using the fundamental principle of skull base surgery to limit brain retraction and minimize trauma to the brainstem and cranial nerves.

Like other standard skull base approaches, the combination of a supratentorial transpetrous with a posterior lateral suboccipital or transmastoid approach was gradually developed and modified by several innovative surgeons over the last half century to provide access to an otherwise inaccessible region. Attempts to combine or extend traditional approaches to the CPA date back more than 100 years, although these approaches were mostly abandoned due to exceedingly high mortality rates.

In 1896, Stieglitz et al. reported on 3 cases of CPA tumors. These authors described an approach that involved a supramastoid craniectomy, with elevation of the occipital lobe and opening of the tentorium. Only 1 patient survived. In 1904, Fraenkel et al. reported on an attempted staged removal of an acoustic neuroma in a 48-year-old man. The first stage involved a wide suboccipital craniectomy, with extension of the craniectomy all the way to where the sigmoid sinus enters the jugular bulb. Fraenkel unfortunately encountered significant hemorrhage from an emissary vein in the subocciput and mastoid. The patient died of hemorrhagic shock 42 hours after the first operation.

As surgeons attempted to expand the standard suboccipital craniectomy, which was being used with increased frequency by prominent neurosurgeons of the time, including Harvey Cushing, a major issue was how to work around the transverse and sigmoid sinuses of the posterior fossa to gain further access to the anterolateral foramen magnum and CPA.

In 1905, Borchardt, a German neurosurgeon, reported on the management of a right CPA tumor in a 45-year-old woman. Similar to Fraenkel’s approach, a wide suboccipital craniotomy was performed over the sigmoid sinus and forward through the labyrinth. The sinus was divided and the CPA exposed. Unfortunately, again, without the ability to obtain adequate hemostasis, severe hemorrhage was encountered from the sinuses, and the patient died the following day.

In 1913, Marx described an approach similar to Borchardt’s, including a wide suboccipital craniectomy, partial mastoidectomy, and division of the sigmoid sinus. This time the patient died on postoperative Day 8. An
autopsy revealed a clot from the lateral sinus at the point of ligature medially to the confluence of the sinuses. Even though he demonstrated that the ligated sinus had thrombosed in this patient, he thought there was still merit in attempting to ligate the sinus to gain wider exposure.

In 1928, Naffziger4 reported on a case in which he performed a supratentorial craniotomy in a patient who had previously undergone a suboccipital craniotomy. To gain wider access, he ligated the transverse sinus. In 1930, Fay3 described a series of 5 patients in which he combined a supratentorial occipital-temporal craniotomy with a suboccipital craniotomy. This technique required making a large osteoplastic cranial flap incorporating bone over the occipital lobe as well as over the posterior fossa. The occipital lobe then retracted superiorly and the tentorium split following ligation of the transverse sinus. Following tumor removal, the sinus ends were then reanastomosed.

Unfortunately, prior to 1960, the results of extension of the standard suboccipital approach to access the supratentorial space or ventral brainstem proved to have an extremely high morbidity and mortality rate. As with other complex neurological approaches, the advent of microsurgical techniques improved instrumentation, and the development of the surgical microscope allowed surgeons to reexplore some of these approaches and to define novel, safer approaches with less morbidity and mortality.

Prior to the 1960s, these approaches were all primarily intradural, which required significant retraction of the brain and dural sinuses to obtain the required exposure. To visualize the ventral brainstem and clivus, this extent of retraction leads to excessive brainstem swelling or damage to the crucial venous sinuses, resulting in venous infarcts or hemorrhage. For this reason, initial attempts to approach this region were uniformly disastrous. Several innovations, as well as philosophical changes in the way surgeons approach the skull base beginning in the early 1960s, allowed surgeons to begin to develop approaches to the ventral brainstem and clivus that were not uniformly fatal. The application of the surgical microscope to neurosurgery by Dr. Gazi Yaşargil in the early 1960s improved visualization of deep structures and made it possible for surgeons to begin to define and safely navigate the temporal bone. The development of the pneumatic drill was also a crucial advancement in the late 1960s that allowed for faster and safer removal of the temporal bone structures to permit approaches that relied on greater exposure from bone removal and less from retraction. The combination of the surgical microscope and pneumatic drill allowed for a change in the philosophy of neurosurgeons and otologists. Additional exposure was obtained by more extensive removal of the skull at the base of the brain and not by additional retraction or sacrifice of neurovascular structures.

