Superciliary keyhole surgery for unruptured posterior communicating artery aneurysms with oculomotor nerve palsy: maximizing symptomatic resolution and minimizing surgical invasiveness

Clinical article

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Object. For oculomotor nerve palsy (ONP) induced by unruptured posterior communicating artery (PCoA) aneurysms, the authors performed surgical clipping via a superciliary keyhole approach as an optimal treatment modality with high efficiency and low invasiveness. In this study, they then evaluated the technical feasibility, safety, clinical outcomes, including recovery from ONP as well as cosmetic results, and durability of the procedure.

Methods. Thirteen patients presenting with complete (7 patients) or incomplete (6 patients) ONP underwent surgery via a superciliary approach. The operative video record was used to evaluate the technical feasibility, neurological examinations and CT were performed to analyze the safety of the treatment, and neuroophthalmological examinations and 3D CT angiography were undertaken to determine the effectiveness and durability of the treatment.

Results. In all cases, the aneurysms were successfully clipped using a 3.5-cm eyebrow incision and supraorbital minicraniotomy. The mean operative time was 108 ± 24 minutes. Twelve (92.3%) of the 13 patients showed complete resolution of the ONP. All 6 patients (100%) with incomplete ONP recovered completely within 1–2 months after surgery, whereas 6 (85.7%) of the 7 patients with complete ONP recovered completely within 1–6 months after surgery. Cosmetic results for the operative wounds were excellent without frontalis palsy. The durability of the treatment was ascertained based on 3D CT angiography obtained 1 year after surgery.

Conclusions. Surgical clipping via a superciliary keyhole approach can be an optimal treatment modality for PCoA aneurysms inducing ONP because it is effective, safe, and durable. (DOI: 10.3171/2011.5.JNS102087)

Key Words • aneurysm • minimal surgical procedure • oculomotor nerve • posterior communicating artery • surgical clipping • vascular disorder

Isolated oculomotor nerve palsy (ONP) induced by an unruptured posterior communicating artery (PCoA) aneurysm is a well-known clinical entity requiring urgent treatment. Surgical clipping of the aneurysm via a pterional approach has been considered the gold standard treatment, as it provides immediate relief from pulsating compression on the oculomotor nerve and durable occlusion of the aneurysm neck. However, given the surgical invasiveness of this procedure and patient reluctance to undergo surgery, endovascular treatment has become a feasible alternative, even though endovascular coiling carries the risk of delayed and incomplete recovery from ONP as well as coil compaction.1,2,5,8,16

Abbreviations used in this paper: AChA = anterior choroidal artery; ICA = internal carotid artery; ONP = oculomotor nerve palsy; PCoA = posterior communicating artery.

Therefore, instead of a conventional pterional craniotomy, we used a superciliary keyhole approach for aneurysm clipping to reduce surgical invasiveness, and then we evaluated the technical feasibility, safety, clinical outcomes, including recovery from ONP as well as cosmetic results, and durability of the treatment.

Methods

Patient Population

Between 2007 and 2010, 15 patients presented with isolated ONP associated with an unruptured PCoA aneurysm. Thirteen of the 15 patients underwent surgery via a superciliary keyhole approach, whereas the other 2 patients were treated using endovascular coiling as their ages were > 75 years. The clinical and angiographic fea-
tudes of the 13 patients who underwent the superciliary keyhole approach are presented in Table 1. The mean age of the patients was 51.5 ± 11.0 years (range 37–69 years).

On preoperative angiograms, the aneurysm height, that is, the maximal perpendicular distance from the neck plane to the top of the aneurysm dome, ranged from 7 to 12 mm (mean ± SD) 8.4 ± 1.7 mm). The maximum transverse diameter of the aneurysm neck ranged from 2 to 6 mm (3.8 ± 1.1 mm), and the maximum aneurysm diameter, which is the largest of all cross-sections along the height of the aneurysm, ranged from 3 to 8 mm (5.0 ± 1.5 mm). The aneurysms had multilobulated configurations with a high aspect ratio (range 2.1–3.5), where the aneurysm aspect ratio was defined as the ratio of the maximum perpendicular height to the average neck diameter.

