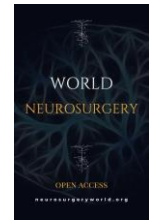
Contents lists available at: WNEURO

World Neurosurgery

Journal homepage: neurosurgeryworld.org



Research Article

Supraorbital Keyhole Approach versus Conventional Pterional Approach for Surgical Treatment in Anterior Circulation Aneurysms: Clinical Outcome and Surgical Techniques

Somkrit Sripontan[1*], Jackree Thanyanopporn[2], Suraphong Thaiyamitr[1], Ratree Jantajit[1] and Supattra Murachai[1]

[1]*Neurological Surgery Unit, Department of Surgery, Mahasarakham hospital, Mahasarakham, Thailand*
[2]*Neurological Surgery Unit, Department of Surgery, Bhumiphol Adulyadej Hospital, Bangkok, Thailand*

ARTICLE INFO

Keywords
Supraorbital keyhole approach
minimal invasive surgery
intracranial aneurysm

ABSTRACT

The supraorbital keyhole approach (SKA) is recognized as a minimally invasive procedure for managing anterior circulation aneurysms, particularly when performed by experienced neurosurgeons. This retrospective, non-randomized, cross-sectional study compared 30 cases of SKA in ruptured anterior circulation aneurysms with 32 cases managed using the conventional pterional approach (PtA). Both groups were comparable in preoperative characteristics. Intraoperatively, SKA demonstrated significant advantages over PtA in operative time (72.17 ± 38.48 vs. 108.12 ± 44.79 minutes) and blood loss (649.67 ± 1224.12 vs. 909.22 ± 890.33 mL). Postoperatively, SKA showed fewer complications and better six-month functional outcomes.

In conclusion, the minimally invasive SKA is a valuable operative technique for anterior and selected middle skull base lesions. When performed by an experienced surgeon, this approach offers improved safety, reduced morbidity, and superior cosmetic results.

1. Introduction

A ruptured intracranial aneurysm is a neurosurgical emergency. Delayed or inappropriate management can lead to serious sequelae, including increased intracranial pressure, focal neurological deficits, cerebral infarction, seizures, vasospasm, or death [1]. Currently, two primary treatment modalities are available: surgical transcranial clipping and endovascular coiling. The endovascular method is preferable for deep-seated, narrow-necked saccular aneurysms, patients with lower-grade subarachnoid hemorrhage (SAH), and those without significant intracranial pathology such as massive intracerebral hemorrhage (ICH) or cerebral infarction [1, 2]. Conversely, transcranial approaches allow prompt management of raised intracranial pressure and reduction of SAH clot burden, with higher rates of complete aneurysm obliteration, albeit with greater risk of brain manipulation [3, 4]. The International Subarachnoid Aneurysm Trial (ISAT) demonstrated that recurrence and rebleeding rates were higher following endovascular therapy than surgical clipping [5]. Moreover, transcranial surgery is available in most hospitals without the need for specialized interventional facilities.

Minimally invasive microsurgical (MIM) techniques for aneurysm clipping were first introduced by Yasargil [6] as alternatives to conventional craniotomy. These approaches aim to reduce brain manipulation, minimize surgical trauma, and facilitate faster recovery. This study compares the outcomes of minimally invasive SKA and conventional PtA for clipping anterior circulation aneurysms, detailing the operative techniques step-by-step.

2. Materials and Methods

This retrospective, non-randomized, cross-sectional study included all patients with ruptured anterior circulation aneurysms (involving the ICA, ACA, ACOM, and selected PCOM aneurysms) who underwent surgery between August 2019 and December 2024 at Mahasarakham Hospital, a general hospital in Thailand. After receiving counseling,

*Corresponding author: *Neurological Surgery unit, Department of Surgery, Mahasarakham hospital, Mahasarakham, Thailand; E-mail: somkrits@hotmail.com* (Somkrit Sripontan)

10.31487/j.WNEURO.2025.03.05
Received 14 November, 2025; Accepted 9 December, 2025
Available online 20 February, 2026

patients and their families chose between the minimally invasive supraorbital keyhole approach (SKA) and the conventional pterional approach (PtA). Preoperative profiles were compared, including age, sex, aneurysm type and side, Fisher grade, Glasgow Coma Scale (GCS), and modified World Federation of Neurosurgical Societies (m-WFNS) score.

The m-WFNS grading system categorizes aneurysmal SAH prognosis as follows: Grade 1 = GCS 15, Grade 2 = GCS 14, Grade 3 = GCS 13, Grade 4 = GCS 7-12, and Grade 5 = GCS 3-6. Lower grades indicate better prognosis [7, 8]. Fisher grading classifies the amount of SAH on CT brain, with Grade 3 showing the highest incidence of symptomatic vasospasm [9]. Intraoperative parameters included operative time (OPT), blood loss (BL), and intraoperative complications. Postoperative outcomes included immediate complications, status at discharge (D/C), and length of hospital stay (LOS). Long-term outcomes were evaluated at six months using the modified Rankin Scale (mRS) and cosmetic satisfaction.

