Posterior Clinoidectomy: Dural Tailoring Technique and Clinical Application

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ABSTRACT

The posterior clinoid process, a bony prominence at the superolateral aspect of the dorsum sellae, has a strategic importance in a transcavernous approach to basilar tip aneurysms. To further optimize this microsurgical technique during posterior clinoidectomy, we performed a cadaveric study of this regional anatomy, describe a technique called dural tailoring, and report initial results in the surgical treatment of upper basilar artery (BA) aneurysm. After 10 adult cadaver heads (silicone-injected) were prepared for dissection, a posterior clinoidectomy with dural tailoring was performed. The dura overlying the upper clivus was coagulated with bipolar electrocoagulation and incised. Stripping dura off the clivus and lateral reflection then exposed the ipsilateral posterior clinoid process and dorsum sellae, thus creating a dural flap. Posterior clinoidectomy with dural tailoring was then used in seven patients with upper BA aneurysms. Our stepwise modification of the posterior clinoidectomy with dural tailoring created a flap that afforded protection of the cavernous sinus and oculomotor nerve. During surgery, there were no recorded intraoperative injuries to neurovascular structures. One patient died postoperatively from morbidity related to severe-grade subarachnoid hemorrhage. Postoperative oculomotor nerve palsy occurred in 3 patients (43%). In all cases, the nerve was anatomically preserved and partial to complete recovery was recorded during the first postoperative year. This technique effectively provided exposure of retrosellar upper basilar aneurysms in seven patients (basilar tip 43% and superior cerebellar artery aneurysms 57%). Outcomes and safety are at least equivalent to or better than basilar aneurysm surgery performed without surgical adjuncts, presumably a less complex subset.

KEYWORDS: Posterior clinoid, clinoidectomy, dural tailoring, basilar artery, oculomotor nerve

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Skull Base 2009;19:183–191. Copyright © 2009 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA. Tel: +1(212) 584-4662.

Received: January 23, 2008. Accepted after revision: July 18, 2008. Published online: October 31, 2008.
DOI 10.1055/s-0028-1096196. ISSN 1531-5010.

The posterior clinoid process (PCP) is a bony prominence at the superolateral aspect of the dorsum sellae. The strategic importance of this process was emphasized by Yasargil¹ and was subsequently described by Dolenc et al² in a report on the transcavernous approach to basilar tip aneurysms.

Posterior clinoid resection has represented the gateway to deeper exposure of the upper basilar artery (BA) through an anterolateral pterional or orbitozygomatic approach. Posterior clinoidectomy is an intricate technique that requires extensive surgical expertise and precise knowledge of the microsurgical anatomy of that region. The PCP is deeply nested in the cranium surrounded by critical neurovascular structures, specifically the cavernous sinus, BA, and cranial nerves. Several reports have briefly described resection of the PCP.¹⁻⁸ Previous descriptions of the surgical technique have been brief and limited to the context of a transcavernous approach in the neurosurgical literature. We hope to demystify this small adjunctive surgical technique in a stepwise fashion and render it more palatable for general consumption.

The purpose of our article is to provide understanding of the microsurgical anatomy of the dura in the posterior clinoid and cavernous sinus region and the technique for creation and lateral reflection of a dural flap as a protective maneuver during drilling. Stepwise dissection in the microsurgery laboratory, video illustration of the procedure from real surgery, and a small representative patient series with clinical results seem reasonable assets for young surgeons seeking specialization in complex cranial surgery.

We started our initial search for an optimum microsurgical technique for posterior clinoidectomy by performing a detailed study of the microsurgical anatomy of that region in the cadaveric laboratory. We then developed a step-by-step approach to expose and resect the PCP by applying constitutive rules set by pioneer experts in cavernous sinus surgery^{2,9,10} and adding some regulative steps (e.g., retraction of the internal carotid artery

[ICA], modification of the dural incision, creation of the dural flap, and so on).

MATERIAL AND METHODS

Cadaveric Preparation

Ten adult cadaver heads were prepared for dissection. Both internal carotid arteries, the vertebro-basilar system, and the jugular veins were cannulated and irrigated with warm tap water. The heads were soaked in 70% ethyl alcohol solution for 24 hours. After the arterial and venous systems were injected with pigmented-silicone latex compound (Dow-Corning, Midland, MI), the silicone compound was allowed to harden overnight. All heads were preserved in 70% ethyl alcohol solution. A posterior clinoidectomy with dural tailoring was performed in which the dura overlying the upper clivus was coagulated with bipolar electrocoagulation and incised. Stripping dura off the clivus and lateral reflection then exposed the ipsilateral PCP and dorsum sellae, thus creating a dural flap.