Seven (53.8%) of the 13 patients presented with complete ONP, and the findings included severe ptosis of the upper lid; ophthalmoplegia causing impairment of the medial, upward, and downward gazes; pupillary dysfunction; and loss of accommodation. The remaining 6 patients (46.2%) presented with incomplete ONP, in which the functions controlled by the oculomotor nerve were affected to varying degrees, including partial ptosis and partial extraocular movement of the upward, medial, and downward gazes. The preoperative duration of ONP ranged from 1 to 20 days in the 13 patients.

All the patients underwent surgery within 12 hours of admission to eliminate the risk of impending aneurysm rupture and improve the resolution of ONP. In 2 patients, an ipsilateral concomitant aneurysm arising from the middle cerebral artery bifurcation was also clipped.

### Operative Technique

The patient is placed supine with the head rotated contralaterally 20° and extended slightly. A superciliary incision is made starting from the midpupillary line to behind the frontal process of the zygomatic bone, approximately 3.5 cm in length. A small (2 × 2.5 cm) craniotomy is performed above the orbital ridge using a high-speed drill with a footplate attachment after making a single frontobasal lateral bur hole posterior to the temporal line. The inner edge of the craniotomy above the orbital rim is drilled and beveled, while the frontal floor prominences and a part of the lesser sphenoid wing are flattened.

After a dural incision in a curved fashion, brain relaxation is achieved by opening the optic nerve and carotid cisterns with minimal brain retraction. Limited opening of the sylvian fissure medially facilitates more frontal lobe retraction without temporal lobe traction, allowing visualization up to the carotid bifurcation. The carotid cistern is opened along the superior or medial aspect of the internal carotid artery (ICA), and the distal PCoA is identified in the opticocarotid triangle. The arachnoid adherent to the ICA is rolled laterally to expose the aneurysm base and the origins of the PCoA and anterior choroidal artery (AChA).

Temporary clips are applied to the proximal ICA and large PCoA. Once the proximal and distal aspects of the aneurysm neck are defined, a permanent clip is advanced between the PCoA and AChA. A straight or gently curved clip is invariably used for most PCoA aneurysms. After clipping the aneurysm’s neck, its fundus is punctured or sharply divided for complete relief from compression on the oculomotor nerve. The aneurysm dome, which is adherent to the oculomotor nerve, is not dissected from the nerve to avoid nerve injury. The clip blades are then inspected to ensure that the aneurysm is completely occluded, that the PCoA and AChA are not compromised, and that the oculomotor nerve is free.

After completing the intracranial procedure, the dural incision is sutured watertight, and any epidural bleeding