2.1. Surgical Techniques

2.1.1. Conventional Pterional Approach (PtA)

A frontotemporal skin incision was made, followed by reflection of the scalp flap and dissection of the temporalis muscle to expose the bone. A frontotemporal bone flap was created, and the dura was widely opened. The subfrontal corridor was used for microsurgical dissection, aneurysm clipping, and closure of all layers in the standard manner.

2.1.2. Minimally Invasive Supraorbital Keyhole Approach (SKA)

This technique emphasizes a compact, targeted exposure (Figure 1). Patient positioning varied with aneurysm type: 15-30° lateral rotation for ACA and ACOM aneurysms, and 30-45° for ICA and PCOM aneurysms. The head was elevated 30-45° above the heart with neck extension. A curvilinear skin incision was made along the outer half of the eyebrow, avoiding the supraorbital nerve (Figure 1a). The subgaleal layer was dissected inferiorly along the superior orbital rim and superiorly for approximately 5 cm. The scalp was tented with 1-0 silk sutures. The temporalis muscle was incised approximately 3 cm from muscle origin while preserving its origin for resuturing (Figure 1b).

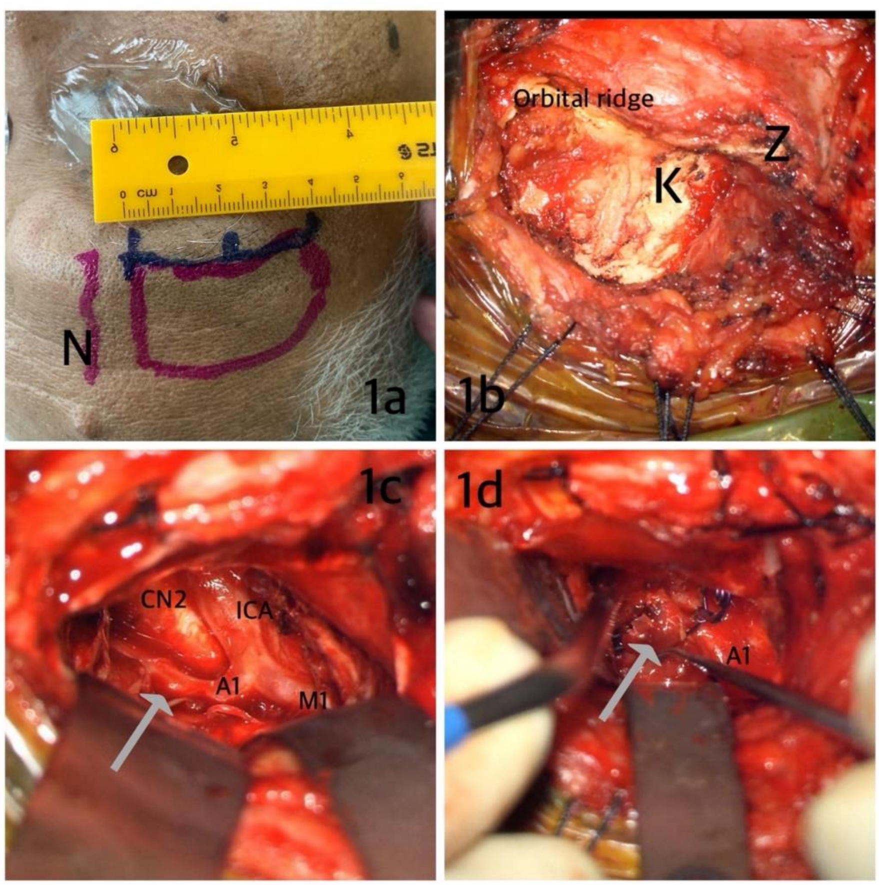


Fig. 1. Step-by-step demonstration of the right supraorbital keyhole approach (SKA).
a) Preoperative planning: The blue line indicates a 5-cm skin incision along the lateral eyebrow, designed to avoid injury to the supraorbital nerve (N). The red square marks the planned bone flap, approximately 5 cm in diameter. **b)** Scalp and muscle elevation: The scalp and temporalis muscle are tented using 1-0 silk sutures. The craniotomy is planned from the superior orbital ridge and keyhole point (K). The medial zygomatic ridge (*Z*) serves as a lateral bony landmark. **c)** Subfrontal dissection: Through the subfrontal corridor, key neurovascular structures are identified, including the optic nerve (CN2), internal

carotid artery (ICA), the first segment of the anterior cerebral artery (A1), and the first segment of the middle cerebral artery (M1). Gentle arachnoid dissection begins from this region. **d)** Aneurysm exposure and clipping: With slight adjustment of the operative angle, the aneurysm (white arrow) is visualized and clipped. The SKA provides sufficient working space for two-hand microsurgical manipulation.

