Accessing the Basilar Artery Apex: Is the Temporopolar Transcavernous Route an Anatomically Advantageous Alternative?

Hakan Sabuncuoğlu, M.D.,¹ Pakrit Jittapiromsak, M.D.,¹
Daniel D. Cavalcanti, M.D.,¹ Robert F. Spetzler, M.D.,¹ and Mark C. Preul, M.D.¹

ABSTRACT

The restricted operative field, difficulty of obtaining proximal vascular control, and close relationship to important anatomic structures limit approaches to basilar apex aneurysms. We used a cadaveric model to compare three surgical transcavernous routes to the basilar apex in the neutral configuration. Five cadaveric heads were dissected and analyzed. Working areas and length of exposure provided by the transcavernous (TC) approach via pterional, orbitozygomatic, and temporopolar (TP) routes were measured along with assessment of anatomic variation for the basilar apex region. In the pterional TC and orbitozygomatic TC approaches, the mean length of exposure of the basilar artery measured 6.9 and 7.2 mm, respectively ($p = \text{NS}$). The mean length of exposure in a TP TC approach increased to 9.3 mm ($p < 0.05$). Compared with the pterional and orbitozygomatic approaches, the TP TC approach provided a larger peribasilar area of exposure ipsilaterally and contralaterally ($p < 0.05$). The multiplanar working area related to the TP TC approach was 77.7 and 69.5% wider than for the pterional TC and orbitozygomatic TC, respectively. For a basilar apex in the neutral position, the TP TC approach may be advantageous, providing a wider working area for the basilar apex region, improving maneuverability for clip application, fine visualization of perforators, and better proximal control.

KEYWORDS: Basilar artery aneurysm, transcavernous approach, temporopolar approach, pterional approach, orbitozygomatic approach, anatomic study

Basilar artery (BA) aneurysms arise from the basilar apex, posterior cerebral artery (PCA), superior cerebellar artery (SCA) junction, and proximal P1 segment.¹ They represent 5 to 15% of all intracranial aneurysms and more than 50% of all vertebrobasilar aneurysms.² The basilar apex and the upper portion of the BA trunk are located in the interpuncular and

upper prepontine cisterns, deep at the center of the cranial base, a crucial area because of the density and deep central location of neurovascular structures.³

Accordingly, approaches to the BA consider the location of the pathology and the anatomic configuration of the basilar apex. The pterional (PT) transsylvian technique is a well-known approach to the superior

¹Division of Neurological Surgery, Barrow Neurological Institute, St. Joseph's Hospital and Medical Center, Phoenix, Arizona.

Address for correspondence and reprint requests: Mark C. Preul, M.D., Newsome Chair of Neurosurgery Research, Barrow Neurological Institute, Division of Neurological Surgery, St. Joseph's Hospital and Medical Center, 350 W. Thomas Rd., Phoenix, AZ 85013 (e-mail: neuropub@chw.edu; mark.preul@chw.edu).

Skull Base 2011;21:23–30. Copyright © 2011 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA. Tel: +1 (212) 584-4662.

Received: December 21, 2009. Accepted after revision: May 25, 2010. Published online: July 26, 2010.

DOI: <http://dx.doi.org/10.1055/s-0030-1262946>.

ISSN 1531-5010.

portion.⁴ This approach gives a direct, ergonomic view to the BA by working through the sylvian fissure while avoiding excessive retraction on the temporal lobe as is associated with the subtemporal approach. However, gaining control of the proximal BA may require additional transcavernous (TC) dissection or access. Using the TC approach, the BA can be tracked down from the apex 12.4 to 13.4 mm, depending on its orientation and elevation.⁵ An orbitozygomatic (OZ) extension provides a wider external bony opening than the PT approach. However, benefits approaching the BA and gaining proximal control are less clear compared with the TC technique. A temporopolar (TP) variation is an interesting option for access to the BA apex. When combined with the TC technique, the TP route may become very useful to access the BA, by widening and improving the surgical corridor.⁶

Few anatomic studies have compared approaches specifically targeting the basilar apex region. This paucity likely reflects the variability in the BA and apex combined with the aneurysms that may occur in this region. However, a quantitative study that addressed at least the major variation of this anatomy (i.e., the basilar apex in the neutral position) would improve understanding of the benefits offered by various approaches to the BA. We previously assessed the effect of each step of the TC approach for accessing the interpeduncular and prepontine cisterns.⁵ In this more refined and restricted study, we intentionally compared the exposures provided by the PT, OZ, and TP approaches to a neutral BA apex when a TC procedure is combined to the approach.

