Extended Lateral Orbital Craniotomy: Anatomic Study and Initial Clinical Series of a Novel Minimally Invasive Pterional Approach

Mithun G. Sattur¹ Karl R. Abi-Aad¹ Matthew E. Welz¹ Rami James Aoun² Chandan Krishna¹
Chad Purnell³ Mohammed Alghoul³ Bernard R. Bendok¹

¹Department of Neurological Surgery, Mayo Clinic Arizona, Phoenix, Arizona, United States

²Department of General Surgery, Ohio State University, Ohio, United States

³Department of Plastic Surgery, Northwestern University, Chicago, Indiana, United States

Address for correspondence Bernard R. Bendok, MD, MSCI, Department of Neurological Surgery, Mayo Clinic Arizona, 5777 East Mayo Boulevard, Phoenix, AZ 85054, United States (e-mail: Bendok.bernard@gmail.com).

J Neurol Surg B 2020;81:88–96.

Abstract

Keywords

- ▶ minimally invasive craniotomy
- ▶ pterional keyhole approach
- ▶ middle cerebral artery aneurysm
- ▶ sphenoid ridge
- ▶ micro surgical clipping
- ▶ frontalis branch of facial nerve
- ▶ Sylvian fissure

Background Of the minimally invasive “keyhole” alternatives to the pterional region, the supraorbital eyebrow approach is the most widely adopted. Yet it can prove disadvantageous when a more direct lateral microsurgical trajectory of attack to the Sylvian fissure and anterior middle fossa are needed.

Objective The extended lateral orbital (XLO) approach was designed to be direct and minimally invasive, with the sphenoid ridge at the center of exposure.

Methods Five injected cadaver heads were used for anatomic study of the XLO approach. The anatomic course of the frontalis branch of facial nerve was studied in relation to the XLO incision. Following XLO incision, the bone exposure was measured. The intracranial microsurgical exposure was assessed subjectively. Application of the technique in representative clinical operative cases is provided.

Results The frontalis nerve was protected in the subgaleal fat pad, with an average minimum distance of 2.3 cm from the XLO incision. The mean calvarial area exposure was 4.95 cm² and consistently centered on the sphenoid ridge. Excellent access to ipsilateral Sylvian’s fissure, perisylvian regions, and supra-/parasellar structures was possible. The main limitations related to exposure of the posterior Sylvian fissure and the expected limitations of microsurgical instrument manipulation from a smaller craniotomy.

Conclusions The XLO approach is a minimally invasive keyhole approach to the pterional region that affords a unique lateral trajectory via a craniotomy centered on the sphenoid ridge. Excellent exposure to properly selected lesions is possible. The incision is at a safe distance from the frontalis branch and shows excellent cosmetic healing.

Introduction

The pterional (frontosphenotemporal) craniotomy is the workhorse approach for providing microsurgical access to a wide range of pathologies located in the suprasellar area, Sylvian and interpeduncular cisterns, and frontotemporal region.¹ Despite its advantages, it has been apparent over the years that the

expansiveness of the exposure may often times be excessive.² There is also significant morbidity in some patients with regard to frontalis weakness, temporalis muscle dysfunction, postoperative pain, and atrophy and soft tissue trauma. Consequently, variations of the standard pterional approach have been described.^{3–12} These modifications focus on variations of

received

July 19, 2018

accepted after revision

November 13, 2018

published online

February 21, 2019

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Stuttgart · New York

DOI <https://doi.org/10.1055/s-0038-1677470>.
ISSN 2193-6331.