A burr hole was made at the sphenopterional (keyhole) point—an area providing simultaneous access to the anterior and middle cranial fossae [10]. A 5 cm bone flap was created along the superior lateral orbital ridge, and the sphenoid wing was flattened with a high-speed drill to widen the surgical corridor. The dura was opened in a U-shaped fashion based on the orbital ridge and tented with 3-0 silk sutures. Mannitol was administered pre-dural opening to facilitate brain relaxation. In cases of brain swelling, external CSF drainage (ventriculostomy or lumbar drainage) was employed. A subfrontal approach was performed under a microscope using self-retaining retractors (Figure 1c). Sharp arachnoid dissection along the sphenoid wing allowed identification of the optic nerve-ICA complex and CSF release, facilitating further relaxation. Two or three retractors provided adequate working space for bimanual microsurgery (Figures 1c & 1d).

The vascular structures—including both ICAs, A1 segments, ACOM, and ipsilateral PCOM—along with the optic apparatus and lamina terminalis, were identified. In thick SAH, opening the lamina terminalis aided brain relaxation. Aneurysm clipping was performed using the two-hand technique (Figure 1d). After clip application, the subarachnoid clot was irrigated with normal saline, and meticulous hemostasis was confirmed. The dura, bone flap, muscle, and scalp were closed in standard fashion. A subgaleal drain was generally unnecessary; gentle pressure dressing was sufficient.

Postoperative period in ICU are closely follow up as the standard guideline [1] until discharge from the hospital. Rehabilitation program and community care are trained, follow up at least 6 months about functional status and cosmetic result.

3. Result

A total of 62 patients with ruptured anterior circulation aneurysms were admitted to Mahasarakham Hospital between August 2019 and January 2025. Of these, 32 patients underwent the conventional pterional approach (PtA), and 30 patients underwent the minimally invasive supraorbital keyhole approach (SKA). The majority of patients were female, with ages ranging from 23 to 79 years. Aneurysm locations included the internal carotid artery (ICA), anterior cerebral artery (ACA, A1 segment), anterior communicating artery (ACOM), and selected posterior communicating artery (PCOM) aneurysms. Most cases presented with Fisher grades 2 or 3. The most common presenting symptoms were sudden severe headache and altered consciousness. Preoperative severity, as measured by the modified World Federation of Neurosurgical Societies (m-WFNS) scale, was variable across both groups. Baseline characteristics between the SKA and PtA groups were not significantly different (Table 1).

Table. 1. Pre-operative profiles in patients with PtA and SKA (n=62).

characteristics		PtA (n=32)	SKA (n=30)
Age (years)		56.84 (26-79)	54.37 (23-77)
Sex (no.)	female	18 (56.3%)	18 (60.0%)
	male	14 (43.8%)	12 (40.0%)
Fisher grade (no.)			
1		2 (6.3%)	1 (3.3%)
2		10 (31.3%)	12 (40.0%)
3		12 (37.5%)	12 (40.0%)
4		8 (25.0%)	5 (16.7%)
Location of aneurysms (no.)			
ACA (A1, ACOM)		19 (59.4%)	23 (76.7%)
ICA		11 (34.4%)	6 (20.0%)
PCOM		2 (6.3%)	1 (3.3%)
Side (no.)			
left		16 (50.0%)	7 (23.3%)
right		16 (50.0%)	23 (76.7%)
m-WFDS (no.)			
1		6 (18.8%)	5 (16.7%)
2		4 (12.5%)	12 (40.0%)
3		8 (25.0%)	5 (16.7%)
4		6 (18.8%)	3 (10.0%)
5		8 (25.0%)	5 (16.7%)

PtA: Pterional Approach, SKA:Supraorbital Keyhole Approach, ACA: Anterior Cerebral Artery, ACOM: Anterior Communicating Artery, A1: First Segment Anterior Cerebral Artery, ICA: Internal Carotid Artery, PCOM: Posterior Communicating Artery, m-WFDS: Modified World Federation Neurosurgery Subarachnoid Score.

Detailed operative findings are summarized in (Table 2). The mean operative time was significantly shorter for SKA than for PtA (72.17 ± 38.48 vs. 108.12 ± 44.79 minutes). Estimated blood loss was also lower in the SKA group (649.67 ± 1224.12 mL vs. 909.22 ± 890.33 mL). The main intraoperative complications were aneurysm rupture and marked brain swelling secondary to infarction in cases with severe vasospasm. In the SKA group, two cases experienced intraoperative rupture with controlled bleeding (1,000 mL and 2,700 mL). Excluding these two cases, the mean blood loss among the remaining 28 SKA cases was 241.92 mL.

Table. 2. Intra-operative and post-operative findings.