MATERIALS AND METHODS

Cadaveric Preparation

Five cadaveric heads (10 sides) with colored silicone-injected arterial and venous systems and no known gross brain pathology were used to obtain measurements of each approach. Predissection stereotactic magnetic resonance imaging was performed to correlate the surgical trajectory to the anatomic dissection. Stereotactic measurements were performed on each head at various points. The reference arc of a frameless navigation device (Stealth TREON Plus Navigation Station; Surgical Navigation Technologies, Medtronic, Inc., Louisville, CO) was mounted on the Mayfield clamp and fixed to the operating station for rigid fixation. These measurements consisted of three-dimensional positional information in the form of Cartesian coordinates.

The dissections were done using standard micro-neurosurgical instruments and a surgical microscope. A frontotemporal incision began at the superior border of the zygomatic arch, close to the tragus cartilage and anterior to the superficial temporal artery. The incision

proceeded superiorly and posteriorly to the highest point of the external ear, curving anteriorly to end just behind the hairline in the frontal region. An interfascial dissection was made to preserve the frontotemporal branch of the facial nerve. The temporalis muscle was dissected from the bone and retracted inferiorly and posteriorly toward the posterior portion of the zygomatic arch. The bone work was performed with a high-speed drill (Ans-pach, Palm Beach Gardens, FL).

A two-piece OZ approach⁷ was first performed. The OZ osteotomy was then refixed rigidly with mini-plates to recreate the PT approach environment before continuing to the next step of dissection. Affixing the bone flap in this manner allowed conversion between PT and OZ approach while taking measurements.

A curvilinear inferior dural incision was made from the temporal fossa across the sylvian fissure. The dura flaps were retracted with sutures to allow a flat inferior line of vision. The intradural dissection was begun by opening the basal cisterns (chiasmatic and carotid). Then the proximal sylvian fissure was opened and widely dissected distally to proximally. The bifurcation of the internal carotid artery (ICA) was determined, and the adhesions between the oculomotor nerve and uncus were dissected. Liliequist's membrane and the arachnoid of the interpeduncular fossa were dissected, and the posterior communicating artery (PCoA) was followed to its junction with the PCA and basilar apex. The BA, bilateral PCAs, and bilateral SCAs were identified.

To enhance exposure to BAs, a TC approach was performed in all specimens. Key steps, including anterior clinoidectomy, release of dural rings, and posterior clinoidectomy, were followed. For anterior clinoid removal, the dura of the oculomotor trigone was incised to open the roof of the cavernous sinus. The incision was medial and parallel to the oculomotor nerve, lateral to the ICA, and extended to the anterior clinoid process. The anterior clinoid process was drilled using an intradural approach, and the distal dural ring of the ICA was cut. The proximal dural ring was divided to mobilize the ICA. The dura over the posterior clinoid process was opened. The posterior clinoid process and part of the dorsum sellae were drilled to expose the upper portion of the BA (Fig. 1A).

Quantification Parameters and Measurements

As described in the preparation step, the PT dissection and TC approach were measured first. A 2-cm tip retractor was applied on the frontal lobe near the sylvian fissure, remaining 3.5 cm from the frontozygomatic suture. Temporary retraction of the ICA and adjustment of the microscope angle were applied to obtain the best view of each anatomic point of interest. After data collection was completed, the OZ bar was removed.

Figure 1 (A) Peribasilar triangles and landmark points for measuring the area and length of exposure of the BA as seen in an orbitozygomatic transcavernous approach. 1, Farthest point of visualization of ipsilateral PCA; 2, basilar apex; 3, farthest point of visualization of contralateral PCA; and 4, most proximal point of visualization of BA. (B) A wide peribasilar area of exposure is seen in the temporopolar transcavernous approach. BA, basilar artery; CN II, optic nerve; CN III, oculomotor nerve; ICA, internal carotid artery; PCA, posterior cerebral artery; SCA, superior cerebellar artery. Note the closer perspective to the anatomy provided by the temporopolar transcavernous approach.