the scalp incision, area of bone removal, and temporalis muscle dissection. Advances in knowledge of microsurgical anatomy, operating microscope technology, microsurgical instrumentation, endoscopy, diagnostic imaging, and stereotactic navigation have allowed neurosurgeons to utilize ever smaller working fields with keyhole approaches to the pterional region. The most widely described keyhole approach is the supraorbital keyhole craniotomy, described by Perneczky and Fries, Reisch and Perneczky, Reisch and colleagues, via an eyebrow incision.^{13–16} The advantages of minimal soft tissue dissection, relatively low risk to the frontalis branch of facial nerve, limited temporalis muscle dissection, and straight subfrontal trajectory to the suprasellar region and surrounding areas have contributed to its popularity. Yet an important limitation of the supraorbital approach is the strictly anterolateral and superior trajectory for lesions located in the lateral Sylvian fissure and anterior temporal region. Minimally invasive approaches to enable a more lateral trajectory of attack centered on the pterional region have been described previously in literature^{5,8,9,17} (see discussion). The common theme with successive modifications appears to be progressive anterior migration of the surgical incision toward the face and orbital region, lesser bone removal, and less extensive temporalis dissection. However, these suffer from one or more of the following: lack of standardization of the incision, relatively indirect reach in comparison to the eyebrow approach, and inadequate anatomic data. We determined the need for a truly minimally invasive lateral approach centered on the sphenoid ridge, with an incision directly overlying the craniotomy. Hence, we devised the extended lateral orbital (XLO) approach (►Fig. 1). Here we describe the anatomic basis of the XLO approach from cadaver studies and also provide illustrative clinical examples.

Materials and Methods

International Review Board approval was not required for the cadaver study. Patients' consent was obtained for all illustrative cases.

Setup

Three injected cadaver heads were used to dissect the facial nerve on both sides (six sides total) with close attention to relationship between frontalis branch and orbital rim. Two additional cadaver heads (four sides) were stabilized with rigid three-point pin fixation in a head holder to perform the XLO incision, measure area of bony exposure, and perform intradural microsurgical dissection.

Facial Nerve Dissection

The frontalis branch of the facial nerve was dissected with $\times 3.5$ loupe magnification along its course from the point of exit from the upper border of the parotid gland to the point of entrance on the deep surface of the frontalis muscle (►Fig. 2A). The spatial relationship of the frontal branch of the facial nerve and the craniotomy incision and plane of dissection was observed and the perpendicular distance from three anatomic points was measured with a standard

Fig. 1 Illustration of the XLO approach in comparison to the supraorbital eyebrow craniotomy and the traditional pterional craniotomy. The XLO incision (red dotted line) extends along the lateral aspect of the supraorbital ridge along the lateral orbital wall to then curve in a zigzag fashion over the anterior root of zygomatic arch. The craniotomy (black solid area) is centered on the Sylvian fissure (sphenoid ridge). The supraorbital keyhole incision (green) and the underlying craniotomy (brown) provide a more anterolateral subfrontal trajectory instead, with the sphenoid ridge at the inferior edge of the exposure. The traditional pterional incision (turquoise) and frontosphenotemporal craniotomy (pink) provides the most extensive exposure of the region with multiple angles of attack but can be excessive in certain cases. XLO, extended lateral orbital.

ruler: anterior origin of the zygomatic arch, lateral canthus, and anterior end of the temporal crest (superolateral angle of the orbit; ►Fig. 2B).

Incision Design

The XLO incision begins at the middle of the eyebrow, medial to the superior temporal line, and curves laterally and inferiorly with the lateral orbital rim 1.5 cm lateral to the inner rim or lateral canthus to the “zigzag” over the anterior origin of the zygomatic arch. The zigzag extension was conceptualized to be “hidden” in crow’s feet wrinkles, as shown in ►Fig. 3. The incision is made through the skin and subcutaneous fat. The orbicularis oculi muscle is then encountered and incised. Retraction hooks are used on the posterior edge of the incision. The incision is carried through the temporalis fascia and fat pad, leaving a cuff at the orbital rim to allow reapproximation at closure. The temporalis muscle is split and retracted posteriorly with fish hooks to expose the bone.

Fig. 2 (A) Cadaveric dissection of the frontalis branch of facial nerve (arrow) with attention to tissue planes. Note the subgaleal fat pad (*) within which the nerve lies. (B) Study of the frontalis branch of facial nerve (black dotted line) in relation to the XLO incision. The three pins represent the points where the distance of frontalis to the anatomic periorbital structures underlying the XLO incision was measured. XLO, extended lateral orbital.

Calvarial Exposure and Craniotomy

The surface area of bone exposed was calculated utilizing an ellipse area equation ($A = \pi ab$, where A = Area, π = pi, a = radius of longest axis, and b = radius of shortest axis). The radii measurements were taken utilizing a compass and measuring ruler. The keyhole was identified at the fronto-zygomatic suture. Burrholes were placed over keyhole and at inferior limit of bony exposure, and connected to complete the craniotomy ($\rightarrow$ Fig. 4). Using a high-speed drill, the sphenoid ridge was flattened to level of superior orbital fissure.