Variable	PtA (n=32)	SKA (n=30)
Operation time (minutes), mean±SD	108.12±44.79	72.17±38.48
Blood loss (mL), mean±SD	909.22±890.33	649.67±1224.12
Intra-operative complication, (no.)		
none	20 (62.5%)	26 (86.7%)
rupture	2 (6.3%)	3 (10.0%)
mark brain swelling due to infartion	10 (31.3%)	1 (3.3%)
Postoperative complication, (no.)		
none	11 (34.4%)	23 (76.6%)
seizure	1 (3.1%)	-
infarction	10 (31.3%)	5 (16.7%)
other (HAP, sepsis)	10 (31.3%)	2 (6.7)
Result at d/c, (no.)		
Dead	9 (28.1%)	5 (16.7%)
Improve	22 (68.8%)	25 (83.3%)
Bed ridden	1 (3.1%)	-
LOS (day), Min-max	2-50	2-35
mRS at 6-month, (no.)		
0	2 (6.3%)	5 (16.7%)
1	6 (18.8%)	15 (50.0%)
2	7 (21.9%)	2 (6.7%)
3	2 (6.3%)	2 (6.7%)
4	3 (9.4%)	1 (3.3%)
5	2 (6.3%)	-
6	10 (31.3%)	5 (16.7%)

PtA: Pterional Approach, SKA:Supraorbital Keyhole Approach, HAP: hospital acquired pneumonia, D/C: Dischage Status, LOS: Lengh of Hospital Stay, mRS: Modified Rankin Score.

Postoperative complications were slightly less frequent in the SKA group. The major postoperative events were infarction and hospital-acquired pneumonia (HAP). Vasospasm was observed in both groups and was associated with thick subarachnoid clots, delayed surgery, and intraoperative hypotension. Overall, most patients in both groups showed improvement at discharge. All fatalities were due to early cerebral infarction. At six-month follow-up, nearly all surviving patients had improved functional status, with some having no major neurological deficits.

As summarized in Table 3, both surgical groups had comparable baseline characteristics, including age, sex, Fisher grade, m-WFNS score, and aneurysm type. Postoperative length of stay and discharge status were also not significantly different. However, the SKA technique demonstrated significant advantages in shorter operative time, reduced intraoperative blood loss, fewer postoperative complications, and improved six-month functional recovery (mRS) ($p < 0.05$).

Table. 3. Comparitive profiles of both operation.

Variable	PtA (n=32)	SKA (n=30)	P value
Age[b]	33.31	29.57	.414
Sex[b]	30.94	32.10	.767
Diagnosis (type of aneurysm)[a]	2.41	2.17	.289
Fisher grade[b]	**32.72**	**30.20**	**.560**
m-WFDS[b]	34.50	28.30	.167
Operation time (minute) skin-to-skin[a]	108.13	72.17	<.001*
Blood loss(mL)[b]	36.28	26.40	.031*
LOS (day)[a]	18.09	15.23	.329
Result at d/c[a]	1.75	1.83	**.465**

mRS at 6-month[b]	37.48	25.12	.005*
Postoperative complication[b]	11.36	6.57	.018*

a Independent-samples t-test ; b Mann-Whitney U test
$p < 0.05$ was considered statistically significant.
PtA: Pterional Approach, SKA:Supraorbital Keyhole Approach, m-WFDS: Modified World Federation Neurosurgery Subarachnoid Score, D/C: Dischage Status, LOS: Lengh of Hospital Stay, mRS: Modified Rankin Score.

Long-term wound and cosmetic outcomes were satisfactory in all patients (Figure 2). At six months postoperatively, the surgical incision line was well-hidden along the eyebrow, with only minimal skin and scalp atrophy and no prominent aesthetic defects. Patients expressed high satisfaction with the small skull flap and short skin incision. None reported facial pain, masticatory discomfort, or numbness during facial movements.

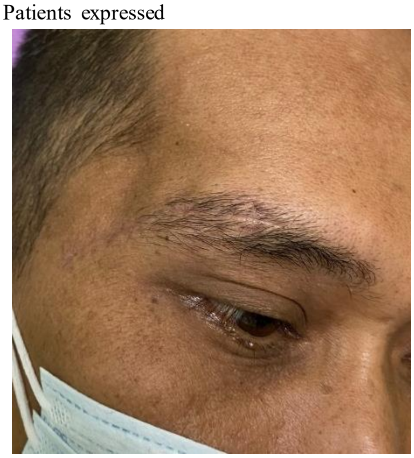


Fig. 2. Six-month postoperative wound appearance showing the incision concealed along the eyebrow. The skin and scalp demonstrate minimal atrophy without noticeable deformity. Patients reported no scalp tenderness or pain during chewing movements.

4. Discussion

Ruptured intracranial aneurysm is a life-threatening neurosurgical emergency. Timely and appropriate management can restore patients to normal life, whereas delayed or inadequate treatment may result in disability or death [1, 11]. Computed tomography (CT) of the brain is the initial imaging modality for diagnosis. The Fisher scale [12] classifies aneurysmal subarachnoid hemorrhage (SAH) by clot thickness and predicts vasospasm risk. The grades are divided as grade 1 (not seen SAH or IVH), grade 2 (diffuse thin <1 mm SAH), grade 3 (localized clot or > 1 mm SAH thickness), and grade4 (diffuse SAH with IVH or ICH). The incidence of symptomatic vasospasm increases with higher Fisher grades—21%, 25%, 37%, and 31%, respectively [13]. Vasospasm is a major complication in aneurysmal SAH that cause arterial infarction especially unappropriated management. Clinically, the modified World Federation of Neurosurgical Societies (m-WFNS) scale grades patients based on the Glasgow Coma Scale (GCS); grades 3-5 (GCS ≤13) are associated with poorer outcomes [7, 8]. These grading systems are crucial for guiding treatment selection and counseling patients' families regarding prognosis.

