Traumatic Supraclinoid Internal Carotid Artery Pseudoaneurysm associated with Carotid-Cavernous Fistula and Contralateral Anterior Cerebral Artery Pseudoaneurysm Treated by Surgical Trapping with High-Flow Bypass and A3-A3 Bypass: A Case Report and Literature Review

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Abstract

Traumatic pseudoaneurysms of the supraclinoid internal carotid artery (ICA) are uncommon, particularly associated with carotid-cavernous fistulas (CCF) or multiple traumatic aneurysms. This report describes a patient with a ruptured left ICA dissecting pseudoaneurysm that caused a direct CCF and a right anterior cerebral artery (ACA) pseudoaneurysm. To eliminate the aneurysm and fistula, we followed the universal bypass strategy by performing an ICA trapping with high-flow bypass, followed by an ACA trapping with A3-A3 side-to-side bypass. Herein, we report the first successful surgical trapping and revascularization of supraclinoid ICA pseudoaneurysm associated with a direct carotid-cavernous fistula.

Keywords
► dissection
► pseudoaneurysm
► carotid-cavernous fistula
► high-flow bypass
► EC-IC bypass

Introduction

Traumatic intracranial pseudoaneurysms are uncommon, comprising less than 1% of intracranial aneurysms.1 Even rarer are pseudoaneurysms originating from the supraclinoid segment of the internal carotid artery (ICA), especially when causing a direct carotid-cavernous fistula. The supraclinoid or intradural ICA pseudoaneurysms treatment includes surgical trapping,1,2 reconstruction clip,3 direct clipping,4,5 and endovascular therapy.6–14 Trapping the parent artery with revascularization could provide complete aneurysm occlusion and prevent rebleeding, aneurysm recurrence, and ischemic complications, regardless of the complexity of the procedure. This report describes the first case of traumatic supraclinoid ICA pseudoaneurysm causing a direct CCF treated with surgical trapping and revascularization to eradicate the aneurysms and fistula.

Case Description

Three days following a motorcycle accident, the patient, a 17-year-old male, was transferred to our department. Physical examination revealed a Glasgow coma score of 13 and grade IV right-sided motor function. No light perception was
present in the left eye due to indirect traumatic optic neuropathy, along with moderate proptosis and conjunctival congestion. Initial brain computed tomography (CT) revealed an intracerebral hemorrhage in the right frontal lobe with diffuse subarachnoid hemorrhage (►Fig. 1A) and an extensive anterior skull base fracture (►Fig. 1B), suggesting a blunt cerebrovascular injury. CT-angiography revealed left cavernous sinus and superior ophthalmic vein enlargement (►Fig. 1C). Additionally, an aneurysm was detected in the right anterior cerebral artery (ACA) (►Fig. 1D). Injection of contrast material into the right ICA revealed a right proximal A2 aneurysm with faint collateral to the left MCA territory (►Fig. 1E). Cerebral angiography of the left ICA injection revealed direct carotid-cavernous fistula (CCF) and cortical reflux to the Sylvian vein (►Fig. 1F). The anterior choroidal artery (AChA) and the left posterior communicating artery (PcomA) were not visible. Along with the pseudoaneurysm and narrowing of the distal ICA, the fistula was rerouted from the supraclinoid ICA. An enlarged cavernous sinus venous pouch that empties into the superior ophthalmic vein and inferior petrosal sinus was seen (►Fig. 1G–I). Injection of the left vertebral artery (VA) demonstrated collateral to the right MCA territory and left cavernous sinus via the PcomA but not to the left MCA territory (►Fig. 1J,K). The patient was diagnosed with a ruptured right ACA traumatic pseudoaneurysm and a left ICA dissecting pseudoaneurysm with direct CCF. The goal of our treatment was to eradicate the aneurysm and fistula to prevent rebleeding.

