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Review Article

Supraorbital keyhole approach for paraclinoid aneurysms clipping: A case series with literature review

Awfa Aktham Abdulateef[1], Shuhei Morita[1], Mustafa Ismail[2], Mayur Sharma[3], Samer S. Hoz[4], Shinichi Numazawa[1], Yasunobu Ito[1], Sadayoshi Watanabe[1], Kentaro Mori[1]

[1]Department of Neurosurgery, Tokyo General Hospital, Tokyo, Japan, [2]Department of Neurosurgery, Neurosurgery Teaching Hospital, Baghdad, Iraq, [3]Department of Neurosurgery, University of Minnesota, Minneapolis, MN, [4]Department of Neurosurgery, University of Cincinnati, Cincinnati, Ohio, United States.

E-mail: *Awfa Aktham Abdulateef - awfa.aktham@gmail.com; Shuhei Morita - morita.shuhei@twmu.ac.jp; Mustafa Ismail - mustafalorance2233@gmail.com; Mayur Sharma - drmayursharmaneuro@gmail.com; Samer S. Hoz - hozsamer2055@gmail.com; Shinichi Numazawa - shin.numazawa@gmail.com; Yasunobu Ito - yasuitoh@mt.strins.or.jp; Sadayoshi Watanabe - s053w@ybb.ne.jp; Kentaro Mori - kentaro.mori@mt.strins.or.jp

***Corresponding author:**
Awfa Aktham Abdulateef,
Department of Neurosurgery,
Tokyo General Hospital, Tokyo,
Japan.

awfa.aktham@gmail.com

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ABSTRACT

Background: Paraclinoid aneurysms (PcAs) are challenging aneurysms due to the complexity of their relation to the surrounding bony and neurovascular structures. Although over the past decade, their management strategy has shifted from transcranial to endovascular approaches; here, we try to revolve around a subcategory to which minimal invasive supraorbital keyhole (SOK) surgery is feasible depending on specific radiological criteria with a literature review.

Methods: A group of unruptured PcAs was managed surgically, with a subset that was clipped through the SOK approach. They were selected by preoperative simulation images using 3D computed tomography (CT) angiography (CTA). We also conducted an extensive literature review based on a database available on PubMed and Google Scholar, the yielded cases from the literature review plus our cases were analyzed according to six parameters including their size, location, dome direction, need for clinoidectomy and proximal cervical control, and surgical outcome.

Results: From February 2009 to August 2022, 49 cases of unruptured PcAs were managed by clipping, and of these, four cases were clipped by the SOK approach, in addition, four cases were yielded through the literature review. The sizes of the PcAs ranged from 3 to 8 mm. Their location fluctuated from anterior to the superomedial wall and their domes pointed superiorly except for one which points posteriorly. Six of eight cases required anterior clinoidectomy, the outcome was uneventful.

Conclusion: A subset of unruptured PcAs are amenable to SOK with criteria such as unruptured small aneurysm (<10 mm) and projected superiorly. These characteristics can be determined preoperatively using CTA.

Keywords: Ophthalmic aneurysm, Paraclinoid aneurysm, Supraorbital keyhole approach

INTRODUCTION

The paraclinoid aneurysm (PcA) was described first by Nutik.[12] Various authors have defined it differently but the most widely used is an aneurysm originating from the internal carotid artery (ICA) distal to the proximal dural ring and proximal to the posterior communicating artery,[9] and further subdivided into ophthalmic, superior hypophyseal, and carotid cave aneurysms. They account for 5–15% of all intracranial aneurysms and challenging due to their proximity to the

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optic nerves and their relationship to complicated bony and dural structures. Therefore, these specific anatomic features render ICA proximal control challenging, to obtain safe aneurysm exposure.[3] Although the advent of endovascular surgery and the development of new flow-diverting devices have become the mainstream in the management of PcA;[4] yet, surgical clipping is still the treatment of choice, permitting a definitive and durable exclusion of ruptured and unruptured aneurysms, regardless of their projection type, with acceptable morbidity and mortality, with 93% of patients reporting good to the moderate outcome, and 71% of them had an improved or unaffected vision.[6,8]

PcA clipping mostly requires anterior clinoidectomy, optic canal opening, and resection of the dural ring, therefore standard or modified pterional approach including the Dolenc skull base technique is preferable; however, a subset of PcA can be clipped through minimal invasive keyhole mini-craniotomy.[11]

The supraorbital keyhole (SOK) surgery provides adequate aneurysmal access while minimizing trauma to the surrounding structures, including the skin, bone, dura, and, most importantly, the brain,[5] yet not applicable to all PcA.

