



Review Article

Keyhole approach in anterior circulation aneurysm: Current indication, advantages, technical limitations, complications and their avoidance

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J Cerebrovasc Endovasc Neurosurg.
2022 June;24(2):101-112

Received: 19 July 2021

Revised: 27 October 2021

Accepted: 28 October 2021

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Keyhole surgery recently evolved as a minimal invasive surgical approach for treatment of anterior circulation aneurysm. This review was done to evaluate the keyhole approach for anterior circulation aneurysms, their indications, advantages, technical limitations, complications and their avoidance. The literature review was performed with the phrase “keyhole approach for anterior circulation aneurysm” as a search term in PubMed central, Medline, Google scholar and Embase data base to identify all the articles published till December 2020. Out of 113 articles searched, 22 were included in this review after screening for eligibility. On analyzing these articles, there was total 2058 aneurysm in 1871 patients. Out of 2058 aneurysm, 988 were ruptured and 547 unruptured. In 5 studies, which include 344 aneurysms in 344 cases, aneurysm ruptured or unruptured status was not specified. The most frequent aneurysm site was anterior communicating artery (n=573). The size of the aneurysm mentioned in most of the study was <15 mm. The rate of complete occlusion was ranged from 93.6-100%. The range of intra operative rupture (IOR) was 0-28.6%. The mean operative time was ranged from 70 min-5.34 hours as reported in 13 studies. Good outcome [Glasgow outcome scale (GOS): 4-5] were seen in 75-100% cases. The frontalis muscle weakness has been reported in 3 studies and ranged from 0-1.99%. Keyhole surgery can be a safe and effective treatment modality for treatment of a selected anterior circulation aneurysm. In the experienced hand it has certain advantages over standard pterional craniotomy.

Keywords Keyhole approach, Anterior circulation aneurysms, Indications and contraindications, Advantages, Technical limitations, Complications and their avoidance

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INTRODUCTION

The pterional craniotomy approach is the most commonly used cranial approaches, but it has certain limitations such as temporal muscle atrophy and damage to a

frontal branch of facial nerve. The supraorbital keyhole approach is an alternative approach in the management of anterior skull base lesions and anterior circulation aneurysms, due to its minimal invasive nature and relatively low complication rates.³¹⁾⁴⁷⁾ Due to advancement in the neuroradiology, microsurgical instrument and surgical techniques, the popularity of supraorbital keyhole approach for anterior circulation aneurysm is increasing.

The supra orbital keyhole approach cannot be applied for every anterior circulation aneurysm. The controversies exist regarding the use of this approach in different aneurysm location, optimal aneurysm size. Also, it is difficult to approach ruptured aneurysm due to brain swelling.¹¹⁾¹⁵⁾ Furthermore, if an unexpected ruptures occurs intra operatively, prior to the proximal control of feeding artery, it may be very difficult for the surgeon to properly manage the bleeding. So it becomes very important for selecting suitable case for this approach.

Most of the previous studies reports on the clinical experience of keyhole technique at a single centre, which limit the generalisability of the results. In this review, the current concept and proper patient selection, advantages and limitations for this approach have been discussed to summarize the reported experience on the keyhole approach specifically in anterior circulation aneurysm.

MATERIAL AND METHODS

The review was designed in accordance to the Preferred Reporting Items for Systematic Reviews and Meta-analysis.

Search strategy

Articles published in PubMed central, Medline, Google scholar and Embase data bases till December 2020, were all searched. In relevant literature, references were manually searched for additional articles. We screened the title and abstract by combining the term “keyhole [All Fields] AND approach [All Fields] AND anterior [All Fields] AND (“blood circulation” [MeSH Terms] OR (“blood” [All Fields] AND “circulation” [All

Fields]) OR “blood circulation” [All Fields] OR “circulation” [All Fields]) AND (“aneurysm” [MeSH Terms] OR “aneurysm” [All Fields]).

Eligibility criteria

Only non experimental, non animal clinical studies were included. Articles written only in English language were considered. We have included only those published articles on keyhole approach which uses supraorbital, lateral supra orbital, superciliary, eyebrow lateral and pterional keyhole approach for treatment of anterior circulation ruptured or unruptured aneurysm. We have excluded those articles in which anterior circulation aneurysm cases were managed either by standard pterional craniotomy or by endovascular treatment. The article mentioning a modified keyhole approach, posterior circulation aneurysm, and an intracranial tumor was also excluded from the review.