Concerning parent vessel sacrifice, we adhered to the universal bypass strategy because this patient had already developed right hemiparesis, indicating that the left cerebral hemisphere would not have been adequately supplied by collateral circulation. Moreover, the patient’s hemiparesis could be attributed to the constriction of the left supraclinoid ICA and the steal phenomenon originating from the CCF. As a result, we decided to simultaneously occlude the left ICA with an extracranial-intracranial (EC-IC) bypass and the right A2 aneurysm with an A3-A3 side-to-side bypass.
Fig. 2 Intraoperative findings following durotomy. (A) Arterialized Sylvian vein with brain congestion due to cortical reflux (arrowheads). (B) Patent STA-MCA anastomosis (asterisk) confirmed with indocyanine green videography. (C) EC-IC bypass using saphenous vein graft (black asterisk) was anastomosed to the superior division of the left M2 segment while the STA graft (white asterisk) supplied the distal flow during temporary occlusion. (D) Saphenous vein graft was then anastomosed to the prepared ECA (asterisk). (E) The left subfrontal approach showing outlined of the pseudoaneurysm (black dotted line) of left ICA anastomosis (asterisk) protruded through the cavernous sinus roof (arrow) with clip application distal to the pseudoaneurysm. Anteroposterior (AP) and lateral view of left ECA injection (F, G) Filling of contrast to the left cavernous sinus from ECA-ICA anastomoses (arrowheads). (H) Gelfoams (asterisk) were packed to obliterate the CCF. (I) Another clip application at proximal supraclinoid ICA. (J) The previous arterialized vein was returned to normal (arrowheads) after fistula obliteration with patent ECIC anastomosis (asterisk). AP and lateral view of left ECA injection showing (K) Patency of the saphenous vein graft (black arrowheads) filling to left cerebral hemisphere and (L) Middle meningeal artery (white arrowheads) supplying the ophthalmic collaterals. (M) Sequential slice showing the retinal blush (arrow) supplied by the ECA collaterals. (N) Left VA contrast injection showing the ACA aneurysm (arrow) by the flow through right PcomA (arrowheads) without filling the fistula.

Operation

The patient was brought to the hybrid operating room on the fifth post-rupture day. We decided to perform an ICA trapping with EC-IC bypass to:

1. Restore the flow to the left cerebral hemisphere for the prevention of ischemia due to hemodynamic change during anesthesia,
2. Eliminate the rupture risk during surgery in which the bleeding could be massive since it was an ICA aneurysm, and
3. Facilitate the subsequent A3-A3 bypass by reducing the brain edema caused by cortical reflux.

Due to the cortical reflux, the arterialized Sylvian vein and moderate brain edema were observed following durotomy (►Fig. 2A). The superficial temporal artery (STA)-middle cerebral artery (MCA) bypass was performed to supply distal flow during the EC-IC bypass (►Fig. 2B). Then, an EC-IC bypass was undertaken using saphenous vein graft (►Fig. 2C,D). During microsurgical dissection, active bleeding occurred; consequently, the cervical ICA was ligated, and a clip was placed on the intracranial ICA proximal to the origin of an anterior choroidal artery. As a result, the pseudoaneurysm and cavernous sinus pouch enlargement were identified (►Fig. 2E). However, the bleeding persisted despite ICA occlusion, which could be explained by retrograde flow from an ophthalmic artery (OA) and external carotid artery (ECA)-ICA anastomosis (►Fig. 2F,G). The cavernous sinus was then packed with Gelfoams, and a second clip was placed adjacent to the cavernous sinus roof to obliterate retrograde flow from an ophthalmic artery (►Fig. 2H,I).

After the fistula was repaired, a red Sylvian vein was turned into normal (►Fig. 2J). Intraoperative digital subtraction angiography (DSA) demonstrated complete aneurysm and fistula obliteration, as well as EC-IC bypass patency (►Fig. 2K). Because the ICA was trapped, an ophthalmic artery could not be visualized, but the ECA injection showed that the retinal blush supplied by the ECA collaterals via the middle meningeal artery (►Fig. 2L,M).