### TABLE 1: Summary of characteristics in 13 patients with a PCoA aneurysm inducing ONP*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Height (mm)</th>
<th>Max Neck Diameter (mm)</th>
<th>Max Aneurysm Diameter (mm)</th>
<th>Aneurysm Characteristic</th>
<th>Severity of ONP</th>
<th>Duration of ONP (days)</th>
<th>Operative Duration (min)</th>
<th>Clipped Concomitant Aneurysm</th>
<th>Resolution of ONP</th>
<th>Time to Complete Resolution of ONP (mos)</th>
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<tr>
<td>1</td>
<td>42, F</td>
<td>7</td>
<td>3</td>
<td>4</td>
<td>2.2</td>
<td>complete</td>
<td>3</td>
<td>120</td>
<td>—</td>
<td>complete</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>68, F</td>
<td>11</td>
<td>4</td>
<td>6</td>
<td>2.8</td>
<td>incomplete</td>
<td>1</td>
<td>120</td>
<td>—</td>
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<td>2</td>
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<tr>
<td>3</td>
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<td>4</td>
<td>2.3</td>
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<td>1</td>
<td>180</td>
<td>MCA aneurysm</td>
<td>complete</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>69, F</td>
<td>7</td>
<td>4</td>
<td>5</td>
<td>2.3</td>
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<td>100</td>
<td>—</td>
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<td>6</td>
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<tr>
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<td>48, M</td>
<td>7</td>
<td>2</td>
<td>5</td>
<td>3.5</td>
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<td>13</td>
<td>90</td>
<td>—</td>
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<tr>
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<td>52, M</td>
<td>12</td>
<td>5</td>
<td>8</td>
<td>3.0</td>
<td>complete</td>
<td>6</td>
<td>90</td>
<td>—</td>
<td>incomplete</td>
<td>—</td>
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<tr>
<td>7</td>
<td>43, F</td>
<td>10</td>
<td>6</td>
<td>7</td>
<td>2.1</td>
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<td>20</td>
<td>90</td>
<td>—</td>
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<tr>
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<td>60, F</td>
<td>7</td>
<td>3</td>
<td>4</td>
<td>2.3</td>
<td>incomplete</td>
<td>4</td>
<td>160</td>
<td>MCA aneurysm</td>
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<tr>
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<tr>
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<td>45, M</td>
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<tr>
<td>11</td>
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<td>9</td>
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<td>5</td>
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<tr>
<td>12</td>
<td>54, M</td>
<td>9</td>
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<td>6</td>
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<td>110</td>
<td>—</td>
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<tr>
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<td>8</td>
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<td>3</td>
<td>2.6</td>
<td>incomplete</td>
<td>3</td>
<td>70</td>
<td>—</td>
<td>complete</td>
<td>1</td>
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</tbody>
</table>

* MCA = middle cerebral artery; Trans = transverse.
is meticulously controlled. An anchor screw technique is commonly used to place the dural tenting sutures, and the bone flap is then fixed in place using low-profile titanium plates and screws. The bur hole and bone gaps around the bone flap are eliminated using a Medpor implant (Porex Surgical, Inc.) or hydroxyapatite paste. Thereafter, the pericranium, temporalis and frontalis muscles, and subcutaneous layer are closed layer by layer. Finally, the skin is closed with a subdermal resorbable suture and reinforced with sterile tape.

Technical Feasibility

The operative report and operative video record were used to evaluate the technical feasibility of the aneurysm neck clipping. In addition, intraoperative blood loss, transfused blood, and duration of the operation were assessed; the duration of surgery was defined as the time taken from the skin incision to the skin closure.

Postoperative Evaluation

Postoperative neurological examinations and CT scanning were used to evaluate any procedure-related intracranial complications, and the clipping status of the aneurysm was ascertained using 3D CT angiography on the 1st postoperative day.

Postoperative ophthalmological evaluations were performed by an ophthalmologist (B.C.) until complete recovery from the ONP or 1 year after surgery. The criteria for complete recovery from ONP were complete resolution of ptosis; normalized ocular motility in the upward, downward, and medial gaze; and complete or partial recovery of pupillary reaction. Normalized ocular motility was verified by the absence of diplopia as reported by the patient; displayed by a full range of ocular motility in the upward, downward, and medial gaze as observed by an examiner; and demonstrated by normalization of the field of binocular single vision as examined using the Goldmann perimeter.

The aesthetic aspect of the operative wound was evaluated more than 6 months after surgery. The length of the incision was measured, and the eyebrow positions and the presence of frontalis palsy and temporalis atrophy were analyzed.

The durability of aneurysm obliteration was ascertained on the basis of repeated 3D CT angiography, which was performed 1 year after surgical clipping of the aneurysm.

Results

Technical Feasibility, Safety, and Durability

For all patients, direct clipping of the aneurysm neck was successfully performed using a straight or gently curved clip. In addition, the small supraorbital craniotomy enabled all requisite surgical maneuvers to be performed without difficulty, including sylvian fissure dissection, visualization up to the carotid bifurcation, exposure of the aneurysm base and origin of the PCoA and AChA, and application of the aneurysm clip.