Data management

Results of literature search were imported to EndNote X9 (Clarivate Analytics, PA, USA). Software utilization sought to reduce data entry errors and bias (i.e., duplicating references). All investigation reports were reviewed to assess for inconsistencies (e.g., design description, outcome presentation, total patients analyzed).

Statistical analysis

Data work entered in Microsoft office excel 2007 and analyzed using SPSS version 24.0 (IBM Corp., IL, USA). Data were analyzed at two levels, descriptive and analytical. Frequency, percentage, range, means and median were used to describe the characteristics of study participants. P value <0.05 was considered statistically significant.

RESULTS

113 articles were identified on searching the PubMed central, Medline, Google scholar and Embase data base.

Out of 113, 62 articles were screened based on removal of duplicates. After screening for eligibility of potential articles, 22 studies were included in this review (Fig. 1).

A total 22 articles including 2058 aneurysm in 1871 patients which were surgically treated for anterior circulation aneurysm via keyhole approach met our inclusion criteria and were included in our review. The age range of these patients was 5-82 years and male to female ratio 1.42:1. The types of keyhole approaches used in these studies were supraorbital keyhole approach (SOKA), lateral supraorbital approach, superciliary keyhole approach and pterional keyhole approach (Table 1).

Out of 2058 aneurysm, 988 were ruptured and 547 unruptured. In 5 studies, which include 344 aneurysms in 344 cases, aneurysm ruptured or unruptured status was not specified. The most frequent aneurysm sites treated in these studies were anterior communicating

artery (n=573), middle cerebral artery (n=552) and posterior communicating artery (n=358). The size of the aneurysm was described differently in different study as shown in Table 2.

Out of 22 studies, 8 studies had mentioned the rate of complete occlusion which ranged from 93.6-100% (Table 3). The rate of intra operative rupture (IOR) of an aneurysm was mentioned in 11 studies, mostly either during perianeurysmal dissection or during clip application. The range of IOR in these studies was 0-28.6% cases. Yu LB et al.⁵¹⁾ (28.6%) and Chen L et al.⁷⁾ (26.1%) have reported maximum number of IOR. Toyooka T et al.⁴⁶⁾ has mentioned no IOR during keyhole surgery for anterior circulation aneurysm.

There were long variation in the mean operative time (ranged: 70 min-5.34 hours) as reported in 13 studies. The mean hospital stay was reported in 7 studies (Table 3).

Glasgow outcome scale (GOS) was measured in 6 studies, ranged from 75-100%. Chalouhi N et al.⁴⁾ reported good outcome (grade 4-5) in 75% cases and Paladino J et al.³²⁾ in 100% cases at the time of discharge. Tang Y et al.⁴³⁾ reported modified Rankin Scale (mRS) of 0-2 in 71.1% of cases at 6 months of follow up. Mori K et al.²⁹⁾ reported good outcome (mRS: 0-1, all patients) at 3 months of follow period.

The frontalis muscle weakness has been reported in 3 studies (Table 3). Mori K et al.²⁹⁾ reported frontalis weakness in 3 (1.99%) cases. Park JS et al.³⁷⁾ and Tang Y et al.⁴³⁾ found no frontalis muscle weakness during keyhole surgery for anterior circulation aneurysm.