In the early 1960s, Hitselberger and House, at the House Ear Institute in Los Angeles, started expanding the current repertoire of approaches to the lateral and posterior skull base. In 1961, House8 described their experience with the middle fossa approach through the anterior petrous bone for intracanalicular acoustic neuromas. By defining the anatomy of the middle fossa and the anterior petrous bone, skull base neurosurgeons could expand this as the front door to the ventral brainstem.

Simultaneously, they were expanding traditional posterolateral approaches to the internal auditory canal and CPA. In 1966, Hitselberger and House described 20 patients who underwent operations between 1965 and 1966 in which a mastoidectomy and translabyrinthine approach were combined with an extended suboccipital craniotomy, with ligation of the sigmoid sinus. The development of these techniques, the anterior petrosectomy and the posterosigmoid approach, was crucial for the development of the current combined petrosal approach.

During the period between 1965 and 1970, there was also a dramatic evolution of the application of microsurgical techniques to skull base surgery. This rapid advance was permitted by further refinements in the operative microscope and pneumatic drill. Additionally, microsurgical instruments including dissectors and microscissors with longer and more slender working channels were developed to meet the needs of these approaches.

In the early 1970s, the primary approaches for the majority of tumors of the lateral skull base, including meningiomas and acoustic neuromas, were primarily intradural. In 1973, Morrison and King in London described an extended translabyrinthine approach in which the dural opening was extended superiorly through the superior petrosal sinus, with preservation of the sigmoid sinus. Additionally, during this time, Malis in New York was using a combined suboccipital retrosigmoid approach, with division of the sigmoid sinus but preservation of the vein of Labbé. Malis used this transsigmoid retrosigmoid approach for more than a decade, with great success.

Starting in the late 1970s, surgeons looking to find safer approaches to the ventral brainstem started to focus on combining supra- and infratentorial approaches. The primary indication for these approaches has been for surgical exposure of large petroclival tumors. Traditionally, firm, fibrous lesions of the clivus and ventral lateral foramen magnum have proven to be especially difficult, because most traditional posterolateral approaches require excessive retraction of the cerebellum and brainstem to expose the more superior ventral portions of the tumor, and supratentorial or anterior petrosal approaches provide a limited window to the caudal CPA.

Additionally, around this time, a group of Japanese skull base surgeons started to focus more on primarily extradural approaches. These approaches relying more on precise microsurgical guidance of extensive drilling of the anterior and posterior temporal bone to allow extensive lateral exposure to the lateral brainstem, clivus, and cavernous sinus, with minimal brain retraction. The fact that the majority of this work is done extradurally theoretically leads to less brain and cranial nerve trauma.

In the late 1970s, Hakuba was a visiting fellow with Malis in New York (Fig. 1); Hakuba had begun his career as an orthopedic surgeon, but after switching to neurosurgery he served as a visiting fellow with Malis. There, he observed several cases in which the transsigmoid retrosigmoid approach was used. Malis’ approach relied on division of the sigmoid sinus to obtain anterior

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exposure via a combined retrolabyrinthine suboccipital approach. Although division of the sinus does provide ventral exposure, it can result in venous infarction and hemorrhage. On returning to Japan, Hakuba built on the work of Hitselberger and House and used an anterior petrosectomy to provide access to the ventral brainstem and clivus such that division of the sigmoid sinus was unnecessary. Hakuba’s approach combined a partial labyrinthectomy with the anterior petrosectomy. This allowed for extradural exposure to the lateral CPA, ventral brainstem, and temporal lobe. Hakuba then opened the dural layer in a Y-shaped fashion: anterior to the sigmoid sinus, anterior and superior over the anterior temporal base, and then posterosuperiorly above the transverse/sigmoid junction. This usually requires division of the superior petrosal sinus.

In 1977, Hakuba et al. reported on 6 cases of petroclival meningiomas treated surgically. In 3 of these cases the authors used this combined suboccipital partial labyrinthectomy transpetrosal approach with preservation of the sigmoid sinus. Although this exposure offers the possibility of hearing preservation, Hakuba’s partial labyrinthectomy often led to at least partial hearing loss.