Measurements were then repeated in the same manner without changing the degree of frontal lobe retraction (3.5 cm from the frontozygomatic suture).

In last step for the TP approach, the OZ bar was refixed, and the bridging veins from the temporal lobe to the sphenoparietal sinus were sacrificed. Dissection was continued laterally to expose the anterior portion of the ambient cistern. The arachnoid attachments between the uncus and oculomotor nerve were opened to increase mobility of the temporal lobe and to decrease the need for retraction. When the cisternal opening was completed, the temporal lobe was elevated posteriorly and superiorly to widely expose the basilar apex (Fig. 1B). TP retraction was kept constant 2 cm away from the sphenoid wing for each approach. The anatomic points were measured in a consistent fashion.

Two peribasilar triangles that were identified around the BA represented the area of exposure obtained in BA apex aneurysm surgery (Fig. 1A). Four anatomic points defined these two peribasilar triangles: (1) farthest point of visualization of the ipsilateral PCA, (2) BA apex, (3) farthest point of visualization of the contralateral PCA, and (4) most proximal point of visualization of the BA. Triangle 1 was formed by points 1, 2, and 4, and triangle 2 was formed by points 2, 3 and 4. The common vertex point of both triangles was point 4. Coordinate data were gathered by touching the digitizing probe to the anatomic points.

Multiplanar working areas were assessed by summation of both triangular areas in each approach. We also evaluated the length of exposure of the BA represented by the distance between the apex and most proximal part of the BA exposed (distance between points 2 and 4). The areas and lengths of exposure were then calculated using the Spherical Area program (Bitwise Ideas Inc., Fredericton, NB, Canada).

The approaches were compared with one-way repeated-measures analysis of variance followed by pairwise comparisons with the Holm-Sidak correction. All statistical analyses were managed by using SigmaStat 3.5 program (Systat Software, Inc., Point Richmond, CA). For all comparisons, $p < 0.05$ was considered significant.

RESULTS

In all specimens, the basilar apices were classified as a normal lying position (vertically within 5 mm from the dorsum sellae level) from predissection imaging study. Without a TC dissection, the basilar apices were already exposed in all specimens. In the PT TC and OZ TC approaches, the mean length of exposure of the BA was 6.9 and 7.2 mm, respectively ($p = \text{NS}$; Fig. 2). Interestingly, the mean length of exposure of the BA was 9.3 mm in a TP TC approach, which was longer than the value provided by the PT TC approach ($p = 0.04$).

Figure 2 Bar graphs representing the length of exposure of the basilar artery in the transcavernous (TC) approach via the pterional (PT), orbitozygomatic (OZ), and temporopolar (TP) routes ($n = 9$). The difference between TP TC and PT TC was significant. *Pairwise comparisons, adjusted $p = 0.04$.

Figure 3 Bar graphs representing the peribasilar area of exposure in the transcranial (TC) approach via the pterional (PT), orbitozygomatic (OZ), and temporopolar (TP) routes ($n=10$). The differences on the ipsilateral side between the TP TC and PT TC and between TP TC and OZ TC were significant. On the contralateral side, significances were found between TP TC and PT TC and between TP TC and OZ TC. * $p < 0.05$; ** $p < 0.01$.

In the PT TC approach, the mean areas of the ipsi- and contralateral peribasilar triangles were 29.0 and 22.9 mm², respectively, compared with 30.2 and 24.2 mm², respectively, in the OZ TC approaches ($p = \text{NS}$). In TP TC approach, the mean areas of the ipsi- and contralateral peribasilar triangles were 54.9 and 37.3 mm², which were greater than the areas of exposure gained through the PT TC and OZ TC approaches ($p < 0.05$; Fig. 3). Ultimately, the multiplanar working area related to the TP TC approach was 77.7 and 69.5% wider than for the PT TC and OZ TC, respectively.