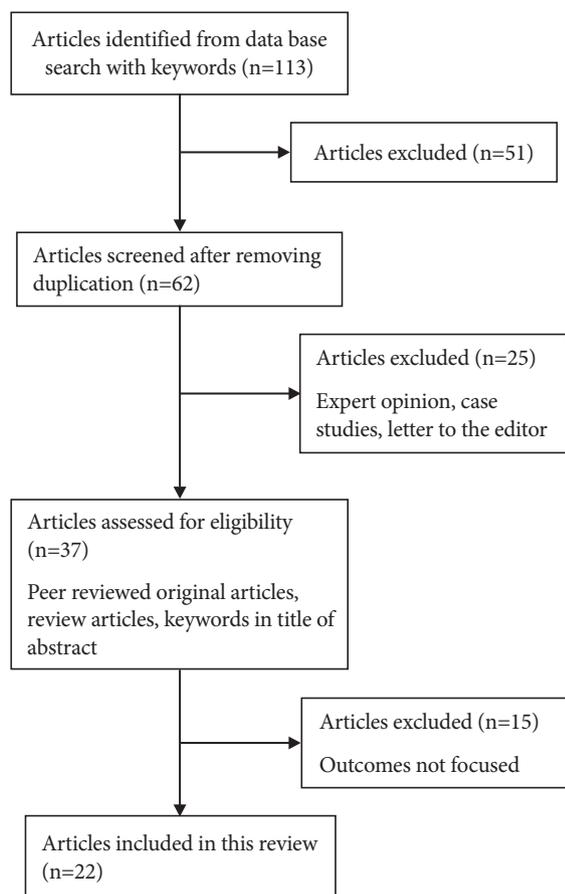


Fig. 1. Flow chart (preferred reporting items for systematic review and meta-analysis) for articles selection (original figures).

DISCUSSION

The pterional craniotomy is most widely used surgical approach to clip the anterior circulation aneurysm.⁴⁷⁾⁵⁰⁾ However it requires a large scalp incision and temporalis muscle dissection which can cause facial nerve injury, depression of temporal fossa and temporo mandibular joint dysfunction. Creation of a large bone flap may result in poor cosmetic outcomes, such as keyhole site depression and the hollows of multiple burr hole sites.²¹⁾²⁷⁾

Table 1. Previous studies and patients characteristics

S. no.	Studies	No of patients/ no of aneurysms	Keyhole approach	Age in years	Male/ female
1	Bhattarai R et al., 2020. ¹¹⁾	85/85	SOK	28-78 Mean±SD: 52.69±9.94	50/35
2	Toyooka T et al., 2019. ⁴⁵⁾	51/51	SOK	35-75 Mean 62.0	24/27
3	Tang Y et al., 2018. ⁴³⁾	356/408	PKA	NA	NA
4	Genesan P et al., 2018. ¹⁶⁾	41/41	SOK	26-82 54.95±12.71	19/22
5	Park JS et al., 2018. ³⁷⁾	188/188	SKA	NA	NA
6	Yu LB et al., 2015. ⁵¹⁾	47/47	PKA	NA	NA
7	Chin Z et al., 2018. ⁸⁾	27/27	Lateral supraorbital approach	39-73 56.1±10.1	21/6
8	Mori K et al., 2017. ²⁹⁾	151/260	PKA+SOK	NA	NA
9	Kim Y et al., 2016. ²²⁾	40/40	SOK	57.10±11.77	20/20
10	Choi YJ et al., 2016. ¹²⁾	124/124	Superciliary keyhole approach	36-74 50.4±9.2	81/43
11	Wang H et al., 2015. ⁴⁸⁾	37/37	Eyebrow lateral keyhole	5-76 46.3	24/13
12	Caplan JM et al., 2014. ³⁾	72/82	PKA	NA	NA
13	Chalouhi N et al., 2013. ⁴⁾	87/87	SKA+PKA	<12 mm 80%	NA
14	Tang C et al., 2013. ⁴²⁾	76/80	SKA	NA	NA
15	Kang HJ et al., 2013. ²⁰⁾	4/4	SOK	Mean 58.5	NA
16	Shin D et al., 2012. ⁴⁰⁾	70/71	Superciliary keyhole approach	33-65 57.0	NA
17	Cha KC et al., 2012. ⁵⁾	61/68	Lateral supraorbital	Mean 54.6	33/28
18	Chen L et al., 2009. ⁷⁾	88/88	SKA	NA	NA
19	Park HS et al., 2009. ³³⁾	50/54	NA	55.7±12.3	31/19
20	Cheng WY et al., 2006. ¹⁰⁾	40/40	PKA	NA	NA
21	Paladino J et al., 1998. ³²⁾	37/37	SOEK	NA	NA
22	van Lindert E et al., 1998. ⁴⁷⁾	139/139	SOEK	NA	NA
	Total	1871/2058			

SOK, supraorbital keyhole approach; SD, standard deviation; PKA, pterional keyhole approach; NA, not available; SKA, supraorbital keyhole approach; SOEK, supraorbital eyebrow keyhole approach

The deep seated lesion in the brain can be treated by small craniotomy because it form “reverse tunnel shaped surgical corridor” with a wide operative field.²⁸⁾ The evolution in the endovascular procedure with a lower complication rate and satisfactory aneurysm treatment, further inspire the surgeon to develop less morbid surgical options for aneurysm surgery. As such, less invasive surgical approaches have been proposed to reduce the extent of pterional craniotomy and expectantly its related complications.¹⁷⁾²⁷⁾ Multiple keyhole approaches have been proposed (i.e. supraorbital and

lateral supraorbital craniotomy).