We intend to propose parameters for selecting the SOK approach in clipping PcA aneurysms by discussing our four PcA aneurysms that were clipped using SOK surgery and reviewing the literature.

MATERIALS AND METHODS

Present cases

From February 2009 to August 2022, a group of patients with unruptured PcAs were managed surgically, and a subset of them was clipped through SOK with maximum craniotomy size (27~30 mm) at Tokyo General Hospital and National Defense Medical College. This study was approved by the Local Institutional Review Boards of Tokyo General Hospital and National Defense Medical College. Patient consent was not required due to the study's retrospective nature from medical records, and patients' identities were not included in the study.

Preoperative simulation

Preoperative planning was based on 3D computed tomography angiography (CTA) with a constant medium. Data were transferred to a workstation (Ziostation 2.4; Ziosoft, Inc., Tokyo, Japan). Optimal keyhole size and location were simulated. The anatomical relationship between PcA and the anterior clinoid process (ACP) was also checked [Figure 1]. At this point if the target aneurysm can be visualized well through this virtual keyhole, we elected the SOK approach for PcA clipping.

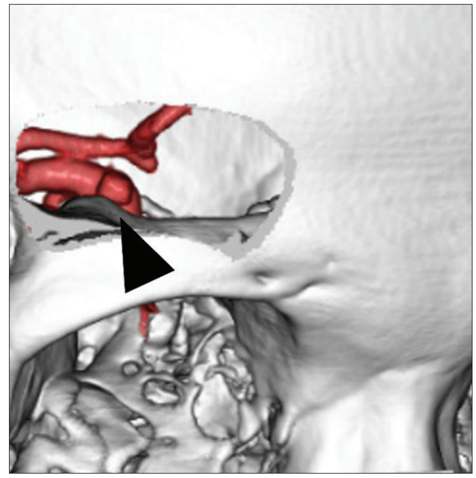

Figure 1: Preoperative simulation 3D computed tomography angiography with a virtual supraorbital keyhole craniotomy the paraclinoid aneurysm of the right internal carotid artery is seen well through this virtual keyhole. The aneurysmal dome is attached to the anterior clinoid process (arrowhead).

Surgical technique

Our surgical technique has been previously published.[10] After the induction of general anesthesia, the patient was positioned supine with his/her head rotated to the opposite side at 30°. The neck was also prepped to expose and secure a cervical ICA. Motor-evoked potential was monitored. A 4–5 cm eyebrow skin incision was made and temporal muscle was partially dissected at McCarty's point. Approximately 27~30 mm × 20~25 mm mini-SOK craniotomy was performed. The frontal fossa was flattened to drill away any bony ridge over the orbit. The dura mater was opened in a curvilinear fashion and lifted. The sub-frontal approach was chosen to access the optic nerve. The carotid cistern was opened and cerebrospinal fluid was aspirated. The medial Sylvian fissure was opened, and the frontal lobe was retracted slightly. The ICA, anterior cerebral artery (A1), and middle cerebral artery (M1) were dissected and exposed to find a PcA. If the ACP hiders the proximal neck, intradural anterior clinoidectomy was partially performed. The dural flap was elevated from the ACP and roofed over the aneurysm dome for protection from the drilling. The ACP was partially drilled using an ultrasonic bone curette. After PcA was dissected from the optic nerve or distal dural ring, the neck was clipped. Dura mater was closed in a water-tight fashion. The bone was fixed back using mini-plates and screws. The temporalis and frontalis muscles are approximated. The skin was meticulously closed in three layers.

Figures 2 and 3 show representative cases of PcAs clipped through a SOK with and without intradural anterior clinoidectomy.