Fig. 3 XLO incision as depicted on a cadaver. It extends from the lateral supraorbital region and curves with the lateral orbital rim 1.5 cm lateral to the inner rim and ends in a zigzag fashion over anterior root of zygoma. Blue: supraorbital eyebrow incision; Red: XLO incision.

Intradural Microsurgical Exposure

Dura was opened in C-shaped and reflected anterolaterally. An operating microscope was used to assess intracranial exposure by the senior author (B.R.B.). Sylvian fissure was

Fig. 4 Shading and calculation of bony exposure following XLO incision is depicted in red. For comparison, the area exposed after the supraorbital keyhole incision is depicted in blue. Note that the XLO incision is centered on the sphenoid ridge and allows a direct lateral angle of attack. In addition, the XLO approach is very similar to the supraorbital keyhole approach in that the craniotomy area of interest lies directly under the skin incision. XLO, extended lateral orbital.

Fig. 5 (A) Intracranial microsurgical exposure after XLO craniotomy with initial assessment of structures visualized. (B) Assessment of manipulation of visualized structures under the operating microscope with microsurgical dissectors and clip applicators. XLO, extended lateral orbital.

widely dissected throughout the length of the exposure. Visualization was noted and ability to manipulate structures was gauged through ease of dissection with microsurgical dissectors and clip applicators (►Fig. 5A and B).

Results

Frontalis Branch of the Facial Nerve

The frontalis branch of facial nerve was situated within the subgaleal fat pad above the superficial temporal fascia, superior to the zygomatic arch until it reached the deep surface of the frontalis muscle. It was completely protected throughout the dissection (►Fig. 2A). The mean distance of the course of the frontal branch of the facial nerve to the anterior end of the zygoma was 3.2 cm (range: 2–4.8 cm), 2.66 cm from the lateral canthus (range: 2–3.6 cm), and 2.3 cm from the superolateral angle of the orbit (range: 2–3 cm). The nerve was thus protected throughout incision and dissection. However, aggressive retraction of the soft tissue posteriorly to expose bone may lead to stretch injury and should be borne in mind. This aspect was not specifically studied.

Calvarial Exposure and Craniotomy

The exposed bone surface area measured a mean of 4.95 cm² (3.5 × 1.8 cm). Sphenoid ridge was consistently at the center of the exposure.

Intradural Microsurgical Exposure

Ipsilateral structures accessible were A1, proximal A2, recurrent artery of Heubner's, supraclinoid carotid and terminus, optic nerve and falciform ligament, oculomotor nerve, posterior communicating artery (Pcom) and the anterior choroidal artery, superior cerebellar artery (SCA), and P1 segment of posterior cerebral artery (PCA), anterior temporal artery, middle cerebral aneurysm (MCA) bifurcation, M1, and proximal M2 segments (►Fig. 6). Midline structures accessed were anterior communicating artery, anterior and superior optic chiasm, and basilar apex. Contralateral structures accessed were A1 segment, carotid terminus, PCom, ophthalmic artery, MCA, M1 segment, oculomotor nerve, MCA bifurcation, and carotid terminus. Ability to manipulate structures with standard microsurgical instruments for accessible ipsilateral structures was significantly better than the contralateral structures.

Illustrative Clinical Case Examples

Case Selection

The ideal lesion is located in the anterior and outer quadrant of the Sylvian fissure (►Fig. 7A). Lesions located deeper in the fissure may still be accessed but the limited exposure may limit maneuverability. Temporal pole and inferior frontal lobe lesions are ideally suited for this approach (see case 3). Lesions requiring optic canal unroofing are

Fig. 6 Schematic representation of structures of Circle of Willis's accessed via a right sided XLO approach are shown in red. Structures not visualized are depicted in black. The green arrow indicates the trajectory of the approach. A1 and A2, segments of anterior cerebral artery; ACom, anterior communicating artery; BA, basilar artery; ICA, internal carotid artery; M1 and M2, segments of middle cerebral artery; P1, segment of posterior cerebral artery; PCom, posterior communicating artery; XLO, extended lateral orbital.

better approached via a more anterior and subfrontal trajectory. Meticulous study of preoperative imaging and patient anatomy is important.