The main goal of supra orbital keyhole approach is the minimization of brain exposure to air and accidental surgical trauma via limited and more specific craniotomy. Moreover, brain retraction is minimized or absent in this procedure. This significantly decreases the approach related surgical morbidity and hospitalization.

Evolution of keyhole surgery

Sir Victor Horsley, first treat the cerebral aneurysm by ligation of ipsilateral common carotid artery in 1855.

Table 2. Aneurysm characteristics

S. no.	Studies	R/U	AcomA	PcomA	AChA	ICA bif	ICA Paraclinoid	MCA	Size (mm)
1	Bhattarai R et al., 2020. ¹⁾	85/0	85	0	0	0	0	0	2-11 5.07±2.36
2	Toyooka T et al., 2019. ⁴⁵⁾	0/51	0	32	15	02	02	0	2-10 5.8±1.8
3	Tang Y et al., 2018. ⁴³⁾	356/0	118 (ACA 18)	105	9	NA	26	50	<25 mm
4	Genesan P et al., 2018. ¹⁶⁾	NA	NA	NA	NA	NA	NA	NA	NA
5	Park JS et al., 2018. ³⁷⁾	188/0	82	44	2	3	1	51	Avg 5.5 mm
6	Yu LB et al., 2015. ⁵¹⁾	47/0	10, ACA-3	15	0	0	0	19	<20 mm
7	Chin Z et al., 2018. ⁸⁾	27/0	0	0	0	0	0	27	NA
8	Mori K et al., 2017. ²⁹⁾	0/151	63	0	0	0	47	150	<10
9	Kim Y et al., 2016. ²²⁾	40/0	NA	NA	NA	NA	NA	NA	NA
10	Choi YJ et al., 2016. ¹²⁾	0/124	0	0	0	0	0	124	3-14.6 5.1±2.1
11	Wang H et al., 2015. ⁴⁸⁾	37/0	37	0	0	0	0	0	1.4-16 4.8
12	Caplan JM et al., 2014. ³⁾	0/72	0	22	1	0	23	36	Avg 5.45
13	Chalouhi N et al., 2013. ⁴⁾	NA	51	26	0	0	7	0	NA
14	Tang C et al., 2013. ⁴²⁾	70/6	33, A1-4	14	0	0	5	17	5-19 mm
15	Kang HJ et al., 2013. ²⁰⁾	0/4	2	2	0	0	0	0	NA
16	Shin D et al., 2012. ⁴⁰⁾	0/71	0	45	17	0	4	0	4-14 6.6±2.3
17	Cha KC et al., 2012. ⁵⁾	0/68	16+3 (A1 seg)	8	8	3	1 (oph seg)	29	NA
18	Chen L et al., 2009. ⁷⁾	88/0	41	18	0	0	0	29	<15 mm 100%
19	Park HS et al., 2009. ³³⁾	50/0	26	13	1	2	2 (oph seg)	10	NA
20	Cheng WY et al., 2006. ¹⁰⁾	NA	9+1 (ACA)	14	0	0	6	10	NA
21	Paladino J et al., 1998. ³²⁾	NA	NA	NA	NA	NA	NA	NA	NA
22	van Lindert E et al., 1998. ⁴⁷⁾	NA	NA	NA	NA	NA	NA	NA	NA
	Total	988/547	573+29 (ACA)	358	53	10	124	552	

R/U, ruptured/unruptured; AcomA, anterior communicating artery; PcomA, posterior communicating artery; AChA, anterior choroidal artery; ICA bif, internal carotid artery bifurcation; MCA, middle cerebral artery; ACA, anterior cerebral artery; NA, not available; oph seg, ophthalmic segment