Surgical clipping remains a definitive treatment for aneurysmal rupture, effectively preventing rebleeding. This study compared the minimally invasive supraorbital keyhole approach (SKA) with the conventional pterional approach (PtA) for ruptured anterior circulation aneurysms. The SKA demonstrated clear advantages in shorter operative time, reduced blood loss, fewer postoperative complications, and superior six-month functional recovery (mRS). Findings from previous studies align with our results, showing that minimally invasive approaches, particularly the SKA, yield faster recovery, less tissue trauma, and better cosmetic outcomes than traditional craniotomy (Table 4).

Table. 4. Summary of related studies comparing minimally invasive and conventional approaches.

Author	Year	N	Outcome
Shao *et al.* [14]	2021	235	Keyhole approach provided faster recovery and favorable surgical outcomes (OPT 148 ± 47 min, BL 201 ± 98 mL). Safe and effective for anterior circulation aneurysms.
Park *et al.* [15]	2009	108	Supraorbital approach reduced intra- and postoperative complications, shortened operative time, and improved cosmetic results (mean OPT 160 min).
Genesan *et al.* [16]	2018	123	SKA patients had better cosmetic outcomes and shorter operations (OPT 192 min, BL 433 mL). No significant difference in major complications.
Fonseca *et al.* [17]	2021	35	Supraorbital minicraniotomy had significantly shorter operative time (~213 min) and better cosmetic outcome.
Cha *et al.* [18]	2012	137	Lateral supraorbital (LSO) approach yielded shorter hospitalization and operative time (mean 117.1 min).

Noiphitak *et al.* [19]	2020	102	After propensity score matching, minimally invasive craniotomy showed shorter operative time (2.8 vs. 4.2 h), shorter hospital stay, and fewer hemorrhagic complications.
Harris *et al.* [20]	2025	90	MIS showed shorter operative time (310 vs. 383 min) and hospital stay; estimated blood loss was not significantly different.
Rocca *et al.* [21]	2018	50	LSO approach reduced early complications, improved masticatory comfort and cosmetics; a safe and effective alternative to PtA. LSO is safe and effective substitute to standard PT craniotomy to treat unruptured ACOM and A1/A2 aneurysms.
Lan *et al.* [22]	2006	105	Keyhole approaches are effective and ideal in the hands of experienced microsurgeons.
Mandel *et al.* [23]	2021	111	MIS superior to PtA for small UIAs regarding cosmetic satisfaction and quality of life.
Chalouhi *et al.* [24]	2013	87	SKA had shorter operative time (205 vs. 256 min) with slightly higher procedural complications; acceptable for small, simple aneurysms.
Lindert *et al.* [25]	1998	139	SKA provided equivalent exposure with fewer intraoperative ruptures and less approach-related morbidity than PtA.

With advances in microsurgical optics and instruments, neurosurgeons can now achieve a wide operative field through a small bony window [26]. This approach reduces brain parenchymal injury, minimizes exposure to the environment, and lowers postoperative complication rates [14, 27]. Regardless of the craniotomy size, both SKA and PtA provide access to the subfrontal region around the keyhole point. When adequate brain relaxation is achieved, the minimally invasive approach can provide the same exposure as a conventional craniotomy. Florez-Perdomo *et al.* [29] performed a systematic review and meta-analysis comparing SKA and PtA, concluding that the supraorbital approach reduces ischemic events and is a safe alternative to traditional methods. However, its use in ruptured aneurysms with cerebral edema or midline shift remains challenging. In experienced hands, SKA is a reliable and effective method for anterior circulation aneurysms and other skull base pathologies [14, 19].

The concept of "keyhole surgery" was first introduced by Wilson in 1971 [29]. Hernesniemi *et al.* [30], after more than 2,000 operations, described the lateral supraorbital approach as a simpler, faster, safer, and less invasive alternative to the classic PtA. For younger neurosurgeons, the main obstacles in adopting SKA are: limited confidence in managing intraoperative complications such as rupture or brain swelling, and concern about the cosmetic outcome.

The key to a successful SKA lies in two main factors: adequate bone work and effective brain relaxation. Bone work: The craniotomy should extend inferiorly to the superior orbital ridge, medially to the lateral half of the superior orbital line, superiorly about 5 cm above the ridge, and laterally toward the anterior temporal fossa (keyhole point). The medial and superior edges should be beveled for smooth skull closure. Drilling and flattening the sphenoid wing is essential to widen the operative view across the anterior and middle cranial fossae (Figure 3). Brain relaxation: Techniques include external ventricular drainage (EVD), lumbar drainage, and osmotic therapy with mannitol or hypertonic saline are prefered. EVD is preferred when preoperative hydrocephalus is present [31, 32], while lumbar drainage is useful in mild hydrocephalus to reduce intracranial pressure [33, 34]. Lumbar drainage can reduce risk of delayed ischemic neurological deficit (DIND), both EVD and lumbar drainage are benefit for postoperative intracranial pressure monitor [35-38]. Osmotic agents further enhance relaxation when administered before dural opening [39-41]. Adequate arachnoid dissection is another critical step. The arachnoid membrane forms an envelope for vessels and bridging veins; careful sharp dissection with concurrent CSF release allows sufficient relaxation and safe exposure [14, 30]. The SKA provides a wide enough operative angle for bimanual microsurgical manipulation, enabling effective treatment of lesions in both the frontal and temporal fossae (Figure 3).