The mean duration of surgery was 108 ± 24 minutes (range 70–160 minutes) among the 13 cases. The operative duration for the 11 cases with a single PCoA aneurysm without concomitant aneurysms ranged from 70 to 120 minutes (100 ± 15 minutes).

The amount of blood loss that occurred during surgery was negligible and was < 50 ml in all cases. No intraoperative blood transfusion or surgical wound drain was required for any patient.

No procedure-related complications were observed based on neurological examinations and CT scans. The postoperative CT scans demonstrated no intracranial hemorrhages or infarcted lesions, and the postoperative CT angiograms revealed complete obliteration of the aneurysm without a residual neck in all cases. Moreover, repeated CT angiograms obtained 1 year after surgery did not reveal any recurrence of aneurysms. Operative durations and surgical outcomes for the patients are summarized in Table 1.

Neuroophthalmological Follow-Up

Twelve (92.3%) of the 13 patients showed complete resolution of the ONP. All 6 patients (100%) with preoperative incomplete ONP recovered completely within 1–2 months after surgery. Meanwhile, among the 7 patients with complete ONP, 6 (85.7%) recovered completely within 1–6 months after surgery. The remaining patient (Case 6) experienced an incomplete recovery in which ptosis and the inability to adduct were nearly completely resolved, although residual limitations of the upward and downward gaze remained at the 1-year follow-up.

Aesthetic Outcomes

The length of the postoperative scar ranged from 3.2 to 3.8 cm (3.5 ± 0.2 cm), and there was no bald spot in the affected eyebrow. The eyebrow positions were balanced in all the patients, and there was no palsy of the frontalis muscle related to a lesion of the frontal branch of the facial nerve. There was no anterior temporal hollow due to atrophy of the temporalis muscle or limited mouth opening (pseudoankylosis of the temporomandibular joint) caused by scarring of the injured temporalis muscle.

Illustrative Cases

Case 6

History and Examination. This 52-year-old man presented with a 6-day history of complete ONP of the right eye caused by an unruptured PCoA aneurysm (Fig. 1A). He had been suffering from severe ptosis of the upper lid and ophthalmoplegia causing severe impairment of the medial, upward, and downward gaze (Fig. 1B).

Operation. He underwent a superciliary approach using a 3.5-cm eyebrow incision and supraorbital mini-craniotomy (Fig. 1C), which allowed aneurysm neck clipping without difficulty (Fig. 1D). When a puncture of the aneurysm fundus revealed an intrasaccular thrombus adherent to the oculomotor nerve, removal of the thrombus and dissection between the aneurysm and the oculomotor nerve were avoided to preclude nerve injury. The surgical procedure took 90 minutes to finish.
Postoperative Course. The preoperative ptosis and inability to adduct were nearly completely resolved within 6 months of surgery (Fig. 1E), and yet the upward and downward gaze were still somewhat limited 1 year after surgery (Fig. 1F). The patient did experience a slight restriction of the binocular visual field, which affected his driving performance. The blind spot from the edge of his peripheral vision to the back of the car, which is not visible in the side mirror, was enlarged on the left side. In addition, the patient reported some difficulties when playing tennis. In particular, serving, overhead smashes, and high volleys were very difficult given the limitation of his upward gaze.

Case 10

History and Examination. This 45-year-old man presented with incomplete ONP and had been suffering from right ptosis and diplopia for 2 days following right retrobulbar pain and a frontal headache. The eye under the lid was oriented slightly down and out when looking straight ahead (Fig. 2A). The upward, downward, and medial gaze of the right eye was significantly impaired. The pupil was also dilated and unreactive to light. A catheter angiogram revealed a PCoA aneurysm with a height of 8 mm and a neck diameter of 3 mm (Fig. 2B).

Operation. The patient underwent surgery via a superciliary approach on the day of admission (Fig. 2C). An aneurysm with the dome attached to the oculomotor nerve was found arising from the ICA between the origins of the PCoA and AChA (Fig. 2D). After clipping the aneurysm neck, a sharp division of the fundus using microscissors relieved the pulsating compression on the oculomotor nerve and allowed complete inspection of the PCoA and AChA (Fig. 2E). The operative duration was 100 minutes.