Dott NM started wrapping of cerebral aneurysm in 1933.¹⁴⁾ Walter Dandy WE used V shaped silver clip to treat cerebral aneurysm in 1935.¹³⁾ Yasargil first used microscope to treat intracranial aneurysm in 1960.²³⁾ Wilson and colleagues first operated intracranial aneurysm through a minimal craniotomy.⁴⁹⁾ In 1978, Brock M used frontotemporal craniotomy for anterior circulation aneurysm clipping.²⁾ In 1982, Jane JA described the supra orbital craniotomy by opening the anterior orbital roof.¹⁹⁾ Later on Paladino and colleagues introduced the concept of keyhole approach.³²⁾ In 1998, van Lindert E and colleagues introduced the supra orbital keyhole

approach.⁴⁷⁾ Various keyhole surgeries described in the literature for anterior circulation aneurysm are (i) supra orbital keyhole approach (ii) lateral supra orbital keyhole approach (iii) pterional keyhole approach (iv) supercilary keyhole approach.

Indication and contraindication

Selecting the appropriate aneurysm for supra orbital keyhole approach is critical due to its technical limitations. These are as follow (Table 4).³⁵⁾

Supraorbital keyhole approach can be applied in an aneurysm with diameter up to 15 mm arising at the level

Table 3. Intra operative findings and post operative outcomes

S.no.	Studies	Complete occlusion	Intraoperative rupture	Operative time (min)	Hospital stay (days)	GOS	mRS	Frontalis weakness
1	Bhattarai R et al., 2020. ¹⁾	100%	3.53%	60-360 268.2±82.8	37.9±24.5	NA	NA	NA
2	Toyooka T et al., 2019. ⁴⁵⁾	100%	0	122-273 171±33	3.4±6.9	NA	NA	NA
3	Tang Y et al., 2018. ⁴³⁾	93.60%	NA	160±57	8.33±2.72	NA	6 months 0-2,71.1%	0
4	Genesan P et al., 2018. ¹⁶⁾	NA	NA	192 mean	NA	NA	NA	NA
5	Park JS et al., 2018. ³⁷⁾	NA	1.06%	NA	NA	Good outcome 91.5%	NA	0
6	Yu LB et al., 2015. ⁵¹⁾	97.87%	28.6%	NA	15.5	Good outcome 83.6%	NA	NA
7	Chin Z et al., 2018. ⁸⁾	NA	NA	146±36.7 m	NA	NA	NA	NA
8	Mori K et al., 2017. ²⁹⁾	96%	NA	177±39	2.7±4.7	NA	0.0±0.3	1.99%
9	Kim Y et al., 2016. ²²⁾	NA	NA	5.34±1.11 hour	18.2±7.05	NA	NA	NA
10	Choi YJ et al., 2016. ¹²⁾	NA	NA	7.8-59 m 29.3±12.3	NA	NA	NA	NA
11	Wang H et al., 2015. ⁴⁸⁾	100%	8.11%	1.5-3.5 hour Mean 2.5 hour	NA	NA	NA	NA
12	Caplan JM et al., 2014. ³⁾	NA	NA	NA	3.96	NA	NA	NA
13	Chalouhi N et al., 2013. ⁴⁾	NA	6.90%	PKA 256 m SKA 205 m	NA	Good outcome 75%	NA	NA
14	Tang C et al., 2013. ⁴²⁾	94%	10.5%	NA	NA	Discharge 4-5; 95%	NA	NA
15	Kang HJ et al., 2013. ²⁰⁾	NA	NA	NA	NA	NA	NA	NA
16	Shin D et al., 2012. ⁴⁰⁾	NA	NA	70-160 m 99.9±17.7	NA	NA	NA	NA
17	Cha KC et al., 2012. ⁵⁾	NA	NA	Mean 117.1 m	NA	NA	NA	NA
18	Chen L et al., 2009. ⁷⁾	92%	26.1%	NA	NA	1 year 5-4, 88.6%	NA	NA
19	Park HS et al., 2009. ³³⁾	NA	NA	70-187 mean 160	NA	NA	NA	NA
20	Cheng WY et al., 2006. ¹⁰⁾	NA	7.5%	NA	NA	NA	NA	NA
21	Paladino J et al., 1998. ³²⁾	NA	8.1%	NA	NA	Good outcome 100%	NA	NA
22	van Lindert E et al., 1998. ⁴⁷⁾	NA	2.1%	NA	NA	NA	NA	None