Left VA injection revealed an ACA aneurysm through the PcomA without filling to the fistula (►Fig. 2N).

The planned ACA trapping with bypass was not performed due to brain edema caused by prior venous congestion, which made the interhemispheric approach difficult. Instead, craniectomy was performed based on brain edema, with consideration for the patency of the anastomosis due to elevated intracranial pressure. The second surgery was performed a week after the brain edema had subsided. First, the bicoronal incision was extended from the previous cut. Then, an additional right pterional in conjunction with a bifrontal craniotomy was performed. Finally, after conducting a side-to-side A3-A3 bypass via an interhemispheric approach (►Fig. 3A,B), the aneurysm was trapped through the lateral subfrontal corridor (►Fig. 3C). Intraoperative DSA
demonstrated the complete disappearance of an aneurysm and A3-A3 bypass patency (Fig. 3D,E).

Postoperative Course
The postoperative course was uneventful. At discharge, the patient was graded on a scale of 1 on the modified Rankin scale (mRS). The motor on the right side has returned to grade V. His left visual acuity improved in response to hand motion. Three months later, CT showed no evidence of infarction (Fig. 3F). CT-angiography revealed complete obliteration of the aneurysms with no remaining fistula, and all anastomoses were patent (Fig. 4A, 4B). The cranioplasty had been planned.

Discussion
To our knowledge, our case is the first to perform successful surgical trapping with EC-IC bypass in traumatic supraclinoid ICA pseudoaneurysm associated with direct CCF. Furthermore, this case was complicated by an ACA pseudoaneurysm where another in situ A3-A3 bypass was required. The reported cases of traumatic supraclinoid ICA dissecting aneurysm associated with carotid-cavernous fistula are summarized in Table 1.

Intracranial Pseudoaneurysm with Direct CCF
Intracranial pseudoaneurysm resulting from blunt cerebrovascular injury can be explained by the following mechanisms: (1) direct injury from skull base fractures, (2) rotational injury or shearing of the carotid siphon, and (3) avulsion by an adjacent bony structure. Consequently, traumatic direct CCFs of the cavernous segment ICA are frequently encountered due to the overstretching of the mobile portion of an ICA and its location near the cranial base. In contrast, injuries originating from the supraclinoid or intradural portion of an ICA are uncommon. When a carotid-cavernous fistula is formed directly between the supraclinoid ICA and cavernous sinus, the rupture of the ICA pseudoaneurysm into the lacerated superior wall of the cavernous sinus could be the cause.

Rupture of the cavernous segment ICA pseudoaneurysm would result in CCFs or massive epistaxis if the pseudoaneurysm protruded into the sphenoid sinus, which could be controlled by packing. In the meantime, bleeding from a supraclinoid ICA pseudoaneurysm can result in a catastrophic SAH with devastating consequences. Hence, in an aneurysm originating from the intradural segment of an ICA, the prevention of re-rupture is therefore crucial.

Reconstructive Techniques
Because the preferred treatment of direct CCF is to close the fistula while preserving the parent artery, endovascular therapy using balloon/coil embolization or stentings may be considered first-line treatment. Concerning lesions in the supraclinoid segment of an ICA, the endovascular
approach has a lower likelihood of distal navigation. However, it carries the risk of pseudoaneurysm rupture due to catheter or coil perforation of the fragile fibrous wall.⁶ Endovascular coil embolization of an intracranial pseudoaneurysm may have the advantage of preserving the ICA with an ophthalmic artery; however, it is risky to rupture the pseudoaneurysm because the embolic material must be densely packed in the fibrous aneurysm wall and attached to the ICA orifice. Despite this, recurrence is a significant concern with coil embolization.¹⁷ However, some authors reported successful endovascular embolization with favorable outcomes for intracranial pseudoaneurysms.⁷–¹⁰,¹²–¹⁴

Regarding the reconstructive strategy, the flow-diverting stent is a potential endovascular treatment option for parent artery reconstruction and promoting epithelialization, which is advantageous for pseudoaneurysm obliteration.¹⁸ The disadvantages are the absence of immediate thrombosis and the need for dural antiplatelets, during which patients are at risk of rebleeding. The reported cases are also limited to lesions originating from the cavernous segment of an ICA. Moreover, the deployment of flow-diverting stents in supraclinoid ICA may be complicated by distal navigation, vascular tortuosity, and perforator preservation. Additional research is required concerning the safety and effectiveness of flow-diverting stents in these conditions.