Case 1: Right Middle Cerebral Artery Aneurysm

A 52-year-old African American male with polycystic kidney disease presented with an incidental unruptured right MCA detected on screening magnetic resonance (MR) angiogram (►Fig. 7A). The aneurysm was noted to be at the bifurcation of a long M1 and was located in a favorable quadrant. At surgery, the patient was positioned with the head in three-pin rigid fixation and extended and rotated to the left by 20 to 30 degrees. The XLO incision was marked (►Fig. 7B and C). Following incision of soft tissue and the temporalis (►Fig. 7D–F), the underlying pterional area was strategically exposed (►Fig. 7G). Craniotomy was performed (►Fig. 7H) and the sphenoid ridge was drilled to obtain an ideal and flat trajectory (►Fig. 7I). Intradural exposure for Sylvian fissure dissection, aneurysm dissection, and clipping were excellent. Postoperative angiography showed complete aneurysm exclusion (►Fig. 7J). Cosmetic healing of the incision was excellent.

Fig. 7 (A) Ideal location (right middle cerebral artery aneurysm, arrow) in the outer and anterior 'quadrant' of the Sylvian fissure for optimal angles of approach via XLO approach. (B) frontal and (C) operative view of XLO incision for illustrative case 1. (D) Progressive soft tissue dissection in XLO exposure in case 1. Following skin and subcutaneous incision, the temporalis fascia attached to the frontozygomatic bone is exposed. (E) Temporalis fascia is incised with a cuff along the bony rim anteriorly for reattachment at closure. (F) Initial temporalis muscle dissection to expose bony area of interest. (G) Surface landmarks over exposed bone. Circle depicts keyhole and the line depicts sphenoid ridge. Note that the sphenoid ridge is at the center of the exposure. (H) Craniotomy is completed. Excellent exposure of the frontotemporal region centered on the sphenoid ridge is obtained. The ridge is partially rongueured. (I) Complete drilling of the sphenoid ridge to obtain a flat trajectory down the Sylvian fissure. (J) Postoperative axial source image reconstruction from 3-D rotational angiography depicting complete aneurysm exclusion. XLO, extended lateral orbital.

Case 2: Right Middle Cerebral Artery Aneurysm

A 70-year-old Caucasian female presented with an unruptured right MCA aneurysm and a prior history of a ruptured left MCA mirror aneurysm that was treated by microsurgical clipping via a traditional pterional approach. The right MCA aneurysm was situated in a strategic quadrant similar to case 1 and the XLO approach was chosen for elective microsurgical clipping (►Fig. 8A and B). Complete microsurgical exclusion was obtained and excellent cosmetic outcome was achieved (►Fig. 8C).

Case 3: Left Inferior Frontal Lobe Tumor

An 80-year-old Caucasian male presented with subacute cognitive dysfunction and headaches and imaging revealed a hemorrhagic left frontal tumor located in the inferior frontal gyrus, extending cranially (►Fig. 9A–C). An XLO approach was chosen and gross total resection was achieved. Even the cranial extension was accessed without difficulty, by strategic angle of attack with the operating microscope (►Fig. 9D–F). Pathology was suggestive of glioblastoma. Excellent cosmetic and oncological outcome was achieved.

Discussion

For minimally invasive keyhole craniotomies, reducing soft tissue trauma via a direct trajectory overlying the area of craniotomy is central to the keyhole concept. The design of the XLO approach incorporates this concept. The numerous advantages of Perneczky's supraorbital craniotomy via the suprabrow incision, chiefly the ability to access extensive areas of the suprasellar and adjoining regions bilaterally, have made it a natural first choice when it comes to keyhole approaches to the region. Yet the approach may prove limited in certain cases. For instance, MCA aneurysms located at the bifurcation of a long M1 and/or aneurysm anatomy requiring more lateral angles of attack may not be adequately or safely addressed. The suprabrow approach uses special, modified (long, bayoneted) instruments to access lesions due to the trajectory of visualization and manipulation. The authors also recommend using the neuroendoscope to improve visualization.¹⁵ However, this may improve visualization but not necessarily able to manipulate from multiple angles. The angles of attack, especially from more lateral and pretemporal vantage points, afforded by

Fig. 8 (A) Planning of XLO incision in case 2. Note strategic placement of the caudal zigzag segment of the incision within the "crow's feet" wrinkles. (B) Craniotomy exposure following XLO approach in case 2. Note "keyhole" size of craniotomy as compared with a quarter. (C) Excellent postoperative cosmetic outcome from XLO approach in case 2. XLO, extended lateral orbital.