Additionally, during this time, surgeons in Japan and Europe started to adapt the combined supra- and infratentorial approach with some of the skull base drilling exposures described by Hitselberger and House and also by Hakuba. Mayberg and Symon presented their series of 35 petroclival meningiomas treated surgically between 1966 and 1985; 18 of these underwent operation via a combined supra- and infratentorial approach (3 before 1975, and 15 between 1976 and 1985). In their discussion, they comment that there was a general shift toward using a combined approach because it afforded better exposure with less cerebellar retraction.

Samii et al. reported on 24 cases of petroclival meningiomas treated between 1978 and 1987. In 6 of these cases, the authors performed an intradural combined retrosigmoid-subtemporal approach. For the first 4 of these cases they ligated the transverse sinus; however, in the last 2 cases they reported that the sinus was preserved.

In 1992, Spetzler et al. reported their experience with 46 ventral petroclival lesions treated surgically by using a combined supra- and infratentorial approach. In this series, a supratentorial craniotomy and anterior petrosectomy were combined with either a retrolabyrinthine mastoidectomy, when attempting to preserve hearing, or a translabyrinthine approach or greater exposure if hearing was to be sacrificed.

Perhaps no one has more experience with this approach than the senior author of the present report. Fukushima has further defined and developed the combined petrosal approach to treat lesions of the petroclival region (Fig. 2). His primary approach involves the combination of an extended middle fossa anterior petrosal “rhomboid” approach with a true labyrinth-sparing retrolabyrinthine mastoidectomy, resulting in preservation of the sigmoid sinus and of hearing. This primarily extradural approach allows for extensive exposure of the CPA, lateral and ventral foramen magnum, clivus, and posterolateral cavernous sinus, and permits safe exposure of the third through
eighth cranial nerves as well as exposure of the posterior cerebral artery, superior cerebellar artery, and anterior inferior cerebellar artery.\(^5\)

Fukushima primarily adapted his technique from that of Hakuba. Although Hakuba’s combined partial labyrinthectomy–anterior petrosectomy approach provides safe and adequate exposure with minimal retraction, there were 3 primary issues that Fukushima aimed to improve. First, Hakuba’s \(Y\)-shaped dural incision requires a posterior limb above the transverse-sigmoid junction. Although this provides additional exposure, it involves ligation of the superior petrosal sinus and potentially risks injury to the vein of Labbé. Fukushima advocates a more complete anterior petrosectomy with full drilling of the “rhomboid”; this allows for additional posterior superior visualization and obviates the need for the posterior limb of Hakuba’s \(Y\)-shaped dural opening. Second, Fukushima’s anterior dural incision is lower, at the tentorial attachment, so that the temporal lobe is not exposed and is protected by the overlying dura mater (Fig. 3). This protects the temporal lobe, decreases swelling, and minimizes any risk of damaging the vein of Labbé, which can cause a large venous infarct and significant neurological deficit. Finally, Fukushima advocates a true retrolabyrinthine approach as opposed to Hakuba’s partial labyrinthectomy, allowing for a true hearing preservation surgery.

In 2005, Little and colleagues\(^9\) presented 137 cases of petroclival meningioma treated surgically between 1993 and 2002; 54 of these patients underwent resection via a combined petrosal approach, with a retrolabyrinthine, translabyrinthine, or transcochlear temporal approach. The combined petrosal approach was reserved for larger tumors that had substantial posterior fossa and supratentorial extension. Over the last 2 decades, Fukushima has expanded and refined this approach to provide optimal exposure to each tumor. In cases requiring further anterior exposure, the retrolabyrinthine petrosectomy can be expanded to a translabyrinthine or transcochlear approach.

Conclusions

Lesions of the ventrolateral brainstem and clivus pose significant challenges for surgeons, and the rate of morbidity and mortality from classic neurosurgical approaches has proven to be unacceptably high. Over the last half century, innovations including the surgical microscope and the pneumatic drill have allowed surgeons to define combined infra- and supratentorial approaches, which rely less on brain retraction, to resect these difficult tumors successfully. These approaches have evolved from primarily extended posterior intradural transtentorial routes combined with mastoidectomy to extradural approaches, which combine extensive microsurgical bone removal through the posterior mastoid as well as through the anterior petrous bone for full exposure of the lateral brainstem, CPA, ventrolateral foramen magnum, and clivus.

Disclosure

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

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