**Deconstructive Techniques**

In cases of failed endovascular therapy or recurrent CCFs, however, surgical trapping with or without bypass may be necessary using the deconstructive strategy.⁵,¹⁹,²⁰ Because neck clipping may not be feasible for pseudoaneurysms, surgical trapping may provide definitive, complete obliteration of the aneurysms and fistulas. As for bypass, there have been reported cases of surgical trapping without revascularization,¹,² in which collateral circulation was sufficient. Nevertheless, up to 20% of patients who pass the balloon test occlusion still develop ischemic complications. As a result, a universal high-flow bypass should be conducted to prevent ischemic complications resulting from the sacrifice of an ICA, particularly in cases where collateral flow is insufficient, as in our case.

Regarding the ophthalmic artery, trapping would be performed by placing a clip proximal to the origin of the ophthalmic artery in conjunction with cervical ICA ligation in the case of a cavernous segment ICA lesion that permits retrograde flow from the distal ICA to the ophthalmic artery.¹⁹,²⁰ In cases of supraclinoid ICA lesions, however, the clip would have been placed distal to the ophthalmic artery origin to achieve complete aneurysm and fistula obliteration. The latter could impair the patient’s vision unless the ECA supplied the ophthalmic collaterals, as in our cases where vision was preserved.

**Conclusion**

The surgical trapping and revascularization of intracranial traumatic pseudoaneurysms are effective for aneurysm obliteration to prevent rebleeding and ischemic complications. However, the management strategy should be individualized depending on the location of the aneurysm, its association with carotid-cavernous fistulas, and the patient’s collateral circulation.
Table 1  Summary of reported cases of traumatic supraclinoid ICA pseudoaneurysm associated with carotid-cavernous fistulas