Fig. 9 (A) Axial and (B) sagittal sequences of hemorrhagic left inferior frontal gyrus tumor in case 3. Note cranial extension (C) of the lesion. Postoperative axial (D) and sagittal (E) MRI sequences depicting complete resection via XLO approach. Note complete resection of the superior extension of the tumor (F) which can be achieved by strategic cranial angling of the operating microscope. MRI, magnetic resonance imaging; XLO, extended lateral orbital.

the traditional pterional approach are thus continually relevant for some lesions.

Attempts to achieve exposure centered on the sphenoid ridge in a less extensive fashion than the traditional pterional approach have been described previously. These are the mini pterional, sphenoid ridge keyhole, and the 'pterional keyhole' approach via an outer canthal incision (→Fig. 9). The mini pterional approach utilizes a temporal curved incision immediately posterior to the hairline where the skin and muscle are pushed anteroinferiorly to expose the pterion.^{9,18,19} However, temporalis muscle is reflected toward the area where its thickest anteriorly causing crowding of the soft tissue. This could compromise exposure in the anterior temporal/pretemporal region. The sphenoid ridge keyhole approach was described first by Nathal and Gomez-Amador.⁸ The incision is curvilinear and close to the temporal hairline and centered over the sphenoid ridge. The temporalis muscle is reflected anteriorly and the craniotomy is centered on the sphenoid ridge, similar to our approach. The technique, somewhat similar to the mini pterional approach, was successfully described in a clinical series of 85 anterior circulation aneurysms but no anatomic study was provided.⁸ Though we have not used the approach personally, the posterior location of the incision relative to the area of bone removal and anterior bulk of the temporalis muscle may be disadvantages.

Mori et al were the first to report on the use of the outer canthal skin incision to clip small (< 10 mm) unruptured middle cerebral artery aneurysms^{17,20} in their first published series they utilized a curved incision ranging between 30 and 35 mm with two horizontal extensions on either ends.¹⁷ In their second larger series of 100 patients with 110 unruptured MCA aneurysms, 3 to 11 mm in size, they modified their incision design from curved to **W**-shaped and increased the length to 4 cm.²⁰ In both series they indicated that the caudal extent of the incision ended 1 cm above the zygomatic arch and the exposure they achieved enabled them to place the keyhole craniotomy over the Sylvian fissure. Our results indicate that the zigzag caudal design of the incision yielded the best exposure of the sphenoid ridge and therefore the Sylvian fissure and middle cranial fossa. In other words, the incision had to be extended beyond the superior border of the zygomatic arch to comfortably expose the Sylvian fissure and middle cranial fossa. In their second publication where they described the **W**-shaped incision, it seems from their operative markings in the published figure that the caudal end of the incision was right at the superior border of the zygomatic arch.²⁰ The authors described retraction of the muscle posteriorly, similar to our approach. However, an anatomic study was not provided. Ours is the first study to explore the spatial and configurational relationship between skin incision, calvarial

exposure, craniotomy size and location, and intracranial exposure for a keyhole approach.

Our frontalis branch dissection results were consistent with previous anatomic studies.^{21–25} Our study showed that the safe distance of separation is at least 2 cm. Previous reports suggested this distance to be 1.5 to 1.8 cm depending on which landmark it is measured from.^{21–24} It seems prudent that given some anatomic variability, the “safe zone,” concerning the frontal branch is within 1.5 to 2 cm from the orbital rim.