DISCUSSION

The management of a posterior inferior cerebellar artery aneurysm by Olivecrona in 1932 and a proximal vertebrobasilar aneurysm by Schwartz in 1948 laid the foundation for basilar or peribasilar artery surgery.¹ Over the intervening years, many skull base approaches have been described to access the BA apex.^{8–14} The PT^{4,15,16} and subtemporal approaches^{4,16,17} are usually employed to manage BA apex aneurysms. The TP,¹⁰ zygomatic,¹² zygomaticotemporal,¹⁸ zygomaticosubtemporal,¹⁹ zygomatico-TP,²⁰ OZ infratemporal,¹⁴ and TC transsellar²¹ approaches are surgical variations that provide about the same direction to the BA apex.

In an anatomic assessment, the TC approach provided wider surgical freedom when compared head-to-head with anterior petrosectomy.²² The TC approach also produced a broader vertical angle of approach. Subsequently, we assessed the isolated impact of each step of the TC approach and found that the complete approach significantly increased the working area compared with shortened forms of the approach.⁵ Whether a specific surgical route would enhance the benefits of a TC approach remains to be addressed. This study was

not designed to review the surgical approaches and anatomy of the BA apex region. Instead, it was inserted to evaluate the advantages and drawbacks of the PT and OZ routes when a TC approach is planned and to clarify that a more seldom used route, the TP, may have anatomic advantages that make it a suitable alternative.

The PT Approach

The PT route described by Yaşargil and colleagues^{4,23} provides access through the space between the optic nerve and ICA or between the ICA and the oculomotor nerve.²³ However, the anterior clinoid process, supraclinoid ICA, oculomotor nerve, and posterior clinoid process limit the carotid-oculomotor window.¹ This approach, familiar to most neurosurgeons, offers less temporal lobe retraction and less manipulation of the oculomotor nerve in exchange for a deep, narrow field and poor proximal vascular control.¹ Although superficial exposure is sufficient in the PT and subtemporal approaches, they do not provide a large area of exposure near the basilar apex.

Using the PT approach, the contralateral P1 segment is easy to expose. However, it may be difficult to gain proximal control of the BA, an especially important problem with low-lying BA bifurcation aneurysms. The entrance of the PT approach to a basilar apex aneurysm is defined by ICA and middle cerebral artery (MCA) above and by the skull base below. The size of the entry mostly depends on the length of those vascular structures. A short ICA or early temporal branching of the MCA can create surgical challenge. The PCoA and posterior clinoid process frequently interfere with successful access to BA apex aneurysms via the PT approach.²⁴ The posterior clinoid process can obstruct vision, especially in the presence of low-lying BA apex aneurysms.²³ In contrast, with high BA apex aneurysms, the MCA or PCoA runs horizontally across the operative field and restricts upward movement. The perforating branches arising from the posterior aspect of the BA are also poorly seen via the PT approach. In brief, this approach is adequate for placing clips to treat uncomplicated basilar apex aneurysms, but its use creates some difficulties in the treatment of giant aneurysms if temporary clipping of the proximal BA may be needed to dissect perforating vessels from the neck of the aneurysm.

The OZ Approach

The OZ approach to the anterior and middle cranial fossae, upper third of the clivus, and posterior fossa was described by Pellerin et al in 1984²⁵ and by Hakuba et al in 1986.¹⁴ Various modifications have been reported to enhance the exposure offered by the OZ approach.^{13,15,26–29} Although the OZ approach improves exposure of the surface of the craniotomy, it does not

appreciably improve exposure in the anterior incisural space. Unfortunately, this approach offers little assistance in the treatment of low- and normal-lying BA apex aneurysms if it is necessary to place a temporary clip. For the treatment of giant BA apex aneurysms, the OZ approach does not offer enough working space³⁰ and only offers accessibility to the aneurysm dome. Furthermore, it cannot accommodate proximal control of the BA. The OZ approach only offers an advantage in the case of high-lying BA apex aneurysm, when the surgeon may want a more inferior line of vision along the sylvian fissure without excessive frontal and temporal lobe retraction.