Patient Population

Between 2002 and 2008, all patients who had surgical treatment for upper BA aneurysms underwent clipping via an orbitozygomatic paracavernous approach.³ Of these five women (71%) and two men (29%), presentation included subarachnoid hemorrhage (SAH) in Patients 1 to 5 and 7 and unruptured aneurysm in Patient 6. Subarachnoid hemorrhage ranged in severity from grades I to III (per World Federation of Neurological Surgery) in five patients and grade V in one patient. Seven patients underwent a posterior clinoidectomy with dural tailoring to expose retrosellar aneurysms that were either low BA tip or superior cerebellar artery (SCA) aneurysms (Fig. 1). However, posterior clinoid resection may also be required to expand the deep

Figure 1 (A) Right vertebral angiography showing a right superior cerebellar artery aneurysm. (B) Postoperative right vertebral angiography showing the superior cerebellar artery aneurysm clipped.

surgical field in large upper basilar aneurysms or to adequately place the clip.

RESULTS

Using the information obtained during cadaveric dissections, we established a step-by-step modification of the posterior clinoidectomy that included dural tailoring of a flap elevated from the PCP and dorsum sellae and reflected laterally to protect the cavernous sinus and the oculomotor nerve. In our clinical findings, posterior clinoidectomy effectively provided exposure of retrosellar upper basilar aneurysms in seven patients (basilar tip 43% and SCA aneurysms 57%). Outcomes and safety were comparable with overall outcomes in most reported BA surgery studies, which may or may not have included posterior clinoidectomy.

Microsurgical Anatomy

The PCP is located at the superolateral aspect of the clivus as part of the posterior upper limit of the sphenoid bone. Considerable variation occurs in the size of the PCPs among individuals and on

either side within the same individual; this structure may also be pneumatized with the sphenoid sinus. The dorsum sellae connects between the paired PCPs. Anteromedial to the PCP is the sella turcica and pituitary gland. Anterolateral to this process is the posterior edge of the cavernous sinus that extends from the process above to the junction of the petrous apex with the body of the sphenoid bone below. The cavernous segment (C4) of the ICA usually has a vertical portion, a posterior bend or medial loop, a horizontal portion, and an anterior bend or anterior loop. The ICA ascends into the posterior aspect of the cavernous sinus where the medial loop is formed lateral to the PCP. The bifurcation of the BA lies posterior to the PCP and dorsum sellae. In 10 cadaveric specimens, the BA bifurcation was at the level of PCP in 5 specimens (50%), above in 3 specimens (30%), and below in 2 specimens (20%). The oculomotor nerve enters the edge of the tentorial dura lateral to the PCP in the oculomotor triangle.

Meningeal Architecture

The cavernous sinus roof is formed by the anterior extension of the tentorium cerebelli and lateral extension of the diaphragma sellae. As the tentorium

Figure 2 Cadaveric photographs, through the microscope of the anterolateral exposure of the upper basilar artery as observed from a frontotemporal-orbitozygomatic approach. (A) Sylvian fissure is widely opened; note the middle cerebral artery (MCA); and the internal carotid artery (ICA) is retracted medially. Liliequist's membrane (LM) is intact between the oculomotor nerve (III) laterally and the posterior communicating artery (PCOM) medially. (B) With dissection of Liliequist's membrane, the posterior clinoid process (PCP) and basilar artery (BA) are exposed. A vertical dural incision (arrow) is made over the posterior aspect of the PCP and dorsum sellae. (C) Dissection of the dura from the PCP creates two dural flaps. The lateral dural flap (DF) is reflected toward the oculomotor nerve and retracted with a microhook. (D) Lower exposure of the BA is obtained after resection of the PCP and the overlying dural flaps. ON, optic nerve.

curves anteromedially, it forms two dural folds. First, the anterior petroclinoid fold extends anteriorly to the anterior clinoid process. Second, the posterior petroclinoid fold extends to the PCP. An interclinoid fold connects the anterior and PCPs. These three folds form the boundaries of the oculomotor trigone, which constitutes the posterior two thirds of the cavernous sinus roof, and, in essence, the lateral extension of the diaphragma sellae. The oculomotor nerve penetrates the oculomotor trigone. The diencephalic layer of the Liliequist's membrane extends from the PCP and dorsum sellae to the inferior surface of the hypothalamus. This layer separates the interpeduncular cistern and the oculomotor cistern from the chiasmatic, carotid, and posterior communicating cisterns (Fig. 2).