Postoperative Course. On the 2nd postoperative day, the right ptosis was completely resolved and no diplopia was experienced in the primary gaze (Fig. 2F). At the next follow-up 2 weeks after surgery, the patient exhibited no diplopia in any gaze direction and demonstrated complete recovery of pupillary reaction (Fig. 2G and H). The cosmetic outcome of the small surgical wound was excellent without palsy of the frontalis muscle.

Discussion

Since the concept of a superciliary keyhole approach using an eyebrow incision and supraorbital minicraniotomy was advocated by Perneczky and colleagues, the procedure has been widely used for lesions of the anterior cranial fossa and parasellar region. In addition, we have proposed it as a reasonable alternative to a pterional approach for unruptured small aneurysms in the anterior cerebral circulation involving the supraclinoid ICA, A1 segment, anterior communicating artery, M1 segment, and middle cerebral artery bifurcation. However, its usefulness, advantages, and clinical outcome in treating an unruptured PCoA aneurysm inducing ONP have not yet been well elucidated. Results of the present study suggest that a superciliary keyhole approach may be an optimal treatment modality based on the 92.3% rate of complete resolution of ONP and the durability of aneurysm obliteration following successful clipping of the aneurysm neck.

Fig. 1. Case 6. A: A 3D CT angiogram demonstrating a PCoA aneurysm. B: Preoperative photograph showing complete ONP of the right eye. C: Intraoperative photograph demonstrating a 3.5-cm eyebrow incision and supraorbital minicraniotomy. D: Intraoperative photograph showing a PCoA aneurysm (arrow). E: Six-month postoperative photograph showing nearly completely resolved ptosis and inability to adduct. F: One-year postoperative photograph showing upward gaze limitation of the right eye.
via a minimally invasive procedure taking approximately 1.5 hours.

Although a superciliary approach involves a small limited craniotomy, which imposes narrow viewing angles and coaxial control of the microinstruments, it offers an adequate opening for dealing with narrow-necked aneurysms arising from the communicating segment of the ICA. In the present case series, the maximum diameter of the aneurysm neck was ≤6 mm, although the aneurysm height ranged from 7 to 12 mm. Minimal retraction of the frontal lobe following only limited dissection of the medial sylvian fissure provides sufficient room to control the proximal ICA and apply a straight or slightly curved clip to the lesion.

Figure 3 depicts the surgical corridor and an intraoperative visualization of the superciliary and pterional approaches. While a pterional craniotomy allows subfrontal, pterional, and multidirectional approaches through a large cranial opening, access to the supraclinoid ICA and the requisite procedures for a PCoA aneurysm can be performed using a subfrontal approach via a supraorbital minicraniotomy. Even though this small supraorbital craniotomy reduces light and sight and also limits the maneuverability of the surgical instruments, it actually provides a straightforward surgical corridor with adequate visualization and access to a PCoA aneurysm. Plus, the technical limitations produced by the small opening can be overcome by applying appropriate surgical indications, including small or narrow-necked aneurysms, technical advancement through a learning curve, and the use of proper microinstruments.

The PCoA aneurysms in the present series were clipped under microscopic control without endoscopic assistance. As most PCoA aneurysms project laterally, the necks of these lesions are clearly exposed under a microscope. Notwithstanding, the use of an endoscope can sometimes enhance the safety and reliability of the surgery by providing additional information on the precise position of the aneurysm clip, the PCoA, adjacent perforators on the posterolateral surface of the ICA hidden behind the aneurysm, and the oculomotor nerve close to the aneurysm. The excellent surgical outcomes in the present series would seem to be related to the narrow necks of the aneurysms despite their complex configuration, the immediate relief from compression on the oculomotor nerve by puncturing the aneurysms, and the technical precautions against surgical trauma to the oculomotor nerve. This minimally invasive surgical technique offers many benefits over a conventional pterional craniotomy, including a smaller incision without scalp shaving, a much smaller craniotomy reducing the risk of a postoperative epidural hemorrhage, decreased trauma to the body including the temporalis muscle, reduced risk of infection in the operative field, a shorter operative time, decreased blood loss, less postoperative pain, and a faster recovery. As a result, superciliary keyhole surgery reduces the reluctance of patients to undergo surgery and facilitates an early return to work postoperatively.