The TP Approach

The TP approach has its roots in the standard PT craniotomy popularized by Yaşargil^{2,4} for the treatment of anterior circulation aneurysms. Sano¹⁰ and Dolenc et al²¹ contributed separately to the technique that most resembles the approach that most neurosurgeons refer to as the TP. Drake^{31,32,35} combined the standard subtemporal approach to BA aneurysms with the PT approach to introduce the so-called “half-and-half” method for aneurysms located above the dorsum sellae.^{31,32,35} The TP approach described by Sano¹⁰ is one modification of the PT approach based on posterior retraction of the temporal lobe. Although it improves the exposure and combines the advantages of both the subtemporal and PT approaches, it is seldom used.²³

Except for very high basilar tip aneurysms, the TP approach provides a nice view and wide working space, which combines the multiple angles of view offered by both the PT and subtemporal routes. If the basilar trunk is not too long, this approach can be applied not only to aneurysms arising from the upper portion of the BA but also to those arising from the lower portion of the BA.³³

If the aneurysm is long, it is necessary to use temporary clips for related vessels or the bulk of the aneurysm must be diminished by puncture or excision. The wide, shallow operating field offered by this approach often makes these procedures easier than a standard approach to the area, and a temporary clip applied to the BA usually does not interfere with the surgeon's view (Fig. 4).

The other advantages of the TP approach are visualization of much of the anterior circle of Willis and the ability to clip incidental aneurysms. With small BA apex aneurysms, the more anterior (oblique) line of vision allows the use of nonfenestrated clips. Fenestrated clips are more difficult to use because they must fit perfectly across the base of the aneurysm or be altered to do so.^{34,35} Still, fenestrated clips are often needed to treat large aneurysms because their neck is wide in the lateral direction. The TP approach offers the flexibility of changing the angle of vision more laterally, as required for clip application in these cases.

The TP approach allows a more anterior line of vision when compared with the subtemporal approach. Hence, visualization of both P1 segments of the PCA is improved, and dissection of the opposite side of the aneurysmal neck is facilitated (Figs. 3 and 4). The TP approach improves visualization and management of the anatomy because of the angle of view is wide. Although posterior retraction of the temporal pole is a disadvantage of this approach and requires sacrifice of the anterior bridging veins, these maneuvers seldom lead to substantial morbidity.^{10,24,34}

The TC Approach

The TC approach attempts to expand the carotid-oculomotor window by mobilization of the ICA and oculomotor nerve after an anterior and/or posterior clinoidectomy has been performed.³ Despite notable

Figure 4 Magnetic resonance and navigation system-assisted images show the trajectory to the basilar artery apex via (A) pterional (PT), (B) orbitozygomatic (OZ), and (C) temporopolar (TP) routes. The trajectory of the PT transcavernous (TC) and OZ TC is similar. As seen in (A), the PT TC approach utilizes an angled sylvian fissure trajectory. The OZ TC (B) also utilizes the sylvian fissure, but from a more subfrontal angled access. The TP TC (C) trajectory images shows the more flat, ergonomically more orthogonal approach, providing more direct lateral and shorter access to the basilar artery apex in front of the anterior third of the temporal lobe. Thus the surgeon has a closer relationship to important anatomic structures.

results associated with the TC approach,^{3,5,21,30,36–39} few neurosurgeons favor such dissection. The TC approach was first recognized by Dolenc et al,²¹ and Fujimoto et al⁴⁰ advocated benefits of such an approach.

The TC approach improves visualization of the basilar trunk, improves the safety of applying temporary clip well below the area of interest, and eliminates obstruction of the neck caused by a temporary clip within the surgeon's view. The TC approach adds several benefits: the optic and oculomotor nerves and ICA are more readily and safely retracted. An important point in improving exposure to the BA is removal of the anterior clinoid process. This bone work disconnects its three main attachments to the surrounding structures: (1) the roof of the optic canal, (2) the optic strut, and (3) the roof of the orbit.⁶ Further cutting of the rings around ICA are important steps. These maneuvers help mobilize the ICA and improve exposure of the posterior clinoid process, dorsum sellae, and upper part of the clivus.³⁰ Opening of the roof of the cavernous sinus medially and parallel to the oculomotor nerve, freeing and further carefully manipulating this nerve and the trochlear nerve up to the point they cross ICA, significantly improves the area of exposure of BA.^{5,21} The posterior clinoid process can be removed radically, thereby extending vision and reach to the midclival region of posterior fossa. This feature is advantageous when approaching low-lying or large BA aneurysms or when proximal control of the BA is required.^{39,41}