GOS, Glasgow outcome scale; mRS, modified Rankin Scale; NA, not available

of circle of willis.³⁶⁾ Aneurysm arising at the posterolateral wall of the internal carotid artery (ICA), posterior communicating artery and anterior choroidal artery aneurysm, superior wall of the ICA and ICA bifurcation aneurysm can be clipped safely using supra orbital keyhole approach. Posterior wall of ICA aneurysm may

necessitate placement of angled fenestrated clip encircling the ICA. It could be done with increasing the size of craniotomy. In addition, low lying supraclinoid or paraclinoid ICA aneurysm that involves drilling of anterior clinoid process also require larger craniotomies.³⁴⁾ Middle cerebral artery (MCA) aneurysm arising beyond

Table 4 . Indication and contraindication

Site	Indication	Contraindication
ICA	1 PcomA aneurysm	1 Posterior wall ICA aneurysm
	2 AChA aneurysm	2 Low lying supraclinoid ICA aneurysm
	3 Superior wall ICA aneurysm	
	4 ICA bifurcation aneurysm	
ACA	1 A1 segment ACA aneurysm	1 Superiorly or posteriorly directing large AcomA aneurysm
	2 Inferiorly or anteriorly directing AcomA aneurysm	2 High positioned AcomA aneurysm
MCA	1 M1 segment MCA aneurysm	3 Pericallosal artery aneurysm
	2 MCA bifurcation aneurysm	1 Aneurysm distal to MCA genu

ICA, internal carotid artery; ACA, anterior cerebral artery; MCA, middle cerebral artery; PcomA, posterior communicating artery; AChA, anterior choroidal artery; AcomA, anterior communicating artery

the genu requires lateral extension of the craniotomy to expose them.⁴⁶⁾ Pterional trans-sylvian approach may require for superior directing and high positioned anterior communicating artery (AcomA) aneurysm. Posterior directing AcomA aneurysm may require anterior inter-hemispheric approach.³⁴⁾

Bhattarai R et al.¹⁾ reported the experience of 85 ruptured AcomA aneurysm via SOKA and stated that SOKA is a safe procedure in an experienced hand for the clipping of ruptured AcomA aneurysm. It provides sufficient intra operative exposure and a high clipping rate. Shin D et al.⁴⁰⁾ treated 71 unruptured supraclinoid ICA aneurysm with diameter ranged from 4-14 mm (mean±SD: 6.6±2.3 mm) via superciliary keyhole approach and stated that, this approach provides sufficient surgical corridor to clip most unruptured supraclinoid ICA aneurysm with advantage of short operative time, small operative wound and no post operative extra dural hematoma. Park JS et al.³⁷⁾ and Chen L et al.⁷⁾ treated 188 and 88 ruptured anterior circulation aneurysm via SOKA respectively and reported that this approach has high clipping rate with good functional outcomes. Mori K et al.²⁹⁾ clipped 260 unruptured anterior circulation aneurysm (63 AcomA, 150 MCA and 47 ICA aneurysms). They emphasized to use SOKA for unruptured aneurysm cases. In ruptured aneurysm cases brain swelling and sub arachnoid hemorrhage clot hinders the operating view and manipulation, so it could be avoided. Wang H et al.⁴⁸⁾ reported the experience of 37 ruptured

anterior circulation aneurysm and emphasize the use of pre operative external ventricular drainage (EVD) in ruptured anterior circulation aneurysm cases.

Advantage of keyhole approach

(1) Minimal soft tissue damage with better cosmetic outcomes

A limited skin incision with in the eye brow, minimal temporalis muscle dissection, small bone flap and closure with the orbicularis oculi muscle/pericranium layer have contributed to better cosmetic outcomes. Temporalis muscle atrophy, so common with standard fronto temporal and pterional craniotomy, can be avoided with eye brow incision.⁴¹⁾ Mori K et al.²⁹⁾ reported frontalis muscle weakness in 3 (1.99%) cases. Park JS et al.³⁷⁾ and Tang Y et al.⁴³⁾ reported no frontalis muscle weakness out of 188 and 356 cases respectively.