The medial wall of the cavernous sinus is one layer formed by the dura propria (extension of the diaphragma sellae) in its sellar part and by the periosteum of the sphenoid bone in its sphenoidal

part. The periosteal part of the medial wall of the cavernous sinus blends with the periosteum of the dorsum sellae and PCP (Fig. 3A). The dura propria of the posterior fossa represents the second dural layer of the dorsum sellae and PCP. The large posterior intercavernous connections lateral to the dorsum sellae run between the two dural layers and open into the basilar and petrosal sinuses. The basilar venous plexus lies on the posterior surface of the dorsum sellae.

Surgical Approach

The patient's head is maintained in three-pin fixation using a Mayfield Skull Clamp (OMI Surgical Products, Cincinnati, OH), positioned in 45-degree contralateral rotation, to establish the zygoma as the highest point in the operative field. The one-piece frontotemporal-orbitozygomatic

Figure 3 Anatomic drawing of the meningeal architecture of the posterior cavernous sinus and PCP. (A) Medial wall of the cavernous sinus (solid line) blends with the periosteum covering the PCP and dorsum sellae. Dura propria (broken line) represents the second dural layer covering the PCP and dorsum sellae. (B) Both dural layers are vertically incised creating a dural flap. The dural flap is reflected laterally toward the oculomotor nerve in preparation for posterior clinoidectomy. PCP, posterior clinoid process; OR, orbit; ON, optic nerve; SOF, superior orbital fissure; ACP, anterior clinoid process; SS, sphenoid sinus; ICA, internal carotid artery; MF, middle fossa; VI, abducens nerve; PF, posterior fossa; III, oculomotor nerve.

approach is performed.¹¹ Extradural anterior clinoidectomy is done to achieve additional exposure to the PCP. The distal dural ring around the ICA is cut circumferentially and the supraclinoid ICA is medially retracted using a 5-mm microvascular retractor blade¹² (Fig. 4). The surgical microscope is angled posteriorly to view the upper part of the clivus, namely the PCP and dorsum sellae.

POSTERIOR CLINOIDECTOMY

Dural Tailoring The dura overlying the upper clivus is coagulated with bipolar electrocoagulation along the line of the anticipated dural incision. A vertical dural incision is made along the PCP and extended down in a longitudinal manner along the adjoining dorsum sellae using a no. 15 blade (Fig. 4A). Venous bleeding from posterior intercavernous connections is controlled by bipolar electro-

coagulation of the dural edges or application of vascular clips. Further tailoring of the dura is achieved by turning a small transverse dural incision at the upper and lower end of the vertical incision, enough to create the dural flap. The dura is stripped off the clivus by using a semisharp microdissector and is reflected laterally to expose the ipsilateral PCP and dorsum sellae, thus creating a dural flap (Fig. 4B). The dural flap includes both the dura propria and periosteal dura that continues as the medial wall of the cavernous sinus (Fig. 3B). Retraction of this lateral dural flap with a microhook or suction tip avoids inadvertent entry into the cavernous sinus during drilling and may help protect important neurovascular structures, namely the oculomotor nerve and cavernous ICA (Figs. 2, 4).

Posterior Clinoid Resection The PCP and the adjoining part of the dorsum sella is progressively resected using an AM-8 diamond burr (Midas Rex, Burlington, MA) under continuous irrigation (Fig. 4C). Venous bleeding from the basilar or cavernous sinus is controlled after packing with Surgicel (Johnson & Johnson Products, Chicago, IL). Excessive drilling may cause violation of the sphenoid sinus or pneumatization of the PCP; in these instances, meticulous packing with bone wax is needed to prevent leakage of cerebrospinal fluid. After posterior clinoidectomy, the dural flap is cut flush with the resected bone creating a lower and wider exposure of the upper BA (Fig. 2).