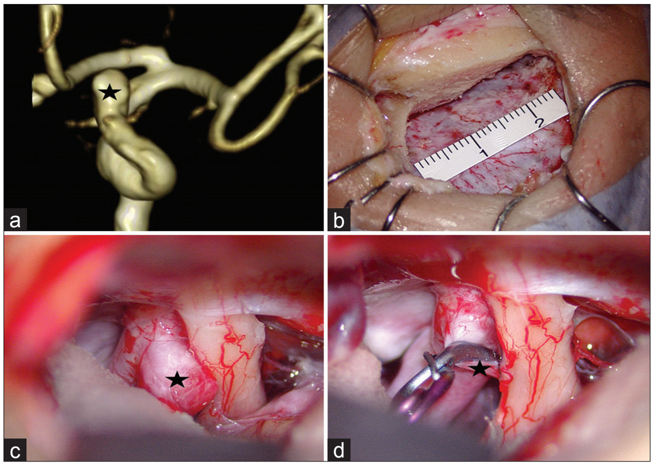

Figure 2: Preoperative image and intraoperative views of the left paraclinoid aneurysm (black star). (a) The preoperative magnetic resonance angiography shows a superiorly projecting anterior wall-type paraclinoid aneurysm. (b) Intraoperative view of Supraorbital keyhole mini-craniotomy craniotomy size. (c) The paraclinoid aneurysm was attached and compressed the left optic nerve but apart from the anterior clinoid process. (d) Intraoperative view post aneurysmal clipping.

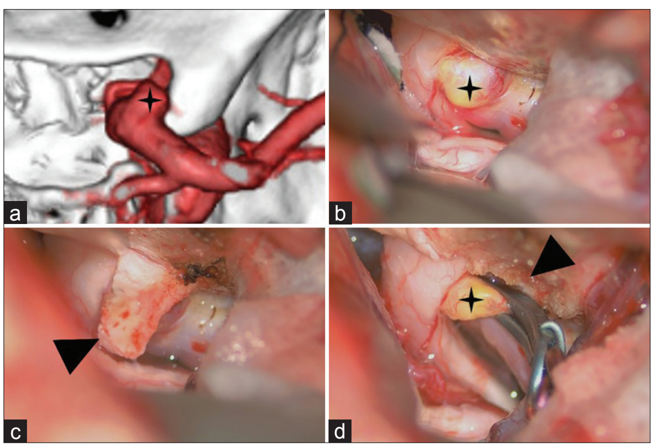

Figure 3: Preoperative image and intraoperative views of the right paraclinoid aneurysm (black star). (a) The preoperative 3D computed tomography angiography shows the paraclinoid aneurysm attaching to the anterior clinoid process (ACP). (b) Intraoperatively, the aneurysmal dome is attached to the right optic nerve and the ACP. (c) The dura mater flap (arrowhead) was peeled from the ACP and covered over the aneurysm for protection during the drilling of the ACP. (d) Post partial removal of ACP (arrowhead) and aneurysmal clipping.

Postoperative imaging

On the day after the operation, CT, 3D CTA, and magnetic resonance including diffusion-weighted images were performed to determine the completeness of the clipping and identified any hemorrhagic and ischemic complications. If no clinical or radiological abnormalities were confirmed, the patient was discharged a few days after the operation.

Literature review

The review of the literature was performed on two different online medical databases (PubMed, and Google scholar), using search terms such as "supraorbital keyhole," "pterional keyhole," "paraclinoid aneurysm" "superior hypophyseal aneurysm," "carotid cave aneurysm," and "juxtadural ring aneurysm" (being SOK and pterional keyhole considered as falling under this definition) (All Fields), combined with the Boolean operators "OR" and "AND." The last search was conducted on August 31, 2022, and went back as far as data were available. The search strategy is summarized in Figure 4.

RESULTS

Present cases

We had 49 patients with unruptured PcA aneurysms, and four of them were selected for SOK based on the preoperative simulation images. Those four unruptured PcA aneurysms have a size range (of 3~6 mm) located on the anterior wall or ophthalmic segment with dome-directed superiorly.

Three patients needed intradural anterior clinoidectomy and one patient required suction decompression through cervical ICA during the clinoidectomy.

None of the patients had residual neck, visual impairment, or neurodeficit [Table 1, cases 1–4].

Literature review

The search initially yielded 33 papers (410 aneurysms) that mentioned SOK or its variants approaches for the PcAs; then, we exclude 32 papers (406 aneurysms) due to incomplete data about aneurysm radiological characteristics, intraoperative data, or the outcome, the final review yielded two papers (four aneurysms).