(2) High occlusion rate

Open surgical procedure for the treatment of anterior circulation aneurysm has high occlusion rate as compare to endovascular treatment.⁴⁴⁾ Pierot L et al.³⁸⁾ reported that endovascular treatment for unruptured aneurysm has complete occlusion rate 59% with 21.7% neck remnant and 19.3% aneurysm remnant. In general, aneurysm recanalization occurs more frequently with endovascular treatment than clipping. On analyzing the literature, good complete occlusion rate of aneurysm has reported with keyhole approach. Bhattarai R et al.¹⁾ and

Wang H et al.⁴⁸⁾ reported 100% occlusion in treatment of ruptured AcomA aneurysms via SOKA. Tang Y et al.,⁴³⁾ Yu LB et al.⁵¹⁾ and Chen L et al.⁷⁾ reported 93.6%, 97.87% and 92% occlusion rate respectively for the treatment of ruptured anterior circulation aneurysm via SOKA. Toyooka T et al.⁴⁵⁾ found 100% occlusion rate for unruptured ICA aneurysm via SOKA.

(3) Less operative time

Tang Y et al.⁴³⁾ and Bhattarai R et al.¹⁾ reported mean operative time 160±57 min and 268.2±82.8 min in a study of 356 and 85 ruptured anterior circulation aneurysm respectively via SOKA. Ganesan P et al.¹⁶⁾ has compared supra orbital keyhole approach (41 patients) and pterional approach (82 patients) on treatment of anterior circulation aneurysm and reported that there was a significant difference in mean operative time between SOKA (192 min) and pterional approach (226 min) ($p=0.007$). Park JS et al.³⁷⁾ also reported similar results. The less operative time in SOKA is because of smaller skin incision, smaller craniotomy and less brain exposure. Kim Y et al.²²⁾ mentioned longer operative time (5.34±1.11 hour) as compared to other studies, this may be due to learning curve.

(4) Less blood loss and requirement of less blood transfusion

Tang Y et al.⁴³⁾ reported average blood loss of 204±100 ml in microsurgical clipping of 356 anterior aneurysm cases by keyhole approach. Shin D et al.⁴⁰⁾ has compared the superciliary keyhole approach and pterional approach in the microsurgical clipping of unruptured supraclinoid ICA aneurysm and found statistically significant advantage to the superciliary approach in terms of shorter operative time and no intra operative blood transfusion requirement ($p=0.0001$). Le Roux PD et al.²⁴⁾ have reported 13.2% incidence of blood transfusions during conventional pterional surgery for unruptured aneurysm. Although, most of the studies have reported that, there is less blood loss and requirement of less blood transfusion during keyhole approach for anterior circulation aneurysm but some differs. Ganesan P et

al.¹⁶⁾ have reported statistically no significant difference in the amount of blood loss between SOKA (433 ml) and pterional approach (437 ml) ($p=0.972$) in the treatment of anterior circulation aneurysm. This was because there is not much difference in blood loss from the skin incision, craniotomy and dural opening. Although, the skin incision and craniotomy size are larger in the pterional approach as compared to SOKA, the most blood loss usually occurs during rupture of an aneurysm.

(5) Early discharge from the hospital

As compared to conventional craniotomy (7.4 days), patients treated with keyhole approach were early discharge from the hospital and matches to that of endovascular surgery (4.5 days).¹⁸⁾ Caplan JM et al.³⁾ reported average hospital stay of 3.96 days in a study of 72 patients operated through supra orbital keyhole approach for anterior circulation aneurysm. Ganesan P et al.¹⁶⁾ stated that the length of surgical procedure and hospitalization were significantly reduced ($p=0.007$) in keyhole surgery for anterior circulation aneurysm as compared to standard technique. Similar findings were also reported by.³⁰⁾

(6) Good functional outcomes

Most of the previous studies reported improved functional outcomes after keyhole surgery. Tang Y et al.⁴³⁾ reported mRS of 0-2 in 71.4% cases at 6 months of follow up. Chen L et al.⁷⁾ reported GOS of 5-4 in 88.6% cases at 1 year of follow up. Mori K et al.²⁹⁾ mentioned that improved outcomes may be due to absence of surgical contusion and avoidance of ischemia and hemorrhagic complications in keyhole approach.