Clinical Cases

Five women (71%) and two men (29%) underwent successful surgical clipping of upper BA aneurysms via a paracavernous approach that included posterior clinoidectomy with dural tailoring (Table 1) as described previously. No intraoperative injuries to vascular or other neural structures were reported. Patient 2 died because of medical consequences of (grade V) SAH that worsened during the postoperative period. The period of postoperative follow-up ranged from 3 to 48 months. Patients

Figure 4 Operative photographs through the microscope for a left-sided approach. (A) The dura overlying the posterior clinoid process (PCP) is vertically incised creating medial and lateral flaps. The supraclinoid internal carotid artery (ICA) is retracted medially using a microvascular retractor blade (asterisk). (B) The lateral dural flap is reflected on the oculomotor nerve (III) using the suction tip (horizontal arrow) to maintain retraction. (C) Extradural drilling of the PCP using an AM-8 diamond burr (Midas Rex, Burlington, MA) (vertical arrow). PCOM, posterior communicating artery; BA, basilar artery.

Table 1 Summary of Clinical Data in Seven Patients Who Underwent Posterior Clinoidectomy

Patient	Sex, Age (years)	Diagnosis			Aneurysm	Outcome
		SAH	Fisher Grade	WFNS		
1	Female, 71	SAH	IV	II	BA tip, 4 mm	No CN III palsy, cognitive deficit
2	Female, 73	SAH	IV	V	Right SCA, 4 mm	Death related to SAH
3	Male, 41	SAH	II	II	BA tip, 8–10 mm	Partial left CN III improved
4	Female, 62	SAH	N/A	I	Right SCA, 10 mm	Preop right CN III improved
5	Female, 51	SAH	III	III	Left SCA, 8 mm	Left CN III 50% improved
6	Male, 55	Unruptured	N/A	N/A	Right SCA, 8 mm	Partial right CN III
7	Female, 51	Ruptured	IV	II	Left ACOM, BA tip, 12 mm	No CN III palsy

SAH, subarachnoid hemorrhage; WFNS, World Federation clinical grading, BA, basilar artery; CN, cranial nerve; III, oculomotor nerve; SCA, superior cerebellar artery; ACOM, anterior communicating artery.

3, 5, and 6 (43%) postoperatively developed a new third nerve palsy; Patient 4 had preoperative third nerve palsy that remained through the postoperative period. All four patients who suffered from third nerve palsy had marked improvement in nerve function within the first 6 months to 1 year after surgery.

DISCUSSION

The concept of posterior clinoidectomy is not a novel idea, but accurate description in the literature would be novel. In our cadaveric study, we reappraised various conventional techniques for resection of the PCP with special emphasis on the meningeal architecture of the posterior cavernous sinus relative to bony and neurovascular anatomy. In our stepwise description of posterior clinoidectomy, we applied a dural tailoring technique that serves as a protective maneuver for the cavernous sinus and oculomotor nerve during drilling. Our seven patients with BA or SCA aneurysms underwent successful clipping via a paracavernous sinus approach using posterior clinoidectomy with dural tailoring. By historical comparisons, our incidence of third nerve palsy is at least equivalent to or better than basilar aneurysm surgery performed without surgical adjuncts, presumably a less complex subset.^{13–16}

Posterior clinoid resection is a useful complement in the cerebrovascular surgeon's toolbox. Ongoing advances in developing sophisticated endovascular techniques have permitted successful management of BA aneurysms, leading to redefinition of the role of surgery in treating these complex lesions. However, direct surgical clipping can still play an important role in management of select basilar aneurysms, such as giant or wide-neck aneurysms or recurrent aneurysms after coil occlusion. Therefore, neurosurgeons should develop and maintain expertise in complex BA surgery guided by the essence of skull base surgery.

As emphasized by Yasargil,¹ posterior clinoidectomy was performed to improve exposure to upper BA aneurysms through a pterional transsylvian approach. The rapid dissemination of posterior clinoidectomy worldwide as an adjunct to upper basilar aneurysm surgery was largely attributed to Dolenc's efforts.^{9,10,17}

Upper BA aneurysms situated low behind the dorsum sellae cannot be adequately visualized through an anterolateral trajectory without the removal of the PCP. With the evolution of modern cranial base techniques, posterior clinoidectomy gained more popularity^{2,5} as an adjunct to the orbitozygomatic approach to enhance the exposure to the interpeduncular and prepontine cisterns. The added exposure offered by resection of the PCP was subsequently documented in several reports.^{3,4,6,8,18} However, the technical difficulty associated with the anatomical complexity in the upper BA region has led many surgeons to refrain from performing posterior clinoidectomy.