The XLO incision provides the ability to carry the craniotomy further anteriorly as the muscle is completely retracted posteriorly. This provides an unrestricted view from a strategic angle. Similar to the supraorbital keyhole craniotomy, the patient is fixed with a Mayfield head holder, two pins on the ipsilateral side and one pin on the contralateral side, with a slight head extension and contralateral head rotation of 20 to 30 degrees. Although the incision is placed on the forehead and face, excellent cosmetic results can be achieved, especially if periorbital rhytides are strategically used to hide the scar. Cosmetic outcomes in patients whom we have treated with this approach have been very satisfactory (►Fig. 8C). When considering intracranial aneurysms, the XLO approach is most suitable for small MCA aneurysms located anteriorly and laterally in the Sylvian fissure. We have found no difficulties with proximal and distal control as well as suitable neck reconstruction using this approach. Other aneurysms including select posterior communicating artery aneurysms and select anterior communicating artery aneurysms may be suitable for this approach. Large and giant aneurysms may require greater degrees of freedom and the small bony opening of this key hole approach may not be adequate. The XLO approach typically affords 2.5 cm of lateral Sylvian fissure exposure when measured from the sphenoid ridge. Aneurysms which require wider opening of the Sylvian fissure would be more suitable for a traditional pterional craniotomy. In summary, the pros and cons of the XLO approach are briefly in ►Table 1.

Study Limitations

One of the limitations of our cadaver study is that we did not quantify angles of exposure or manipulation using neuroana-

vigation software. This will be a parameter of interest in further studies of the approach. The use of neuroendoscopic visualization would have potentially added more information on intradural exposure. For the clinical series, we intend to quantify temporalis muscle atrophy in comparison to the standard pterional approach. Also, postoperative pain medication requirement and cosmetic outcome scales will be explored. In addition, we are investigating the ability of the XLO approach in providing enough microsurgical corridors for a true keyhole amygdalohippocampectomy as part of epilepsy surgery.

Conclusions

The XLO approach provides a versatile lateral corridor of microsurgical attack, centered over the sphenoid ridge. It is well-suited for properly selected lesions, such as ipsilateral laterally placed MCA aneurysms, temporal polar tumors or cavernomas, meningiomas of the pterional region, and intra-axial lesions of perisylvian region. The lateral orbital incision with its caudal extension ensures protection of the frontalis branch of the facial nerve and has excellent cosmetic outcome.

Conflict of Interest

None declared.

References

- 1 Yasargil MG, Fox JL. The microsurgical approach to intracranial aneurysms. *Surg Neurol* 1975;3(01):7–14
- 2 van Lindert E, Perneczky A, Fries G, Pierangeli E. The supraorbital keyhole approach to supratentorial aneurysms: concept and technique. *Surg Neurol* 1998;49(05):481–489, discussion 489–490
- 3 Hage ZA, Charbel FT. Clipping of bilateral MCA aneurysms and a coiled ACOM aneurysm through a modified lateral supraorbital craniotomy. *Neurosurg Focus* 2015;38(VideoSuppl1):o19
- 4 Cha KC, Hong SC, Kim JS. Comparison between lateral supraorbital approach and pterional approach in the surgical treatment of unruptured intracranial aneurysms. *J Korean Neurosurg Soc* 2012;51(06):334–337
- 5 Mori K. Keyhole concept in cerebral aneurysm clipping and tumor removal by the supraciliary lateral supraorbital approach. *Asian J Neurosurg* 2014;9(01):14–20
- 6 Salma A, Alkandari A, Sammet S, Ammirati M. Lateral supraorbital approach vs pterional approach: an anatomic qualitative and quantitative evaluation. *Neurosurgery* 2011;68(2, Suppl Operative):364–372, discussion 371–372
- 7 Yeremeyeva E, Salma A, Chow A, Ammirati M. Microscopic and endoscopic anterior communicating artery complex anatomy as seen through keyhole approaches. *J Clin Neurosci* 2012;19(10):1422–1425
- 8 Nathal E, Gomez-Amador JL. Anatomic and surgical basis of the sphenoid ridge keyhole approach for cerebral aneurysms. *Neurosurgery* 2005;56(1, Suppl):178–185, discussion 178–185
- 9 Figueiredo EG, Deshmukh P, Nakaji P, et al. The minipterional craniotomy: technical description and anatomic assessment. *Neurosurgery* 2007;61(05, Suppl 2):256–264, discussion 264–265
- 10 Dare AO, Landi MK, Lopes DK, Grand W. Eyebrow incision for combined orbital osteotomy and supraorbital minicraniotomy: application to aneurysms of the anterior circulation. Technical note. *J Neurosurg* 2001;95(04):714–718

Table 1 Pros and cons of the XLO approach

Pros	Cons
Access to lateral Sylvian fissure	Limited access to posterior Sylvian fissure
Access to anterior temporal region	Small craniotomy can limit angles of approach for large and complex aneurysms
Enhances cosmetic outcome by drawing incision along skin creases	Not suitable for most cases which require bypass
Incision avoids frontalis branch of facial nerve	

Abbreviation: XLO, extended lateral orbital.