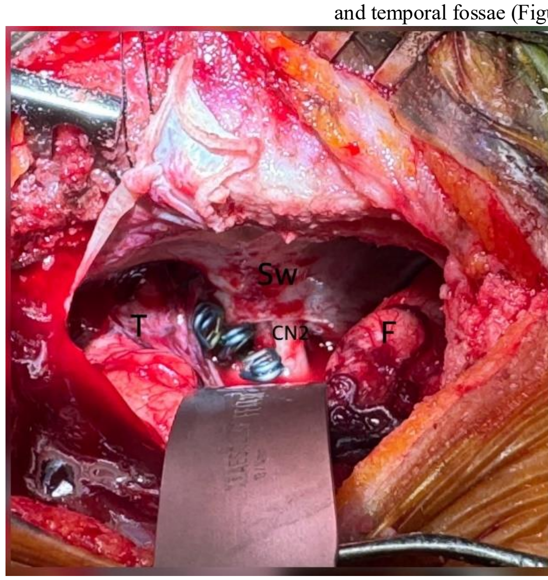


Fig. 3. Key elements of the SKA include sphenoid wing drilling (SW), sharp arachnoid dissection, and brain relaxation, allowing exposure of the optic nerve (CN2), frontal (F) and temporal (T) fossae.

Conclusion

The minimally invasive supraorbital keyhole approach (SKA) is an excellent technique for managing anterior circulation aneurysms in the hands of experienced neurosurgeons. Compared to the conventional pterional approach, SKA offers significant advantages in operative time, blood loss, postoperative morbidity, and long-term functional recovery. Critical factors for success include meticulous bone exposure, sufficient sphenoid wing drilling, and appropriate management of brain swelling. The limitation of this study are single-center design, retrospective nature, surgeon experience variability. Beyond aneurysm surgery, the SKA can be effectively applied to other anterior and middle cranial fossa pathologies, such as tumors, third ventriculostomy via lamina terminalis fenestration, pituitary macroadenomas, and repair of cerebrospinal fluid leaks.

References

[1] Brian L Hoh, Nerissa U Ko, Sepideh Amin-Hanjani, et al. "2023 Guideline for the Management of Patients With Aneurysmal Subarachnoid Hemorrhage: A Guideline From the American Heart Association/American Stroke Association." *Stroke*, vol. 54, no. 7, pp. e314-e370, 2023. View at: Publisher Site | PubMed

[2] Antti Lindgren, Mervyn DI Vergouwen, Irene van der Schaaf, et al. "Endovascular coiling versus neurosurgical clipping for people with aneurysmal subarachnoid haemorrhage." *Cochrane Database Syst Rev*, vol. 8, no. 8, pp. CD003085, 2018. View at: Publisher Site | PubMed

[3] L M Auer, M Mokry "Disturbed cerebrospinal fluid circulation after subarachnoid hemorrhage and acute aneurysm surgery." *Neurosurgery*, vol. 26, no. 5, pp. 804-808, 1990. View at: Publisher Site | PubMed

[4] Y Handa, B K Weir, M Nosko, et al. "The effect of timing of clot removal on chronic vasospasm in a primate model." *J Neurosurg*, vol. 67, no. 4, pp. 558-564, 1987. View at: Publisher Site | PubMed

[5] Andrew J Molyneux, Richard S C Kerr, Jacqueline Birks, et al. "Risk of recurrent subarachnoid haemorrhage, death, or dependence and standardised mortality ratios after clipping or coiling of an intracranial aneurysm in the International Subarachnoid Aneurysm Trial (ISAT): long-term follow-up." *Lancet Neurol*, vol. 8, no. 5, pp. 427-433, 2009. View at: Publisher Site | PubMed

[6] M G Yasargil, J L Fox "The microsurgical approach to intracranial aneurysms." *Surg Neurol*, vol. 3, no. 1, pp. 7-14, 1975. View at: PubMed

[7] Hirotoshi Sano, Akira Satoh, Yuichi Murayama, et al. "Modified World Federation of Neurosurgical Societies subarachnoid hemorrhage grading system." *World Neurosurg*, vol. 83, no. 5, pp. 801-807, 2015. View at: Publisher Site | PubMed

[8] "Report of World Federation of Neurological Surgeons Committee on a Universal Subarachnoid Hemorrhage Grading Scale." *J Neurosurg*, vol. 68, no. 6, pp. 985-986, 1988. View at: Publisher Site | PubMed

[9] Gaillard F. Radiopaedia "Fisher scale of subarachnoid hemorrhage | Radiology Reference Article.