The reviewed PcAs were located either in the ophthalmic segment or the subarachnoid hemorrhage (SAH) segment or in the carotid cave. Their domes were directed superior or superomedial (one was posterior), and their size was <10 mm, three of them required complete clinoidectomy only.

All of them were unruptured and there were no postoperative complications [Table 1, case 5–8].[1,7]

In total the eight patients all had unruptured aneurysms, their dome size was less than 10 mm and directed superior (one is posterior), but none is inferior. Six out of the eight cases required either complete or partial anterior clinoidectomy, the outcome for all was uneventful, and mRS 0 or 1.

DISCUSSION

In this study, we analyzed eight PcAs treated through SOK. All aneurysms were unruptured, small (<10 mm), neck located at

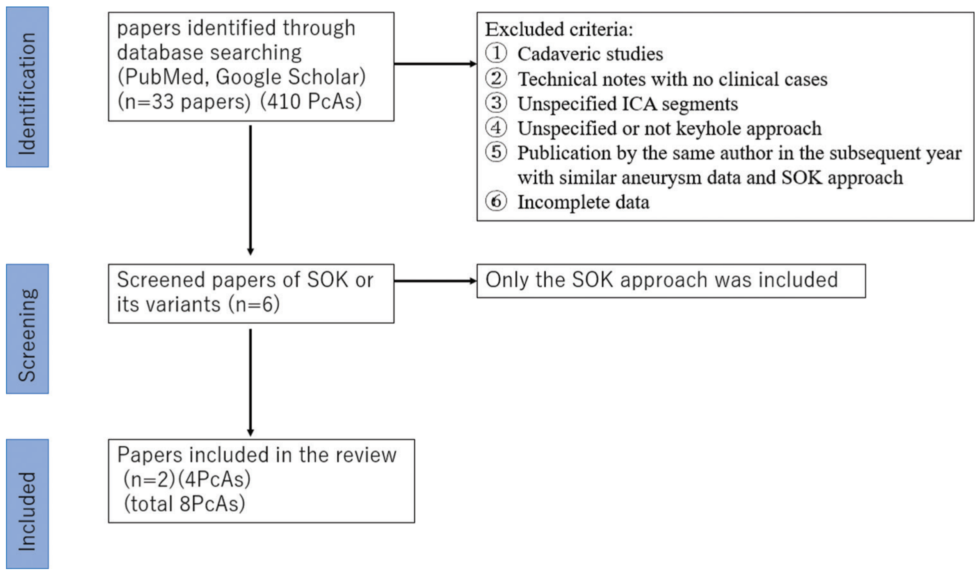

Figure 4: PRISMA flowchart showing the review sources, search strategy, and study selection. ICA: Internal carotid artery, n: number, PcAs: Paraclinoid aneurysms, PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses, SOK: Supraorbital keyhole.

Table 1: Paraclinoid Aneurysms clipped by supraorbital keyhole.

Author	Age/Gender	Side	Site	Size	Direction	Proximal control	Clinoidectomy	mRS
Present cases	72/M	Rt	Anterior wall	3 mm	Superolateral	No	Partial	0
	75/M	Lt	Ophthalmic	3 mm	Superior	Yes	Partial	0
	55/F	Lt	Anterior wall	6 mm	Superiomedial	No	NO	0
	75/F	Rt	Ophthalmic	4 mm	Superomedial	No	Partial	0
Choque-Velasquez *et al*. 2018[7]	51/F	Lt	Ophthalmic	2.8 mm	Superior	No	NO	0
Andrade-Barazarte *et al*. 2016[1]	68/F	Lt	Ophthalmic	N/A	Superior	No	Complete	1
	60/F	Lt	SHA	N/A	Superiomedial	No	Complete	0
	26/F	Lt	Carotid cave	8 mm	Posteromedial	No	Complete	0

SAH: Superior hypophyseal artery, F: Female, M: Male, Rt: Right, Lt: Left, mRS: Modified ranken scale, N/A: Not available.

the ophthalmic segment, SAH segments or carotid cave, and dome pointed superiorly except in one case. Six cases required anterior clinoidectomy and no one required the opening of the optic canal, one case only needs neck exposure for succession decompression, and classical microneurosurgical instruments were used, all cases were clipped completely without any neurological deficits including visual impairment. Therefore, SOK can be applied to this subset of PcAs safely.