<table>
<thead>
<tr>
<th>Author, Year</th>
<th>Age (years)/sex</th>
<th>Dissection/pseudoaneurysm location</th>
<th>Presentations</th>
<th>Treatment</th>
<th>Complete occlusion</th>
<th>Complications/second treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benoit et al, 1973&lt;sup&gt;1&lt;/sup&gt;</td>
<td>45/M</td>
<td>Right supraclinoid ICA pseudoaneurysm-CS fistula</td>
<td>Right direct CCF</td>
<td>Surgical trapping with cavernous sinus packing</td>
<td>Yes</td>
<td>Oculomotor paresis</td>
</tr>
<tr>
<td>Reddy et al, 1981&lt;sup&gt;2&lt;/sup&gt;</td>
<td>14/M</td>
<td>Left supraclinoid ICA giant pseudoaneurysms-CS fistula</td>
<td>Left direct CCF</td>
<td>Surgical trapping with cavernous sinus packing</td>
<td>Yes</td>
<td>Transient abducens nerve palsy</td>
</tr>
<tr>
<td>Komiyama et al, 1991&lt;sup&gt;6&lt;/sup&gt;</td>
<td>42/M</td>
<td>Right supraclinoid ICA dissection with pseudoaneurysms-CS fistula</td>
<td>Right direct CCF</td>
<td>Transarterial balloon embolization</td>
<td>Yes</td>
<td>Ruptured of the pseudoaneurysm /ICA proximal occlusion by balloon</td>
</tr>
<tr>
<td>Masana et al, 1992&lt;sup&gt;3&lt;/sup&gt;</td>
<td>28/M</td>
<td>Left supraclinoid ICA pseudoaneurysms-CS fistula</td>
<td>Left direct CCF</td>
<td>Surgical reconstruct clipping</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Tytle et al, 1995&lt;sup&gt;4&lt;/sup&gt;</td>
<td>46/F</td>
<td>Right PcomA-CS fistula</td>
<td>Right direct CCF</td>
<td>Surgical clipping of PcomA origin</td>
<td>Residual</td>
<td>None</td>
</tr>
<tr>
<td>Komiyama et al, 1995&lt;sup&gt;7&lt;/sup&gt;</td>
<td>24/M</td>
<td>Left PcomA-CS fistula</td>
<td>Left direct CCF</td>
<td>Transvenous coil embolization</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Fu et al, 2002&lt;sup&gt;5&lt;/sup&gt;</td>
<td>16/M</td>
<td>Right PcomA-CS fistula</td>
<td>Right direct CCF</td>
<td>Direct surgical clipping of aneurysm neck and PcomA origin</td>
<td>Yes</td>
<td>None</td>
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<tr>
<td>Weaver et al, 2003&lt;sup&gt;8&lt;/sup&gt;</td>
<td>42/M</td>
<td>Left PcomA-CS fistula</td>
<td>Left direct CCF</td>
<td>Transarterial coil embolization</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Lee et al., 2004&lt;sup&gt;9&lt;/sup&gt;</td>
<td>19/M</td>
<td>Right supraclinoid ICA dissection with pseudoaneurysms-CS fistula</td>
<td>SAH and ICH, Right direct CCF</td>
<td>Transarterial and transvenous coil embolization with stenting</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Oran et al, 2004&lt;sup&gt;10&lt;/sup&gt;</td>
<td>30/M</td>
<td>Right supraclinoid ICA-CS fistula</td>
<td>Right direct CCF</td>
<td>Transarterial coil embolization</td>
<td>Yes</td>
<td>None</td>
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<tr>
<td>Cho et al, 2006&lt;sup&gt;11&lt;/sup&gt;</td>
<td>31/M</td>
<td>Right supraclinoid ICA-CS fistula</td>
<td>Right direct CCF</td>
<td>Transarterial coil embolization</td>
<td>Yes</td>
<td>Second coil embolization at 2 wks due to recurrence</td>
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<tr>
<td>Zhao et al, 2012&lt;sup&gt;12&lt;/sup&gt;</td>
<td>40/M</td>
<td>Left supraclinoid ICA giant pseudoaneurysms-CS fistula</td>
<td>Left direct CCF</td>
<td>Balloon-assisted transarterial coil and onyx embolization</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Karanam et al, 2014&lt;sup&gt;13&lt;/sup&gt;</td>
<td>40/M</td>
<td>Left supraclinoid ICA pseudoaneurysms-CS fistula</td>
<td>Left direct CCF</td>
<td>Transarterial coil embolization</td>
<td>Yes</td>
<td>None</td>
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<tr>
<td>Narayan et al, 2018&lt;sup&gt;14&lt;/sup&gt;</td>
<td>29/M</td>
<td>Left supraclinoid ICA giant pseudoaneurysms-CS fistula</td>
<td>Left direct CCF</td>
<td>Transarterial coil embolization</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Present case, 2022</td>
<td>17/M</td>
<td>Left supraclinoid ICA dissection and pseudoaneurysms-CS fistula and right A2 segment of ACA</td>
<td>SAH and ICH, left direct CCF</td>
<td>Left ICA trapping with EGIIC bypass and cavernous sinus packing, right A2 trapping with A3-A3 bypass</td>
<td>Yes</td>
<td>None</td>
</tr>
</tbody>
</table>

Abbreviations: ACA, anterior cerebral artery; CCF, carotid-cavernous fistula; CS, cavernous sinus; EGIIC, extracranial-intracranial; F, female; ICA, internal carotid artery; ICH, intracerebral hemorrhage; M, male; PcomA, posterior communicating artery; SAH, subarachnoid hemorrhage.
Conflict of Interest
None declared.

Informed Consent
A written informed consent was obtained.

References