- 11 Hopf NJ, Stadie A, Reisch R. Surgical management of bilateral middle cerebral artery aneurysms via a unilateral supraorbital key-hole craniotomy. *Minim Invasive Neurosurg* 2009;52(03):126–131
- 12 Brydon HL, Akil H, Ushewokunze S, Dhir JS, Taha A, Ahmed A. Supraorbital microcraniotomy for acute aneurysmal subarachnoid haemorrhage: results of first 50 cases. *Br J Neurosurg* 2008; 22(01):40–45
- 13 Perneczky A, Fries G. Endoscope-assisted brain surgery: part 1—evolution, basic concept, and current technique. *Neurosurgery* 1998;42(02):219–224, discussion 224–225
- 14 Reisch R, Perneczky A. Ten-year experience with the supraorbital subfrontal approach through an eyebrow skin incision. *Neurosurgery* 2005;57(4, Suppl):242–255, discussion 242–255
- 15 Reisch R, Perneczky A, Filippi R. Surgical technique of the supraorbital key-hole craniotomy. *Surg Neurol* 2003;59(03):223–227
- 16 Fischer G, Stadie A, Reisch R, et al. The keyhole concept in aneurysm surgery: results of the past 20 years. *Neurosurgery* 2011;68(1, Suppl Operative):45–51, discussion 51
- 17 Mori K, Osada H, Yamamoto T, Nakao Y, Maeda M. Pterional keyhole approach to middle cerebral artery aneurysms through an outer canthal skin incision. *Minim Invasive Neurosurg* 2007;50(04):195–201
- 18 Mocco J, Komotar RJ, Raper DMS, Kellner CP, Connolly ES, Solomon RA. The modified pterional keyhole craniotomy for open cerebrovascular surgery: a new workhorse? *J Neurol Surg A Cent Eur Neurosurg* 2013;74(06):400–404
- 19 Kang H-J, Lee Y-S, Suh S-J, Lee J-H, Ryu K-Y, Kang D-G. Comparative analysis of the mini-pterional and supraorbital keyhole craniotomies for unruptured aneurysms with numeric measurements of their geometric configurations. *J Cerebrovasc Endovasc Neurosurg* 2013;15(01):5–12
- 20 Mori K, Esaki T, Yamamoto T, Nakao Y. Individualized pterional keyhole clipping surgery based on a preoperative three-dimensional virtual osteotomy technique for unruptured middle cerebral artery aneurysm. *Minim Invasive Neurosurg* 2011;54(5, 6):207–213
- 21 Yaşargil MG, Reichman MV, Kubik S. Preservation of the frontotemporal branch of the facial nerve using the interfascial temporalis flap for pterional craniotomy. Technical article. *J Neurosurg* 1987;67(03):463–466
- 22 Babakurban ST, Cakmak O, Kendir S, Elhan A, Quatela VC. Temporal branch of the facial nerve and its relationship to fascial layers. *Arch Facial Plast Surg* 2010;12(01):16–23
- 23 Agarwal CA, Mendenhall SDI III, Foreman KB, Owsley JQ. The course of the frontal branch of the facial nerve in relation to fascial planes: an anatomic study. *Plast Reconstr Surg* 2010;125(02):532–537
- 24 Tokimura H, Hirabaru M, Miyajima S, et al. Electrophysiological mapping of the temporal branch of the facial nerve. *J Neurol Surg A Cent Eur Neurosurg* 2014;75(02):116–119
- 25 Salas E, Ziyal IM, Bejjani GK, Sekhar LN. Anatomy of the frontotemporal branch of the facial nerve and indications for interfascial dissection. *Neurosurgery* 1998;43(03):563–568, discussion 568–569