Despite its surgical complexity, the TC approach stands as an alternative to more traditional routes. Compared with the PT, OZ, and TP routes alone, the TC approach provides a more ample distance along the BA for proximal control. The satisfactory outcomes support the use of this approach for complex BA apex aneurysms. This study was performed as an extension of our anatomic studies in which posterior clinoidectomy was used, and thus for comparison and consistency of measurements, it was employed here.^{5,22} Nevertheless, such challenging maneuvers associated with the TC approach should not be a routine part of every approach to a BA apex aneurysm. Instead, each step related to the TC approach should be performed according to the particular complexity of the aneurysm, which is directly related to a progressive need for more surgical space or access. For many complex aneurysms, posterior clinoidectomy provides sufficient exposure to allow proximal control and clip application.^{39,41}

Advantages of a TP TC Approach

In this study, our data demonstrate a wider working area around the basilar apex and its surrounding vascular structures with the TP TC approach when compared with the PT TC and OZ TC approaches under the same conditions of bone removal. Because of its view, the TP

TC approach may increase the safety of managing complex basilar apex aneurysms. The TP TC approach can provide access to the BA apex through a route between the oculomotor and trochlear nerves. In some patients, it is possible to cut the dura between the oculomotor nerve and the insertion of the trochlear nerve. Reflection of the tentorial edge then improves visualization of the more proximal segment of BA (proximal to the origin of the SCA). For BA apex aneurysms that cannot be treated by endovascular means, the TP TC approach may be a viable option.

Limitations of TP TC Approach

The most important limitation of the TP TC approach is venous bleeding. The procedure is extensive and usually time-consuming. Bleeding, which may occur from the cavernous sinus, the basilar venous plexus, inadvertent ICA injury during drilling of the anterior clinoid process, or drilling of the posterior clinoid process, is a major risk during this approach.

Venous infarction or swelling of the temporal lobe seldom occurs with the TP approach. Clinical studies of outcome using the TP approach show that as many as 75% of patients have at least some degree of third nerve dysfunction after undergoing a TP TC approach. However, almost 95% recovered function at 90 days, and all but handful recovered at 120 days.^{33,34,38} When the anterior posterior clinoid process is drilled or the optic canal is deroofed, the optic nerve may suffer heat injury. Injury to the trochlear nerves is also a potential complication of the TC approach.^{4,33,34,38}

Limitations of the Study

The present assessment is based on an anatomic study, and it is therefore difficult to predict actual surgical risks. Quantitative studies supported by cadaveric models provide important data for comparing the role of specific surgical approaches. However, fixed tissues may not recreate the stiffness of brain tissue and resistance to fine retraction, factors that critically affect a surgical dissection. Although we performed quantitative analysis of the TP TC approach and compared it with the PT TC and OZ TC approaches, such procedure requires experience and confidence in one's knowledge of the related microanatomy. Furthermore, in all of our cadaveric models, the BA apexes were in the neutral position. Nonetheless, the findings suggest that the TP TC method may be useful for treating BA pathology in all but the very highest position.

CONCLUSION

In the management of basilar apex aneurysms, there are two key points: early proximal control and clear

visualization of the perforating vessels proceeding from the ipsilateral and contralateral P1 segments. The TP approach depends on the use of the cisternal spaces in the brain to minimize retraction and produces a wide working area around BA apex when combined with a TC route. In our study, the TP TC approach offered a significantly wider operative field by combining multiple angles of view offered by the PT and subtemporal approaches. A longer length of exposure of the BA compared with PT TC and OZ TC also improves the ability to attain vascular control.

Although the TP TC approach necessitates dealing with several key anatomic structures along the way, it appears suitable for the treatment of giant, low, or normal-lying BA bifurcation aneurysms or aneurysms with an inconvenient neck-to-dome ratio. Such an approach may be especially helpful for treating difficult cases such as aneurysmal recurrence after endovascular treatment.