[10] Baltazar Leão Reis, Roberto Leal Da Silveira, Sebastião Nataniel Silva Gusmão "Sphenopterional Point: Strategic Point for Burr Role Placement in Frontotemporal Craniotomies." *World Neurosurg*, vol. 105, pp. 399-405, 2017. View at: Publisher Site | PubMed

[11] Sebastian Sanchez, Jacob M. Miller, Edgar A. Samaniego "Clinical Scales in Aneurysm Rupture Prediction." *Stroke: Vascular and Interventional Neurology*, vol. 4, no. 1, pp. e000625, 2023. View at: Publisher Site

[12] C M Fisher, J P Kistler, J M Davis "Relation of cerebral vasospasm to subarachnoid hemorrhage visualized by computerized tomographic scanning." *Neurosurgery*, vol. 6, no. 1, pp. 1-9, 1980. View at: Publisher Site | PubMed

[13] Jennifer A Frontera "Decision Making in Neurocritical Care." *Thieme*, pp 356, 2011.

[14] Dongqi Shao, Yu Li, Zhixiang Sun, et al. "Keyhole Approach for Clipping Anterior Circulation Aneurysms: Clinical Outcomes and Technical Note." *Front Surg*, vol. 8, pp. 783557, 20221. View at: Publisher Site | PubMed

[15] Heung Sik Park, Sang Kyu Park, Young Min Han "Microsurgical Experience with Supraorbital Keyhole Operations on Anterior Circulation Aneurysms." *J Korean Neurosurg Soc*, vol. 46, no. 2, pp. 103-108, 2009. View at: Publisher Site | PubMed

[16] Pravinna Genesan, Mohammad Saffari Mohammad Haspani, Saiful Razman Mohd Noor "A Comparative Study between Supraorbital Keyhole and Pterional Approaches on Anterior Circulation Aneurysms." *MJMS*, vol. 25, no. 5, pp. 59-67, 2018. View at: Publisher Site | PubMed

[17] Ricardo Brandão Fonseca, Alyne Oliveira Correia, Raysa Siqueira Vieira, et al. "Comparative study between minimally invasive supraorbital craniotomy and pterional craniotomy for treating anterior circulation cerebral aneurysms in a low-resource setting." *Sci Rep*, vol. 11, no. 1, pp. 5555, 2021. View at: Publisher Site | PubMed

[18] Ki-Chul Cha, Seung-Chyul Hong, Jong-Soo Kim "Comparison between Lateral Supraorbital Approach and Pterional Approach in the Surgical Treatment of Unruptured Intracranial Aneurysms." *J Korean Neurosurg Soc*, vol. 51, no. 6, pp. 334-337, 2012. View at: Publisher Site | PubMed

[19] Raywat Noiphithak, Vich Yindeedej, Warot Ratanavinitkul, et al. "Comparison of Minimally Invasive and Pterional Craniotomies for Ruptured Anterior Circulation Aneurysms: A Propensity Score Matched Analysis." *World Neurosurg*, vol. 138, pp. e289-e298, 2020. View at: Publisher Site | PubMed

[20] Peter Harris, Hayes H Patrick, Keaton Piper, et al. "Comparison of patient-centric factors in minimally invasive transcranial versus classic approaches: a matched cohort study." *J Neurosurg*, vol. 143, no. 4, pp. 1048-1058, 2025. View at: Publisher Site | PubMed

[21] Giuseppe La Rocca, Giuseppe Maria Della Pepa, Carmelo Lucio Sturiale, et al. "Lateral Supraorbital Versus Pterional Approach: Analysis of Surgical, Functional, and Patient-Oriented Outcomes." *World Neurosurg*, vol. 119, pp. e192-e199, 2018. View at: Publisher Site | PubMed

[22] Qing Lan, Zhigang Gong, Dezhi Kang, et al. "Microsurgical experience with keyhole operations on intracranial aneurysms." *Surg Neurol*, vol. 66, pp. S2-S9, 2006. View at: Publisher Site | PubMed

[23] Mauricio Mandel, Rafael Tutihashi, Yiping Li, et al. "MISIAN (Minimally Invasive Surgery for Treatment of Unruptured Intracranial Aneurysms): A Prospective Randomized Single-Center Clinical Trial With Long-Term Follow-Up Comparing Different Minimally Invasive Surgery Techniques with Standard Open Surgery." *World Neurosurg*, vol. 151, pp. e533-e544, 2021. View at: Publisher Site | PubMed

[24] Nohra Chalouhi, Pascal Jabbour, Ibrahim Ibrahim, et al. "Surgical Treatment of Ruptured Anterior Circulation Aneurysms: Comparison

of Pterional and Supraorbital Keyhole Approaches." *Neurosurgery*, vol. 72, no. 3, pp. 437, 2013. View at: Publisher Site | PubMed

[25] E van Lindert, A Perneczky, G Fries, et al. "The supraorbital keyhole approach to supratentorial aneurysms: concept and technique." *Surg Neurol*, vol. 49, no. 5, pp. 481-489, 1998. View at: Publisher Site | PubMed