Keyhole surgery for ruptured anterior circulation aneurysm

Multiple studies have reported their experience of keyhole surgery for ruptured anterior circulation aneurysm.¹⁾⁷⁾⁸⁾²²⁾³³⁾³⁷⁾⁴³⁾⁴⁸⁾⁵¹⁾ Bhattarai R et al.¹⁾ reported their experience of keyhole surgery of 85 ruptured AcomA aneurysm of size ranged 2-11 mm. They stated that, keyhole surgery is suitable for patients with Hunt and

Hess grade I-III, including conscious patients and patients without any severe intracranial pressure. It is generally not suitable for patients with poor Hunt and Hess grade (grade IV-V) with severe complications including intracranial hypertension, brain herniation and requirement for enlargement of the bone window for decompression.

In the keyhole approach, sufficient space may be obtained for clipping ruptured aneurysm by completely removing the anterior skull base and releasing cerebrospinal fluid (CSF) from the cistern. In addition, if necessary, pre operative EVD and/or resection of part of the gyrus rectus may be performed intra operatively.¹¹⁾¹⁵⁾

Yu LB et al.⁵¹⁾ performed a randomized controlled trial on keyhole craniotomy (70 cases) and pterional craniotomy (70 cases) for ruptured AcomA aneurysm. They reported that, there was lower incidence of surgical complication in keyhole group (10.5%) as compare to pterional group (32.9%). Ganesan P et al.¹⁶⁾ retrospectively have done a comparative study between supraorbital keyhole and pterional approach for anterior circulation aneurysm. They stated that regardless of treatment option, functional outcomes after subarachnoid haemorrhage (SAH) are dependent upon clinical presentation prior to intervention. Patients in good world federation of neurosurgical societies (WFNS) grade had good functional outcomes as compare to patients in poor WFNS score.

Technical limitations and their solutions

(1) Narrow viewing angle and reduced intra operative light

Small cranial opening with bimanual hand movements produces reduce light at the operating field. Angled endoscope can be used for better illumination and to look around the corners or behind structures.³⁹⁾

(2) Limited maneuverability of the instruments

The small size of craniotomy of 2-2.5 cm creates difficulty in maneuverability of the instruments. Single shaft, slender type of instrument including micro forceps, micro scissors and aneurysm clip applicators along with long bipolar coagulation forceps can be used to overcome this issue.³⁵⁾

(3) Decrease intra operative orientation

Small working space may create confusion in identification of neurovascular structures intra operatively. The neuro navigation tool can be used to overcome this issue.⁶⁾

(4) Unidirectional surgical corridor

The surgical corridor of dissection cannot be changed during surgery. The pre opening information regarding exact location and size of craniotomy to determine precise trajectory is an essential part of keyhole approach. The Tailor made keyhole surgery with computer simulation using 3D computed tomography angiography is useful. The various shape and sizes of virtual small craniotomy can be generated by modern work station to visualize the target lesion through the keyhole.²³⁾

Complications related to supra orbital craniotomy and their avoidance

Staying at least 5 mm lateral to the supra orbital notch or foramen with the craniotomy may significantly reduce the risk of supraorbital nerve palsy.⁹⁾²⁶⁾ A more medial craniotomy can be performed without damage to supraorbital nerve by dissecting below the calvarium and elevating the pericranium with the supra orbital nerve.²⁵⁾

The frontalis branch of facial nerve can be injured if the incision extends greater than 13 mm lateral to the zygomatic process of frontal bone.²⁵⁾ Therefore limiting the lateral extension of the incision as well as use of cautery in the temporalis muscle below the zygomatic process reduces the risk of this nerve injury.²⁵⁾²⁶⁾

A large frontal sinus can be injured during making supraorbital keyhole craniotomy, and may led to CSF leakage post operatively as sinus repair with pericranial patch is not possible in such a small craniotomy. So a large frontal sinus coming in planned craniotomy site of supraorbital keyhole surgery is a contraindication for keyhole surgery.²³⁾

CONCLUSIONS

Keyhole surgery evolved as a minimally invasive, safe and effective treatment modality for treatment of selected ICA, AcomA and MCA aneurysms. The approach may be most suitable for properly oriented, small; preferably unruptured aneurysms of anterior circulation. In the experienced hand, keyhole approach can be used in patients with ruptured anterior circulation aneurysm in good WFNS grade. This technique has the advantages over standard pterional craniotomy such as minimal soft tissue damage with better cosmetic outcomes, satisfactory aneurysm occlusion rate, less operative time, less blood loss and patients can be discharge early from the hospital. In future, further modifications in the surgical instrument, computer simulation and advance microscope may further improve the safety of procedure.

Disclosure

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

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