REFERENCES

1. Youssef AS, Abdel Aziz KM, Kim EY, Keller JT, Zuccarello M, van Loveren HR. The carotid-oculomotor window in exposure of upper basilar artery aneurysms: a cadaveric morphometric study. *Neurosurgery* 2004;54:1181–1187; discussion 1187–1189
2. Yaşargil MG. Vertebrobasilar aneurysms. *Microneurosurgery: Clinical Considerations, Surgery of the Intracranial Aneurysms and Results*. Stuttgart: Georg Thieme; 1984
3. Chanda A, Nanda A. Anatomical study of the orbitozygomatic transsellar-transcavernous-transclinoidal approach to the basilar artery bifurcation. *J Neurosurg* 2002;97:151–160
4. Yaşargil MG, Antic J, Laciga R, Jain KK, Hodosh RM, Smith RD. Microsurgical pterional approach to aneurysms of the basilar bifurcation. *Surg Neurol* 1976;6:83–91
5. Figueiredo EG, Zabramski JM, Deshmukh P, Crawford NR, Preul MC, Spetzler RF. Anatomical and quantitative description of the transcavernous approach to interpeduncular and prepontine cisterns. Technical note. *J Neurosurg* 2006;104:957–964
6. Krisht AF. Transcavernous approach to diseases of the anterior upper third of the posterior fossa. *Neurosurg Focus* 2005;19:E2
7. Zabramski JM, Kiriş T, Sankhla SK, Cabiol J, Spetzler RF. Orbitozygomatic craniotomy. Technical note. *J Neurosurg* 1998;89:336–341
8. Hernesniemi J, Ishii K, Karatas A, et al. Surgical technique to retract the tentorial edge during subtemporal approach: technical note. *Neurosurgery* 2005;57(4 Suppl):E408; discussion E408
9. Lemole GM Jr, Henn JS, Zabramski JM, Spetzler RF. Modifications to the orbitozygomatic approach. Technical note. *J Neurosurg* 2003;99:924–930
10. Sano K. Temporo-polar approach to aneurysms of the basilar artery at and around the distal bifurcation: technical note. *Neurol Res* 1980;2:361–367
11. Smith RR, Al-Mefty O, Middleton TH. An orbitocranial approach to complex aneurysms of the anterior circulation. *Neurosurgery* 1989;24:385–391
12. Fujitsu K, Kuwabara T. Zygomatic approach for lesions in the interpeduncular cistern. *J Neurosurg* 1985;62:340–343
13. Jane JA, Park TS, Pobereskin LH, Winn HR, Butler AB. The supraorbital approach: technical note. *Neurosurgery* 1982;11:537–542
14. Hakuba A, Liu S, Nishimura S. The orbitozygomatic infratemporal approach: a new surgical technique. *Surg Neurol* 1986;26:271–276
15. Samson DS, Hodosh RM, Clark WK. Microsurgical evaluation of the pterional approach to aneurysms of the distal basilar circulation. *Neurosurgery* 1978;3:135–141
16. Sugita K, Kobayashi S, Shintani A, Mutsuga N. Micro-neurosurgery for aneurysms of the basilar artery. *J Neurosurg* 1979;51:615–620
17. Chou SN, Ortiz-Suarez HJ. Surgical treatment of arterial aneurysms of the vertebrobasilar circulation. *J Neurosurg* 1974;41:671–680
18. Neil-Dwyer G, Sharr M, Haskell R, Currie D, Hosseini M. Zygomaticotemporal approach to the basis cranii and basilar artery. *Neurosurgery* 1988;23:20–22
19. Pitelli SD, Almeida GG, Nakagawa EJ, Marchese AJ, Cabral ND. Basilar aneurysm surgery: the subtemporal approach with section of the zygomatic arch. *Neurosurgery* 1986;18:125–128
20. Shiokawa Y, Saito I, Aoki N, Mizutani H. Zygomatic temporopolar approach for basilar artery aneurysms. *Neurosurgery* 1989;25:793–796; discussion 796–797
21. Dolenc VV, Skrap M, Sustersic J, Skrbec M, Morina A. A transcavernous-transsellar approach to the basilar tip aneurysms. *Br J Neurosurg* 1987;1:251–259
22. Figueiredo EG, Zabramski JM, Deshmukh P, Crawford NR, Spetzler RF, Preul MC. Comparative analysis of anterior petrosectomy and transcavernous approaches to retrosellar and upper clival basilar artery aneurysms. *Neurosurgery* 2006;58(1 Suppl):ONS13–ONS21; discussion ONS13–ONS21
23. de Oliveira E, Tedeschi H, Siqueira MG, Peace DA. The pretemporal approach to the interpeduncular and petroclival regions. *Acta Neurochir (Wien)* 1995;136:204–211
24. Ikeda K, Yamashita J, Hashimoto M, Futami K. Orbitozygomatic temporopolar approach for a high basilar tip aneurysm associated with a short intracranial internal carotid artery: a new surgical approach. *Neurosurgery* 1991;28:105–110
25. Pellerin P, Lesoin F, Dhellemmes P, Donazzan M, Jomin M. Usefulness of the orbitofrontomalar approach associated with bone reconstruction for frontotemporosphenoid meningiomas. *Neurosurgery* 1984;15:715–718
26. Alaywan M, Sindou M. Fronto-temporal approach with orbito-zygomatic removal. Surgical anatomy. *Acta Neurochir (Wien)* 1990;104:79–83
27. Delashaw JB Jr, Tedeschi H, Rhoton AL. Modified supra-orbital craniotomy: technical note. *Neurosurgery* 1992;30:954–956
28. McDermott MW, Durity FA, Rootman J, Woodhurst WB. Combined frontotemporal-orbitozygomatic approach for tumors of the sphenoid wing and orbit. *Neurosurgery* 1990;26:107–116
29. Sekhar LN, Kalia KK, Yonas H, Wright DC, Ching H. Cranial base approaches to intracranial aneurysms in the subarachnoid space. *Neurosurgery* 1994;35:472–481; discussion 481–483