[26] Kentaro Mori "Keyhole concept in cerebral aneurysm clipping and tumor removal by the supraciliary lateral supraorbital approach." *Asian J Neurosurg*, vol. 9, no. 1, pp. 14-20, 2014. View at: Publisher Site | PubMed

[27] Mohamed Elnokaly, Gordon Mao 1, Khaled A Aziz "Transpalpebral Approach "Eyelid Incision" for Surgical Treatment of Intracerebral Aneurysms: Lessons Learned During a 10-Year Experience." *Oper Neurosurg*, vol. 18, no. 3, pp. 309-315, 2020. View at: Publisher Site | PubMed

[28] William A Florez-Perdomo, Cesar E Zabala-Otero, Harrison R Herrea, et al. "Supraorbital vs pterional keyhole for anterior circulation aneurysms: A systematic review and meta-analysis." *World Neurosurg X*, vol. 19, pp. 100177, 2023. View at: Publisher Site | PubMed

[29] D H Wilson "Limited exposure in cerebral surgery. Technical note." *J Neurosurg*, vol. 34, no. 1, pp. 102-106, 1971. View at: Publisher Site | PubMed

[30] J Hernesniemi, K Ishii, M Niemelä, et al. "Lateral supraorbital approach as an alternative to the classical pterional approach." *Acta Neurochir Suppl*, vol. 94, pp. 17-21, 2005. View at: Publisher Site | PubMed

[31] Giacomo Pavesi, Davide Nasi, Elisa Moriconi, et al. "Management and safety of intraoperative ventriculostomy during early surgery for ruptured intracranial aneurysms." *Acta Neurochir (Wien)*, vol. 164, no. 11, pp. 2909-2916, 2022. View at: Publisher Site | PubMed

[32] Jae Hoon Kim, Hee In Kang "Intraoperative Ventriculostomy Using K Point in Surgical Management of Aneurysmal Subarachnoid Hemorrhage." *World Neurosurg*, vol. 122, pp. e248-e252, 2019. View at: Publisher Site | PubMed

[33] Sunil Munakomi; Joe M. Das "Brain Herniation." In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025. View at: PubMed

[34] Toshitsugu Terakado, Yoshiro Ito, Koji Hirata, et al. "Efficacy and Safety of Lumbar Drainage before Endovascular Treatment for Ruptured Intracranial Aneurysms." *J Neuroendovasc Ther*, vol. 18, no. 2, pp. 29-36, 2024. View at: Publisher Site | PubMed

[35] E S Connolly Jr, A A Kader, V I Frazzini, et al. "The safety of intraoperative lumbar subarachnoid drainage for acutely ruptured intracranial aneurysm: Technical note." *Surg Neurol*, vol. 48, no. 4, pp. 338-344, 1997. View at: Publisher Site | PubMed

[36] Stefan Wolf, Dorothee Mielke, Christoph Barner, et al. "Effectiveness of Lumbar Cerebrospinal Fluid Drain Among Patients With Aneurysmal Subarachnoid Hemorrhage: A Randomized Clinical Trial." *JAMA Neurol*, vol. 80, no. 8, pp. 833-842, 2023 View at: Publisher Site | PubMed

[37] Cheol Young Lee, Kyoung Min Jang, Seong Hyun Wui, et al. "The Benefits and Feasibility of External Lumbar Cerebrospinal Fluid Drainage for Cerebral Vasospasm in Patients with Aneurysmal Subarachnoid Hemorrhage: Meta-Analysis and Trial Sequential Analysis." *World Neurosurg*, vol. 167, pp. e549-e560, 2022. View at: Publisher Site | PubMed

[38] Paul Klimo Jr, John R W Kestle, Joel D MacDonald, et al. "Marked reduction of cerebral vasospasm with lumbar drainage of cerebrospinal fluid after subarachnoid hemorrhage." *J Neurosurg*, vol. 100, no. 2, pp. 215-224, 2004. View at: Publisher Site | PubMed

[39] Yuming Peng, Xiaoyuan Liu, Aidong Wang, et al. "The effect of mannitol on intraoperative brain relaxation in patients undergoing supratentorial tumor surgery: study protocol for a randomized controlled trial." *Trials*, vol. 15, pp. 165, 2014. View at: Publisher Site | PubMed

[40] Hee-Pyoung Park "Erratum. A prospective randomized trial of the optimal dose of mannitol for intraoperative brain relaxation in patients undergoing craniotomy for supratentorial brain tumor resection." *J Neurosurg*, vol. 129, no. 2, pp. 551-552, 2018. View at: Publisher Site | PubMed

[41] Hyungseok Seo, Eugene Kim, Haesun Jung, et al. "A prospective randomized trial of the optimal dose of mannitol for intraoperative brain relaxation in patients undergoing craniotomy for supratentorial brain tumor resection." *J Neurosurg*, vol. 126, no. 6, pp. 1839-1846, 2017. View at: Publisher Site | PubMed