In the past few years, endovascular therapies, mostly after the introduction of flow diversion, have gained popularity and have become a first-line treatment for such aneurysms, though associated with a lower rate of complete aneurysm occlusion and more frequent recurrences.[8] Added, the need for long-term follow-up and prolonged use of double antiplatelet therapy are drawbacks of endovascular therapy.[7]

Recently, SOK was introduced as an alternative approach for clipping ICA aneurysms,[15] due to an increase in the demand for a shorter operation time and a less invasive method for achieving a better effect without complications,[4] However, reports about surgical treatment of PcA through this approach are limited.

The SOK is not generally indicated to clip PcA, as suggested by Toyooka *et al*., who performed keyhole clipping in only two PcAs (3.7%) among the 54 PcAs, which were very small in size and required partial anterior clinoidectomy;[15] yet, this limitation of SOK is explained by SOK that has a straight-axis trajectory, so limited operative angle hinders multidirectional observation and the manipulation of the target aneurysm. Therefore, in our opinion, the indication can be influenced by a sum of three criteria related to the aneurysm, including its dome size, direction, and neck sites. Therefore, preoperative virtual simulation using 3D CTA is mandatory for the selection of PcA amenable to SOK.

The aneurysm condition whether intact or ruptured will not affect the selection of SOK practically, nevertheless, all presented eight cases were unruptured. Under the condition of brain swelling and dark operative field after subarachnoid hemorrhage, it should be difficult and dangerous to dissect ruptured PcA through a narrow SOK bone window.[13]

The location of the PcAs and dome direction was extremely crucial because the inferiorly or anteromedially directed aneurysm requires further manipulation of the ICA, drilling of the ACP, and optic nerve traction. This means the need for a wide area that SOK cannot provide. Most of the operated aneurysms plus the aneurysms in reviewed papers' direction range from superomedial to lateral. No papers had discussed in detail the relationship between the dome direction and choosing the SOK.

The complete or partial anterior clinoidectomy through SOK in both presented and reviewed patients was mandatory for proximal neck security in six cases of the eight PcAs. The surgeon needs meticulous surgical technique to remove ACP through a narrow keyhole mini-craniotomy.

The residual neck (dog-ear remnant) is the most documented complication of SOK, due to a lack of visualization of the clip condition[2] and it usually occurs in posterity-located or directed aneurysms so it will require more careful checking for aneurysmal dome direction and origin before selection of the approach, high rates of visual impairment generally after PcA clipping had been reported, as Rouchaud *et al.*[14] found that 39% experienced postoperative visual complications. The visual impairments occur due to the optic nerve injury during anterior clinoidectomy and aneurysmal dissection from optic nerve or retinal artery embolism. Contrary to these facts, none of the presented cases or the reviewed ones treated by SOK had experienced postoperative visual deficits due to their small size. Therefore, selecting only small PcAs for clipping through SOK is reasonable.

Proper preoperative patient selection using the radiological simulation with small aneurysmal size located in the range from lateral to the anteromedial wall or superior wall and direction superiorly or superomedial but not inferiorly considered to be favorable factors.

Limitations

The present study has several limitations. Including the patients' data being retrospectively collected, despite being based on a prospectively maintained database, complete data were not available for 406 aneurysms clipped by SOK, and these patients were excluded from the study.

The presented cases are single-surgeon experiences that may have impacted outcomes.

In addition, formal neuro-ophthalmological evaluation was performed in all the presented cases but not all of them.

Finally, although this study demonstrates the efficacy of SOK clipping for PcAs with good clinical outcomes, further studies larger groups, and randomized control trials, are needed to establish the superiority of SOK over alternative surgical approaches for this subset of PcAs.

CONCLUSION

For unruptured PcAs, the SOK approach may be appropriate in selected patients. Unruptured, small size and superior projection are favorable characteristics for the SOK approach, which can be determined preoperatively.

Declaration of patient consent

Patients' consent not required as patients' identities were not disclosed or compromised.

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Conflicts of interest

There are no conflicts of interest.

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