In most patients, recovery from PCoA aneurysm-induced ONP follows a typical pattern after surgical clipping or endovascular coiling. The levator palpebrae muscle improves first, followed by the medial rectus muscle, the inferior rectus muscle, and finally the superior rectus muscle and parasympathetic fibers of the pupil.\textsuperscript{18} However...
Superciliary approach for PCoA aneurysms

Fig. 3. Illustrations depicting surgical corridor and intraoperative visualization of superciliary (upper) and pterional (lower) approaches. While the frontal lobe retraction is exaggerated in this illustration, its real size is minimal (≤ 1 cm). Printed with the permission of J. Park, 2011.

Nevertheless, if resolution of the ONP is not complete, residual ONP can disturb important daily living activities such as driving, ascending and descending stairs, reading, and exercise and can also prevent patients from resuming their previous occupations. Thus, the treatment modality that is most likely to result in complete recovery from ONP should be recommended.

Previous literature provides a limited comparison of surgical clipping and endovascular coiling as regards recovery from ONP induced by a PCoA aneurysm. As the degree of preprocedural ONP is a major factor determining postprocedural recovery of the deficit, the rate of complete recovery of preprocedural complete ONP can be used as a comparative value. Chen et al. reported complete recovery after complete ONP in 3 (50%) of 6 patients who underwent clipping and in 2 (29%) of 7 patients who underwent coiling. Thus, the complete recovery rate after complete ONP in the present series, 83% (5 of 6 patients), is comparable to the favorable surgical results in previous studies.

Posterior communicating artery aneurysm–induced ONP can be improved after endovascular coiling, and yet complete recovery is considered less likely than after surgical clipping. Hanse et al. reported complete recovery after complete ONP in only 3 (20%) of 15 patients who underwent coiling. Moreover, in the study by Stiebel-Kalish, no complete recovery after complete ONP was recorded among 11 patients who underwent coiling, although 4 (36%) exhibited minimal residual ONP with only mild diplopia when looking up. Meanwhile, the case of incomplete recovery from ONP in the present series (Case 6) was a partially thrombotic aneurysm and resembled an endovascularly coiled aneurysm. While the aneurysmal pulsation was removed, reducing the mass effect on the oculomotor nerve was not completely achieved.

Although the concept of keyhole surgery is ideal for unruptured aneurysms, it can also be applied to some ruptured aneurysms in the absence of remarkable brain swelling, and yet the latter situation carries the risks of an unexpectedly swollen brain and intraoperative rupture. Nonetheless, despite a lack of consensus on when a keyhole approach is appropriate for ruptured aneurysms, patients with a good clinical grade and smaller subarachnoid hemorrhage can be treated using this approach.

Even though this report covers only a small series from a single institution, we suggest that an unruptured PCoA aneurysm inducing ONP can be surgically treated in a minimally invasive manner with favorable functional and cosmetic outcomes. This is the first study reporting on the clinical experience of a superciliary approach for unruptured PCoA aneurysms inducing ONP.

Conclusions

Surgical clipping via a superciliary keyhole approach can be an optimal treatment modality for an unruptured PCoA aneurysm inducing ONP as it provides favorable outcomes, including a high probability of complete recovery from ONP, complete and durable obliteration of the aneurysm, and excellent cosmetic results for the surgical wound, using a minimally invasive procedure.

Disclosure

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Author contributions to the study and manuscript preparation include the following. Conception and design: Park. Acquisition of data: Kang, Chun. Analysis and interpretation of data: Park. Drafting the article: Park. Critically revising the article: Chun. Administrative/technical/material support: Kang. Study supervision: Park, Chun.
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