30. Seoane E, Tedeschi H, de Oliveira E, Wen HT, Rhoton AL Jr. The pretemporal transcavernous approach to the interpeduncular and prepontine cisterns: microsurgical anatomy and technique application. *Neurosurgery* 2000;46:891-898; discussion 898-899
31. Decker RE, Malis LI. Surgical approaches to midline lesions at the base of the skull: a review. *Mt Sinai J Med* 1970;37:84-102
32. George B, Dematons C, Cophignon J. Lateral approach to the anterior portion of the foramen magnum. Application to surgical removal of 14 benign tumors: technical note. *Surg Neurol* 1988;29:484-490
33. Sano K, Shiokawa Y. The temporo-polar approach to basilar artery aneurysms with or without zygomatic arch translocation. *Acta Neurochir (Wien)* 1994;130:14-19
34. Heros RC, Lee SH. The combined pterional/anterior temporal approach for aneurysms of the upper basilar complex: technical report. *Neurosurgery* 1993;33:244-250; discussion 250-251
35. Drake CG. The treatment of aneurysms of the posterior circulation. *Clin Neurosurg* 1979;26:96-144
36. Nutik SL. Pterional craniotomy via a transcavernous approach for the treatment of low-lying distal basilar artery aneurysms. *J Neurosurg* 1998;89:921-926
37. Krisht AF, Kadri PA. Surgical clipping of complex basilar apex aneurysms: a strategy for successful outcome using the pretemporal transzygomatic transcavernous approach. *Neurosurgery* 2005;56(2 Suppl):261-273; discussion 261-273
38. Shiokawa Y, Saito I, Aoki N, Mizutani H. Zygomatic temporepolar approach for basilar artery aneurysms. *Neurosurgery* 1989;25:793-796; discussion 796-797
39. Day JD, Giannotta SL, Fukushima T. Extradural temporepolar approach to lesions of the upper basilar artery and infrachiasmatic region. *J Neurosurg* 1994;81:230-235
40. Fujimoto Y, Ikeda H, Yamamoto S. Pterional transcavernous approach for large basilar top aneurysm-significance of the exposure of Dolenc's triangle. *Surg Cereb Stroke* 1992;20:191-195
41. Youssef AS, van Loveren HR. Posterior clinoidectomy: dural tailoring technique and clinical application. *Skull Base* 2009;19:183-191