Resection of the PCP requires both analytical and empirical judgment that should be based on a complete analysis of aneurysm morphology, precise knowledge of microsurgical and meningeal anatomy, and experience with the surgical technique.

Meningeal Architecture and Dural Tailoring

As described by Dolenc, a transverse dural incision is made over the PCP.² The PCP is thus exposed and drilled off either partly or completely, depending on how much space is required. Also, the PCP can be drilled from the inside of the sella in a posterior direction after cutting the diaphragma sellae in front of the PCP in a maneuver described as a transclinoid–trans-sellar–transcavernous approach.¹⁷ In a different technique described by Seoane et al,⁶ the dura overlying the PCP and dorsum sellae was preserved during drilling as a protection against inadvertent damage to the elements of the interpeduncular cistern. After drilling is complete, the dura can then be cut with regular microscissors.

The concept of extradural drilling appeals to most cranial base surgeons because of the protection provided by the dural layer to neurovascular structures and by the provision of a clean surgical field. Previous anatomical and histological studies^{7,19} have shown continuity of the medial wall of the cavernous sinus with the dura covering the PCP and dorsum sellae. In our dural tailoring technique, we expose the PCP transdurally through a vertical dural incision over the dorsum sellae and upper clivus. The creation of a dural flap and its lateral retraction serve several purposes. First, this maneuver sets a lateral boundary continuous with the medial wall of the cavernous sinus that protects against lateral migration of the drilling into the cavernous sinus. Second, dural tailoring facilitates extradural drilling of the PCP in a clean operative field. Third, this maneuver may create additional space for manipulation of surgical instruments and the aneurysm clip while protecting the oculomotor nerve.

Complication Avoidance

The benefits of posterior clinoidectomy should be balanced against its potential complications that have been historically associated with this sophisticated procedure. These complications include venous bleeding from the basilar plexus, cerebrospinal fluid fistula from excessive drilling into the sphenoid sinus, oculomotor nerve injury lateral to the PCP, abducens nerve injury in Dorello's canal, and possible injury to the medial loop of the cavernous carotid artery. Coagulation of the dura overlying the dorsum sellae and clivus is performed prior to sharp incision to avoid venous bleeding. Venous bleeding from the basilar plexus can be controlled with either electrocoagulation or vascular clip application over the dural edges, or after packing with Surgicel. The tailored dural flap may afford protection against injury to the cavernous sinus and oculomotor nerve. Drilling of the PCP and dorsum sellae should be limited to the actual need to adequately expose retrosellar upper basilar aneurysms. Inadvertent

entry into the sphenoid sinus is meticulously occluded with bone wax to seal off potential development of cerebrospinal fluid fistula.

Clinical Application

The dural tailoring technique described in our cadaveric study of posterior clinoidectomy was then successfully adapted to a small clinical series of seven patients who underwent surgical clipping of upper BA aneurysms. There were no recorded intraoperative injuries to neurovascular structures. Patient 2 died during the postoperative period from morbidity related to severe-grade SAH. Postoperative oculomotor nerve palsy occurred in three patients (43%). In all patients, the nerve was anatomically preserved and partial to complete recovery was recorded during the first postoperative year. The overall incidence of oculomotor nerve palsy varies from 30 to 75% after surgical treatment of BA aneurysm¹³⁻¹⁶ and has been higher with SCA aneurysms.¹⁵ To the best of our knowledge, the incidence of oculomotor nerve palsy remains unknown specific to patients who underwent posterior clinoidectomy. Several factors suggested to contribute to postoperative oculomotor nerve palsy have included aggressive manipulation of the nerve in a narrow surgical field, large aneurysms, backward projection of an SCA aneurysm, and vascular injury to small perforating arteries.^{14,15}

CONCLUSIONS

The dural tailoring technique to be used during posterior clinoidectomy was developed in a cadaveric study and then applied in a small patient series for the treatment of aneurysms of the upper BA and SCA. By historical comparisons, our incidence of third nerve palsy is at least equivalent to or better than basilar aneurysm surgery performed without surgical adjuncts, presumably a less complex subset. In our dural tailoring technique, we expose the PCP

transdurally through a vertical dural incision over the dorsum sellae and upper clivus by creation of a dural flap that is then retracted laterally.

ACKNOWLEDGEMENT

The authors thank Dr. Siviero Agazzi for his contributions to the operative photographs.

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